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(EISG) PROGRAM**

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High-Efficiency Air-Conditioner on Single-Phase Electricity

EISG AWARDEE

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High-Efficiency Air-Conditioner on Single-Phase Electricity.

Subtitle

PHASE-ABLE^R ENABLER^R PERFORMANCE

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Smith and Sun^R

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Abstract

One purpose is to save billions of dollars in the electricity bills of air-conditioned homes and motels. Another is to prevent brown-outs and power outages of an overloaded electricity grid. Another purpose is to improve the power quality in the residence by preventing light dimming and light flickers when the air-conditioner starts. Another purpose is to keep the customer voltage constant at both air-conditioner running and not running times. Another purpose is to diminish the public utility loads in the summer by increased efficiency of the air conditioners.

An objective of this work is a demonstration that a three-phase compressor motor with a Semi-Hex electrical connection to the 230-volt single-phase supply has an equal or higher efficiency than the original motor. Another is a demonstration that this new system has a higher efficiency than available single-phase systems and that the electricity costs are reduced.

Our objectives were to discover unexpected problems and unexpected benefits and invent improvements. One discovery was a serious starting problem in conventional systems and one outcome was our invention of improved starting methods and engineering components.

One discovery was that the Semi-Hex connection of capacitors increased the motor efficiency to be higher than balanced applied voltages could achieve. Our Semi-Hex connection of a single-phase supply to the three windings of a three-phase motor had an EER of **11.19** at the standard ARI-540 conditions. A same compressor from the same production line had only a 10.21 EER with a single-phase motor. The improvement Ratio of using the Semi-Hex 3-phase motor in the single-phase system is $11.19 / 10.21$, which is **1.096**. This saves **9.6%** of the electricity cost.

New consumers can save millions of dollars in their electricity bills, with this new method, compared to any alternative. Our system uses robust metallized polypropylene run-capacitors and no power electronics. We discovered that the Enabler capacitors reduce the parasitic harmonic losses in the motor and increase the motor efficiency. Dr. Smith discovered that Potential Relays (PR) fail during brown-outs. An interval timer was invented for reliable and safer starting.

An efficiency increase in the electrical supply for the air-conditioning industry is an invention of radiative heat rejection from a steam turbine condenser.

Our conclusions are that all single-phase air-conditioners more than one kilowatt, more than 10,000 BTU/hour of cooling capacity, can benefit from these Semi-HexTM connections which have lower electricity costs and lower current pulses in the residential systems. Each of these new single-phase air-conditioners can be sold with a three-phase motor in the hermetically-sealed chamber with the compressor. The initial cost is less for both the manufacturer and the customer. The reliability and robustness of our system is better than the single-phase systems now provided.

The power-company sees the beneficial leading power-factor of our load current, not the detrimental lagging power-factor in the motor. The power-company will have less large-current pulses due to motor startings. Our new systems have lower harmonic, pulse, and spike distortion, and less voltage sag at full load. All components are readily available at low costs.

Key Words: efficiency, cost, single-phase input, 3-winding motor, starting current, power-factor.

Executive Summary

Introduction

Air-conditioning loads in August stress our power systems to their maximum capabilities. Companies bring on-line their least efficient generators to maintain stability, and their incremental costs might exceed their retail customer rates fixed by regulations. Customers have their maximum electrical usage at the August stress time, and their rate tiers may produce an unexpected and almost catastrophic electrical bill. Nearly all residential and motel air-conditioners are designed for a single-phase electrical supply. It might be 115 volts for the smallest units, and 208 volts or 230 volts for most units. The single-phase motor for these compressors is inefficient, compared to a three-phase motor. Three-phase motors are well designed to utilize the copper, iron, and frame shape for high efficiency and low cost. Their torques are smooth and not vibrating and not varying during the shaft rotation.

With previous examples of excellent functioning Semi-Hex™ systems, we wanted to apply the same benefits to air-conditioners, and have proved it with this project of nominal 60 kbtu-per-hour using a 5.2 KW motor. 5.2 KW could be translated to 7.0 HP, or nominal 60 kbtu/hour.

Project Objectives

- (1) Operate a 5.2-KW three-phase motor as a four-terminal motor (Semi-Hex™) connected to 230-volts single-phase.
- (2) Test an identical 3-terminal 3-phase motor on balanced 3-phase supply voltage.
- (3) For comparison, test a similar 5.2-KW compressor with the best A.O. Smith single-phase motor available.
- (4) For each, measure Locked-Rotor starting currents, full-load winding currents, power-line current, power-line watts, power-factor, and calorimeter values of cooling btu/hour at the ARI-540 standard test conditions of temperature and pressure of the refrigerant fluid in various portions of the calorimeter.
- (5) Verify that our starting current is near to the minimum for the desired torque and that the starting current is near to unity-power-factor.
- (6) Verify that the full-load single-phase line current is leading power-factor and beneficial to the power company by compensating for the lagging motor loads of other customers.

Our overall major objectives were to:

- (7) Discover unexpected problems and unexpected benefits and
- (8) Invent improvements. One discovery was a serious starting problem in conventional systems and one outcome was our invention of improved starting methods and engineering components.

Project Outcomes

At ARI-540 cooling conditions, our systems were superior to the alternatives:

- (1) Our Semi-Hex™ Enabler^R was

Watts input =	5,053.6	watts from the single-phase supply
Line Power-Factor =	81.29%	leading
EER =	11.19	

- (2) Our basic original three-phase motor alone with a 3-phase wattmeter was:

Watts input =	5,197.5	watts three-phase
Line Power-Factor =	87.74%	lagging
EER =	10.88	

(3) The single-phase motor that can be replaced has:

Watts input =	5,580.25	watts
EER =	10.2077	

The efficiency improvement ratio is 1.096 of the Semi-Hex™ Enabler^R efficiency divided by the single-phase motor efficiency. The savings in the electricity cost is 9.62%.

The high efficiency of our PhaseAble^R control is because our run-capacitor injects a correct specified current into a motor winding. High efficiency and high EER achieved with our low-cost run-capacitors is more economic than the high costs of much larger radiators, condensers, larger pipes, flow rates and fans. Our Semi-Hex™ systems were superior in robustness, starting current, voltage sag, pulsed-load currents, and costs.

(4) For Our Semi-Hex™ Enabler^R

Locked-Rotor motor starting current =	116	amperes
Locked-Rotor line starting current (LRA) =	78	amperes
Locked Rotor motor power factor =	32.5%	lagging
Locked Rotor line power factor =	98%	lagging
Full-Load winding current =	14.5	amperes
Full-Load power-line current, (RLA) =	26.96	amperes
Power-Line Watts =	5,054	watts
Power-Line Power Factor =	81.3%	leading
Calorimeter Btu/Hour =	56,545	Btu/Hour cooling
RATIO (LRA) / (RLA) =	2.89	= 78 / 27

This is twice as good as the single-phase motor, and 2.67 times as good as the three-phase motor on a three-phase supply.

- (5) Starting current above of 78 amperes at 98% lagging power-factor is near to unity power factor, and is minimum current. Unity power-factor is NOT minimum current because of the electrolytic capacitor losses.
- (6) Full-load leading power factor above of 81.3% leading is a current leading the voltage by 35.6 degrees. This is a great benefit to the power-company, bringing up the distribution voltage.

The above tests were repeated for many systems. Repeats of tests (1) and (2) were useful.

Outcome (2) with the basic original three-phase motor alone measured with a 3-phase wattmeter was:

Watts input =	5,197.5	watts, three-phase
Line Power-Factor =	87.74%	lagging
EER =	10.88	

Outcome (4) tests corresponding to paragraph (4) above for this SemiHex motor were:

Locked-Rotor motor starting current =	116	amperes
Locked-Rotor line starting current =	116	amperes
Locked Rotor motor power factor =	32.5%	lagging
Locked Rotor line power factor =	32.5%	lagging
Full-Load winding current =	14.78	amperes
Full-Load power-line current =	14.78	amperes
Power-Line Watts =	5,197.5	watts
Power-Line Power Factor =	87.74%	lagging
Calorimeter Btu/Hour =	56,549	Btu/Hour cooling

The thermodynamic efficiency is EER, the abbreviation for Energy Efficiency Ratio, the cooling BTU per electrical watt-hour.

Four winding terminals of an electrical three-phase motor with a heat-pump or air-conditioning compressor are connected in an electrical circuit which is a half-hexagon configuration named a Semi-Hex™ circuit. My single-phase efficiency ratio EER matches the high-efficiency of the 3-phase motor-compressor, which saves electricity compared to the single-phase unit now sold.

Our system electrical turn-on starting current was measured to be less than three times the full-load current. For high-torque starting, our starting capacitor controls, timer, contactor, and capacitors have been shown in many other installations which have been running for many years to be reliable, robust, economic, and long life. Our starting currents are approximately balanced, yielding high starting torques that are adequate if desired.

Our starting current was **2.77** times the full-load current. This is twice as good as the three-phase motor itself, and better than the single-phase motor which it can replace. The phase of the full-load current in the power line leads the phase of the voltage, called a leading power-factor, instead of the undesired lagging power-factor in the motor. Our line power-factor is **83%** leading.

A discovery (7) was that the Enabler^R connection of a three-phase winding reduced the parasitic harmonic losses of the fifth and seventh harmonics and thereby increased the motor efficiency above the expected value.

It was discovered (7) that measured calorimeter values for comparison purposes must have the Subcooling temperature of the refrigerant fluid specified and controlled to these specifications, and recorded, as well as the ARI-540 temperature specifications, else the calorimeter values will vary wildly and can not be used for comparison purposes.

One discovery (7) was that the Semi-Hex™ connection of capacitors increased the motor efficiency to be higher than balanced applied voltages could achieve. Our Semi-Hex™ connection of a single-phase supply to the three windings of a three-phase motor had an EER of

11.19 at the standard ARI-540 conditions. A similar compressor from the same production line had only a 10.21 EER with a single-phase motor. The improvement Ratio of using the Semi-Hex™ 3-phase motor in a single-phase system is 11.19/10.21, which is **1.096**. This saves **9.6%** of the electricity.

One discovery (7) was a serious starting problem in conventional systems and one outcome (8) was our invention of improved starting methods and engineering components.

An invention (8) was the use of an improved interval timer instead of a potential relay for reliable starting. The timer connects the starting capacitors immediately and disconnects the starting capacitors as the shaft speed approaches the full-load speed. This improved system is independent of brown-outs and excessively low voltages due to high demands during a summer heat storm or heat wave.

Conclusions

Measured Data: My compressor delivered 11.2 EER from a line power of 5 KW and a line power-factor of 81.3% leading. This saves 9.6% of the customer's electricity bill compared to the old inefficient single-phase motor. Starting current is only 78 amperes, which is less than three times the full-load current of 27 amperes, and benefits the power company. Our conclusions are that all new air-conditioning compressors larger than one kilowatt or larger than 10,000 btu per hour cooling capacity can and should be driven by three-phase motors, both those hermetically sealed, and semi-hermetic large installations.

Another conclusion is that manufacturers can provide higher quality units at lower cost than now, and at a higher profit for the manufacturer. A new product requires an initial capital investment or cost, for tooling, for catalogs, for service instructions, for service manuals, and for educating the engineering staff. This initial needed "financial bump" is a capital investment which must be provided by the manufacturer or by subsidies or tax incentives. Professional societies could provide one-week training sessions and work-shops to deliver the know-how quickly.

Recommendations

An important conclusion of these tests is that all single-phase air conditioners can and should use three-phase-motor compressors, whenever available. High efficiency and high EER achieved with low-cost run-capacitors is more economic than the high costs of much larger radiators, condensers, and fans.

Above one kilo-watt electric, this generalization holds up through 6 kilowatts to 10 kilowatts. In the largest sizes not usually sold for a single-phase supply, the indoor and outdoor fans would be three-phase fans, each with its own Enabler to connect it to the single-phase supply.

There is a need for a national testing laboratory to certify air-conditioning compressor efficiencies. Regulated ac power-supplies could be large enough to supply starting currents of many times rated current without any voltage drop at the output into the air-conditioner.

All electrical measurements and calibrations could be traceable to NIST, our national "Bureau of Standards". The tests reported herein took more than ten months.

Independent certified measurement values are important for all society. A new facility should be available to state commissions, customers, and manufacturers. It should be independent of manufacturers, to provide independent corroboration of claimed efficiencies and EER. It should have a competent staff of Registered Professional Engineers in fields of Thermodynamics, Circuits, Motors, Controls, and Electrical Power. It should have a large 24-hour competent staff of engineers to make continuous data recording runs of 24 hours and 36 hours. It should have adequate funding to provide test results in a timely manner for air-conditioning companies.

Public Benefits to California

The new customers will pay less for electricity than anticipated. Our new air-conditioners do not make the lights flicker on starting, and the full-load voltage on computers does not change with the air-conditioning load. The new-customer quiet units are better than the noisy vibrating systems and light flickers of their neighbors.

The power company will be enthusiastic about these new high-power-factor current loads. We tested **81% leading** current-power-factor. The leading power-factor of these new loads will partially compensate for the lagging power-factor of all nearby refrigerators, freezers, furnace fans, washers and dryers, pumps, and neighbor's air conditioners. The distribution efficiency of the power-company is increased by our Phase-Able^R and Enabler^R systems.

The power-company will see a reduced rate of increase in load due to these new air-conditioning loads, which reduction could be beneficial to long-term planning.

Higher-efficiency air-conditioners will produce less global warming than the replaced low-efficiency single-phase compressors.

A most important public benefit is that three-phase motors in single-phase air-conditioners can reduce electricity costs by **9.6%** of the electricity bill for 60,000 BTU/Hour of cooling. Similar savings apply to new units of other sizes.

The Energy Information Administration of our federal government estimates California air-conditioning electricity growth rate as new annual costs of 666 million dollars in 2005. Assume that with unprecedentedly increased air temperatures in the last several years, that the growth rate of new installations is now 1.5% per year. Applied to the EIA estimates, the growth value in 2006 would be 676 million dollars annually in California. Assume market penetration of 50%. Assume average Enabler^R savings of 7% for all sizes. The Enabler^R saving in the first year 2007 would be 23.66 million dollars, M\$. The second year savings would be $24.015 + 23.66 = 47.675$ M\$. The third year savings would be $24.375 + 47.675 = 72.050$ M\$. The tenth year savings would be 293.227 M\$. The sum of all ten-year savings would be 1,430.65 M\$, which is \$B1.4.

The appendices have lists of engineering measurements pertinent to each of the above paragraphs and economics of Enablers^R.

Introduction

Most air-conditioners for residences, motels, small commercial, and rural installations have only a single-phase electrical supply available. Electrical motors for connection to a single-phase supply are traditionally low efficiency, vibrate, noisy, and have shorter life than a comparably sized three-phase motor. To achieve high efficiency on a single-phase supply, Dr. Smith has invented many different methods of connecting high-efficiency three-phase motors to single-phase electrical supplies. Dr. Smith has had operating for many years a 40-horsepower Baldor motor for the pump for a center-pivot irrigation system, with a motor efficiency of 94.5%. Dr. Smith has had operating a 10-HP three-phase pump motor for a poplar-tree plantation drip irrigation, with a motor efficiency of 91%. This Phase-Able^R control on 230-volts single-phase is called a SemiHexTM configuration.

This current project used a Bristol three-phase 5.2-KW nominal 60-kbtu/hour compressor with a 230-volt three-phase motor. Dr. Smith designed and built the SemiHexTM circuit to connect the motor and compressor to a 230-volt single-phase supply. Dr. Smith measured the Locked-Rotor values for the system. An independent testing laboratory with meter calibrations traceable to NIST measured the ARI-540 thermal BTU/HOUR outputs. All measured values listed in this report are either from the Intertek testing Lab or from Dr. Smith's measurements.

The unit mentioned above is a large reciprocating compressor for which Bristol sells a single-phase motor, and for which the identical compressor is available with a three-phase motor.

The electrical principle of this SemiHex™ circuit is that only two motor terminals are connected to two wires of the single-phase electrical supply. When the motor is rotating, voltages are generated by the rotating flux in the motor air-gap, and these voltages appear on all of the winding terminals. This is called “free-wheeling-flux”. Each terminal not connected to the power supply is NOT connected to a voltage, but instead, has a current injected into the terminal by a capacitor chosen to inject exactly the desired full-load amperes at a specified phase angle or power-factor.

In the SemiHex™ circuit configuration in Figure 1, winding terminals W1 and W3 are connected together to form the corner terminal T13 and connect it to the Power-Line L1. Winding terminals W4 and W5 are connected together to form a corner terminal T45 and a pseudo-neutral. Winding terminal W2 is connected to Power-Line L2 and terminal T2. Winding Terminal W6 is connected to terminal T6. This completes the half-hexagon circuit for which the SemiHex™ circuit configuration is named.

Phase winding D is between W6 and T13. Phase winding A is between T13 and T45. Phase Winding B is between T45 and W2. Many of the published references describe how to design this system and the capacitor banks. This is history and preliminary to the design of the capacitor banks and controls used in this current project.

As an introduction, the simplest injection algorithm for running at full load is to inject nameplate current into Terminal T6 by capacitor C1. Nameplate current is also injected into Terminal T45 by Capacitor C2. These are the injection currents used for the systems operated and measured in this project. This simplest algorithm yielded our system efficiency which exceeded the single-phase efficiency by almost ten percent.

Run capacitor C1 of approximately 150 mfd is permanently connected between T2 and T6. Run capacitor C2 of approximately 300 mfd is permanently connected between T45 and T13.

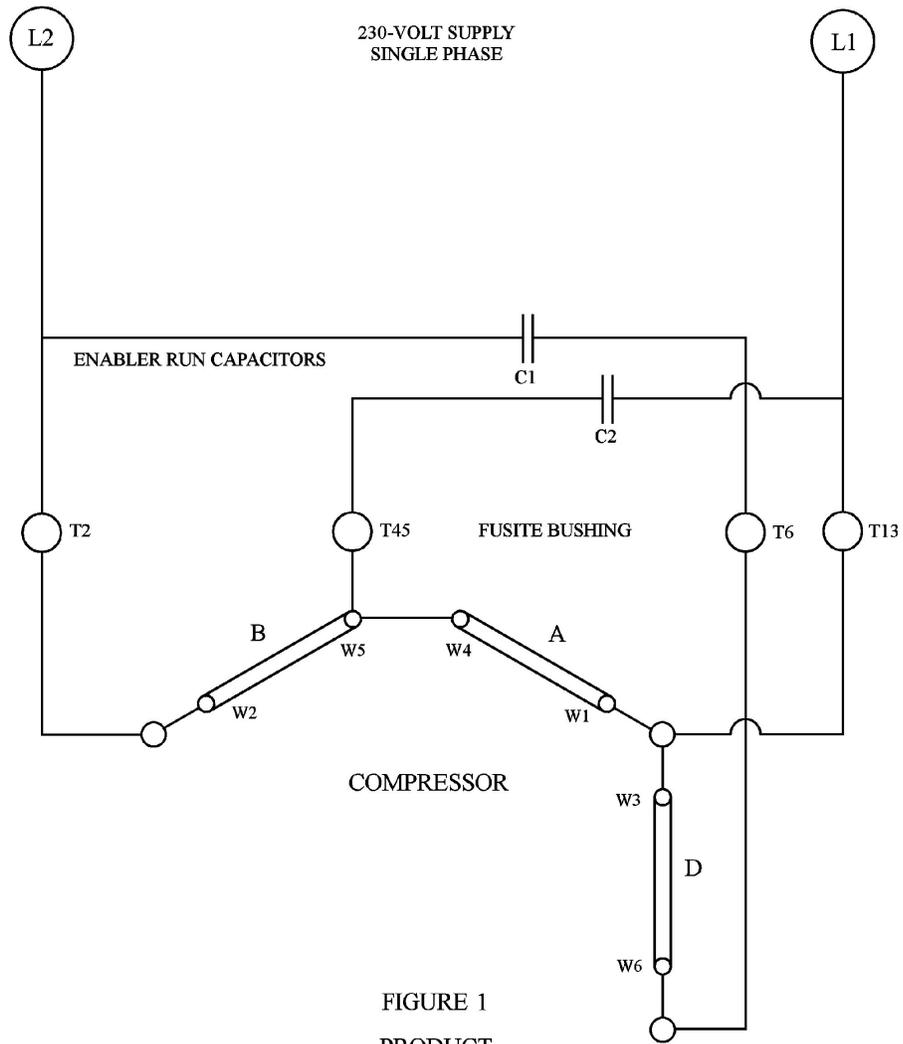


FIGURE 1
 PRODUCT
 3-WINDING COMPRESSOR SUPPLIED FROM 230-VOLTS SINGLE-PHASE
 FUSITE CONDUCTOR TERMINALS T2, T6, T13, AND T45
 RUN CAPACITORS C1 AND C2

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FIGURE 1: PRODUCT 3-WINDING COMPRESSOR WITH 230-VOLTS SINGLE-PHASE SUPPLY

The capacitor values are $C1 = (10^6) (15) / (266 \times 377) = 150$ microfarads.
 The capacitor values are $C2 = (10^6) (15) / (133 \times 377) = 300$ microfarads.

Figure 2 shows the addition of electrolytic starting capacitors CX3 and CX9 and the poles of the starting contactor SC. Phase winding D is between T6 = W6 and T13. Phase winding A is between T13 and T45. Phase Winding B is between T45 and W2.

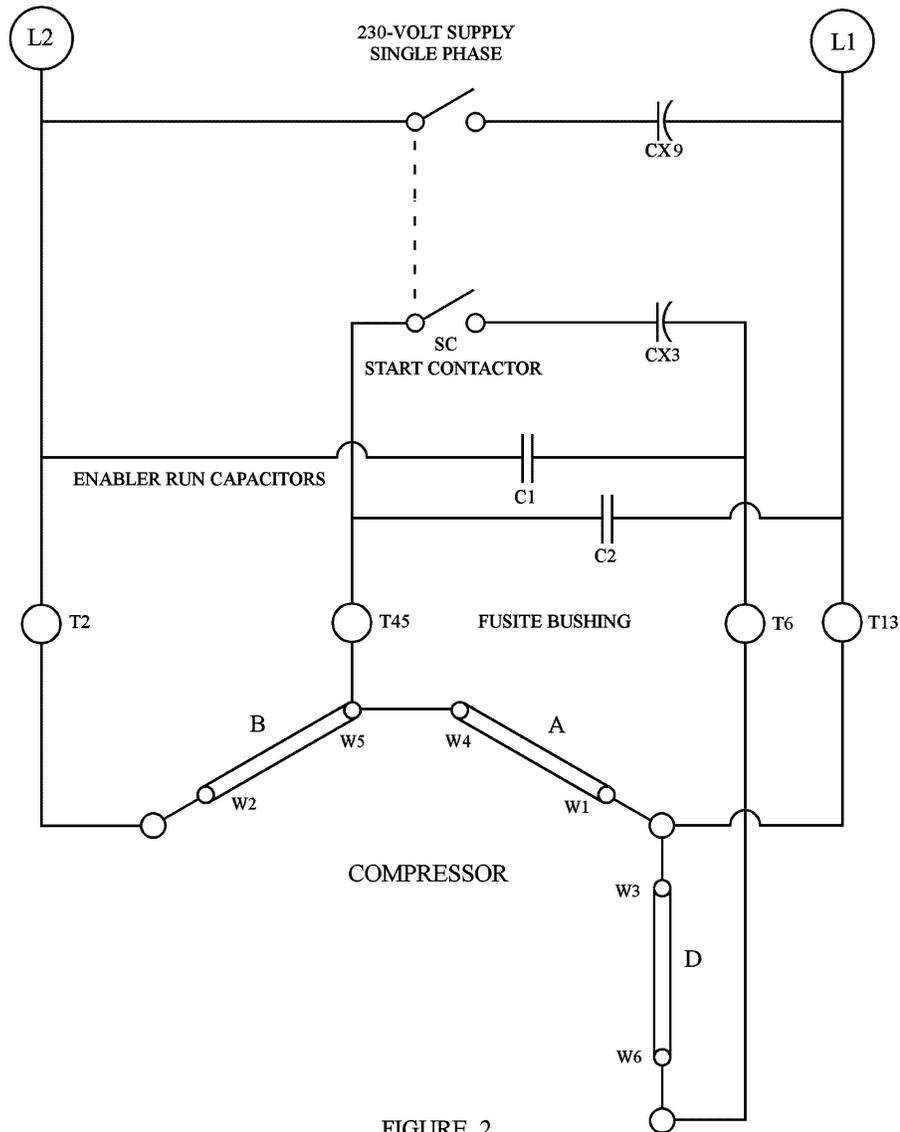


FIGURE 2
STARTING CONTACTOR SC AND STARTING CAPACITORS CX3 AND CX9

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FIGURE 2: STARTING CONTACTOR SC & STARTING CAPACITORS CX3 AND CX9

The D winding is the Driven winding, receiving the rated 15 amperes. The T45 terminal is the pseudo center or neutral of the WYE configuration, and it needs the 15 amperes so that the sum of the three currents at T45 is zero. With these currents at full load, all of the windings have balanced currents and balanced voltages and the nameplate efficiency.

Using catalog approximations for current, the injected current is 15 amperes and the capacitor voltages are 266 volts for C1 and 133 volts for C2.

$2 \pi f = \omega = \text{omega} = 377 \text{ radians per second in } 60 \text{ Hertz systems.}$

The run capacitor calculations are

$C = (10^6) (15) / (V_c \times 377) \text{ microfarads.}$

The run capacitor values are $C1 = (10^6) (15) / (266 \times 377) = 150 \text{ microfarads.}$

The run capacitor $C2 = (10^6) (15) / (133 \times 377) = 300 \text{ microfarads.}$

The starting capacitors have two different functions. The major starting capacitor CX3 is connected between T45 and T6 to provide torque for acceleration up to near full-load speed. This provides most of the starting torque.

The function of the starting capacitor CX9 is to bring the power-company line current to unity power-factor, so that the voltage is maintained high during the large starting current. CX9 is connected between T2 and T13, which is across the single-phase power supply and minimizes the power-line starting current. The leading capacitive vars of these two starting capacitors can cancel all of the lagging magnetic vars of the motor, so that the power-company only needs to provide the watts loss and watts for acceleration.

Project Objectives

1. Demonstrate that a three-phase compressor motor with a Semi-Hex™ connection to the 230-volt single-phase supply has a higher efficiency than the original motor.
2. Demonstrate that this new system with a Semi-Hex™ connection has a higher efficiency than available single-phase systems and that the electricity costs are reduced.
3. Measure the high efficiency of the three-phase motor alone connected to a balanced three-phase supply.
4. Measure our system electrical turn-on starting current to be less than three times the full-load current.
5. Verify that our starting current is near to unity-power-factor current.
6. Verify that the full-load single-phase line current is leading power-factor.
7. Discover a starting problem in a single-phase air-conditioner.
8. Discover an unexpected efficiency increase due to the Enabler.
9. Invent an efficiency increase in the electrical supply for the air-conditioning industry.
10. Invent a more reliable and safer starting method for air-conditioners.

Project Approach

Dr. Smith invented, designed and built the control system shown in Figure 2. Capacitor C1 = 150 mfd. marked on can. Capacitor C2 = 300 mfd. marked on can. Full-load currents in C1 and C2 and in each winding A, B, and D were 14.5 amperes average.

CX3 was 858×10^{-6} farads = 858 microfarads = $858 \mu F$ = 858 mfd. CX9 was 517 mfd. Locked-Rotor starting currents were also measured and recorded.

For each test, the start contactor was closed for less than one second. Shaft load was the standard ARI-540 thermodynamic conditions on the compressor output. Compressor performance in Btu/Hour was measured and calculated by the independent testing laboratory. Each test was 30 minutes duration with data recorded each 10 minutes.

Watts input from the power supply L1, L2, and currents and voltages in all of the windings were measured. Percentage unbalance in all multi-phase measures were measured and calculated.

This complete ARI-540 test was repeated for a 3-terminal 3-phase motor.

This complete ARI-540 test was repeated for a 2-terminal single-phase motor.

There were many other tests to document:

- (1) Semi-HexTM performance with phase-adjusting transformer,
- (2) Sensitivity to parameter variations, and
- (3) Single-phase Enabler performance with Star connection and transformer.

This research is iterative, and the Project Objectives are repeated many times for many different circuits and many different tests. The logical scientific sequence is by TESTS, not by objectives.

Project Outcomes

For the specific objectives above, our Semi-HexTM connection of a single-phase supply to the three windings of a three-phase Bristol compressor yielded:

- (1) A three-phase compressor motor with a Semi-HexTM connection to the 230-volt single-phase supply has an EER of 11.19 which is higher efficiency than the EER of 10.88 of the original motor.
- (2) This new system has a higher efficiency (EER = 11.19) than available single-phase systems with 10.2 EER. The efficiency increase is 9.7%. The electricity costs are reduced to 91%.
- (3) The high efficiency of the three-phase motor alone not connected with the Semi-HexTM circuit was EER = 10.88, which compared to the single-phase motor with EER = 10.2, is an efficiency potential improvement of 6.6%. The Semi-HexTM circuit increases this efficiency to a 9.7% improvement over the single-phase motor.

- (4) Our system electrical turn-on starting current is $LRA = 75.4$ amperes. The full-load single-phase supply current is $FLA = 26.95$ amperes.
Starting $RATIO\ SR = 75.4 / 26.95 = 2.8$. SR is less than three.
- (5) Locked-Rotor Watts input was 17,342 watts. $LRA = 75.4$ amperes.
Our starting Volt-Amperes VA is $(75.4)(230) = 17,342$ also. This is unity-power-factor current.
- (6) The Figure 3 single-phase Line input complex power in (watts plus j reactive vars) is $(P + j Q)_L = 5,053.55 + j 3,621.34$, where 5,053.55 is the watts from the power company, and $+ j 3,621.34$ is the leading vars fed into the power company by the capacitors C1 and C2. The phasor equation is $(P + j Q)_L = (5,053.55 + j 3,621.34) = 6,217.111 \angle +35.625^\circ$. The Line power-factor is $\cos(35.625)$ which is 0.81285 leading. The volt-amperes is 6,217.11 and the line current is $(6,217.11 / 230.605) = 26.96$ amperes.

Notes for (6) above: An inductive impedance is a reactance of $+ j X_L$ series ohms. A capacitive impedance is a reactance of $- j X_C$ series ohms.

The abbreviation VAR means **V**olt-**A**mperes-**R**eactive and these power measures have the sign of the phase angle of the Amperes with respect to the Voltage. In a capacitor, the current leads the voltage and the phase angle is almost 90 degrees. The **POSITIVE VARS** means that the current is **LEADING** Phase Angle in capacitors.

The **NEGATIVE VARS** means that the current is **LAGGING** Phase Angle in inductors and motors. Power Companies pay extra to get leading capacitive vars.

The motor alone had average winding currents of 14.53 amperes with line-to-neutral winding voltage of 134.46 volts, and equivalent line-to-line voltage of 232.9 volts. The motor alone complex power was $(P - j Q)_M = (5,053.55 - j 2,969.73)$ where the lagging magnetic vars are the $- j 2,969.73$. The capacitor vars must be the difference of $+ j 3,621.34 - (- j 2,969.73)$ which is **CAPVARS** = $+ j 6,591.07$ vars (leading). These leading capacitive vars are more than twice as much as the motor lagging magnetic vars.

The equation for Line $+ j Q_L$ shows that the line has leading power-factor.

- (7) The Potential Relay PR for AC starting shown in Figure 7 self-destructed on the first energization.
- (8) The efficiency of the terminal connections in Figure 1 was higher than the efficiency of the three-phase compressor on balanced rated 3-phase voltage. The capacitors C1 and C2 reduce the usual parasitic harmonic losses in the motor.
- (9) The invention reported in References 1 and 2 can increase the electrical power output of a Rankine-cycle steam-turbine generator system.
- (10) The interval timer with no dead time shown in Figures 6B and 6C can start the AC with reliable timing independent of the applied voltage and particularly reliable during brown-out or reduced supply voltage.

Figure 3 shows a circuit improvement over Figure 2 in that the added starting capacitor CX4 injects into winding D a starting current component which adjusts the phase angle of the injected current into D to make the phasor sum match the Locked-Rotor winding current phase angle for balanced locked-rotor currents and voltages. CX3 is connected between T13 and T6 during starting. The sum of the three starting capacitances is chosen to balance out all of the lagging current of the motor at the locked-rotor state, so that the power-company provides only the accelerating torque and the losses.

Objective (6) for Test 1A reported the extensive measurements listed in Table I . The complex power phasor Line equation of $(P + j Q)_L = (5,053.55 + j 3,621.34) = 6,217.111 / + 35.625^\circ$ is derived from the measurements of watts, volts , and amperes listed in Table I.

An important measurement of this project is the Calorimeter reading and calculation of the thermal capacity delivered by the 3-winding Bristol compressor of 56,545.082 Btu/Hour of cooling. The efficiency to be reported and quoted is the EER, the Energy Efficiency Ratio, which is the Btu/watt-hour.

$$\mathbf{EER = 56,545.082 / 5,053.55 = 11.1892}$$

This is an excellent efficiency for a system supplied by only single-phase power. Single-phase power is typical of most residential and motel air-conditioner systems in the United States. The motor itself in Table I shows the usual performance deviations from perfection, due to manufacturing techniques and to design choices to minimize cost. Practical wires can not be made of silver or gold. Magnetic flux densities in iron are limited to keep eddy-current and hysteresis losses reasonable. Our research is not to improve motor designs.

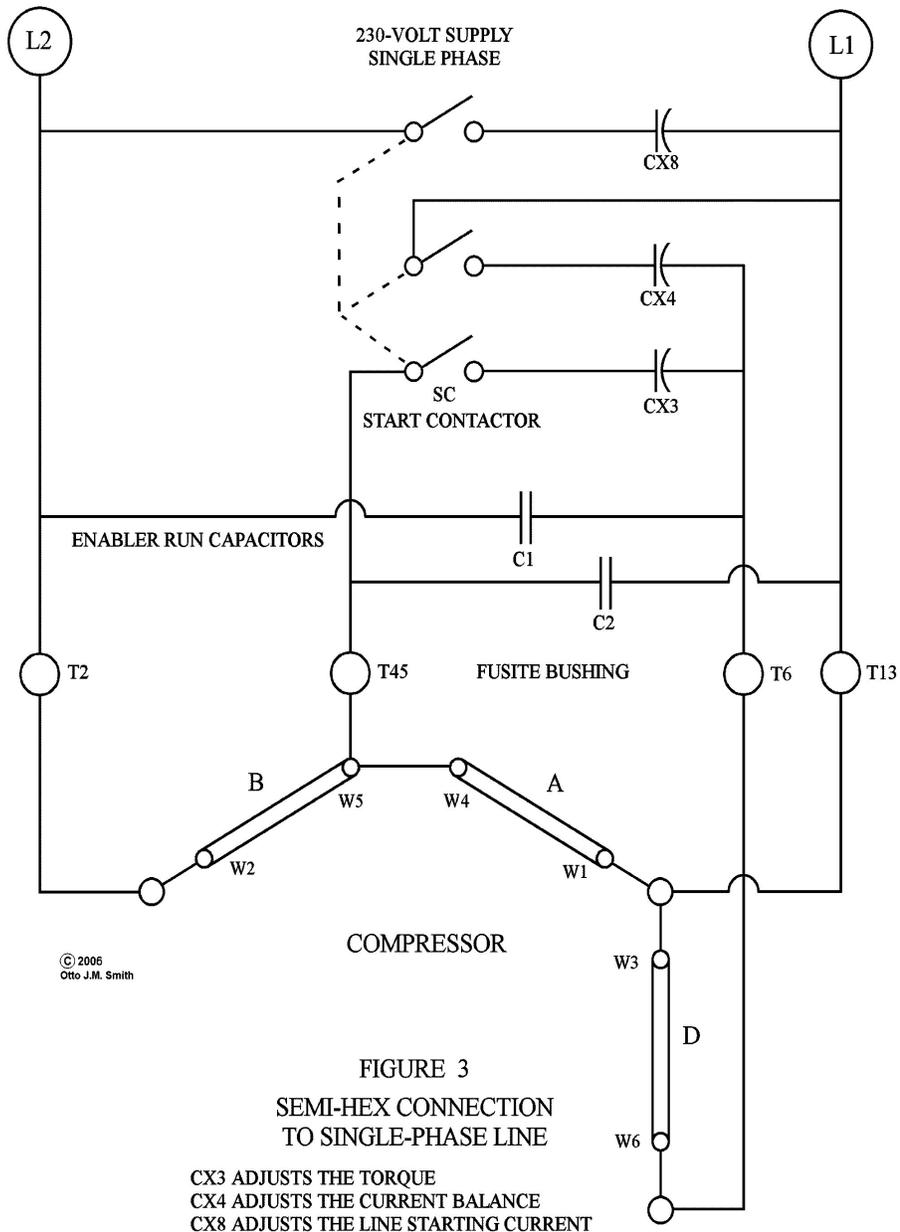


FIGURE 3: SEMI-HEX CONNECTION TO SINGLE-PHASE LINE

Test 1A. FIGURE 3 PRODUCT.

TABLE I
SEMI-HEX WITHOUT PHASE-ADJUSTING TRANSFORMER
ARI-540, **20° F-Subcooling.**

AC WATTS INPUT, 230-VOLT LINE

AC Input Power, 1-phase wattmeter,

P, raw data, digital	5,052.5	watts
P, raw data, WH meter,	5,054.6	watts
P, average	5,053.55	watts
Single-Phase volts	230.605	volts
Single-Phase amperes, RLA	26.96	amps
Single-Phase Volt-Amperes	56,217.111	va
Single-Phase % Power-Factor, leading	81.285%	
Line Leading Current Angle	+ 35.625°	
Thermal Capacity	6,545.082	Btu/Hour
EER	11.189	Btu/WH

AC Power, 3-phase wattmeter,

<u>Percent unbalance %</u>			
Watts	5,053.55	watts	
Volts per winding	134.46	volts, average	1.58% ub
Current, each phase,	14.53	amps, average	9.1587% ub
Volt-Amperes, average	5,861.	va	
Magnetic vars	j 2,969.734	vars, lagging	
Motor (P - j Q) _M	5,053.55 - j 2,969.734	watts – jvars	

% unbalance voltages = 1.58%

% unbalance currents = 9.159%

The Ratio of % current unbalance to % voltage unbalance = 5.8, which is good.

The quality of the ARI fit to the ARI-540 Fahrenheit temperature specifications is:

ARI Specifications: °F	130	45	65	95
ARI test measures: °F	129.0443	45.01988	64.28725	95.09645

The average error between the specifications and the test temperatures above is the

Temperature Error Average TEAR = 0.4462°F

The calorimeter Heat Balance = 1.5379%

In the contract, the stated “. . . goal of this project is to determine the feasibility of low-cost circuit designs that allow air conditioners to operate from single-phase electrical supplies . . .”

Figure 3 and the tests and measurements for this figure in Table I verify this goal.

The Line leading power-factor is typical of all Enabler^R, PhaseAble^R, and SemiHexTM systems.

The contribution of this research is to show that the SemiHexTM electrical circuit yields high efficiencies. There are two aspects to this comparison. One aspect is to know the efficiency of the single-phase motor being replaced. This aspect will be addressed in Table III with Test 1G. The other aspect is the efficiency of the three-phase motor which will be used along with the SemiHexTM electrical circuit. This aspect will be addressed below by Test 1C listed in Table II.

The ARI-540 temperature specifications are not sufficient for a unique reproducible specification state. The degrees of refrigerant subcooling must also be specified for a sufficient unique specification which is reproducible, and the calorimeter then has numerical comparative meaning when the degrees of Subcooling are held to the specifications. This is illustrated in

Table VII in the first three rows, for which comparisons are valid.

In the Table I above, the subcooling of 20° F is also specified.

One purpose of this Test 1A was to demonstrate that the 4-terminal Semi-HexTM winding connection above would perform better than the balanced-voltage 3-phase compressor motor of identical construction. This next Test 1C in Table II contains the measurements on the three-phase motor with a balanced 3-phase voltage supply. The three-winding motor is constructed for a “Wye” connection with a central neutral node to which one end of each winding is electrically connected. This is the same identical motor used in Figure 3, for which all six winding terminals were available.

In Test 1C in Table II, Terminals W1, W2, and W3 were connected to a three-phase supply, and terminals W4, W5, and W6 were connected together for the central node of the wye circuit. The three-phase supply was nominal 230 volts 60 Hertz. A three-element three-phase wattmeter was used. Each element measured the power in one winding from the line to the central neutral node. Deviations in these measurements are to be expected due to manufacturing deviations in the winding reactances and unbalanced voltages from the power-line. Three-phase motors are very sensitive to unbalanced voltages, with resulting unbalanced currents having a % current unbalance often as large as ten times the % voltage unbalance. This characteristic of the motor industry and the power-company inability to keep low percent voltage unbalances is responsible for actual motor performances and efficiencies less than the nameplate values.

Table II represents the constraint of the world. It is the best motor available, and we must live with it and design our engineering to be successful with this constraint.

TABLE II
THREE-PHASE MEASURES ON THREE-PHASE MOTOR. STAR CONNECTION

Test 1C THREE-PHASE INPUT WITH BALANCED VOLTAGES.

THREE-PHASE MOTOR, 4 TERMINALS. STAR (WYE) connection

AC WATTS INPUT

AC Power, 3-phase 3-element wattmeter	<u>Volts</u>	<u>Average</u>	<u>% UNBALANCE</u>
Phase Voltage, Line to Neutral, A-N,	132.775		
B-N	134.700		
C-N	133.250		
Average Volts		133.575 volts	0.8422% ub
	<u>Amps</u>		
Phase Current, Line to Neutral, A-N	14.3025		
B-N	14.0825		
C-N	15.9675		
Average Amps		14.7842 amps	8.004% ub
	<u>VA</u>		
Phase Volt-Amperes, Phase A	1,899.014		
Phase B	1,896.913		
Phase C	2,127.669		
Average VA		1,974.532 va	7.7556% ub
Total VA	5,923.596		
	<u>Watts</u>		
Watts, Line-to-Neutral Phase A	1,655.00		
Phase B	1,711.00		
Phase C	1,831.50		
Average Watts		1,732.5 watts	5.7143% ub
Total Watts, all three phases	5,197.5		

	<u>- j vars.</u> <u>lagging</u>		
Phase Lagging Vars in the Motor, Phase A	-j 931.2514		
Phase B	- j 818.998		
Phase C	- j 1,082.8588		
Average Vars, all three phases,		- j 944.3694	14.665% ub
Total Vars, all three phases	- j 2,833.1082		

THREE-PHASE MOTOR COMPLETE,

$$(P - j Q)_M = 5,197.5 - j 2,833.1082 = 5,919.5024 \angle -28.5944^\circ \quad \Phi = -28.5944^\circ$$

This VA of 5,919.5024 checks well within 0.07% of the 5,923.596 Total VA above.

3-phase power factor is - 87.803% lagging.

	<u>Volts</u>	<u>Average</u>	<u>%</u> <u>UNBALANCE</u>
Volts, Line to Line A-B	230.8675		
B-C	230.6450		
C-A	229.5525		
Average Volts		230.355 volts	0.348375% ub

Calculation from averages:

$$\text{Volt-Amperes,} = (\text{FLA})(\text{V})(1.73205)$$

$$\text{VA} = (14.7842) (230.355) (1.732) = 5,898.70 \text{ va}$$

This calculation is only 0.35% too low.

Summary Test 1C.

	<u>Average</u>	<u>%</u> <u>UNBALANCE</u>
Average Volts, Line-Line, V_L	230.355 volts	
Average Volts per winding	133.575 volts	0.3484% ub
Average Current, each winding, A_L	14.784 amps	0.8422% ub
Average Watts, each winding	1,732.5 watts	8.004% ub

Watts, total	5,197.5 watts	5.7143% ub
--------------	------------------	------------

The current unbalance of 8.004% is **9.5** times the voltage unbalance of 0.8422%. This ratio of **9.5** should be kept in mind for all air-conditioning and motor control studies and designs. Current unbalance means watts loss and low efficiency.

CALORIMETER MEASURE OF THERMAL CAPACITY OF COMPRESSOR = 56,548.585 Btu/Hour.

The Calorimeter Heat Balance is 1.10084%.

Calculated EER = 56,548.585/5,197.5 = 10.88

The quality of the ARI fit to the ARI-540 Fahrenheit temperature specifications is:

ARI Specifications: °F	130	45	65	95
ARI test measures: °F	129.5664	44.8186	66.4323	95.6322

The average error is TEAR = 0.4537 °F

The subcooling of **20° F** is also specified.

This efficiency (of 10.88 EER) is with a Star connection of the three windings and almost balanced applied three-phase voltage.

We expect the efficiency with a Semi-Hex™ connection of the terminals to be similar to or better than this three-phase efficiency with the identical compressor. The measurements are

SemiHex™ Table I EER = Btu/WH 11.189

Three-Phase Star, Table II, EER = 10.88

The SemiHex™ efficiency is 2.84% better than the three-phase efficiency.

In TABLE I, for the Semi-Hex™ connection of the identical windings, the compressor capacity was measured to be 56,545.082 Btu/Hour. This difference is less than 0.007%. This proves that the compressor is working at exactly the same conditions for the comparison of these two tests in TABLE I and TABLE II.

The % unbalance of the currents is important.

Ratio Phase current % unbalance to Phase voltage % unbalance = 8.004 / 0.8422 = 9.50

Ratio Phase current % unbalance to Line-to-Line voltage % unbalance = 8.004/0.3484 = 22.98

SemiHex Ratio Phase current % unbalance to Phase voltage % unbalance = 5.8

The SemiHex connection is 1.6 times better than the almost balanced voltage circuit with respect to winding current unbalances and corresponding vibration and increased losses.

The important difference is that the TABLE II Star connection needs 5,197.1 watts whereas the Semi-Hex™ connection needs only 5,053.6 watts from the single-phase supply. This difference is 143.5 watts, or 2.84%. Part of this difference might be due to meter calibration differences. Most of this difference might be due to reduction in harmonic flux losses. The system efficiency with the Semi-Hex™ connection in these tests is 2.84% higher than the three-phase star connection efficiency of the same motor.

Superior Harmonic Flux Benefit:

The magnetic iron in the motor has a non-linear magnetization curve, which is not a linear straight line. With a sine-wave of current, the voltage wave is “flattened”.

With a sine-wave of voltage, the current wave is “peaked”. At an exactly sine-wave voltage of 60 hertz applied, the magnetizing current has third, fifth, and seventh harmonics of 60 Hertz. These harmonic currents change the voltage difference between the applied voltage at the terminals, and the generated voltage in each phase due to the rotating magnetic flux. One result is that the actual rotating flux in the air-gap usually has significant harmonic distortions and significant harmonic parasitic watts losses. It is well known that the fifth harmonic flux distortion reduces the starting torque (or pull-up torque) and diminishes the motor quality and capability.

The motor stator currents are magnetically coupled to the air-gap flux and the rotor currents. These stator currents interact with the SemiHex™ connected run capacitors to significantly reduce the parasitic losses associated with the fifth and seventh space harmonic distortions.

The Star 3-Phase connection uses more watts than the SemiHex™ single-phase connection.

SemiHex™ compared to STAR.

The Semi-Hex connection interacts with the harmonic distortion of the air-gap flux, and reduces the losses due to these harmonics. The increase in Efficiency is probably beneficial for many designs and many sizes. The SemiHex™ circuit resonates to increase the leg voltage by approximately 0.66%. These tests are for a 4-terminal Enabler^R which is the type that would be used in a commercial product. This commercial product would use a 4-terminal (4-pin) Vitrus or Fusite hermetic bushing similar to those shown in Figures 12 and 13, perhaps with screw terminals. Our actual tests had two 3-terminal Fusite bushings for more versatile connections if desired, and also permitted current and voltage measurements in individual windings.

This Figure 3 is the circuit design that could be manufactured and sold.

All of these Enabler systems are **Robust, Efficient, Reliable and Re producible, RERAR.**

SEMI-HEX™ DESIGN SEQUENCE FROM FACTORY DATA

The factory data which is available is equivalent to averages from Table II. The published catalog values will be

FLA = RLA = 14.7842 amperes.

3-phase % power factor is PF = – 87.803% lagging.

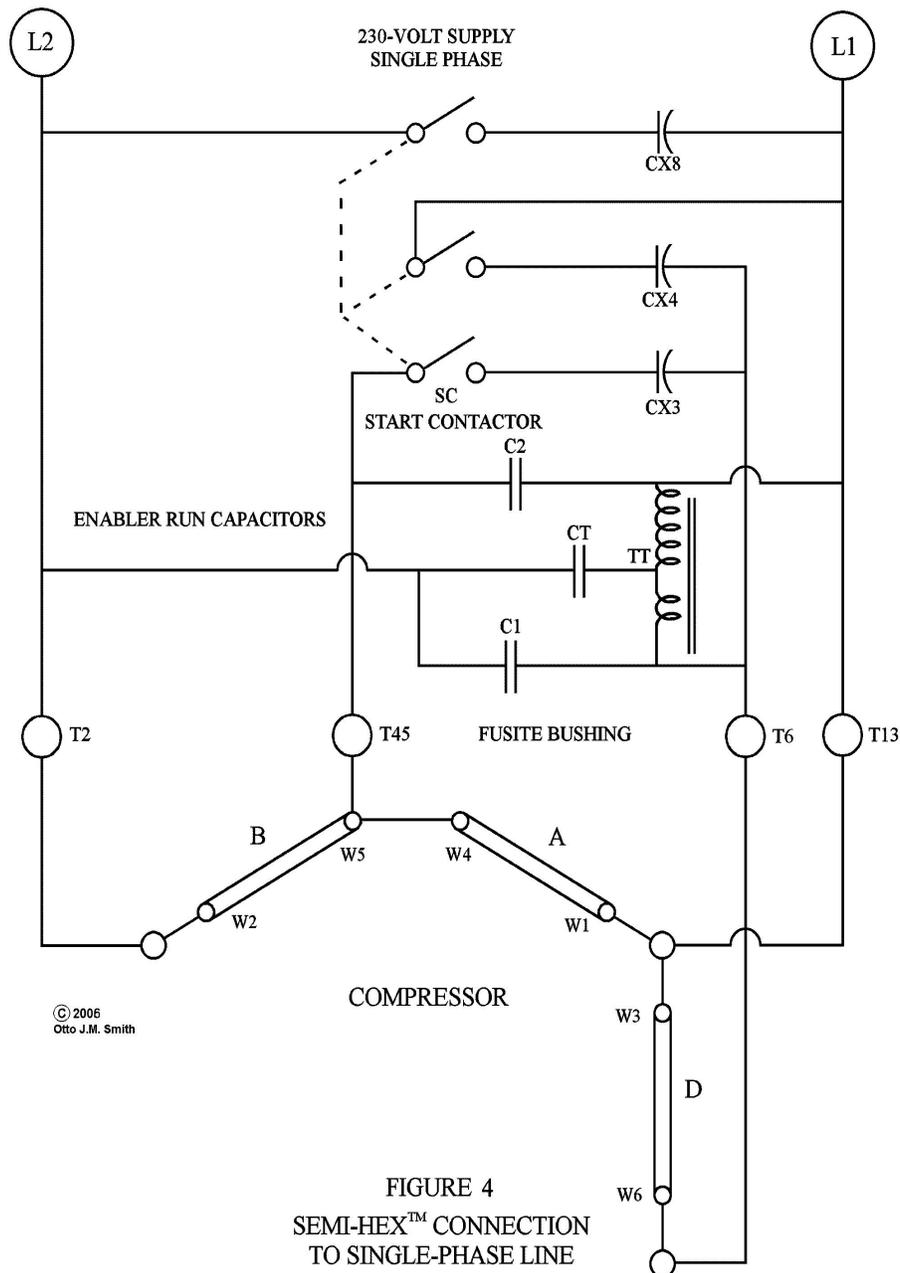
The current lagging angle is $\Phi = -28.5944^\circ$

This is a “high-power-factor” motor. If we are constrained by cost to use only capacitors C1 and C2, then each should carry the RLA. The voltage across C1 is 266 volts, and the voltage across C2 is 133 volts. The capacitances are:

$C1 = (10^6)(14.784) / (266 \times 377) = 147.2$ microfarads, (mfd).

$C2 = (10^6)(14.784) / (133 \times 377) = 294.8$ mfd.

The phase angles of the injected currents lag 30 degrees, not the required angle of 28.594 degrees. We can design and build a circuit which will inject exactly the correct phase angle. One circuit with a transformer is shown in Figure 4.



TRANSFORMER FOR HIGH POWER-FACTOR MOTOR

FIGURE 4: SEMI-HEX CONNECTION TO SINGLE-PHASE WITH TRANSFORMER FOR HIGH-POWER-FACTOR MOTOR
Capacitor C1 injects a current into D lagging the voltage by 30 degrees. Capacitor CT injects a

current into Transformer center-Tap TT which passes through the low voltage winding and also is injected into terminal T6 and W6 and winding D. The transformer turns ratio is 5 to 1. The voltages are given in Table III.

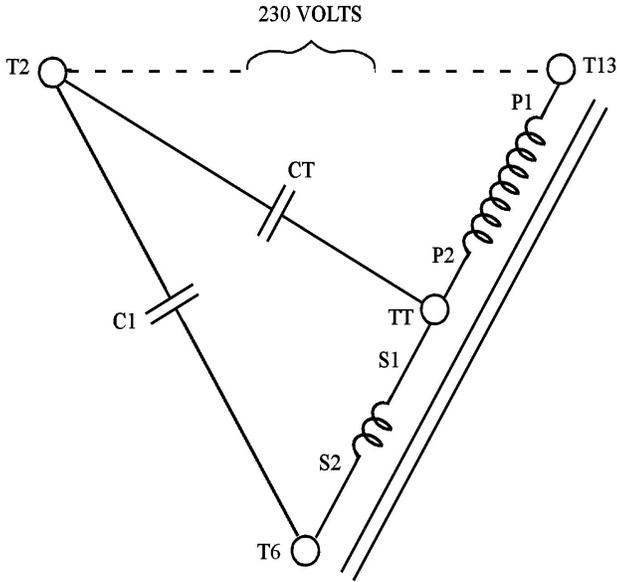


FIGURE 5

TRANSFORMER FOR HIGH POWER-FACTOR MOTOR

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FIGURE 5: TRANSFORMER FOR HIGH-POWER-FACTOR MOTOR

TABLE III

FIGURE 4 FOR SEMI-HEX CONNECTION OF 4 TERMINALS 3-WINDING MOTOR TEST 1B WITH PHASE-ADJUSTING TRANSFORMER. VOLTAGES AND CURRENTS

<u>VOLTAGES</u>	<u>Terminal Connection</u>	<u>Voltage Magnitude</u>	<u>Voltage Phasor</u>
Supply	T2 to T13	230	230 + j 0
VD	T13 to T6	132.8	132.8 / - 90°
Primary	P1 to P2	110.66	110.66 / - 90°
Secondary	S1 to S2	22.13	22.13 / - 90°
Capacitor CT	T2 to TT	255.24	255.24 / - 25.694°
Capacitor C1	T2 to T6	265.59	265.59 / - 30°
<u>CURRENTS</u>		<u>Amperes Magnitude</u>	<u>Amperes Phasor</u>
I26	S1 to S2	4.83	4.83 / + 64.306°
I30	2 to T6	9.963	9.963 / + 60°

Test 1B EER **11.0901** Btu/Watt-Hour.

The current in each run capacitor leads the voltage by 90 degrees. Capacitor C1 injects into winding D at terminal T6 a current phase angle of 60 degrees, which lags the winding voltage from T6 to T13 by 30 degrees. Call this current I30. Capacitor CT injects into winding D through S1 to S2 a phase angle of 64.306 degrees, which lags the winding voltage from T6 to T13 by 25.694 degrees. Call this last current IS = I26. The phasor sum of I26 and I30 should equal the desired correct injection current of RLA = 14.7842 / - 28.5944° with respect to the D winding voltage.

RLA is resolved into the two oblique components I26 and I30 in the oblique coordinates of 25.694° and 30° respectively. Define a constant $K = 1 / [\sin(30 - 25.694)] = 13.3186$.

$$I26 = K (RLA) \sin (30 - 28.5944) = (196.905) (0.0245299) = 4.83005 \text{ amperes.}$$

$$I30 = K (RLA) \sin (28.5944 - 25.694) = (196.905) (0.05060) = 9.9634 \text{ amperes.}$$

The algebraic magnitude sum of these two currents is 14.7934 amperes.

The phasor sum of these two currents is 14.784 / - 28.5944° with respect to the D winding voltage.

$$\text{The capacitor } C1 = (10^6)(I30) / \{ 265.59 \times 377 \} = 99.51 \text{ mfd.}$$

The current I26 of 4.83 amperes requires a current of one-fifth in the primary P1-P2 of the transformer. IP = 0.966 amperes. At the center-tap TT, these two currents add with exactly the same phases, so that the current from CT into TT is the sum

$$ICT = I26 + IP = 5.796 \text{ amperes.}$$

$$\text{The capacitor } CT = (10^6)(ICT) / \{ 255.24 \times 377 \} = 60.23 \text{ mfd.}$$

If the transformer were a perfect lossless transformer, then with these two capacitors, the EER of the circuit in Figure 5 would be slightly higher than the EER of **11.189** in Figure 3 for Test 1A in Table I. The actual Test 1B for Figure 5 measured a net EER of **11.0901**. The transformer losses were slightly higher than the Figure 5 circuit improvement by a net of only 0.09% loss. This method is applicable if a solid-state electronic substitute is used instead of a transformer with iron.

Test 1B measurements are in the Appendix Table A-II, and summaries are in Tables VI and VII.

A commercial product now being sold is a single-phase motor. Test 1G is our test of the single phase motor being supplied for the same compressor as Tests 1A, 1B, and 1C.

TABLE IV
SINGLE-PHASE COMPRESSOR. Single-Phase winding. Test 1G

These measurements and methods were intended to be pioneering and unique in that the calorimeter used water for heat transfer, instead of the glycol mixture required for freezers.

At ARI-540 standard conditions the calorimeter yielded:

1-Phase BTU/HOUR CALORIMETER	56,961.463	btu/hour in the cooling mode
1-Phase AC WATTS INPUT, raw data	5,580.250	watts
1-Phase EER = BTU / (WATT- HOUR)	10.2077	btu/wh
AC Power, 1-phase wattmeter	5,580.25	watts
Single-Phase volts	230.8125	vac
Single-Phase amperes (RLA)	24.599	amperes
Volt-Amperes	5,677.7567	va
Single-Phase System Power-Factor	0.982827	PF Line, lagging
Percent Single-Phase Power-Factor	- 98.2827%	% PF Line, lagging
Single-Phase EER	10.2077	btu/wh

2-WINDING MOTOR 60 mfd run capacitor,

Line Lagging Phase Angle	- 10.634°	degrees
Line Magnetic vars, Q_L	- j 1,047.727	var _L lagging.
Quadrature winding voltage		

$= (1.174) \times \text{Supply voltage} =$	270	V_{QUAD}
Run Capacitor Voltage $= (1.542) \times \text{Supply voltage} =$	355	$V_{\text{RUN-CAP}}$
Run Capacitor Current	8.02	amperes
Run Capacitor Vars Leading	+ j 2,845.7	Var_C Leading
Motor Lagging Vars = $Q_L - j \text{Var}_C$ $= -j 1,047.727 - j 2,845.7 =$	- j 3,893.43	Var_M Lagging
Magnetic Motor $(P - j Q)_M =$	(5,580.250 - j 3,893.43)	watts - j vars
Magnetic Motor $(P - j Q)_M =$	(6,804.262) { $\cos \Phi - j \sin \Phi$ }	(VA) {PF - j sin Φ }

where $\Phi = \underline{-34.904^\circ}$, and where motor winding power factor = $\text{PF}_M = 0.8201 = (\cos \Phi)$.

The injected phase angle of the run capacitor current is -49.479° .

Factory-specified Locked-Rotor Starting current = (LRA) = 147 amperes at 230 volts.

RATIO of LRA/RLA = $147/24.6 = 5.98$

Tested 1-phase motor was Bristol Model No. H29A623-CBCA, York Part No. 015-035-56001.

Tested 3-phase motors were Bristol Model No. H29A623-DBL, York Part No. 015-032-54001.

Compare this to the same power rating 3-phase motor, with a 3-phase % power factor of 88.18% lagging. (See Tests 1C and 1D; where the current-lagging-phase-angle is less than 30 degrees.)

The single-phase EER in Test 1G above is **10.2077** Btu/Wh. The 3-phase EER was **11.1892** in Test 1A for Figure 3. The 3-phase system efficiency improvement was **9.615%**.

This is a substantial electrical cost savings. The goal of these tests is not to change the design of single-phase motors, but instead to document this much higher efficiency of the existing three-phase motors.

These measurements and methods are pioneering and unique because this compressor is probably the largest single-phase reciprocating compressor available from Bristol.

COMPARATIVE COSTS.

Johnstone Order # B81-100 three-phase **200**-230 volt, nominal 5 tons, 60.8 kBtu/Hour Capacity, Price for Bristol unit was \$635.86.

Johnstone Order # B81-099 single-phase **208**-230 volt, nominal 5 tons, 60.8 kBtu/Hour Capacity, Price for the Bristol "raw" unit was \$582.54.

The minimum voltage at which the single-phase "raw" unit will start is 208 volts, compared to the smaller voltage 200 volts for the three-phase unit. The three-phase unit has higher torque.

To improve the starting torque of the single-phase unit, the customer must also purchase a Run Capacitor G22-827, \$19.31; a Start Capacitor G22-846, \$7.04; and a Relay B10-037, \$37.82.

The sum of these three additional components is \$64.17; consequently the single-phase “raw” system plus the se three extra components is \$646.71, which makes the single-phase cost 1.7% higher than the 3-phase cost for comparable performance.

STANDARD ARI-540 TEST.

A standard test proceeds as follows:

Install all plumbing from compressor to calorimeter.

Connect all electrical circuits and all transducers.

Operate the compressor and charge it with the refrigerant to charge specifications.

The above takes two full days.

Operate the compressor and adjust to ARI-540 temperature specifications takes three hours minimum. Each precision run is 30 minutes with four sets of measurements. Two different electrical systems would be another run needing another hour. Computer processing of data is at least three hours. Under the best conditions, three and one-half days minimum is required.

The quality of the ARI fit to the ARI temperature Fahrenheit specifications for Test 1G is:

ARI Specifications: °F	130	45	65	95
ARI test measures: °F	129.1843	45.9985	65.4949	95.2370

Average Error TEAR = 0.6365°F

Heat Balance = 0.4045%

Our Semi-Hex connection of a single-phase supply to the three windings of a three-phase motor had an EER of **11.19** at the standard ARI conditions. A same compressor from the same production line had only a 10.208 EER with a single-phase motor.

The improvement Ratio of using the Semi-Hex 3-phase motor in the single-phase system instead of the single-phase motor is 11.19 / 10.21, which is **1.096**. The customer saves **9.6%** of his electricity bill for cooling.

UNEXPECTED and unanticipated DISCOVERIES and INVENTIONS are not in a preconceived list of benefits. Important contributions of this research are:

1. Discovery of the failure of conventional Potential Relay (PR) controls during brown-out and distribution heavily-loaded conditions. A PR can self-destruct on starting. Our PR did self-destruct as shown in Figure 7.

2. During normal operation of a single-phase air-conditioner, a power-company switching operation can cause several air-conditioners to stall, and not either turn-off or restart normally according to the Southern California Edison Company. This is another example of the incompetence of the usual controls.

3. Discovery that the Semi-Hex connection of the terminals of a three-winding motor yields higher efficiency than the same motor connected to a balanced three-phase supply. The improvement is probably due to reduced harmonic parasitic losses.

4. Discovery that the refrigerant Subcooling must be controlled to the same specified value for each calorimeter reading to be reproducible, reliable, and correct.

5. Discovery that electrical wattmeters for motors must be calibrated for all possible lagging and leading power-factors. Charts and curves should be available for 80% lagging power-factor, 50% lagging power factor, 25% lagging power-factor, unity power-factor, 25% leading power-factor, 50% leading power-factor, 75% leading power-factor, and 99% leading power-factor.

6. Invention of a no-dead-time interval timer for air-conditioner starting control, to replace the potential relay.

TABLE V
SIMILAR THERMODYNAMIC LOADINGS, ARI-540 CONDITIONS

<u>20° F Subcooling</u>					
<u>Test</u>	<u>Btu/Hour</u>	<u>TEAR° F</u>	<u>3-Phase Watts</u>	<u>Heat Balance</u>	<u>EER</u>
1CC 3-phase Star	56,492.75	1.0395° F	5,187.5	-1.759%	10.890
1A Fig. 3	56,545.082	0.4462°	5,053.55	1.53792%	11.189
1B Fig. 4	56,260.236	0.4044°	5,073.025	1.7856%	11.090
1C Star	<u>56,546.585</u>	0.4537°	5,197.50	1.10084%	10.880
Average	56,461.163				
<u>15° F Subcooling</u>					
Star	55,621.8001	0.49068	5,198.75	1.4095%	10.699

The average of the Btu/Hour of the first four rows is 56,461.163, with extremes of – 0.36% and + 0.15%. The major differences are in the input watts and the corresponding EER.

Figures 3 and 4 are single-phase with Semi-Hex connections. Star are three-phase with almost balanced three-phase voltages applied.

The compressor runs at a constant speed, synchronous minus slip speed or slip frequency, so with constant ARI conditions, all of the Btu/Hour values listed of the compressor should be and were tested to be the same.

TABLE VI
DESIGN IMPROVEMENTS

There were many winding measurements, all for the same cooling. The average winding currents and the % unbalances were:

<u>Test</u>	<u>Figure</u>	<u>Table</u>	<u>Winding Amperes</u>	<u>% Unbalance.</u>
1A	3:-pg 14	I:-pg 15	14.531	9.16%

1AA	3:-pg 14	A-V:-pg 74	14.6017	5.690%
1BB	4:-pg 21	A-V:-pg 74	14.5575	7.608%
1C	Star	II:-pg	14.784	8.004%
1CC	Star	A-VI:-pg 76	14.90	5.4792%
1D	Star	A-VII:pg 81	<u>14.922</u>	1.8206%
Average			14.716	

An approximate design for C1 and C2 is

$$C1 = (10^6) (14.716) / [(265.9275) (377)] = 146.8 \text{ microfarads.}$$

$$C2 = (2)(C1) = 293.6 \text{ microfarads.}$$

This average amperes is not weighted inversely as the percentage unbalance, as it might have been for better statistical treatment.

Changes in the motor efficiency produce only a microscopic change in the slip frequency and slip speed. The difference between the Star tests in the first row and the fourth row is only 10 watts, (0.2%), which is negligible.

In the EISG grant application information, there was a strong emphasis on commercialization and practical systems which could be marketed immediately. We use reliable single-phase starting with an interval timer and contactor better than the Potential Relay PR now used.

Figure 6A is the oscillographic trace of a conventional interval timer which has an initial “dead time delay” of 3 cycles or 50 milliseconds. During this dead time, no current goes to the starting contactor, so the starting capacitors are not connected in the SemiHex™ system.

During the dead time in Figure 6A, the three-phase motor winding is connected across a single-phase supply. This is called “single-phasing” a three-phase motor. This is known to cause enormous currents and rapid destruction of a three-phase motor.

A suitable Interval Timer must have no dead time. Figure 6B is the oscillographic trace of the Model 21 Interval Timer which has no dead time. The load closed-circuit timing starts at exactly the same instant and phase as the application of the power. The starting capacitors are energized and the motor starting locked-rotor state is balanced voltages and currents in all of the windings.

The starting capacitors are removed at the end of the timing interval, not as a function of a change in voltage in one of the windings. For the Bristol compressor, we measured satisfactory starting with timing settings of 0.4 seconds up to 2.6 seconds, and all values in between.

Figure 6C is a photograph of the Model 21 circuit board before potting. Subsequent designs have diminished these dimensions.

The lowest-cost poor quality control could have only one electrolytic starting capacitor, CX3. Higher quality more sophisticated systems can have two, three, or four poles on the starting contactor and two, three, four, or five individual starting capacitors. These methods would be applicable to freezers and chillers of 10 through 80 tons.

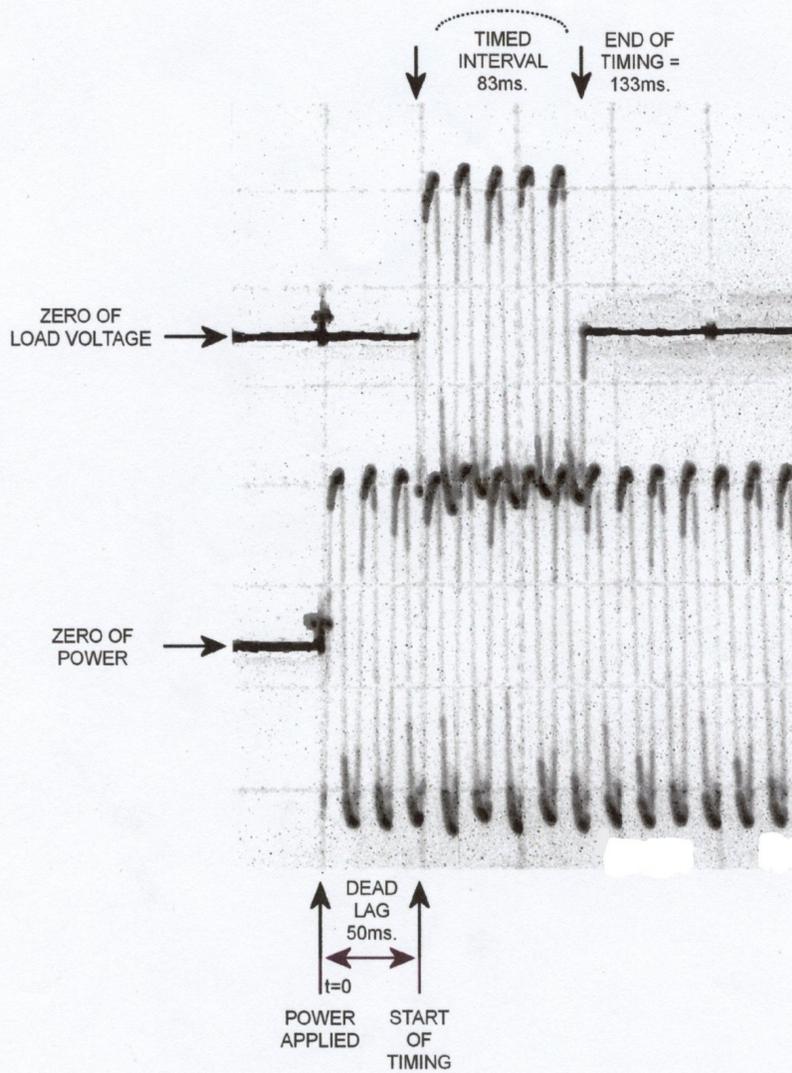


FIGURE 6A
 ARTISAN INTERVAL TIMER
 MODEL 4300

SWEEP = 50 ms. PER SQUARE
 DEAD LAG = 3 CYCLES, TIMED = 5 CYCLES

FIGURE 6A OSCILLOGRAM- ARTISAN INTERVAL TIMER

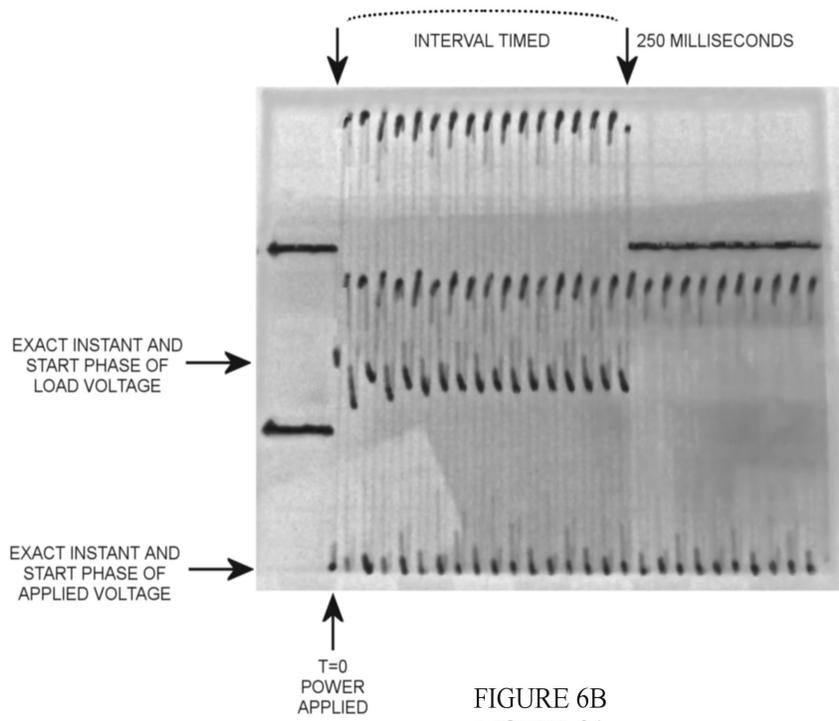


FIGURE 6B
 MODEL 21
 INTERVAL TIMER, NO DEAD TIME

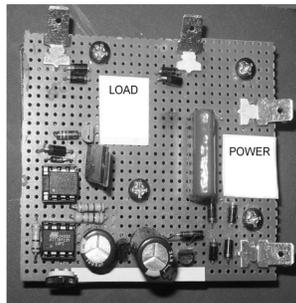


FIGURE 6C
 MODEL 21
 INTERNAL BOARD

FIGURE 6A-6B: OSCILLOGRAM MODEL 21 123Phase INTERVAL TIMER

Our starting current was **2.77** times the full-load current. This is twice as good as the three-phase motor itself, and better than the single-phase motor which can be replaced by our three-phase motor. The phase of the full-load current in the power line leads the phase of the voltage, called a leading power-factor, in contrast to the undesired lagging power-factor in the motor.

Our line power-factor was **83%** leading. The thermodynamic efficiency was EER, the cooling BTU per electrical watt-hour. Our Test 1A had an **11.189** EER.

New consumers can save millions of dollars in their electricity bills, with this new method, compared to an alternative. Our system is robust, using metallized polypropylene run-capacitors and no power electronics. In the **Public Benefits to California** on page 45, it is shown that when PhaseAble Enabler air-conditioners are available, with a 50% penetration of the new market, the new customers will save 1.4 Billion Dollars of their electricity cost in ten years.

STARTING PROBLEM.

Figure 7 shows a Potential Relay (PR) in a single-phase motor starter which responds to the rise in voltage across a quadrature winding during acceleration. The sensed voltage is applied to an electrical coil around a magnetic portion of the relay. The relay armature has one NC pole contact which connects the starting capacitor initially. Normally, near 80% of full-load speed, this PR armature pulls up and opens the NC contact, disconnecting the starting capacitor.

In the event of excessive loads on a power-system and corresponding reduced customer voltages, or during a brown-out, or when many air-conditioners attempt to start at the same time, the reduced customer voltage is insufficient to make the PR armature pull up, even at full speed.

Now the electrolytic starting capacitors are continuously connected, the motor winding currents are many times the rated current, and the thermal protection in the windings has not yet reached the insulation-destruction state so the circuit breaker has not opened. At this full speed, the electrolytic losses are substantial and the capacitor is ready to explode. The wire insulation is cooking and the wires are smoking. The PR NC contact is melting. Parts of the motor are smoking. The thermal protection has not opened the circuit breaker.

The end result is that the electrolytic capacitor explodes and the NC contacts melt. The motor can continue to run, but it will not start again.

Our Figure 7 demonstrates that this PR system is unreliable and should not be used.

The PR can be replaced by an Interval Timer and contactor for reliable performance.

All of our PhaseAble^R and Enabler^R systems have BALANCED locked-rotor currents with balanced rated voltage on all windings at the instant of starting. There is negligible voltage change with change in shaft speed.

Figure 7 is a photograph of the destruction of a starting capacitor and the potential relay.

For our SemiHexTM system, interval timers like Figure 6A should not be used. The Fig. 6C interval timer is best. Expensive 2PDT octal time-delay relays are also OK.

Another problem arises during switching transients and brown-outs. When a single-phase compressor is running normally, and a power system switching transient drops the voltage to one-half or to zero, the loss of voltage causes the motor to stall in a fraction of a second.

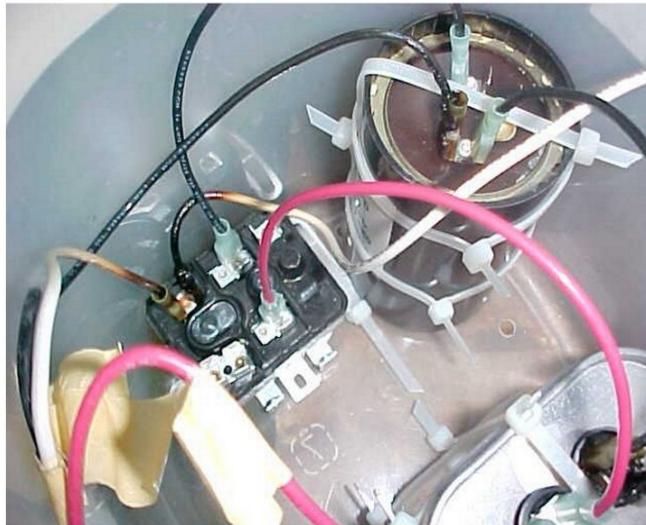


FIGURE 7

DESTRUCTION OF BOTH ELECTROLYTIC STARTING CAPACITOR
AND POTENTIAL RELAY

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FIGURE 7: DESTRUCTION OF ELECTROLYTIC STARTING CAPACITOR AND POTENTIAL RELAY

The motor has thermal protection, so that after a long time, before the windings burn up, the motor might be automatically re-energized, and if the power-system has then restored sufficient voltage, the motor might restart.

The problem is that the motor might not have a stall sensor, and neither does several hundred other air-conditioners on the same power distribution section, so that all stalled motors simultaneously have locked-rotor starting currents of many times the full-load current, so that the power company is overloaded and its voltage is continuously depressed below the value necessary for normal starting.

ELECTRICAL MEASURES AT ARI-540 CONDITIONS

The standard ARI-540 test conditions for the compressor refrigerant fluids are:

Ambient Temperature = 95° F

Suction Temperature = 65° F

Subcooled Liquid Temperature = 115 ° F

Suction Pressure = 76 PSI

Discharge Pressure = 297 PSI

Subcooling amount °F = 20° F

This is ARI Standard 540-1999, “*Positive Displacement Refrigerant Compressors and Compressor Units*,” published by the Air-Conditioning and Refrigeration Institute.

The ARI-540 temperature specifications are not sufficient for a unique reproducible specification state. The degrees of subcooling must also be specified for a sufficient unique specification. In the Table I above, the subcooling of 20° F is also specified.

The performance of the Bristol compressors are consistent with respect to the constant temperatures of the ARI-540 specifications. Only these ARI-540 test conditions were measured.

Our thermodynamic tests and measurements included the Btu/Hour measured by a thermal calorimeter. Thermodynamic measurements with this thermal calorimeter were variable and unreproducible unless the degrees of subcooling were also measured and controlled. In further tests in this report, where the degrees of subcooling were approximately 15° F, and not recorded and not carefully controlled, the averages of many calorimeter measurements were used, not a single measurement.

Since all tests for the same three-phase compressor, at the same temperatures, same refrigerant, same frequency, and same shaft speed, a single average of all three-phase calorimeter values will be used for each EER calculation for tests at 15° F subcooling.

There is a small difference here in that the single-phase compressor has a slightly larger slip frequency and a slightly larger slip speed, and has a slightly less thermal capacity.

ADDITIONAL TESTS.

Tests 1A, 1B, and 1C were for respectively SemiHex™ Figure 3, SemiHex™ Figure 4 with a phase-adjusting transformer, and Star (Wye) connection of the three windings. The photograph in Figure 8 is the same 6-terminal 3-phase compressor used for all of these tests. An identical set of three tests are designated Tests 1AA, 1BB, and 1CC respectively. The consistency of these measurements can be observed visually.

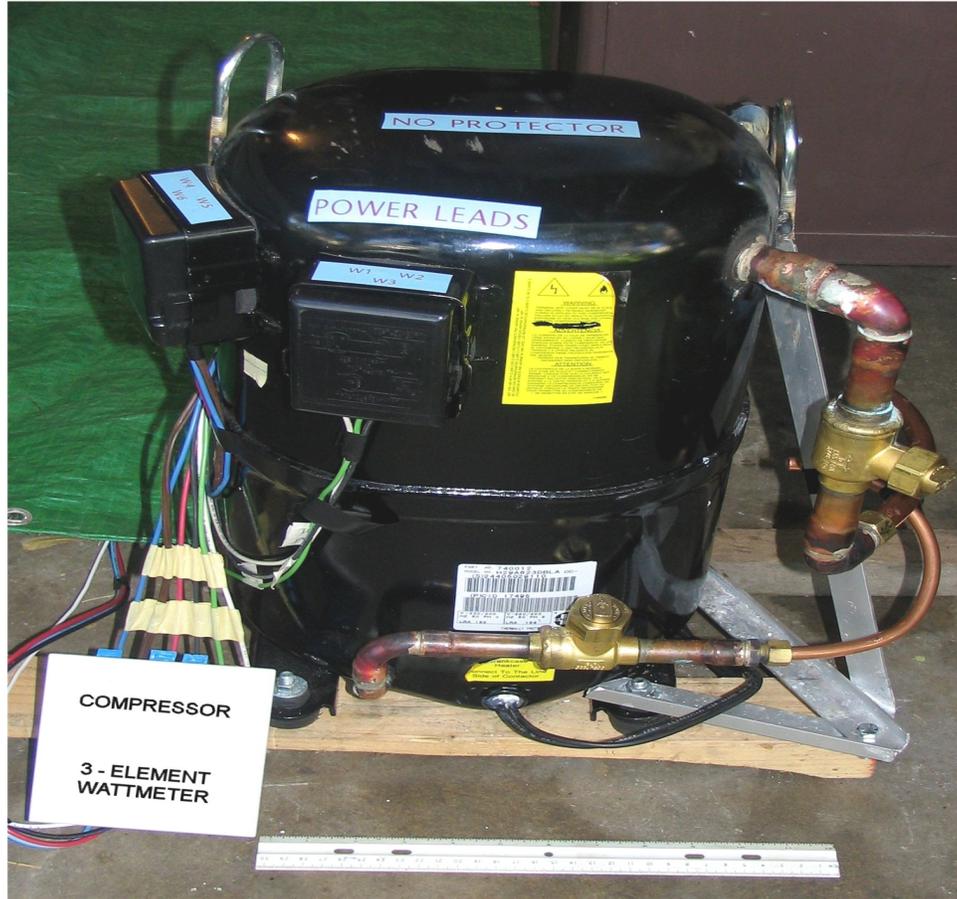


FIGURE 8

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FIGURE 8: 5.4-KW COMPRESSOR WITH ALL WINDING TERMINALS AVAILABLE

The compressor is at the bottom, and the lower output port is the hot high pressure refrigerant fluid. The suction input port is at the top on the right side. The ac motor is in the top part of the enclosure, and all six terminals of the three windings are brought out at the left through the two glass-to-metal bushings with six electrical pins.

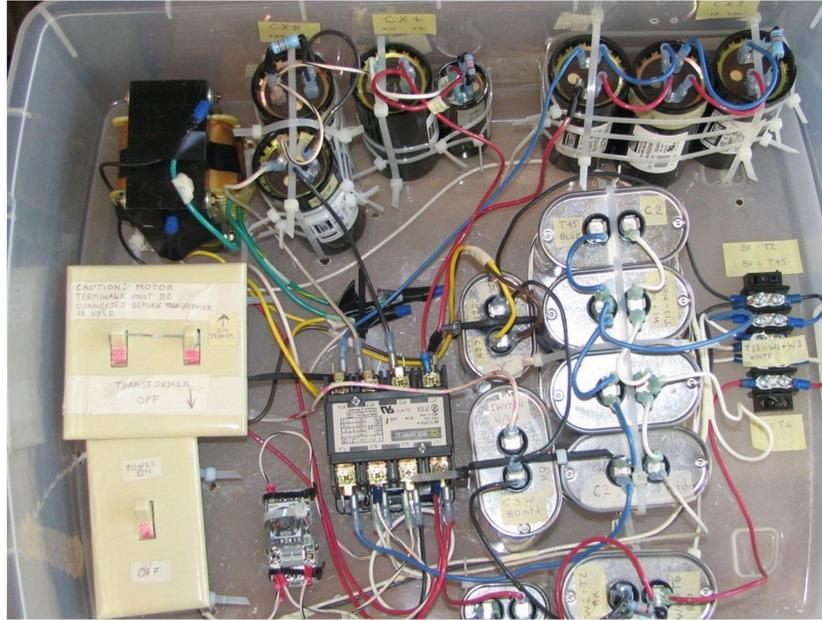


FIGURE 9

SEMI-HEX™ CONTROLS

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FIGURE 9: SEMI-HEX CONTROL CIRCUITS

The starting capacitors are black cylindrical plastic-cased in the upper third of the enclosure. The circular light spot on the top of each is a vent designed to rupture and discharge gasses and a white chemical powder when the capacitor explodes. This is evidence that the industry knows that these electrolytic capacitors are an unsatisfactory weak link in many motor designs.

These start capacitors dissipate kilowatts equal to approximately eight percent of the kilovars, which are large numbers. All of our designs operate these starting capacitors at almost one-half voltage and almost one-fourth watts dissipated. We aim for a 40-year life. The run capacitors are the oval metal capacitors in the lower right. In the lower left is an IDEC adjustable Time-Delay relay with DPDT contacts. The switches were to insert the phase-adjusting transformer for Figure 4, and to remove the transformer for Figure 3. The transformer is in the upper left corner.

A commercial product can be in a much smaller enclosure.

In most of these tests, we measured the three-phase compressor input watts as well as the power-supply single-phase watts which is metered. Figure 10 shows the circuit to connect a

3-element 3-phase wattmeter to a four-terminal electrical load. All four terminals T2, T13, T45, and T6 carry rated winding current of 15 amperes. Any one of these four terminals could be chosen as the voltmeter neutral for the three voltage elements. In Figure 10, I have chosen T13 as the arbitrary neutral for the three voltage elements.

The wattmeter automatically measures the current in the terminal T6 for W6 for winding D.

The wattmeter automatically measures the current in the terminal T2 for W2 for winding B. The current in winding A must be measured independently with an ammeter at W1 or W4.

For the SemiHex™ circuits the motor winding watts were measured using the connection in Figure 10. The Wattmeter A element has approximately 14.8 amperes leading by 1.4 degrees and the voltage “coil” is 230 volts at zero degrees. This is approximately 3,403 watts. The wattmeter C element has approximately 14.8 amperes leading by 61.4 degrees and the voltage “coil” is 133 volts at 90 degrees leading. The angle difference is 28.6 degrees. The wattmeter element C reads 1728 watts, slightly less than half of the reading of the A element. The wattmeter B element is carrying 14.8 amperes at -120 degrees, and the voltage coil is 133 volts at -30 degrees. The phase angle between the voltage and the current is 90 degrees. The wattmeter B reading is $(14.8)(133)[\cos(90)] = (1,968.4)(0.0) = 0.00$. This calculation of the cosine has an error e due to round-off, harmonics, random noise, and the thermal load on the compressor is continuously changing. The B reading is $(1,968)(e)$ which might be 50 watts. The total watts might be $5,132. + 50$. This might be an error of one percent. We would prefer accuracy of twenty times better than this.

Tests 1A and 1AA are for the proposed PRODUCT to be manufactured and sold.

Tests 1B and 1BB are with a phase-adjusting transformer, like Figure 4. This is academically interesting but not economic enough for a Product for sale. The switch for inserting the phase-adjusting transformer in Figure 4 for Tests 1B and 1BB is shown in Figure 14.

Tests 1C and 1CC are with the Star (Wye) connections of the same windings. This displays the characteristics and advantages of the motor that is being utilized in Tests 1A and 1AA.

A different 3-terminal 3-phase motor with the same size compressor is hermetically sealed into the enclosure which was used for all other tests listed below.

Test 1D is for a three-phase 3-terminal motor on a balanced 3-phase supply.

Tests 1E and 1F are the 3-terminal compressor connected to a single-phase supply through an Enabler^R with a 3-kva transformer. This circuit is shown in Figure 11.

Test 1G is of the same compressor with a single-phase motor on a single-phase supply.
 All of the A tests were with the Semi-Hex™ electrical connections shown in Figure 3, and recommended for a commercial Product.

FOUR-WIRE THREE-PHASE WATTMETER CONNECTIONS

SEMI-HEX™ COMPRESSOR CONNECTIONS

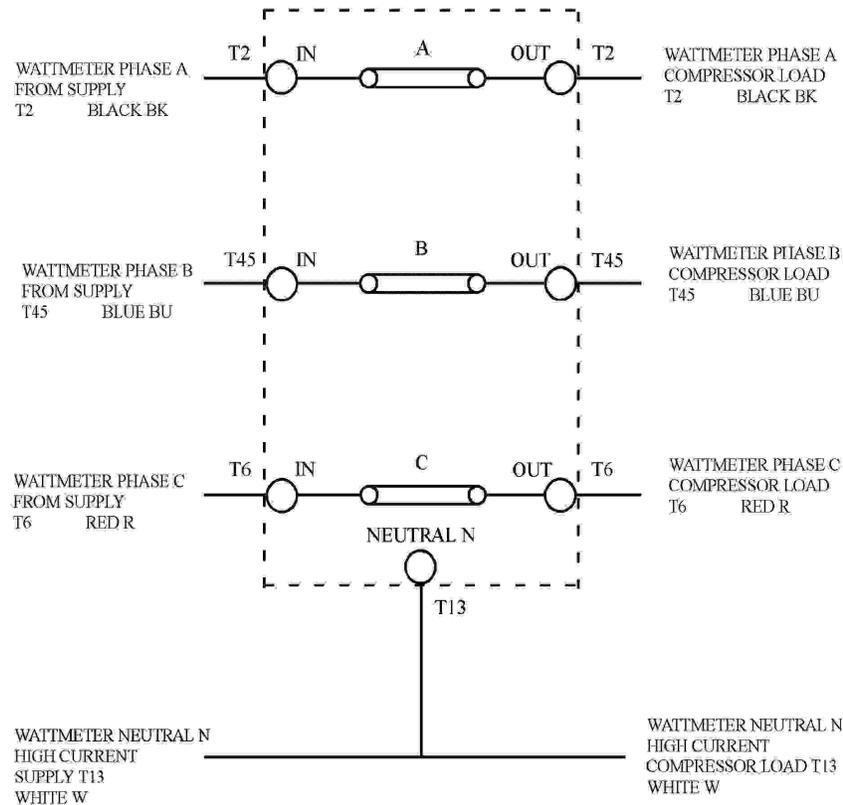


FIGURE 10

WATTMETER VOLTAGE ELEMENTS

PHASE A to N	230 VOLTS
T2 to T13	
PHASE B to N	133 VOLTS
T45 to T13	
PHASE C to N	133 VOLTS
T6 to T13	

All leads, including the neutral N, carry starting current.

FIGURE 10: THREE-ELEMENT THREE-PHASE WATTMETER

Test 1D is one base-line Star 3-Phase test. The measured Btu/Hour cooling mode was measured at the ARI-540 Calorimeter conditions. The input wattages will be different for the additional tests with different electrical circuits.

TABLE VII
SUMMARY AND GUIDE, TEN SYSTEMS

<u>Test</u>	<u>Figure</u>	<u>Winding Current % unbalanced</u>	<u>line % leading power factor</u>	<u>1-phase line watts</u>	<u>3-phase line watts</u>
1A	3, SemiHex	9.159%	+ 81.2845%	5,053.55	
1B	4, SemiHex	18.45%	+ 76.3254%	5,073.025	
1C	Star, 3-Phase	8.004%	-87.742 LAG		5,197.50
1AA	3, SemiHex	8.23%	+ 81.34%	5,050.1	
1BB	4, SemiHex	7.61%	+ 77.91%	5,069.6	
1CC	Star, 3-Phase	5.479%	-87.02 LAG		5,187.5
1D	Star, 3- Phase	1.821%	-88.18 LAG		5,264.25
Average of CC and D	Star, 3- Phase	~ 3.65%	-87.60 LAG		5,225.87
1DD	Star				5,198.75
1E	11, 3-terminal	5.847%	+87.96% LEAD	5,451.5	
1F	11, 3-terminal	22.93%	+91.79% LEAD	5,441.75	
1G	1-Phase		-98.28% LAG	5,580.25	

ELECTRICITY COST is reduced by the lower watts input of the single-phase Semi-Hex connection.

Minimum current imbalance is best for the product.

Minimum LEADING Power-Factor is best for the power company.

Current Imbalance is another way of saying Unbalanced Currents.

TABLE VIII
BTU/HOUR CALORIMETER MEASURE

<u>Test</u>	<u>Name</u>	<u>Figure</u>	<u>1-Phase Watts</u>	<u>3-Phase Watts</u>	<u>Btu/Hour 20° F SUBCOOL</u>	<u>EER Measured btu/hr</u>
-------------	-------------	---------------	--------------------------	--------------------------	-----------------------------------	------------------------------------

1A	SemiHex	3	5,053.55		56,545.082	11.1892
1B	SemiHex	4	5,073.025		56,260.236	11.0901
1C	3-Phase, 4 terminals			5,197.50	56,546.585	10.8796
					<u>Btu/Hour 15°F</u> <u>SUBCOOL</u>	<u>EER</u> <u>Averaged</u> <u>btu/hr</u>
1AA	SemiHex	3	5,050.1		54,906.09	11.359
1BB	SemiHex	4	5,069.6		55,423.42	11.315
1CC	3-Phase, 4 terminals			5,187.5	56,492.754	11.058
1D	3-Phase, 3 terminals			5,264.25	60,623.97	10.897
11	3 TERM		5,451.5		58,370.930	10.522
11	3 TERM		5,441.75		<u>58,357.680</u>	10.541
AVERAGE OF ALL THREE-WINDING MEASURES 15°F					57,362.474	

Our Base-Line Btu/Hour is:

BTU/HOUR CALORIMETER MEASURE = **57,362.474** Btu/(Hour), all 15° F Subcooling mode. (Three-Phase above.)

SINGLE-PHASE MOTOR ALONE

BTU/HOUR CALORIMETER MEASURE

<u>Test</u>	<u>Name</u>		<u>1-Phase</u> <u>Watts</u>		<u>Btu/Hour 20° F</u> <u>SUBCOOL</u>	<u>EER</u> <u>Measured</u> <u>btu/hr</u>
1G	Single-Phase		5,580.25		56,961.46	10.2077

The single-phase motor delivers 0.7% less calories, partially because the shaft speed is approximately 99.3% of the three-phase motor full-load shaft speed.

The single-phase EER is 10.2077

MOTOR WINDING MEASURES

With the SemiHex™ connection, for Tests 1A, 1B, 1AA, and 1BB, the three-phase measures for the motor windings used the three-element three-phase wattmeter connection shown in Figure 10 for the values listed in Table I. For Tests 1A and 1AA on Figure 3, there was no transformer and this would be the standard for a product. Tests 1B and 1BB on Figure 4 used a small phase-adjusting transformer, and this was shown to be undesirable because of the losses in this small transformer.

Figure 11 for Tests 1E and 1F used a power transformer on a Star-connected 3-terminal compressor motor. This method has been used on a large center-pivot irrigation motor. For rural and agriculture applications, this is satisfactory for water pumps, chillers and freezers.

Residential and urban locations have space constraints to be considered. The SemiHex™ connection to a 4-terminal motor is preferable, as in Figure 3 and Table I.

When a three-terminal Star motor is required, the transformer in Figure 11 can be replaced by a proprietary invention of an electronic solid-state replacement for the transformer, with higher efficiency and smaller space. This is beyond the scope of this present report.

This report Test 1E on Figure 11 showed satisfactory EER values. Test 1F was an example of robustness, typical of all Enablers^R and Phase-Able^R systems.

TABLE IX
3-TERMINAL PERFORMANCE ON SINGLE-PHASE SUPPLY
FIGURE 11 STAR + TRANSFORMER ARI TESTS 1E and 1F

	MFD CTT	<u>1-Phase Meter</u>		<u>3-Phase Meter</u>		<u>Unbalance</u>		<u>WATTS</u>	<u>EER</u>
		Amps	PF%-Lead	Volt	Amp	%v	%a		
Correct Design	400	27.04	87.96	130.1v	15.12	4.02	5.85	5,260.4	10.9046
Sensitivity to MFD	320	24.28	91.79	132.7v	17.11	6.64	22.93	5,279.2	10.8658

Row 1 is the Correct Design.

Row 2 shows sensitivity to Capacitance.

Percent change in Microfarads = - 20%. Percentage change in EER = - 0.356%.

These tests show low sensitivity to parameter changes, and high robustness.

These tests show that a 3-electrical-terminal compressor can be operated satisfactorily with an Enabler connection to single-phase supply. The transformer losses respectively were 206 watts, 4.1%; and 225 watts, 4.5%.

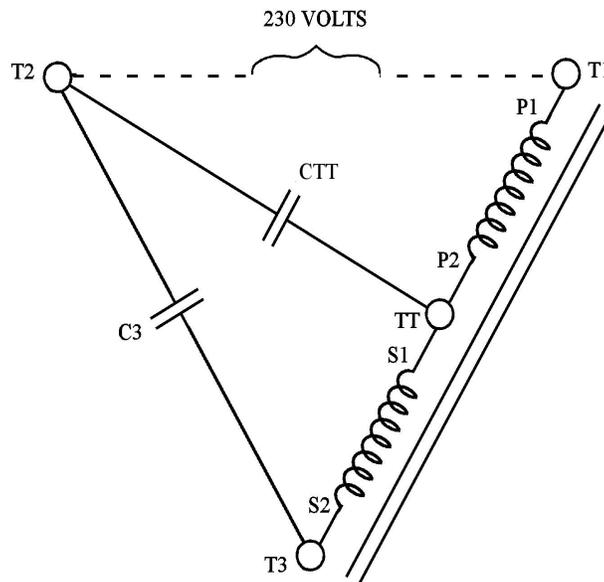


FIGURE 11

TRANSFORMER INJECTION
FOR 3-TERMINAL STAR COMPRESSOR

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FIGURE 11: TRANSFORMER INJECTION FOR 3-TERMINAL STAR COMPRESSOR

Run Capacitor CTT injects a current I_{30} into T3 which lags the line-to-neutral voltage by 30 degrees and has an 86.6% power-factor. Run capacitor C3 injects a current I_{60} which has a 50% power-factor and lags the voltage by 60 degrees. For the Bristol compressors, C3 is zero, I_{30} is 14.8 amps, and CTT carries 29.6 amperes. $CTT = (10^6)(29.6) / [200 \times 377] = 395$ mfd.

The SemiHex connection with four terminals is superior to the Star connection in cost and efficiency. Four-pin bushings in the wall of the compressor enclosure are available. Figure 12 shows photographs. Figure 13 has dimensional drawings.



FIGURE 12
PHOTOGRAPHS OF 4-TERMINAL FUSITE BUSHING

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FIGURE 12: PHOTOGRAPHS OF 4-TERMINAL FUSITE BUSHING

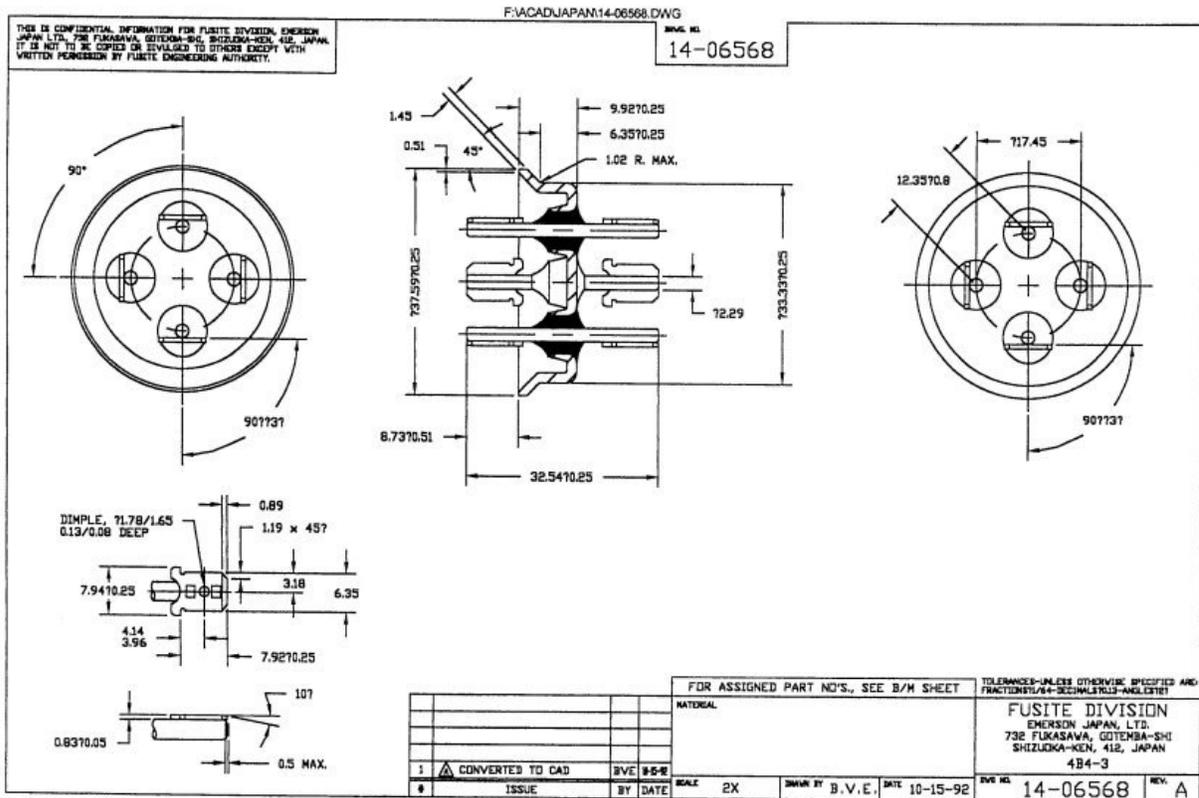


FIGURE 13
DIMENSIONAL DRAWING OF A 4-TERMINAL FUSITE BUSHING

FIGURE 13: DIMENSIONAL DRAWING OF 4-TERMINAL FUSITE BUSHING

Figure 14 has the circuits for the switches at the left in Figure 9 and the circuits in Figure 4 for inserting and removing the phase-adjusting transformer. When the switches are in the “up” position, both CST and CTT are in parallel, and are connected between TT and T2. The sum is 117 microfarads, which is injecting into the transformer a high-power-factor current I25 which lags the voltage by 25.6 degrees. C30 of 60 mfd is injecting a 30-degree lagging current I30 into T6. The sum of these two current components lags the winding voltage by 28.6 degrees.

When the switches are in the “down” position, TT and S4 are both disconnected and the transformer is removed from the circuit. CST is in parallel with C30. The sum is 152.5 microfarads. This injects a different I30 into T6 for the circuit for the injected current of 14.8 amperes at the approximate lag angle of 30 degrees.

When the run capacitors are packaged in a single can to save cost, there will be four terminals. The required rated voltages between these four terminals are shown in Figure 15. The actual voltages in an installed system are larger than the design voltage of 230 volts. Here in Berkeley, the supplied voltage is usually 242 volts, and can be above 250 volts for switching conditions.

Our air-conditioners must be capable of withstanding these conditions. We should design for a safety margin of ten percent. Ten percent overvoltage on each winding is 146 volts. Capacitor can ratings of 150 volts are reasonable. The nominal voltage from T2 to T6 is 266 volts.

Ten percent safety margin is 300 volts rating between T2 and T6 in Figure 15.

CIRCUIT CONNECTIONS FOR PHASE-ADJUSTING
TRANSFORMER IN FIGURE 4

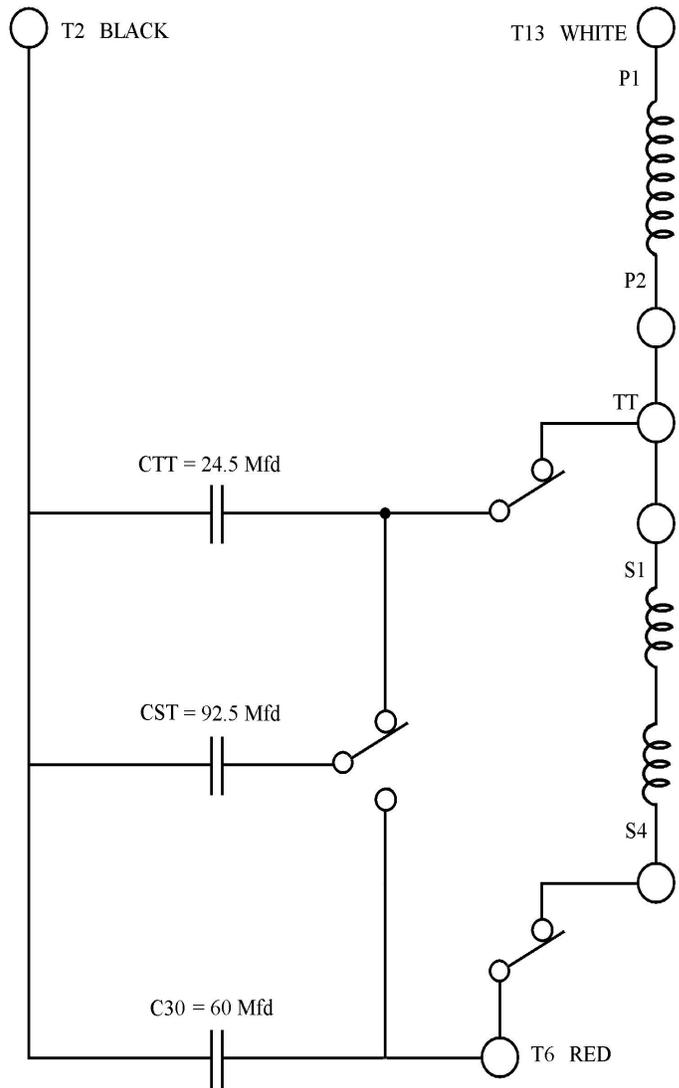
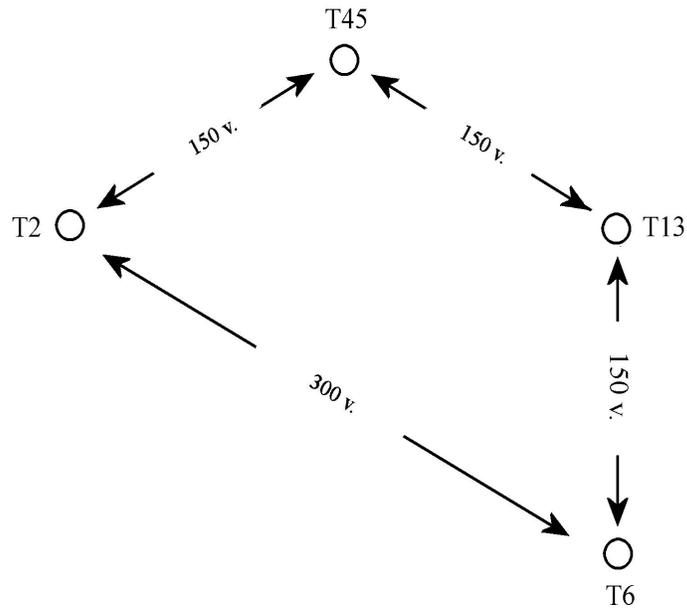


FIGURE 14

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FIGURE 14: SWITCH TO INSERT TRANSFORMER FOR FIGURE 4



VOLTAGE RATINGS ON A
4-TERMINAL RUN-CAPACITOR CAN

VC1 = 300v. (T2 to T6)
VC2 = 150v. (T13 to T45)

FIGURE 15

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FIGURE 15: VOLTAGE RATINGS ON A 4-TERMINAL RUN-CAPACITOR CAN

STARTING METHODS

U.S. Patent No. 6,049,188, issued April 11, 2000, to O. J. M. Smith, titled: “*Single-Phase Motor Starters*”, and U.S. Patent No. 7,023,167, issued April 4, 2006, to O. J. M. Smith, titled “*Control Arrangement for an Induction Motor Compressor Having at Least Three Windings, a Torque-Augmentation Circuit, a Starting Capacitor and a Resistive Element,*” contain circuits with Positive Temperature Coefficient Thermistors, PTC, for starting, circuits with starting capacitors, and circuits combining PTC with starting capacitors. These methods will not be discussed herein.

In motels, one can find a warning notice adjacent to the ON-OFF switch, that if the air-conditioner is manually turned off, one should wait several minutes before manually turning the air-conditioner back on. Otherwise, attempting to turn-on the air conditioner against high back pressure in the output of the compressor will trip the circuit breaker, and the air-conditioner might not start.

The referenced patents have methods for achieving higher torques with capacitors that increase the air-gap fluxes to values that are larger than normal, and correspondingly augmented larger torques. These methods are useful for situations of a motor starting against high static back pressure.

There is an advantage in new systems to have sufficient starting torque at low line voltages and satisfactory currents to be able to start against the high back pressure at the compressor.

This report is directed to achieve maximum starting torque and locked-rotor balanced voltages and balanced winding currents.

In Figure 2, starting capacitor CX3 of 858 mfd. delivers the major starting torque. In Figure 3, the additional Capacitor CX4 of 328 mfd. adjusts the phase angle of the injected starting current so that the motor winding currents and voltages are better balanced on locked-rotor. Shaft starting torque is the nameplate torque for three-phase balanced full voltage of 230 volts.

Figure 2, CX3 = 858 mfd,
CX9 = 517 mfd.

Figure 3, CX2 = 858 mfd,
CX4 = 328 mfd,
CX8 = 397 mfd.

Capacitors CX9 in Figure 2 and CX8 in Figure 3 have no influence on the locked-rotor conditions in the motor. CX8 adjusts the phase angle of the current provided by the power company, so that the power-company current is minimized. Also CX8 improves the customer’s observation of undesired spikes and pulse darkening on electrical circuits close to the air conditioner.

The starting performance for Figure 3 is summarized in Table X.

The power-company line sees a RATIO of starting current to line current of 2.89

The motor windings have a RATIO of starting current to load current of 7.98
 The Semi-Hex™ electrical connection has made an improvement of more than two and a half in this RATIO for the power supply.
 For a reduced-cost starter, one could use a single CX3 of 1000 mfd or less.
 Less capacitance is lower torque, higher line current, and less cost.

TABLE X
 LOCKED-ROTOR PERFORMANCE FOR FIGURE 3

Locked-Rotor LR winding currents =	116 amperes,
LR motor watts =	15,008. Watts
LR motor Volt-Amperes =	46,211. va
LR motor power-factor =	32.48% lagging,
LR lag angle Φ =	-71.048° degrees
LR Supply Line Current, LRA, =	78 amperes.
LR Supply Line Power =	17,600 watts
LR Supply Line Power-Factor =	98% percent power-factor.
RLA, rated load line amps, =	26.96 amperes.
RATIO of (LRA) / (RLA)	2.89 = 78/26.96
INTERNAL WINDING AMPERES,	
LRA	116 a
Rated-load Table I, =	14.53 a
RATIO of (LRA)/(RLA) =	7.98 = 116/14.53

STARTING DESIGN

Our currents will be described as vectors or phasors, with respect to a voltage vector or phasor with a phase angle of zero degrees.

The reference voltage is the voltage across winding D from w6 to w3.

Full load current vector is FLA (or Rated Load Current, RLA) at a lagging angle of (a).

FLA \angle -(a) = real current component - j (quadrature current component.)

FLA \angle -(a) = (ir) - j (iq)

$(ir)^2 + (iq)^2 = (FLA)^2$

(ir) = (FLA)(cos a)

(iq) = (FLA)(sin a)

The RUN capacitors deliver this { (ir) - j (iq) } into terminal w6 of winding D.

LOCKED-ROTOR CURRENT.

The vector or phasor Locked-Rotor current is LRA at a lagging angle of (b).

$LRA \angle(b) = \text{real current component} - j (\text{quadrature current component.})$

$$LRA \angle(b) = (I_r) - j (I_q)$$

$$(I_r)^2 + (I_q)^2 = (LRA)^2$$

$$(I_r) = (LRA)(\cos b)$$

$$(I_q) = (LRA)(\sin b)$$

To create this current (LRA), we will define and generate an eXtra current made by the electrolytic starting capacitors. This eXtra current is

$$X = LRA \angle(b) - FLA \angle(a) = (I_r) - j (I_q) - \{ (i_r) - j (i_q) \} = X_r - j X_q.$$

$$X_r = (I_r) - (i_r)$$

$$X_q = (I_q) - (i_q)$$

The phase angle of lag of this X current is $\beta = \tan^{-1} (X_q / (X_r))$

The magnitude of X in amperes satisfies $| X |^2 = (X_r)^2 + (X_q)^2$

$$| X | = [|(X_r)^2 + (X_q)^2 |^{0.5}]$$

The angle β is different than the locked-rotor angle (b), because the run capacitors are left connected, and consequently the starting capacitors are much smaller than those derived from LRA alone. With the starting capacitors delivering current X, and the RUN capacitors delivering $\{ (i_r) - j (i_q) \}$ into terminal w6 of winding D, the total input to winding D is LRA.

FIGURE 3 EXAMPLE

From Table II,

$$FLA \angle(a) = (i_r) - j (i_q) \text{ becomes } 14.784 \angle -28.667^\circ = (12.972) - j (7.09224) \text{ amperes.}$$

From Table X,

$$LRA \angle(b) = (I_r) - j (I_q) \text{ becomes } 116 \angle -71.05^\circ = (37.67) - j (109.713) \text{ amperes.}$$

$$X \angle-\beta = X_r - j X_q = 24.698 - j 102.621. \text{ amperes.}$$

$$\beta = - \text{atan} (102.621 / 24.698) = - 76.47^\circ \text{ degrees.}$$

$$| X | = 105.551 \text{ amps.}$$

Assume that half of the current is provided by a capacitor across 230 volts and half of the current is provided by a capacitor across 133 volts. Together these contribute + j vars of 19,158 and also electrolytic losses of approximately 1,500 watts. Converted to equivalent line current, this is approximately 3.8 real amperes (loss) in each phase. This loss will be added to the X phasor above.

$$\text{Modified } X \angle-\beta = X_r - j X_q = 28.498 - j 102.621.$$

$$\beta = - \text{atan} (102.621 / 28.498) = - 74.48^\circ$$

$$| X | = 106.504 \text{ amps.}$$

This X current will be resolved into two oblique coordinates of - 60 degrees and - 90 degrees.

$$X_{60} = (2 \times 106.504) [\sin (90 - 74.48)] = 56.996 \text{ amps.}$$

$$X_{90} = (213.008) [\sin (74.48 - 60)] = 53.261 \text{ amps.}$$

The starting capacitors are

$$CX_{60} = 56.996 \times 10^6 / (230 \times 377) = 657.3 \text{ mfd.}$$

$$CX_{90} = 53.261 \times 10^6 / (133 \times 377) = 1,062 \text{ mfd.}$$

In Fig. 3, use the correct size of CX₆₀ of 657.3 mfd to replace the CX₃ preliminary value of 858.

Use the correct value of CX₉₀ of 1,062 mfd instead of the CX₄ preliminary value of 328.

These equations can yield the maximum LR starting torque. However, due to fifth-harmonic flux distortions in the air-gap, there can be a large negative torque at one-fifth shaft speed, so that the “pull-up” torque is less than the locked-rotor torque.

If the load curve of torque is less than the locked-rotor torque, and the pull-up torque required is more than the pull-up torque generated at one-fifth speed, then the shaft can not go above this one-fifth speed, called the “crawling” speed.

One optimum design is to have the X current produce a torque larger than the required “pull-up” torque of the known load at one-fifth speed.

Other design methods are given in the Appendix.

In test 1G, the run plus starting capacitors connected to the quadrature winding sum to approximately 350 microfarads. These start this compressor.

In test 1A, the run plus starting capacitors connected to terminal W₆ of winding D sum to 1525 microfarads. These produce maximum starting torque. The compressor does not need this high starting torque. This design is an “over-kill” of more than a factor of four.

One electrolytic starting capacitor of 290 microfarads in CX₃ might be sufficient for starting, because the run capacitor C₁ of 150 mfd is also connected.

COSTS OF CAPACITORS

The run capacitors are a significant component of total cost. Capacitor manufacturers have suggested that they could provide two or three run capacitors in a single can, with only four electrical terminals (bushings) at a significant reduction in the costs for OEM purchases. The voltages are shown in Figure 15 for capacitors C₁ and C₂.

Smaller sizes of air-conditioner motors will have lower power factors, and the capacitor banks will have a third capacitor, C₃, connected between T₄₅ and T₆. The labor savings of having all capacitors in a single can is important. Note that the capacitor C₁ from T₂ to T₆ is in series with the capacitor C₃ from T₆ to T₄₅, and continuing in series with the capacitor C₂ from T₄₅ to T₁₃, so that the series connection of these three capacitors is across the power line from T₂ to T₁. This bank “shorts out” the harmonic distortions in the power-supply voltage, and also “shorts out” the harmonic distortions generated by the compressor motor itself, so that the voltages are improved, and some harmonic distortion losses are reduced, increasing the system efficiency.

Conclusions

Single-phase air-conditioners more than one kilowatt, more than 10,000 BTU/hour of cooling capacity, can benefit from these Semi-Hex™ connections which have lower electricity costs and lower current pulses in the residential systems. Each of these new single-phase air-conditioners can be sold with a three-phase motor in the hermetically-sealed chamber with the compressor. The initial cost can be less for both the manufacturer and the customer. The reliability and robustness of this system is better than the single-phase systems now provided and used.

The power-company sees the beneficial leading power-factor of this load current, not the detrimental lagging power-factor in the motor. The power-company will have less large-current pulses due to motor startings. These new systems have lower harmonic, pulse, and spike distortion, and less voltage sag at full load. All components are readily available at reasonable costs.

Manufacturers can provide higher quality units at lower cost than now, and at a higher profit for the manufacturer. A new product requires an initial capital investment or cost, for tooling, for catalogs, for service instructions, for service manuals, and for educating the engineering staff.

Recommendations

All single-phase air conditioners can and should use three-phase-motor compressors, whenever available. High Efficiency and High EER achieved with low-cost run-capacitors is more economic than the high costs of much larger grills and fans.

Above one kilo-watt electric, this generalization holds up through 6 kilowatts to 10 kilowatts. In the largest sizes not usually sold for a single-phase supply, the indoor and outdoor fans would be three-phase fans, each with its own enabler to connect it to the single-phase supply.

There is a need for a national testing laboratory to certify air-conditioning compressor efficiencies.

All electrical measurements and calibrations could be traceable to NIST, our national “Bureau of Standards”. Regulated ac power-supplies should be large enough to supply starting currents of several times rated current without any voltage decrease at the variac output and input to the air-conditioner.

A new facility should be available to state commissions, customers, and manufacturers. It should be independent of manufacturers, to provide independent corroboration of claimed efficiencies and EER. It should have a competent staff of Registered Professional Engineers in fields of Thermodynamics, Circuits, Motors, Controls, and Electrical Power. It should have a large 24-hour competent staff of engineers to make continuous data recording runs of 24 hours and 36 hours. It should have adequate funding to provide test results in a timely manner for air-conditioning companies.

Public Benefits to California

The new customers of Semi-HexTM and three-phase motors in single-phase air conditioners connected to single-phase residential supplies will pay less for electricity than with single-phase motors. These new air-conditioners do not make the lights flicker on starting, and the full-load voltage on computers does not change with the air-conditioning load. The new customers can compare their quiet systems to the vibration and noisy systems and light flickers of their neighbors. Presently, in motels, the single-phase air-conditioners can be so noisy that the customer might rather be overheated than subjected to the noise. Presently, motel air-conditioners can not be manually turned off and immediately turned on again. Our new systems can restart against high back pressure in the compressor.

The power company might be enthusiastic about these new high-power-factor current loads. We tested **81% leading** current-power-factor. This will partially compensate for the lagging power-factor of all nearby refrigerators, freezers, furnace fans, washers and dryers, pumps, and neighbors' air conditioners. The distribution efficiency of the power-company is increased by our Phase-Able^R and Enabler^R systems. The leading power-factor in the power line almost eliminates any voltage sag between no-load and full-load.

The power-company will see a reduced rate of increase in load due to these new air-conditioning loads, which reduction could be beneficial to long-term planning.

Higher-efficiency air-conditioners will produce less global warming than the replaced low-efficiency single-phase compressors would have produced.

A most important public benefit is that three-phase motors in single-phase air-conditioners can reduce electricity costs by **9.6%** of the electricity bill for 60,000 BTU/Hour of cooling. Similar savings can apply to new units of other sizes.

Assume that with unprecedentedly increased air temperatures in the last several years, that the growth rate of new AC installations in California is now 1.5% per year. Using EIA estimates, the growth value of AC load in 2006 would be 676 million dollars annually. Assume market penetration of 50%. Assume average Enabler savings of 7% for all sizes.

The Enabler saving in the first year 2007 would be 23.66 million dollars, M\$. The second year savings would be $24.015 + 23.66 = 47.675$ M\$. The third year savings would be $24.375 + 47.675 = 72.050$ M\$. The tenth year savings would be 293.227 M\$. The sum of all ten-year savings would be 1,430.65 M\$, which is 1.4 billion dollars.

Economists can measure growth rates and electrical rate schedules and document the savings.

The air-conditioning system includes both the air-conditioner and the electrical power system which provides the electricity. Beneficial to the air-conditioning system is increased generation from wind turbines and from economic solar-electric systems.

Radiative heat rejection in the first two references below can increase the power capabilities of a Rankine-cycle steam-turbine system.

The air-conditioning system includes both the air-conditioner and the electrical power system which provides the electricity. Many power-plants discharge their condensate heat into a cooling pond or a river or a bay, contributing to global warming, and modifying the ecology of the water. These condensate temperatures are all influenced by global warming and heat storms and heat waves.

Condensate high temperatures reduce the efficiencies and reduce the available electrical power from all power plants which use steam and have a condenser. All coal, oil, and nearly all gas electrical power plants can have their power capabilities increased by decreasing the temperature of the exhaust from the low-pressure turbine into the cold condenser.

The component that can add high reliability to the electrical output of the power plant is a radiative heat rejection from the condenser instead of, or modifying, the conventional cooling pond. The infra-red radiation is from a thin colloidal suspension or emulsion film of Titanium Dioxide in light oil floating on the cooling water to be cooled for several days of base-load operation.

This Infra-red radiation at night is in equilibrium with cold interstellar space and intervening clouds. This is beneficial in all operating conditions, and particularly valuable during heat storms and heat waves, when the power systems have rolling blackouts disconnecting the air conditioners.

Radiative heat rejection should be studied and implemented to increase the efficiencies of most Rankine-cycle turbines generating electricity particularly during heat storms. The importance of air conditioning is reflected in the facts that nearly 80% of U.S. homes have air conditioning and one-sixth of the annual residential electricity consumed is for air conditioning.

The electrical supply portion of the air-conditioning system should include augmented support for non-polluting electrical supplies like wind-turbine farms and large solar-thermal-electric base-load installations.

These appendices have lists of engineering measurements pertinent to the comments above.

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- 17 Web Site: <http://phaseable.com>

Glossary

ARI	Air-Conditioning and Refrigeration Institute
ARI Standard 540-1999	Published Standardized Calorimetric Tests.
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.,
A	Phase A, one winding of a Star connection.
B	Phase B, a second winding of a Star connection.
BTU	British Thermal Unit (of energy) = (0.293,071,070 E ⁻⁰³) watt-hours.
C	Run Capacitor, metallized polypropylene.

COP	Coefficient Of Performance = $(0.293071) \times \text{EER}$.
CX	Capacitor for starting, electrolytic.
D	Phase D, a third winding of a Star connection.
D	Driven winding.
EER	Energy Efficiency Ratio = $(\text{BTU}/\text{Hour}) / (\text{Electrical Watts})$
EER	Energy Efficiency Ratio = $(\text{BTU}) / (\text{Watt-Hours})$
EER =	$(3.412,141,635) \times (\text{COP})$
Φ =	the phase angle between sinusoidal volts and amperes.
IT	Interval Timer.
I25	Current magnitudes of phasors 25.6-degrees from the voltage reference phasor.
I30	Current magnitudes of phasors 30-degrees from the voltage reference phasor.
I60	Current magnitudes of phasors 60-degrees from the voltage reference phasor.
I90	Current magnitudes of phasors 90-degrees from the voltage reference phasor.
KW	Kilo-Watts = 1000 watts.
LR	L ocked- R otor, shaft at stand-still.
LRA	Locked-Rotor Amperes
LR-SLA	Locked-Rotor Supply Line Amperes
LR-Torque	Locked-Rotor Torque, either Newton-Meters, Pound-Feet (lb.-ft.), or Watts/RPM.
LR-WA	Locked-Rotor Winding Amperes.
MD	M ax D ifference = $\text{MAX}\{ (V_{\text{AVE}} - V_1) , (V_{\text{AVE}} - V_2) , (V_{\text{AVE}} - V_3) \}$
MFD	Microfarads of capacitance value.
Oblique	Graphical coordinates who are not 90-degrees apart, not orthogonal.
PR	P otential R elay
$(P + j Q)$	Electrical Complex Power = watts + j vars
$(P - j Q)_M$	Electrical Complex Power of Motor.
$(P - j Q)_L$	Electrical Complex Power of Power-Line
RLA	Rated Load Amperes
SC	S tarting C ontactor
SLA	Supply Line Amperes
SR	S tarting R atio = $\text{LRA} / \text{RLA} = (\text{Locked-Rotor Amperes}) / (\text{Rated Load Amperes})$
Star	3 windings connected at a point with 120 degrees electrical between the voltages.
Star =	Wye
TDR	T ime- D elay R elay.
TEAR	Temperature Error Average ARI.
Ti	Circuit terminal numbered i.
%ub	Percent unbalance
V	Electrical sinusoidal voltage.
VA	V olt- A mperes, Sinusoidal Voltage x Amperes.
$V_{\text{AVE}} =$	$(+ V_1 + V_2 + V_3) / 3$
Vars =	Volts x Amperes x $\sin \Phi$

Watts = Real power = Volts x Amperes x $\cos \Phi$, where Φ is the phase angle between volts and amperes.
Watts = Real power = projection of phasor amperes on phasor volts.
Wi Winding terminal numbered i.
WV Winding or Leg Voltage.
Wye 3 windings connected at a point with 120 degrees electrical between the voltages.
Wye = Star.
%UB= %ub = % unbalance = $(100) \times (\text{MD}) / V_{\text{AVE}}$, where $V_{\text{AVE}} = (+ V_1 + V_2 + V_3) / 3$;
 and $\text{MD} = \text{MAX}\{ (|V_{\text{AVE}} - V_1|) , (|V_{\text{AVE}} - V_2|) , (|V_{\text{AVE}} - V_3|) \}$

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Appendices

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BIOGRAPHY OF DR. OTTO J. M. SMITH

[http://en.wikipedia.org/wiki/Otto J. M. Smith](http://en.wikipedia.org/wiki/Otto_J._M._Smith)

Dr. Smith is an expert in high-efficiency consumer products, energy, solar and wind electrical systems.

Dr. Smith has supervised research and taught laboratories and lectures in electrical machinery, power systems, solar systems, high voltage, automatic control, economic optimization, industrial electronics, transportation, and interdisciplinary feedback systems.

He has published 150 technical articles and books and 43 patents. His patents are in the fields of electrical motors and generators, conventional power generating electrical plants, solar power plants, test and measurement apparatus, and Rankine-cycle condenser radiative heat rejection. He has been a consultant for hundreds of companies and to several foreign governments.

HONORS

Listed in the “Leaders of the Pack” InTech’s 50 most influential industry innovators since 1774. Dr. Smith invented the Smith Predictor, Posicast controls of resonant systems, and controls of flow and dead-time systems. He is listed along with James Watt, Wright brothers,

Siemens brothers, and Leeds and Northrup. **InTech, 50-th Anniversary Issue 01 August 2003.** Instrument Society of America, 67 Alexander Drive, Research Triangle Park, NC 27709, USA, 1(919)549-8411.

R&D100 Award for one of the most technologically significant new products of the 1999 year.

Fellow, American Association for the Advancement of Science.

Fellow, Institute of Electrical and Electronics Engineers.

Guggenheim Fellow

Visiting Research Fellow in Economics and Engineering, Monash University, Victoria, Australia.

Honor Societies Sigma Xi, Phi Kappa Phi, Tau Beta Pi (Engr.), Phi Lambda Upsilon (Chemistry), and Eta Kappa Nu (EE).

CHRONOLOGY OF APPOINTMENTS:

Research Engineer, Smith and Sun^R, 1988 to present.

Professor Emeritus of Electrical Engineering and Computer Sciences, University of California at Berkeley. He has been continuously on the University of California faculty since 1947. He became Emeritus in 1988.

Professor, Escola Federal de Engenharia de Itajubá, Itajubá, Minas Gerais, Brasil, March-Sept., 1974. Taught Post-Graduate courses in power system planning and system stability.

Visiting Professor, Technical University Eindhoven, The Netherlands, Jan.-Feb., 1974.

NSF Appointee, U.S.-Romania Cooperative Science Program. Sept.-Dec., 1973. Academia Studii Economica and Institutui Studii si Proiectari Energetici. Optimum long-term economic planning.

Visiting Lecturer, Escola Federal de Engenharia de Itajubá, Itajubá, Minas Gerais, Brasil, and University of Chile, Santiago, Chile, 1971.

Senior Research Fellow in Economics and Engineering, Monash University, Melbourne, State of Victoria, Australia, 1966-1967.

Guggenheim Fellow, Technische Hochschule Darmstadt, Germany, 1960.

Professor, Instituto Tecnológico de Aeronáutica, São José dos Campos, Estado de São Paulo, Brasil. 1954-56.

Research Engineer, Summit Corporation, Scranton, Pennsylvania, 1945-1947.

Research Engineer, Westinghouse Research Laboratories, Forest Hill, Pennsylvania 1944-1945.

Assistant Professor, Denver University, 1943-1944, taught microwaves and automatic control.

Instructor, Electrical Engineering, Tufts University, Medford, Massachusetts 1941-1943.

Taught Machinery, Power, High Voltage, High Voltage Laboratory, and Circuits.

Test Engineer, Doble Engineering Company, Medford, Massachusetts. Insulation power-factor and 30-KV losses testing of high-voltage transformers, generator windings, circuit breakers, cables, current transformers, and bushings. 1941-1943.

Research Assistant, H. J. Ryan High-Voltage Laboratory, Stanford University, Stanford California, 1938-1941, 2-million-volt AC tests, 1-million-volt DC tests, and corona studies.

Test Engineer, Southwestern Light & Power Company, Lawton, OK, 1937 summer. Tested 30 KV high-voltage dielectric losses and rebuilt capacitor bushings up to 100 KV.

DEGREES

Ph.D. in Power and High Voltage, Stanford University, 1941.

B.S. in Electrical Engineering, University of Oklahoma, Norman, 1938.

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PROFESSIONAL

Registered Professional Engineer, State of California, E666.

Inventor of Synthesized Wave-Forms and Hewlett-Packard's Low-Frequency Sine-Function Generators.

Inventor of the control system that Enables a high-efficiency three-phase motor to operate from a single-phase supply. PhaseAble^R Enabler^R is used on large motors up to 100 HP.

Inventor of Control-Stabilized Parallel-Inverter (Ignitrons) for the Lawrence Berkeley National Laboratory LBNL Bevatron used for the life of the Bevatron.

Inventor of Variable-Speed Constant-Frequency Wind-Turbine Generators.

Inventor of Posicast Control for Stepping Motors.

Inventor of Westinghouse's X-Ray Thickness Gauge for steel rolling mills.

Inventor of Optimal AC-Power Transmission System Stabilization Methods.

Author of "Feedack Control Systems", McGraw-Hill 1958. Russian and Chinese translations available.

Author, "Workable Alternative Energy Sources", 6th Information Transfer Meeting Conference Proceedings, Minerals Management Service U.S. Department of the Interior, Sept. 1991, pages 69-75 and 112-130.

Chief of Party of an EPA team studying District Heating and Energy Efficiency in Krakow, Poland, 1992. Jointly with Polish Academy of Economics.

Listed in American Men and Women in Science, page 853. Listed in Who's Who in Science and Engineering. Listed in Who's Who in Finance and Business.

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Hewlett-Packard Note:

William R. Hewlett died January 12, 2001, at the age of 87. He invented resistance-capacitance tuned oscillators which were the foundation of the Hewlett-Packard company. A revolutionary concept, synthesized wave forms, was invented in 1948 by Dr. Otto J. M. Smith resulting in U.S. Patent No. 2,748,278, issued May 29, 1956.

These Smith sine-function generators contributed substantially to the economic success of the HP company. The Smith sine-function generators were the foundation for over 14 models, the HP Models 202A, 203A, 3245A, 3300A, 3302A, 3312A, 3314A, 3325A, 3325B, 3326A, 8111A, 8116A, 8165A, and 8904A. These have had a spectacularly long life, over 50 years, and will live for 100 years more because this is the best way to generate sine-function and triangle waves. These models use a square-wave generator, integrate to a triangle, and shape with a nonlinear or digital sine-function.

William R. Hewlett wrote the introduction to the book: *“Inventions of Opportunity: Matching Technology with Market Needs,”* published 1983 by the Hewlett-Packard Company, 3000 Hanover Street, Palo Alto, CA 94304. On page ix, Bill writes:

“The Low-Frequency Function Generator (*page 13*)

“This article is a good example of what was referred to earlier as engineering of opportunity. Although we had RC oscillators that operated as low as 1 Hz, there were needs for much lower-frequency sources. [A student paper in 1950] described a novel method of extending the frequency range of an ‘oscillator’ to extremely low frequencies. It was obvious that this was the method needed to meet known requirements. Arrangements were made . . . [with Dr. Smith in 1950] to acquire the rights to this technique, and in a very short length of time we were able to produce an oscillator that operated very satisfactorily at frequencies as low as 0.01 Hz. Incidentally, it also gave triangular and rectangular waves. The basic technique was the use of waveform shaping, a common enough approach now, but very new at that time.”

The article “A New Generator of Frequencies Down to 0.01 CPS” on pages 13 to 16 of the HP book above is a reprint from the HP Journal Vol. 2, No. 10, of June 1951. “Footnote⁽¹⁾ This basic generator circuitry is due to Dr. O. J. M. Smith of the University of California, Berkeley.” The above describes the HP 202A, the first of the Smith sine-function products.

In the HP Journal, Vol. 16, No. 11, July 1965, on pages 1 through 7, is the article: “A LOW-FREQUENCY OSCILLATOR WITH VARIABLE-PHASE OUTPUTS FOR GAIN-PHASE EVALUATIONS”. This provides adjustable-phase sine- and square-wave outputs from 0.005 cps up to 60 kilocycles-per-second. This Model HP203A was the second Smith sine-function product.

In the HP Journal, Vol. 17, No. 3, November 1965, on pages 2-9, is the article: “A VOLTAGE-PROGRAMMABLE LOW-FREQUENCY FUNCTION GENERATOR WITH PLUG-IN VERSATILITY”. This Model 3300A was the third Smith sine-function product.

In the HP Journal, Vol. 40, No. 5, October 1989, on pages 6 through 13, is the article: “40 Years of Chronicling Technical Achievement”. In Figure 2, on page 8, the Smith Low-Frequency Function Generator is featured and displayed alongside Bill Hewlett’s Resistance-Tuned Oscillator, reprinted from the HP Journal articles in November 1949 and June 1951. Quote: “This [Smith sine-function] generator also had the ability to produce triangular and square waveform shapes — a big deal at the time. See Fig. 2b.”

This 50-year life of the HP products and patent protection is evidence of the robustness of the Smith invention. Dr. Otto Smith is still active in producing revolutionary inventions for market needs for air conditioners, freezers, water-pump motors, irrigation, and solar power plants. His goals are market-oriented, high-reliability, long life, and low cost.

U.S. Patents issued to Dr. Smith.

US Patent No. Date

2,583,132. Jan. 22, 1949. “Inspection Apparatus”, X-Ray thickness gauge for steel rolling mill, jointly with William Altar.

In September 1948, Dr. Smith presented the paper “The Space Charge Due to Corona”, at the AIEE Pacific General Meeting in Spokane, Washington. This paper is published in the

Transactions of the AIEE, Vol. 67, Part II, 1948, pp. 1137-44. In September 1948, Dr. Smith invented the Sine-Wave Function Generator which included the Triangle-Wave Function.

2,748,278. May 29, 1956. "Sine-Wave Generator". (HP Model 202A ultra-low frequency 0.01 Hz.; Invented September 1948, 9 Claims.)

3,483,463. Dec. 9, 1969. "System and Method for Alternating Current Machines, and Apparatus Therefor". (Variable-speed, Precision frequency, originally filed Dec. 5, 1952, Pat. Application No. 324,318.). (50 Claims.)

3,051,883. Aug. 28, 1962. "Dead-Beat Response, Resonant Load, Control System and Method". (Posicast control, 30 Claims.)

3,060,378. Oct. 23, 1962. "Method and Apparatus for Generating a Signal and a System for Utilizing the Same". (Complex-Zero Generator, 38 Claims.)

3,084,859. April 9, 1963. "Number Storage Apparatus and Method". (Phase-shift Counter.) (28 Claims.)

3,141,982. July 21, 1964. "Control System for Use in Control of Loops With Dead Time Stabilization". (18 Claims.)

3,241,129. Mar. 15, 1966. "Delay Line". 29 Claims, jointly with Richard Dye.

3,388,305. June 11, 1968. "System, Apparatus and Method for Improving the Stability of Synchronous Machines". (Optimal Excitation Control, 101 Claims.)

3,526,761. Sept. 1, 1970. "Method, Apparatus and System for the Identification of the Relationship Between Two Signals". (41 Claims.)

3,529,174. Sept. 15, 1970. "Power System With Transient Control and Method". (94 Claims, switched capacitors).

3,662,251. May 9, 1972. "Method and System For Measuring Acceleration and Velocity". (47 Claims.)

3,662,252. May 9, 1972. "Tachometer and Method For Obtaining a Signal Indicative Of Alternator Shaft Speed". (25 Claims.)

3,051,883. Aug. 28, 1962. "Dead-Beat Response, Resonant Load, Control System and Method". (Posicast control, 30 Claims.)

3,060,378. Oct. 23, 1962. "Method and Apparatus for Generating a Signal and a System for Utilizing the Same". (Complex-Zero Generator, 38 Claims)

3,084,859. April 9, 1963. "Number Storage Apparatus and Method". (Phase-shift Counter.) (28 Claims.)

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3,526,761. Sept. 1, 1970. "Method, Apparatus and System for the Identification of the Relationship Between Two Signals". (41 Claims.)

3,529,174. Sept. 15, 1970. "Power System With Transient Control and Method". (94 Claims, switched capacitors).

- 3,662,251. May 9, 1972. "Method and System For Measuring Acceleration and Velocity". (47 Claims).
- 3,662,252. May 9, 1972. "Tachometer and Method For Obtaining a Signal Indicative Of Alternator Shaft Speed". (25 Claims.)
- 3,742,391, June 26, 1973. "Method, Apparatus and System for the Identification of the Relationship Between Two Signals". (13 Claims.)
- 4,117,682, Oct. 3, 1978. "Solar Collector System". (Multiple towers, 52 Claims.)
- 4,164,123. Aug. 14, 1979. "Solar Thermal Electric Power Plant". (42 Claims.)
- 4,204,407. May 27, 1980. "Heated Piping System for a Fusible Salt Heat Exchange Fluid in a Solar Power Plant". (2 Claims)
- 4,219,729. Aug. 26, 1980. "Method of Aligning and Locating the Mirrors of a Collector Field With Respect to a Receptor Tower". (20 Claims.)
- 4,247,182, Jan. 27, 1981. "Heliostat With a Protective Enclosure". (24 Claims.)
- 4,249,386. Feb.10, 1981. "Apparatus for Providing Radiative Heat Rejection From a Working Fluid Used in a Rankine Cycle Type System". Joint with Phyllis S. Smith. (6 Claims.)
- 4,330,714. May 17, 1982. "Wind Turbine System". (12 Claims.)
- Design Pat. 267,951, Feb. 15, 1983. "Wind Turbine System".
- 4,792,740. Dec. 20, 1988. "Three-Phase Induction Motor With Single Phase Power Supply". (44 Claims.)
- 5,300,870. Apr. 5, 1994. "Three-Phase Motor Control". (69 Claims.)
- 5,545,965. Aug. 13, 1996. "Three Phase Motor Operated From a Single-Phase Power Supply and Phase Converter". (26 Claims.)
- 6,025,693. Feb. 15, 2000. "Motor Starter". (54 Claims.)
- 6,049,188. Apr. 11, 2000. "Single-Phase Motor Starters". (50 Claims.)
- 6,356,041 B1. Mar. 12, 2002. "Master Three-Phase Induction Motor with Satellite Three-Phase Motors Driven by a Single-Phase Supply". (24 Claims.)
- 7,023,167 B2. Apr. 4, 2006. "Control Arrangement for an Induction Motor Compressor Having at Least Three Windings, a Torque-Augmentation Circuit a Starting Capacitor and a Resistive Element". (7 Claims.)

Introduction.

The single-phase electrical motor is analogous to a single-cylinder engine, with pulsating torque, and less efficient utilization of the space and components. The goal of this project was to prove that all air conditioners on electrical single-phase supplies could beneficially use in their compressors three-phase motors whenever they are available.

Our good experience in a variety of different applications has been documented. A 10-HP three-phase motor and a 40-HP 3-phase motor have each been operating connected to single-phase Idaho Power Company lines since 1996 and 1997 respectively, ten and nine years. These motors run at the name-plate high efficiencies of 94.5% for 40-HP and 91% for 10 HP. A three-phase submersible motor with only three leads also uses the same Phase-Able^R Enabler^R system to be supplied from single-phase electrical power. The constraint of only 3 leads is common to

most air-conditioning compressors. With these excellent functioning previous examples, we wanted to apply the same benefits to air-conditioners, and have proved it with this project of nominal 60 kbtu-per-hour using a 5.2 KW motor. 5.2 KW could be translated to 7.0 HP.

II Project **Outcomes**

At ARI cooling conditions, our SemiHex™ Enabler^R system was superior to any alternative. Ours was:

Watts input = 5,053.55 watts from the single-phase supply.

Line Power-Factor = 81.285% leading.

EER = 11.189

The single-phase motor that can be replaced has:

Watts input = 5,580.25 watts.

EER = 10.2077

These units tested were:	<u>Single-Phase</u>	<u>Three-Phase</u>
Bristol Model No.	H29A623-CBCA	H29A623-DBL
York Part Number	015-035-56001	015-032-54001
EER	10.2077	11.189

The efficiency improvement ratio is 1.0961 of the Semi-Hex™ Enabler^R efficiency divided by the single-phase motor efficiency. The savings in the electricity cost is 9.61%.

Our Semi-Hex Systems were superior in robustness, starting current, voltage sag, pulsed-load currents, and costs.

Each of these Enabler^R systems is **Robust, Efficient, Reliable and Reproducible, RERAR.**

The power-company would see increased distribution efficiency because of the leading power-factor of the new air-conditioning motor.

The minimum starting current would be desired both by the power-company, and by the customer who wishes to reduce light flickers and to reduce voltage pulses during starting.

Each of these components and contributions were carefully studied, tested, and changed if desirable. The motor design and performance was a fixed constraint which we accept and utilize.

A single-phase supply for a motor has a starting capacitor and controls to connect and disconnect the starting capacitor. Both our system and a conventional system provide the capacitor and the controls. The starting capacitors should be robust and reliable, with a 40-year life.

The non-motor components were a major emphasis of this report.

The high efficiency of our PhaseAble^R control is because our capacitor injects a correct specified current into a motor winding. High Efficiency and High EER achieved with our low-cost run-capacitors is more economic than the high costs of much larger grills, radiators and fans.

III Conclusions

Our conclusions are that: Regulatory agencies could reward or require these higher efficiency systems to save imported energy for our society. To encompass all sizes and designs, the best regulation would be that all new air-conditioning compressors larger than one kilowatt or larger than 10,000 btu per hour cooling capacity should be driven by three-phase motors, both those hermetically sealed, and semi-hermetic large installations.

Another conclusion is that manufacturers could provide higher quality units at reasonable cost, and at a higher profit for the manufacturer. A new product requires an initial capital investment or cost, for tooling, for catalogs, for service instructions, for service manuals, and for educating the engineering staff. The CEC could provide this needed “financial bump” to subsidize in dollars the first line of completely three-phase motors on single-phase systems, one line for each manufacturer. Professional societies could provide one-week training sessions and work-shops to deliver the know-how quickly. A firm can expand after they have in-house capabilities.

There is a problem built into a company where the shop administration has started at the bottom, and worked itself up to “know how things are done”. The administration might not have an engineering background and might not know the fundamentals of why things work the way they do. The manager who is now in charge might not want any changes that will threaten his position, which is based on seniority and experience. Competence in a new situation might not have a high priority.

Someone in this position might guarantee that a proposed better system being tested is “sabotaged” to “prove” that it will not function. Dr. Smith can document examples of this problem: both in a university laboratory and in a compressor manufacturing plant.

The education should be across-the-board: vice-presidents for research and development, department heads, and the technicians.

IV Recommendations

The important conclusion of these tests is that all single-phase air conditioners should use three-phase-motor compressors, whenever available. Above one kilo-watt electric, this generalization should hold even up through 6 kilowatts to 10 kilowatts. In the largest sizes not usually sold for a single-phase supply, the indoor and outdoor fans would be three-phase fans, each with its own enabler to connect it to the single-phase supply. CEC could schedule work-shops, training seminars, and classes. Dr. Smith coordinated a several-day work-shop in Port Townsend, Washington, where the participants made a complete controller for an high-inertia band-saw for a boat manufacturing facility. It worked perfectly with the contributions of the participants. Everybody went home knowing that he could make an enabler control.

The State of California could initiate and maintain a certified testing facility for measuring the efficiency and EER of the basic components of compressors and motors. The staff should include electrical engineering experts in circuits, measurements, and motors. All electrical measurements and calibrations should be traceable to NIST, our Bureau of Standards.

All wattmeters should have complete calibration charts from zero percent power-factor lagging inductive currents up through unity power factor for resistive currents and further up through capacitive currents all of the way up to zero power-factor leading capacitive currents. This facility would be desirable for all air-conditioning manufacturers. Regulated ac power-supplies should be large enough to supply starting currents of nearly ten times rated current without any voltage drop at the output.

The tests reported in this report took more than ten months. The total time of actual set-ups and testing was one month. The air-conditioning industry deserves better than this. The State of California could require better than this. Independent certified measurement values are important for all society. The public can not afford to wait for many months to find the facts concerning an air-conditioning product.

This new facility could be available to state commissions, customers, and manufacturers. It should be independent of manufacturers, to provide independent corroboration of claimed efficiencies and EER. It should have a competent staff of Registered Professional Engineers in fields of Thermodynamics, Circuits, Motors, Controls, and Electrical Power. It should have a large 24-hour competent staff of engineers to make continuous data recording runs of 24 hours and 36 hours. It should have adequate funding to provide test results in days or weeks for air-conditioning companies. A “timely manner” should be defined in weeks and dollars.

V Public Benefits to California

The new customers will see less electricity cost than anticipated. Our new air-conditioners do not make the lights flicker on starting, and the full-load voltage on computers does not change with the air-conditioning load. The new customers can compare their quiet systems to the vibration and noisy systems and light flickers of their neighbors.

The power company will be enthusiastic about these new high-power-factor current loads. We tested **81% leading** power-factor current. These will partially compensate for the lagging power-factor of all nearby refrigerators, freezers, furnace fans, washers and dryers, pumps, and neighbor’s air conditioners. The distribution efficiency of the power-company is increased by our Phase-Able^R and Enabler^R systems.

The power-company will see a reduced rate of increase in load due to these new air-conditioning loads, which reduction could be beneficial to long-term planning.

Higher-efficiency air-conditioners will produce less global warming than the replaced low-efficiency single-phase compressors.

A most important public benefit is that three-phase motors in single-phase air-conditioners can reduce electricity costs by 9% of the electricity bill for 60,000 BTU/Hour of cooling. Similar savings could apply to new units of other sizes.

The Energy Information Administration of the U.S. Government lists California air-conditioning electricity costs as 640 million dollars in 2001, and 666 million dollars in 2005. The past growth rate of new installations has been one percent per year. With unprecedentedly enormously increased documented air temperatures in the last several years, the growth rate of new installations will be approximately 1.5%. Applied to the EIA estimates, the growth value in

2006 would be 676 million dollars annually. Assume market penetration of 50%. Assume average Enabler^R savings of 7% for all sizes. The Enabler^R savings in 2007 year would be 23.66 million dollars.

The second year savings would be $24.015 + 23.66 = 47.675$ million dollars.

The third year savings would be $24.375 + 47.675 = 72.050$ million dollars.

Subsequent years are shown in Appendix section XXXVII.

The ninth year savings would be $26.653 + 199.5214 = 266.1744$ million dollars.

The tenth year savings would be $27.053 + 266.174 = 293.227$ million dollars.

The sum of all ten-year savings would be 1,430.654 million dollars.

This is 1.4 billion dollars of electricity savings in California in ten years due to 50% market penetration of the Enabler^R method.

While I was writing this report, on Saturday, 22 July, 2006, the temperature in Berkeley, California was 90°F and PG&E failed for 15 minutes to provide any power for the excessive air-conditioning loads. In the week of July 20 to 26, in California, 81 persons died because of the “heat storm” (heat wave).

Deaths from heat stroke are more than an inconvenience. It is a societal responsibility to require most air-conditioners to have symmetrical 3-winding (3-phase) motors in the compressors to save energy. This is similar to requiring disk brakes for the safety of the populace.

On Monday, 24 July, 2006, the U.S. electrical power companies were incapable of providing the electricity needed by the citizens of the United States. The air in Phoenix, Arizona was 114° F. The air temperatures were 110° F in Fresno, Stockton, and Modesto. These high temperatures reduce both the efficiencies and reduce the available electrical power from all power plants which use steam and have a condenser.

Dry cooling towers of the nuclear plants are readily visible. Many power-plants discharge their condensate heat into a cooling pond or a river or a bay, contributing to global warming, and modifying the ecology of the water. These condensate temperatures are all influenced by global warming and heat waves. The Tennessee Valley Authority, the largest public utility in the US, set a record of 32,037 MW at peak demand on Tuesday, 18 July 2006.

All coal, oil, and nearly all gas electrical power plants can have their power capabilities increased by decreasing the temperature of the exhaust from the low-pressure turbine into the cold condenser.

The component that can add reliability to the electrical output of the power plant is a radiative heat rejection from the condenser instead of, or modifying, the conventional cooling pond. The infra-red radiation is from a thin colloidal suspension or emulsion film of Titanium Dioxide in light oil floating on the cooling water to be cooled for several days of base-load operation.

This radiation at night is in equilibrium with cold interstellar space and intervening clouds. Infra-red radiation cooling can increase the turbine output when electricity is needed at the peak loads. The new power-plant with the new cold condenser is less sensitive to climate heat waves and hot air. The radiative cooling is beneficial in all operating conditions, and particularly

valuable during heat storms (heat waves), when the power systems have rolling blackouts disconnecting the air conditioners.

It is a societal responsibility that this method should be studied and implemented to augment all Rankine-cycle turbines generating electricity by the installation of radiative heat rejection to send away from the earth most of the carbon-derived rejected heat, to cool the condensate temperature, and to increase the electrical capability and reliability.

The importance of air conditioning is reflected in the facts that nearly 80% of U.S. homes have air conditioning and one-sixth of the annual residential electricity consumed is for air conditioning.

VI PROJECT OUTCOMES

PHASE-ABLE^R ENABLER^R PERFORMANCE OF BRISTOL AIR-CONDITIONING COMPRESSORS. TESTS, MEASUREMENTS, AND DESIGNS. ELECTRICAL MEASURES AT ARI CONDITIONS

The standard ARI-540 test conditions for the compressor refrigerant fluids are:

Ambient Temperature = 95°F

Suction Temperature = 65°F

Subcooled Liquid Temperature = 115°F

Suction Pressure = 76 PSI

Discharge Pressure = 297 PSI

This is ARI Standard 540-1999, “*Positive Displacement Refrigerant Compressors and Compressor Units*,” published by the Air-Conditioning and Refrigeration Institute.

The performance of the Bristol compressors are consistent with respect to the constant temperatures of the ARI specifications. Only these ARI-540 test conditions were measured.

Our thermodynamic tests and measurements included the Btu/Hour measured by a thermal calorimeter. This measurement is sensitive to the refrigerant quantity and pressure, and the degrees of subcooling of the refrigerant in the calorimeter. We used test comparisons made at similar calorimeter readings.

The compressor runs at a constant speed, synchronous minus slip frequency, so with constant ARI conditions, the Btu/Hour of the compressor should always be the same. All significant changes will be in the motor electrical controls and motor winding efficiencies. The compressor output is a constant, and we will use as a reference base line the average of the measured Btu/Hour of this three-phase Bristol compressor for all ARI-540 runs at 15° F Subcooling, and a different base-line of thermal cooling capacity for 20° F Subcooling.

There were three 3-phase tests on two different compressors, with Star (Wye) connections, and they are reported as Tests 1C, 1CC, and 1D. Other tests can be compared to these basic three-phase Star base-line performances.

There were two sets of tests made on the Semi-HexTM connections. The tests are reported as Tests 1A, 1B, and 1C for 20° F subcooling. The tests reported as Tests 1AA, 1BB, and 1CC were at 15° F subcooling. Tests 1A and 1AA are with no phase-adjusting transformer, Figure 3.

Tests 1B and 1BB are with a phase-adjusting transformer, Figure 4.

Tests 1C and 1CC are with the Star (Wye) connections of the same windings.

All of the above are with the same 6-terminal 3-phase compressor. All of the A and B tests were with the Semi-Hex™ electrical connections shown in Figures 3 and 4, and recommended for a commercial Product.

A different 3-terminal 3-phase motor with the same size compressor is hermetically sealed into the enclosure which was used for the other tests.

Test 1D is one base-line Star 3-Phase test. The measured Btu/Hour of 57,362.474 btu/(hour) cooling mode was measured at the ARI-540 Calorimeter conditions at 15° F subcooling. The input wattages will be different for the additional tests with different electrical circuits.

The run capacitors modify in a beneficial manner the space harmonic fluxes in the motor air gap. The result is that Semi-Hex™ circuits and Enabler^R circuits have higher motor efficiencies than perfectly balanced voltages on star (wye) connections with an unavailable neutral. The Semi-Hex™ connection in Figure 3 has higher efficiency than the same windings connected in star (wye) in Test 1C in Table IV. This is shown below in Table A-I.

The superiority of the Semi-Hex™ connection is due to more uniform air-gap flux and lower harmonic losses. Harmonics due to magnetization of the iron are modified by our Semi-Hex™ circuit coupling to the run capacitors. Fifth-harmonic distortion of the flux in the air-gap is well known for its effect on starting transients. We only measured the efficiency improvements.

TABLE A-I
SEMI-HEX IMPROVEMENT OVER STAR CONNECTION

	<u>Semi-Hex</u> <u>Measurements Test 1A</u>	<u>3-Phase Star, 3-Terminal Circuit</u>	
		<u>Test 1C</u>	<u>Test 1D</u>
P, watts,	5,053.55 watts	5,187.5	5,264.25 w.
Winding Volts Unbalance %	1.5726% ub	0.963%	8.793%
Winding Amps Unbalance %	5.690% ub	5.495%	1.82% ub
Winding Amps	14.6017 a	14.90 a.	14.922 a
Line Amps, single-phase	26.9525 a		
Line Power-Factor %	81.337% leading	87.02% lag	88.18%lag.
ARI Error TEAR:	0.766°F	1.0395°F	1.0375 °F

The Star (Wye) connection uses 2.72% more watts than the SemiHex™ connection.

The SemiHex™ connection saves 2.65% of the input watts, shaft loading unchanged, compared to the Star (Wye)connection.

The SemiHex™ connection saves 10.4% of the input watts, compared to the single-phase motor which draws 5,580.25 watts at the ARI conditions.

TABLE A-II
SEMI-HEX WITH PHASE-ADJUSTING TRANSFORMER

Test 1B. FIGURE 4. ARI-540, 20F-Subcooling. {TABLE VII }

<u>AC WATTS INPUT</u>		
AC Input Power, 1-phase wattmeter	5,073.025 watts	
Single-Phase volts	231.165 volts	
Single-Phase amperes	28.7525 amps	
Single-Phase Volt-Amperes,	6,646.5717 va	
Single-Phase Power-Factor	+ 76.32544% leading	
Line Leading Current Angle,	+ 40.2481°	
Calorimeter Heat Capacity Btu/Hour	= 56,260.2361	
EER = Btu/Wh =	11.090	
<u>MOTOR</u>		<u>Percent unbalance %</u>
AC Power, 3-phase wattmeter, P =	5,180.55 watts	
Volts per winding,	135.7133 volts, average	2.43% ub
Current, each phase	15.205 amps, average	18.448% ub
Volt-Amperes	5,887.374 va	
Power-Factor	87.740% lagging	
Lagging Phase Angle	-28.669 ° degrees	
Magnetic vars,	j 2,824.488 vars, lagging	
Motor (P - j Q) =	5,165.60-j2,824.488watts-jvars	
% unbalance voltages		2.43%
% unbalance currents		18.45%

Note wattmeter inconsistency: Single-Phase = 5,073.025 watts, correct.

Three-Phase wattmeter reads = 5,180.55 watts, calibration error.

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications:	130°F	45°F	65°F	95°F
ARI test measures:	129.344°F	45.0263F	64.2135°F	95.1488°F

The average error is TEAR = 0.4044 °F

Heat Balance = 1.53792%.

	<u>Figure 3, Measurements Above. 1A</u>	<u>Figure 4, Measurements 1B, with Phase Adjusting Transformer</u>
P, Input watts	5,050.1 watts	5,179.1 watts
Winding Volts Unbalance %	1.5726% ub.	1.884% ub.
Winding Amps Unbalance %	5.690% ub	7.6078% ub
Winding Amps	14.6017 a	14.5575 a
Line Amps, single-phase	26.9525 a	28.1075 a. leading
Line Power-Factor %	+ 81.337% leading	+ 77.909% leading
ARI Error TEAR:	0.766°F	0.645°F

With this comparison, the Single-phase Product in Figure 3 is slightly better than the Figure 4 circuit with a phase-adjusting transformer. The transformer loses 2.55% of the motor power.

Tests 1B and 1BB illustrate the losses in the phase-adjusting transformer, which losses diminish the usefulness of the “perfect” phase angle of the injected run currents.

Figure 10 shows the connection of a three-element three-phase wattmeter to the Semi-Hex™ circuit for Figures 3 and 4. The motor watts P are the sum of the three watt values in the three phases of the wattmeter.

Single-Phase Motor with Tests 1G.

SEMI-HEX IMPROVEMENT. Test 1A, Fig. 3.

	<u>Semi-Hex</u>	<u>Single-Phase</u>	<u>Savings</u>	<u>Save%</u>	<u>Cost per cooling unit.</u>
Line Watts	5,053.35	5,580.25	526.9 w	9.4%	
EER	11.1892	10.2077	0.9815	9.6%	Save 9.6%

TABLE A-III

THREE-PHASE INPUT WITH BALANCED AC VOLTAGES

Test 1C STAR (WYE) connection. 4 TERMINALS

AC Power, 3-phase 3-element wattmeter

	<u>Phase Voltage, Line to Neutral Volts</u>	<u>% UNBALANCE</u>
A-N	132.775 v	
B-N	134.700 v	
C-N	133.250 v	
Average V	133.575 v	0.8422% ub

<u>Phase Current, Line to Neutral Amps</u>		<u>% UNBALANCE</u>
A-N	14.3025 a	
B-N	14.0825 a	
C-N	15.9675 a	
Average amps	14.7842 a	8.004% ub
<u>Phase Volt-Amperes VA</u>		<u>% UNBALANCE</u>
Phase A	1,899.014 va	
B	1,896.913 va	
C	2,127.669 va	
Average VA	1,974.532 va	7.75560% ub
Total VA	5,923.596 va	
<u>Watts Line-to-Neutral</u>		<u>% UNBALANCE</u>
Phase A	1,655.00 w	
Phase B	1,711.00 w	
Phase C	1,831.50 w	
Average Watts	1,732.5 w	5.7143% ub
Total Watts	5,197.5 w	
<u>Lagging - j vars in the motor</u>		<u>% UNBALANCE</u>
Phase A	- j 931.2514	
Phase B	- j 818.998	
Phase C	- j 1,082.8588	
Average Vars	- j 944.3694	14.665% ub
Total Vars	- j 2,833.1082	

MOTOR COMPLETE,

$$(P - j Q) = 5,197.5 - j 2,833.1082 = 5,919.5024 \angle -28.5944^\circ \quad \Phi = -28.5944^\circ$$

The total VA checks well within 0.07% of the 5,923.596 above. 3-phase power factor is -87.803% lagging.

Volts, Line to Line A-B	230.8675 v	
B-C	230.645 v	
C-A	229.5525 v	
Average Volts	230.355 v	0.348375%

Calculated Volt-Amperes, = (FLA)(V)(1.732)

$$VA = (14.7842)(230.355)(1.732) = 5,898.70 \text{ va}$$

This calculation is only 0.35% too low.

Summary Test 1C.

Volts, Line-Line, V_L	230.355 volts average	0.3484% ub
Volts per winding,	133.575 volts average	0.8422% ub
Current, each winding, A_L	14.784 amps average	8.004% ub
Watts, each winding	1,732.5 watts average	5.7143% ub
Watts, total	5,197.5 watts total	

The quality of the ARI fit to the ARI-540 Fahrenheit temperature specifications is:

ARI Specifications	130°F	45°F	65°F	95°F
ARI test measures:	129.5664°F	44.8186°F	66.4323 °F	95.6322 °F

The average error is TEAR = 0.4537 °F

VII Superior Harmonic Flux Benefit

The motor stator currents are magnetically coupled to the air-gap flux and the rotor currents. These stator currents interact with the connected run capacitors to significantly reduce the parasitic losses associated with the fifth and seventh space harmonic distortions. The SemiHex™ connection reduces the motor losses by 147 watts.

This is a 2.83% reduction in the Star connection watts. The Star connection uses 2.91% more watts than the SemiHex™ connection. The measured increase in efficiency was 2.83% for the connection of the SemiHex™ Circuit.

Total Watts

Test 1A, SemiHex connection, 1-phase wattmeter, $P = 5,053.55$ watts

Test 1C, Star connection 3-phase wattmeter, $P = 5,197.5$ watts.

The SemiHex connection saves 143.95 watts and increases the motor efficiency by 2.77% .

The Semi-Hex connection interacts with the harmonic distortion of the air-gap flux, and reduces the losses due to these harmonics. The increase in Efficiency of 2.8% is probably beneficial for many designs and many sizes. There are possibly large random and calibration errors in these values.

Volts per winding, SemiHex connection, 1A, 134.49 volts average, 1.5726% ub.

Leg Voltage, Star connection, 1C 133.242 volts average, 0.9629% ub

Difference is 1.248 volts, or 0.9366%.

Supply voltage SemiHex connection = 230.550 volts.

Supply voltage Star connection = 230.334 volts.

The supply voltage is practically the same for the two connections, but the SemiHex circuit resonates to increase the leg voltage by approximately 0.94%.

The SemiHex increase in efficiency of 2.6% is in addition to the higher efficiency of the three windings compared to the low efficiency of the single-phase motor with a quadrature winding.

This Figure 3 is the design that should be manufactured and sold.

All of these Enabler systems are **R**obust, **E**fficient, **R**eliable and **R**e producible, RERAR.

TABLE A-IV
SEMI-HEX WITHOUT PHASE-ADJUSTING TRANSFORMER
Test 1AA FIGURE 3 PRODUCT.

AC Input Power, 1-phase wattmeter,

P, raw data, digital	5,046.0 watts	
P, raw data, WH meter	5,054.2 watts	
P, average	5,050.1 watts	
Single-Phase volts	230.550 volts	0.117% unbalance at variac
Single-Phase amperes	26.9525 amps	0.083% unbalance at variac
Single-Phase Volt-Amperes	6,213.90 va	
Single-Phase Power-Factor, leading	81.337%	
Line Leading Current Angle	+ 35.735°	

MOTOR - AC Power, 3-phase wattmeter,

Volts per winding	134.49 volts, average	1.5726% unbalance
Current, each phase	14.6017 amps, average	8.2299% unbalance
Volt-Amperes	5,889.0055 va	
Power-Factor	87.58% lagging	
Lagging Phase Angle	28.86° degrees	
Magnetic vars	- j 2,489.426 vars, lagging	not accurate
Motor (P - j Q) =	5,050.1 - j 2,489.426	watts - j vars
% unbalance voltages	1.5726%	
% unbalance currents	5.690%	

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications	130°F	45°F	65°F	95°F
ARI test measures	128.98°F	44.698°F	66.562°F	95.181°F

The average error is TEAR = 0.766°F

One purpose of this test was to demonstrate that the 4-terminal Semi-Hex winding connection would perform as well as or better than the balanced-voltage 3-phase compressor motor.

	<u>Semi-Hex</u>	<u>3-Phase, Star 3-terminal Circuit</u>	
<u>TEST</u>	<u>1AA</u>	<u>1CC</u>	<u>1D</u>
P, watts	5,050.1 watts	5,187.5 watts	5,264.25 watts
Winding Volts Unbalance %	1.5726% ub.	0.963%	8.793%
Winding Amps Unbalance %	8.230% ub	5.495%	1.82% ub
Winding Amps	14.6017 a	14.90 a	14.922 a
Line Amps, single-phase	26.9525 a		
Line Power-Factor %	81.337% leading.	87.02% lag	88.18% lag
ARI Error TEAR	0.766°F	1.0395°F	1.0375°F

The SemiHex connection saves 2.65% of the input watts, shaft loading unchanged.

TABLE A-V
SEMI-HEX WITH TRANSFORMER

Test 1BB, FIGURE 4. TABLES VI and VII

AC Input Power, 1-phase wattmeter	5,063.8 watts	
Single-Phase volts	231.5075 volts	0.414% unbalance at variac
Single-Phase amperes	28.1075 amps	0.2046% unbalance at variac
Single-Phase Volt-Amperes,	6,507.097 va	
Single-Phase Power-Factor	78.919% leading	
Line Leading Current Angle	+ 37.89°	
Transformer Watts loss	14. watts,	
Transformer – j vars, assumed	- j 1.4	

MOTOR

Volts per winding,	135.164 volts, average	1.884% unbalance
Current, each phase	14.5575 amps, average	7.6078% unbalance
Volt-Amperes	5,873. va	
Power-Factor	87.740% lagging	not accurate
Lagging Phase Angle	-28.669° degrees	
Magnetic vars,	- j 2,824.488 vars, lagging	not accurate

Motor (P - j Q) =	5,050.1 - j 2,824.488	watts – j vars
% unbalance voltages	1.884%	
% unbalance currents	7.6078%	

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications	130 °F	45 °F	65°F	95°F
ARI test measures	128.81°F	44.81°F	65.03°F	96.17°F

The average error is TEAR = 0.645 °F

	<u>Figure 3, Measurements Above, 1AA</u>	<u>Figure 4, Measurements 1BB, with Phase Adjusting Transformer</u>
P, Input watts	5,050.1 watts	5,063.8 watts
Winding Volts Unbalance%	1.5726% unbalance	1.884% unbalance
Winding Amps Unbalance%	5.690% unbalance	7.6078% unbalance
Winding Amps	14.6017 a	14.5575 a
Line Amps, single-phase	26.9525 a	28.1075 a leading
Line Power-Factor%	+ 81.337% leading	+ 77.909% leading
ARI Error TEAR	0.766°F	0.645°F

Tests 1B and 1BB illustrate the losses in the phase-adjusting transformer, which losses diminish the usefulness of the “perfect” phase angle of the injected run currents. Watts 1BB above = 5,063.8 watts. Watts 1AA above = 5,050.1 watts. The difference of 13.7 watts is the loss in the transformer.

With this comparison, the Single-phase Product in Figure 3 is slightly better than the Figure 4 circuit with a phase-adjusting transformer.

Figure 10 shows the connection of a three-element three-phase wattmeter to the Semi-Hex™ circuit for Figures 3 and 4. The motor watts P are the sum of the three watt values in the three phases of the wattmeter.

TABLE A-VI
 THREE-PHASE INPUT WITH BALANCED VOLTAGES
 Test 1CC STAR CONNECTION THREE-PHASE MOTOR, 4 TERMINALS

AC Power, 3-phase 3-element wattmeter

<u>Phase Voltage, Line to Neutral Volts</u>		<u>% UNBALANCE</u>
A-N	132.25	
B-N	134.525	
C-N	132.95	
Average Volts	133.242	0.9629% unbalance
<u>Phase Current, Line to Neutral Amps</u>		<u>% UNBALANCE</u>
A-N	14.585	
B-N	14.4375	
C-N	15.7375	
Average Amps	14.90	5.4792% unbalance
<u>Phase Volt-AmperesVA</u>		<u>% UNBALANCE</u>
Phase A	1,928.866	
Phase B	1,942.205	
Phase C	2,092.274	
Average VA	1,987.782	5.2567% unbalance
Total VA	5,963.345	
<u>Watts, Line-to-Neutral Watts</u>		<u>% UNBALANCE</u>
Phase A	1,682.5	
Phase B	1,717.5	
Phase C	1,787.5	
Average Watts	1,729.1667	3.3735% unbalance
Total Watts	5,187.5	
<u>Phase Lagging Vars in the Motor, - j vars. lagging</u>		<u>% UNBALANCE</u>
Phase A	- j 943.2485	
Phase B	- j 906.8374	
Phase C	- j 1,087.407	
Average Vars	- j 979.1643	11.0546% unbalance

Total Vars	- j 2,937.493
------------	---------------

MOTOR COMPLETE,

$$(P - j Q) = 5,187.5 - j 2,937.493 = 5,961.461 \angle -29.521^\circ \quad \Phi = -29.521^\circ$$

The total VA checks well with the 5,963.345 above.

3-phase power factor is - 87.0173% lagging.

	<u>Volts, Line-to-Line A-B Volts</u>	<u>% UNBALANCE</u>
A-B	230.9575	
B-C	230.7775	
C-A	229.2675	
Average Volts	230.3342	0.4631% unbalance

Current Unbalance of 5.48% divided by Line Voltage Unbalance of 0.463% is **11.83**. This large ratio of 11.83 should always be remembered. This is why three-phase motors should **NOT** be connected to three-phase supplies. 3-phase motors should be connected by Enablers to single-phase supplies to obtain the nameplate efficiency.

Calculated, using averages, Volt-Amperes, = (FLA)(V)(1.732)

$$VA = (14.90)(230.3342)(1.732) = 5,944.36 \text{ va}$$

This calculation is 0.3% too low.

Summary

Volts, Line-Line, V_L	230.334 volts average	0.4631% unbalance
Volts per winding	133.242 volts average	0.9629% unbalance
Current, each winding, A_L	14.90 amps average	5.479% unbalance
Watts, each winding	1,729.167 watts average	3.3735% unbalance
Watts, total	5,187.5 watts total	

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications	130°F	45°F	65°F	95°F
ARI test measures	128.665°F	44.877°F	66.38°F	96.32°F

The average error is TEAR = 1.0395 °F

Test 1AA of the Semi-Hex connection shows the power improvement over the star connection of the same windings in Test 1CC. The improvement is $5,187.5 / 5,050.1 = 1.02721$, which means a 2.721% saving of the electricity cost, due to the Semi-Hex connection reducing the parasitic losses.

	<u>Watts Input</u>	<u>% Watt Savings</u>	<u>EER</u>
Figure 3, Semi-Hex connection	5,050.1	2.65% of Star	11.359

Figure 4, Semi-Hex with transformer	5,063.8	2.38% of Star	11.33
Star (Wye) connection	5,187.5		11.058
Single-Phase Motor from Test 1G	5,580.25	9.5%	10.208
Fig. 3, Watt Savings over 1-Phase		9.5%	
Fig. 3, EER Improvement over 1-Phase,			7.87%

SEMI-HEX IMPROVEMENT. Test 1AA, Fig. 3.

	<u>Semi-Hex</u>	<u>Single-Phase</u>	<u>Savings</u>	<u>Save %</u>	<u>Cost per cooling unit</u>
Line Watts	5,050.1	5,580.25	530.15 watts	9.50%	
EER	11.011	10.2077	0.803	7.87%	Save 7.87%

Superior Harmonic Flux Benefit, Total Watts:

Test 1AA, SemiHex connection, Line watts, P = 5,050.1 watts

Test 1CC, Star connection 3-phase wattmeter, P = 5,187.5 watts.

The SemiHex connection saves 137.4 watts and increases the motor efficiency by 2.65% .

VIII BTU/HOUR CALORIMETER CALCULATION

Since all tests for the same three-phase compressor, at the same temperatures, same refrigerant, same frequency, and same shaft speed, a single average of all three-phase calorimeter values of 57,362.474 Btu/Hour will be used for each EER calculation of 15°F Subcooling.

There is a small difference here in that the single-phase compressor has a larger slip frequency and a larger slip speed, and has consequently a slightly less thermal capacity of 56,961.463 Btu/Hour.

Our Base-Line Btu/Hour is:

BTU/HOUR CALORIMETER MEASURE = **57,362.474** btu/(hour) cooling mode.

The EER calculated for these Tests 1AA, 1BB, 1CC, and 1DD are

<u>Section</u>	<u>Name</u>	<u>Figure</u>	<u>1-Phase Watts</u>	<u>3-Phase Watts</u>	<u>EER</u>
1AA	SemiHex	3	5,050.1		11.36
1BB	SemiHex	4	5,063.8		11.33
1CC	Three-Phase, 4 terminals			5,187.5	11.06
1D	Three-Phase, 3 terminal			5,264.25	10.90

SINGLE-PHASE MOTOR ALONE

1G	Single-Phase		5,580.25 w. Btu/Hr = 56,961.5	10.2077
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The single-phase motor delivers one-half of one percent less calories, primarily because the shaft speed is approximately 99.5% of the three-phase motor full-load shaft speed.

The single-phase EER is 10.2077

IX SEMI-HEX PERFORMANCE,

CALCULATION METHOD APPLIED TO TARGET NOMINAL VALUES:

Nominal values:

Supply voltage, 230 / 0.0 volts

RLA = $15.1397 / - 27.3406^\circ = 13.4485 - j 6.9534$ amperes.

From shop measurements for each phase:

$(VA)_i = (V)_i \times (I)_i$

$Q_i = [(VA)_i^2 - (P)_i^2]^{0.5}$ vars

Total motor values,

$Q_m = \Sigma Q_i$ vars

$P_m = \Sigma P_i$ watts

$| (VA)_m | = [P_m^2 + Q_m^2]^{0.5}$ volt-amperes

Calculation method:

$(VA)_A = 3,482.138$

$P_A = 3,478.387$

$Q_A = + j 161.566$

$(VA)_B = 2,010.413$

$P_B = 93.280$

$Q_B = - j 2,008.248$

$(VA)_C = 2,010.413$

$P_C = 1,785.834$

$Q_C = - j 923.341$

Motor $P_m - j Q_m$

$P_m = 5,357.50$

$Q_m = - j 2,770.023$

$(VA)_m = [P_m^2 + j Q_m^2]^{0.5} = 6,031.238 / - 27.341^\circ$

Power-Factor_m = $\cos (27.341^\circ) = 0.888292$

Winding current average = $(6,031.238) / \{ (132.790) \times 3 \} = 15.1397$ amperes.

To determine the phase angle of the current in phase A, note that this current is the winding current from T2 to T45. Winding voltage = $132.79 / + 30^\circ$. Current I_A lags this phasor by 27.341° . The current phasor angle is the difference $(30 - 27.341) = + 2.659$ degrees.

The current phasor is $I_A = 15.1397 / + 2.659^\circ$.

The reference voltage phasor is $(230 + j 0.00)$. This is the applied voltage.

The complex power is the complex conjugate of the voltage times the phasor current, which is

$P_A + j Q_A = 3,482.14 / + 2.659^\circ = 3,478.39 + j 161.566$ watts + j vars.

The plus sign on the vars show that the current is leading the reference voltage. This determines the sign of the Q_A in the first line in the calculation method above. The square-root calculation gives only a magnitude value, and the phasor method can be used to present a graphical unambiguous geometrical presentation.

Motor $(P - j Q)_M = 5,357.5 - j 2,770.02$

Current, each winding, A_L	14.92167 amps average	1.8206% unbalance
Watts, each winding	1,754.75 watts average	6.967% unbalance
Watts, total	5,264.25 watts total	

RATIO (A_L unbalance)/(V_L unbalance) = **5.73**

Volt-Amperes va

Voltamperes. each winding. A = 1,910.754

B = 1,933.8162

C = 2,128.279

Average / winding = 1,990.9496 va 6.8977% unbalance.

TOTAL motor = 5,972.849 va

Calculated (1.732)($V_L A_L$) = 5,967.1986 va

Use average of the above: 5,970.024 va

Power-Factor = watts/va .88178 = 88.178% lagging

Lagging Phase Angle Φ = - 28.142°degrees

Magnetic vars = - j 2,815.823 vars lagging

Motor ($P - j Q$)_M = (5,264.25 - j 2,815.823) watts - j vars

% unbalance of applied voltages 0.31762% unbalance

% unbalance of line currents 1.82062% unbalance

RATIO unbalance of line currents/unbalance of line voltages, Ratio = 5.732

This fundamental high ratio is due to low winding impedances.

This fundamental high ratio is responsible for reduced three-phase motor efficiencies on typical 3-phase supplies and power companies, compared to exactly balanced three-phase voltages, which are rarely available.

TABLE A-VII
THREE-PHASE SUPPLY TO THE THREE-PHASE MOTOR, DETAILS
 Test 1D. Star connection.

These test measurements were after reassembling the thermal calorimeter. This is one of the Star (wye) circuit reference tests, for ARI standard thermal loading conditions.

This second 3-phase test reported here is for the 3-terminal compressor used in Test 1E.

THREE-PHASE MOTOR, 4 TERMINALS

AC Power, 3-phase 3-element wattmeter

	<u>Phase Voltage, Line to Neutral Volts</u>	<u>% UNBALANCE</u>
A-N	127.575	

B-N	127.75	
C-N	145.275	
Average V	133.533	8.793% unbalance
<u>Phase Current, Line to Neutral Amps</u>		<u>% UNBALANCE</u>
A-N	14.9775	
B-N	15.1375	
C-N	14.65	
Average A	14.9217	1.8206% unbalance
<u>Phase Volt-Amperes VA</u>		
Phase A	1,910.755	
Phase B	1,933.816	
Phase C	2,128.279	
Average VA	1,990.9496	6.8977% unbalance
Total VA	5,972.8489	
<u>Watts, Line-to-Neutral Watts</u>		<u>% UNBALANCE</u>
Phase A	1,632.5	
Phase B	1,774.75	
Phase C	1,857.0	
Average Watts	1,754.75	6.9668% unbalance
Total Watts	5,264.25	
<u>Phase Lagging Vars in the Motor - j vars. lagging</u>		<u>% UNBALANCE</u>
Phase A	- j 992.9393	
Phase B	- j 768.0539	
Phase C	-j 1,039.7704	
Average Vars	- j 933.588	17.7309% unbalance
Total Vars	- j 2,800.7636	

MOTOR COMPLETE,

$$(P - j Q) = 5,264.25 - j 2,800.7636 = 5,962.936 \angle -28.0145^\circ \quad \Phi = -28.0145^\circ$$

The total VA checks well with the 5,972.85 above.

3-phase power factor is -88.2829%, lagging.

THREE-PHASE MOTOR, SUMMARY

AC Power, 3-phase 3-element wattmeter

Volts, Line-Line, V_L	230.8833 volts average	0.3176% unbalance
Volts per winding	133.5333 volts average	8.7931% unbalance
Current, each winding, A_L	14.92167 amps average	1.8206% unbalance
Watts, each winding	1,754.75 watts average	6.967% unbalance
Watts, total	5,264.25 watts total	

Average VA / winding = 1,990.9496 va 6.898% unbalance.

TOTAL motor VA = 5,972.849 va

Calculated $(1.732)(V_L A_L) = 5,967.1986$ va

Use average of the VA above, 5,970.024 va

Power-Factor = watts/va = - 88.178% lagging

Lagging Phase Angle $\Phi = - 28.142^\circ$ degrees

Magnetic vars = - j 2,815.823 vars lagging

Motor $(P - j Q)_M = (5,264.25 - j 2,815.823)$ watts - j vars

% unbalance of applied voltages = 0.31762% unbalance

% unbalance of line currents = 1.82062% unbalance

RATIO unbalance of line currents/unbalance of line voltages, Ratio = 5.732

This fundamental high ratio is due to low winding impedances.

This fundamental high ratio is responsible for reduced three-phase motor efficiencies on typical 3-phase supplies of power companies, compared to exactly balanced three-phase voltages, which are rarely available.

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications	130°F	45°F	65°F	95°F
ARI test measures	128.81°F	45.97°F	65.88°F	96.32°F

Average Test 1D Error = TEAR = 1.0909°F

From Test 1G, **Single-Phase** Motor, identical new calorimeter, same compressor,

1-Phase BTU/HOUR CALORIMETER 56,961.463 btu/hour

1-Phase AC WATTS INPUT 5,580.250 watts

1-Phase **EER** = BTU / (WATT-HOUR) **10.2077** btu/wh

The three-phase efficiency at test 1D divided by the single-phase efficiency is the 3-phase EER divided by the Single-Phase EER, which is Improvement Ratio = **10.897 / 10.2077 =**

1.0675

The 3-phase motor system (Star connection) is 6.75% more efficient than the single-phase motor system. Using the three-phase motor and compressor in the single-phase air-conditioner will save at least 6.75% of the customer's electricity cost, for the same cooling. The Semi-Hex connection in Test 1A of Fig. 3 has an EER of 11.189. The improvement Ratio is = **11.189 / 10.2077 = 1.0961**.

Using the Semi-Hex connection of the three-phase motor and compressor in the single-phase air-conditioner will save **9.61%** of the customer's electricity cost, for the same cooling.

X COMPARISON WITH PUBLISHED SPECIFICATIONS.

<u>3-Phase, Compressor</u>	<u>Test 1C</u>	<u>Test 1D</u>	<u>Bristol Specifications</u>
Capacity, Btu/Hour	56,548.845	57,362.474	61,100 Btu/Hour
AC Watts, Pw	5,197.50	5,264.25	5,250 watts
EER	10.88	10.897	11.638
<u>Single-Phase</u>	<u>Test 1G</u>		
Capacity, Btu/Hour	56,961.46		61,100 Btu/Hour
AC Watts, Pw	5,580.25		5,350 watts
EER	10.208		11.4

There are differences between the 3-phase and single-phase systems which can be tested and listed, but not explained or interpreted. The single-phase line watts input was 5,053.55 w.

The three-phase magnetic power-factor above was -88.18% with a lagging current angle of -28.142°, which is quite small. The single-phase motor magnetic power-factor in Test 9G was lagging - 82.01% with a lagging current angle of - 34.904° without the run capacitor.

The goal of these tests and this research project is to document the high performance of the existing three-phase motors and Enabler systems, and not to modify or redesign the single-phase motor. Factors that might influence the EER difference which can be mentioned, but not explained, are the motor rotor casting, pitch and aluminum cross-section, the high magnetic power-factor of the 3-phase stator and the low magnetic power-factor of the 1-phase stator, and the higher losses of a main and a quadrature winding in the single-phase stator, compared to the lower losses of the symmetrical 3-phase winding. Very important are the air-gap spatial harmonic flux distortions in both the single-phase motor and the three-phase motor, which contribute to reduced torque, increased slip, lower shaft speed to the compressor, and lower output of the compressor. These components are part of the manufacturing process and constraints.

In addition, what seems to be very important, is that the run capacitors in the Enabler systems modify the harmonic distortions in the air-gap flux, in the winding currents, and in the winding voltages so that the Enabler system has higher efficiency than the original motor.

The important conclusion of these tests is that all single-phase air conditioners should use three-phase-motor compressors, whenever available. Above one kilo-watt electric, this

generalization should hold up through 6 kilowatts to 10 kilowatts, and for semi-hermetic units up to 100 kilowatts.

In the largest sizes not usually sold for a single-phase supply, the indoor and outdoor fans should be three-phase fans, each with its own enabler to connect it to the single-phase supply.

These three-phase tests are the **base-line** test to which all other tests can be compared.

XI Test 1E ENABLER FOR 3-TERMINAL COMPRESSOR WITH TRANSFORMER.

Test 1E was to demonstrate that single-phase connections could operate the 3-phase compressor at almost exactly the conditions that it had for balanced three-phase voltages.

[Test 1F below is to obtain the sensitivity of the EER and the transformer voltage to changes in the run capacitor CTT value.]

Test 1E was with a run capacitor CTT of 400 Mfd. Test 1F will be with a smaller run capacitor CTT of 320 Mfd. Both tests included the losses in the phase-adjusting transformer.

TABLE A-VIII
STAR ENABLER WITH TRANSFORMER

Test 1E, 3-TERMINAL STAR MOTOR (Figure 11) CTT = 400 MFD. C3 = 0.0

AC Power, 1-phase wattmeter = 5,451.5 watts
Single-Phase volts = 229.225 volts
Single-Phase amperes = 27.0375 amperes
Single-Phase Power-Factor = 0.87960 power-factor
EER Single-Phase Line = 10.522

3-PHASE MOTOR

AC Power, 3-phase, 3-element wattmeter = 5,263.75 watts
Volts, Line-Line = 225.70 volts average
Volts per winding = 130.10 volts average
Current, each phase = 15.122 amperes average
Volt-Amperes = 5,902 va
Power-Factor = 0.89186 lagging
Lagging Phase Angle = -26.892° degrees
Magnetic vars = - j 2,669.53 vars lagging
Motor (P - j Q) = 5,263.75 - j 2,669.53 watts - j vars
% unbalance of Line voltages = 1.163% line unbalance
% unbalance of Winding currents = 5.847% winding unbalance
% unbalance of Star leg voltages = 4.016% leg voltage unbalance
Calorimeter Capacity, cooling mode, = 57,362.474 btu/hour.
EER, Three-Phase = 57,362.474/5,263.75 = 10.898 btu/wh.

EER = BTU / (WATT-HOUR) = 10.898 Btu/(Watt-Hour) at the compressor.

Including the transformer losses in Figure 11,

Transformer Loading, VA = 1,704 va

Transformer loss = 187.75 watts.

Including the transformer losses in Figure 11, the composite

EER = BTU / (WATT-HOUR) =

57,362.474 / 5,451.5 = **10.5223** Btu/(Watt-Hour) including the transformer losses.

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications	130°F	45°F	65°F	95°F
ARI test measurements	129.1343°F	45.8804°F	65.2833°F	96.1944°F

Average error is TEAR = 0.806°F

XII WATTMETER PRECISIONS.

The three-phase wattmeter is less accurate than the single-phase wattmeter. In these 1E tests, the three-phase wattmeter has a lagging load due to the compressor motor. The single-phase wattmeter has a leading load due to the dominant capacitors with leading vars magnitude almost twice that of the lagging vars of the motor. The input single-phase accurate watts input is 5,451.5 watts.

Our three-phase 3-element wattmeter reads 5,263.75 watts input to the compressor with current unbalance of 5.847% winding unbalance on Test 9E.

The difference is 187.75 watts. This difference is mostly the losses in the transformer, and a small part is the inaccuracy of the 3-phase wattmeter on a lagging load.

In Tests 1D, the same compressor and the same wattmeter read 5,264.25 watts. The current balance was excellent, 1.8206% ub. The same wattmeter read almost exactly the same value on the two tests, which displays the consistency of this wattmeter, but does not infer anything about its accuracy.

A 3-phase wattmeter with 3 elements and equal currents in the three elements, and with a lagging load power-factor higher than 85%, should have high accuracy compared with calibrations with a resistive load. Assuming that our 3-element wattmeter has high accuracy, then the difference of 187.75 watts is the loss in the transformer in Tests 1E and Figure 11.

Two-element wattmeters measuring 3-phase loads have enormous inaccuracies. One of the internal digital calculations is the product of a large sinusoidal current times a large sinusoidal voltage times the cosine of the angle (which is near 90 degrees) between the two sine waves, which cosine is near zero. This product is so inaccurate and so large that it destroys the usefulness of a 2-element 3-phase wattmeter.

Our tests used only 3-element 3-phase wattmeters. For Tests 1D and 1E, the three element currents were approximately balanced. For the SemiHex™ circuits, when the motor winding

watts were measured using the connection in Figure 10, the accuracy was poor because the B phase has large currents and voltages approximately 90-degrees apart, so that the Phase B watts is quite inaccurate.

Notes on Voltages Measured:

The voltage across the transformer is called VT. In Figure 11, this is the voltage {T1-T3}. On the wattmeter, it is White to Red, A-B. It reads 227.175 volts. The reference voltage is T1 to T2 in Figure 11. This is called VR. It is White to Black. It reads 228.45 volts. Define Voltage Deviation as $VD = VR - VT = 1.25$ volts. This means that the capacitor CTT is too small and should be increased.

XIII SENSITIVITY

TABLE A-IX
SENSITIVITY, Test 1F
ENABLER^R WITH TRANSFORMER, REDUCED CAPACITANCE TO 80%,
3-TERMINAL STAR COMPRESSOR.

CTT = 320 mfd. C3 = 0.0

Figure 11.

Test 1F was to obtain the sensitivity of the system EER to changes in the major run capacitor CTT.

Test 1E was with a run capacitor CTT of 400 Mfd. Test 9F was with a smaller run capacitor CTT of 320 Mfd. Both tests included the losses in the phase-adjusting transformer. These two tests were made following each other, so that there would be little variation in any component except the Capacitor change from 400 mfd to 320 mfd. The Test 1E was at 16:45 pm.

It was repeated at 16:56 pm. The Test 1F was at 16:50 pm. Test 1E was at the normal variac voltage of 229.225 volts. Test 1F was at a 3.3% increased variac voltage of 237.50 volts. The watts change and the EER change were negligible.

Test 1F.

AC Power, 1-phase wattmeter = 5,441.75 watts

Single-Phase volts = 237.50 volts

Single-Phase amperes = 24.28 amperes

Single-Phase Power-Factor = 0.9437 power-factor

EER Single-Phase = 10.7241, EER at single-phase line.

MOTOR

AC Power, 3-phase wattmeter = 5,293.25 watts

Volts, Line-Line = 230.008 volts average

Volts per winding = 132.733 volts average

Current, each phase = 15.126 amperes average

Volt-Amperes = 6,023.16 va

Power-Factor = 0.878816 lagging

Lagging Phase Angle = -28.50°degrees
 Magnetic vars = -j 2,874.01 vars lagging
 Motor (P - j Q) = 5,293.25 - j 2,874.01 watts – j vars
 % unbalance of Line voltages = 2.583% unbalance
 % unbalance of Star Leg voltages = 6.636% unbalance

Leg Currents,
 Phase A-N = 16.61 amps
 Phase B-N = 11.65 amps
 Phase C-N = 17.11 amps
 Average = 15.13 amps 22.93% unbalance

BTU/HOUR CALORIMETER

Thermodynamic BTU/H = 57,362.474 btu/h
 BTU/WH = 57,362.47/5,293.25 = 10.837 Btu/(Watt-Hour), neglecting transformer losses.
 EER = BTU / (WATT-HOUR) = 10.837 Btu/(Watt-Hour) at the compressor.
 Transformer Loading, VA = 1,739.5 va
 Transformer losses, Watts = 148.50 watts
 Including the transformer losses in Figure 11, the composite
 EER = BTU / (WATT-HOUR) = 10.541 Btu/(Watt-Hour) including the transformer losses.

ANALYSIS OF THESE STANDARDS TESTS.

Note that the Section 1E tests with 100% capacitance were made at a supply voltage of 229.225 volts. The Section 1F tests for 80% capacitance were made at a supply voltage of 237.50 volts. This is 3.26% higher than normal. This higher voltage compensated for the 20% smaller main run capacitance.

The higher voltage showed up in the
 Line Amperes, decreased by -10.2%
 Power-Factor, increased (less leading) by +7.29%
 Watts input, Single-Phase, decreased by -0.18%

These two changes partially compensated for each other. The net effect was that the EER in Test 1E was 10.522; the EER in Test 1F was 10.541. The difference is negligible.

This is robustness with respect to capacitance change. Less capacitance results in larger harmonics and larger harmonic losses. Higher voltage has the opposite effect.

These two runs of Star connected to Enabler with transformer demonstrated that a large compressor, like 20 KW, 25 HP, could be operated from a single-phase supply.

This is applicable to large semi-hermetic freezers and ice-makers where a transformer can be installed external to the usual system. The circuit in Figure 11 is not appropriate for small residential air conditioners.

These tests of these Enabler designs are summarized:

<u>In Section</u>	<u>Capacitor</u>	<u>Supply Volts</u>	<u>Thermal Capacity</u>	<u>Input ac Watts</u>	<u>EER Btu/wh</u>
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	<u>MFD</u>		<u>BTU/Hour</u>		
1E	400	229.2	57,362.47	5,451.5	10.522
1F	320	237.5	57,362.47	5,441.75	10.541
Change %	-20%	+3.62%		-0.179%	+0.181%

The quality of the ARI fit to the ARI Fahrenheit temperature specifications is:

ARI Specifications	130°F	45°F	65°F	95°F
ARI test measures	128.8385°F	45.8091°F	65.2865°F	95.2041°F

Average Error TEAR = 0.6153°F

XIV SINGLE-PHASE COMPRESSOR

TABLE A-X
SINGLE-PHASE COMPRESSOR, Single-Phase winding. Test 1G

These measurements and methods were intended to be pioneering and unique in that the Intertek rebuilt calorimeter used pure water for heat transfer, instead of the glycol mixture required for freezers.

At ARI standard conditions:

The newly calibrated calorimeter yielded:

1-Phase BTU/HOUR CALORIMETER	56,961.463 btu/hour in the cooling mode
1-Phase BTU/HOUR CALORIMETER	56,961.463 btu/hour
1-Phase AC WATTS INPUT, raw data	5,580.250 watts
1-Phase EER = BTU / (WATT-HOUR)	10.2077 btu/wh

AC Power, 1-phase wattmeter = 5,580.25 watts

Single-Phase volts = 230.8125 vac

Single-Phase amperes = 24.599 amperes

Volt-Amperes = 5,677.7567 va

Single-Phase System Power-Factor = 0.982827 PF Line

Percent Single-Phase Power-Factor = 98.2827%%PF Line

Single-Phase EER = **10.2077** btu/wh

2-WINDING MOTOR

60 mfd run capacitor,

Line Lagging Phase Angle = -10.634°degrees

Line Magnetic vars, $Q_L = -j 1,047.727 \text{ var}_L$ lagging

Quadrature winding voltage = (1.174) x Supply voltage = 270 V_{QUAD}

Run Capacitor Voltage = (1.542) x Supply voltage = 355 V_{RUN-CAP}

Run Capacitor Current 8.02 amperes

Run Capacitor Vars Leading +j 2,845.7 Var_C Leading

Motor Lagging Vars = Q_L - j Var_C = -j 1,047.727 - j 2,845.7 = -j 3,893.43 Var_M, Lagging.

Magnetic Motor (P - j Q)_M = (5,580.250 - j 3,893.43) watts - j vars

Magnetic Motor (P - j Q)_M = (6,804.262) { cos Φ - j sin Φ } (VA) { PF - j sin Φ }

where Φ = -34.904°, and where motor winding power factor = PF_M = 0.8201 = (cos Φ).

The injected phase angle of the run capacitor current is -49.479°. Factory - specified Locked-Rotor Starting Current, 147 amperes.

XV NEW PRODUCT

FIGURE 1 shows the electrical circuit for this new product. The hermetically-sealed three-phase compressor has three electrical windings with internal terminals marked W1 and W4 for a winding named A. The winding named B has internal terminals marked W2 and W5. The winding named D has internal terminals marked W3 and W6.

Photographs of a four-terminal Fusite bushing are shown in Figure 12. Figure 13 shows dimensional drawings of a different four-terminal Fusite bushing. Similar units are recommended for commercial products.

Vitrus makes a 4-terminal hermetic bushing for SemiHex connections. A bushing with four electrical conductors would be in the wall of a new compressor enclosure. Conductor marked T2 is connected to winding terminal W2. Conductor marked T6 is connected to winding terminal W6. Conductor marked T13 is connected electrically to both winding terminals W1 and W3 inside of the enclosure. Conductor marked T45 is connected electrically to both winding terminals W4 and W5 inside of the enclosure.

There is an advantage in providing a 5-pin, 5-terminal feed-through bushing. In this case, the interior connections are T1=W1; T2=W2; T3=W3; T6=W6; and T45 = W4 + W5. For Single-Phase Semi-Hex, the exterior connection is T13 = T1+T3. For a 3-phase Star or Wye connection, the exterior connection is N = T6 + T45. No changes would be made in the compressor for either single-phase or 3-phase operation. The same identical compressor is used for both single-phase and 3-phase.

Externally is an "Enabler" circuit with two motor-run capacitors. Capacitor C1 is connected between T2 and T6. Capacitor C2 is connected between T45 and T13. The single-phase power line is connected to T13 and T2.

Table II is the nominal performance at the ARI test conditions. This is for balanced winding currents of 15 amperes in each winding. The circuit in the Product in Figure 1, however, does not have balanced winding currents, but instead has a minimum cost and minimum complexity. (Figure 1 has only two capacitors, and no transformer.)

Figure 2 has the run capacitors from Figure 1, and also has two starting capacitors CX3 and CX9. These starting capacitors are inserted and removed by a Starting Contactor SC.

Starting Capacitor CX3 provides the starting torque with a current in the Driven winding D at terminal T6 which lags the winding voltage by 60 degrees. This is a Locked-Rotor (LR)

phasor current in D of plus 30-degrees angle, with respect to the supply voltage at zero degrees phasor.

TABLE A-XI
SEMI-HEX COMPONENTS AND NOMINAL TESTS

COMPRESSOR Bristol Model No. H29A623DBLA NOMINAL 60,000 BTU/HOUR
MOTOR NOMINAL
3-PHASE, 5.3 KW @ 230-VOLTS LINE-TO-LINE, WYE-WOUND,
133 VOLTS LINE-TO-NEUTRAL, 15 AMPERES LINE CURRENT.

RUN CAPACITOR	Microfarads	AC voltage rating
C1	150 mfd	370 volts
C2	300 mfd	370 volts

Full-Load Semi-Hex™ Nominal Performance, Not Measured Performance, Figure 1.

C1=150, Current I1 = 15 amperes, Voltage VC1 = 266 volts ac., Leading Vars = +j 4,000.
C2=300, Current I2 = 15 amperes, Voltage VC2 = 133 volts ac. Leading Vars = +j 2,000.
Three-Phase Motor (P - j Q)_M = 5,358 - j 2,647 (watts - j vars lagging).

Motor Power Factor 89.66% Lagging, $\Phi_M = \underline{-26.3^\circ}$ Current lagging voltage.

Single-Phase Line (P - j Q)_L = 5,358 + j 3,353 = (6,321) +32° (watts + j vars leading).

Line Power Factor 84.77% **Leading**, $\Phi_L = \underline{+32^\circ}$ Current **leading** voltage.

Single-Phase Line Volt-Amperes (VA)_L (VA)_L = 6,321 va,

Single-Phase Line Current, 27.5 amperes, 84.8% power-factor leading.

XVI STARTING AND LOCKED-ROTOR CONDITIONS

In Figure 2, Starting Capacitor CX3 provides the starting torque.

Starting Capacitor CX9 is across the single-phase power line, and changes the phase angle of the line current to be almost unity power-factor, and to be a minimum starting current magnitude.

XVII SINGLE-PHASE POWER LINE

At 230 volts, 75.4 amperes, unity power factor, LR Line input is 17,342 watts input.
Electrolytic Losses were 8% of vars = 2,334 watts. With 8% losses, Line (P - j Q)_L is:
(P - j Q)_L = (15,008 + 2,334 - j 34,422 + j 34,923) = (17,342 + j 501) =
(P - j Q)_L = 17,342 +1.655°

Supply Line Amperes = SLA = LRA = 17,342 / 230 = 75.4 amperes. (Calculated.)

Actual measured line current, LR-SLA = 75.4 amperes. (Near unity power-factor.)

An important benefit of this PRODUCT in Figure 2 is that the starting current is LRA of 75.4 amperes when the **Rated Line Current (RLA)** is 27.5 amperes. Our Starting Ratio of LRA to RLA is $75.4 / 27.5$, which is **2.74**. This is excellent.

TABLE A-XII
LOCKED-ROTOR MEASURES

PRODUCT Starting Semi-Hex™ Component Values and Actual Performance, Figure 2.

Electrolytic Start Capacitors

<u>Capacitor</u>	<u>Microfarads</u>	<u>Volts</u>	<u>Amperes</u>	<u>+j Vars, leading</u>
CX3	858	240	77.6	+j 18,630
CX9	517	230	44.8	+j 10,310
Total	1,375			+j 28,940

Assume watts losses = 8% of vars.

Watts Losses = 2,315 watts.

LOCKED-ROTOR LR Preliminary Tests:

LR Line Voltage LV = 230 volts

SLW Supply-Line Watts (1Φ) = 17,200 watts

SLA Supply Line Amperes (1Φ) = 77 amperes

SL PF Supply Line Power-Factor, (1Φ) = 97% power-factor

LR-WA Locked-Rotor Winding Amperes (3Φ) = 91.2 amperes

LR-VA Locked-Rotor Volt-Amperes (3Φ) = 36,349 volt-amperes

LR-PF Locked-Rotor Power-Factor (3Φ) = 0.404 = 40.4%

LR-W Locked-Rotor Watts (3Φ) = 14,685 watts

Capacitor Losses in watts = 2,315 watts

LR-W Locked-Rotor Line Watts input (1Φ) = 17,200 watts

Ratio SLA/RLA = $77 / 27.4 = 2.81$

SYSTEM MEASUREMENTS:

LR Motor only, three-phase (3Φ),

LR (P - j Q)_{LR} (3Φ) (15,008 - j 34,422) = watts - j vars lagging

LR (P - j Q)_{LR} = VA / - Φ = $37,551 / - 66.443^\circ$ = Volt-Amps / - lag angle

LR WA = $37,551 / 230 = 94.351 / - 66.443^\circ$ = winding amperes. (At Full Torque.)

LR WA Phase angle lag = $/ - 66.443^\circ$

LR WA Power-Factor = 40.4% lagging.

LR Winding Complex Phasor Amps = (37.709 - j 86.488) amperes, with respect to supply volts.

LR Electrolytic Cap Losses = 2,334 watts.

LR Stator copper loss = 5,998 watts.

LR Air-Gap Synchronous Power = 9,010 watts.

LR Torque = 2.5 Watts/RPM

LR Torque = 17.6 lb.-ft.

LR Torque = 23.9 NM, Newton-Meters

RATIO LRA/FLA = 94.351 / 15.07 = **6.261**

= Three-Phase Ratio (Power-Line Locked-Rotor Amps) to rated winding amperes.

<u>With CX3 and CX9</u>	<u>Amperes</u>	<u>Vars</u>	<u>Phasor Current with respect to supply voltage</u>
CX3	77.6	+j 18,630	67.20 + j 38.80 amps
CX9	44.8	+j 10,310	44.8 +j 0.00 amps

Single-Phase Line Current = 75.4 amps

Line VA (1Φ) = 17,342 va

Line Watts = 17,200 watts

Line Power-Factor = 99.18%

Our Starting Ratio of **2.74** calculated above is excellent, considering that the 3-phase motor itself has a Starting Ratio (SR) of $SR = 94.35 / 15.07 = 6.261$.

The Enabler^R Semi-HexTM had a factor of 2.3 times better than the manufactured 3-phase motor with respect to power-line starting current.

CONSIDERATIONS OF THE PRODUCT in Figure 2:

The LR motor winding voltages average 132 volts with percent unbalance (%UB) of 2.9%.

The LR motor winding currents average 94.4 amperes with percent unbalance (%UB) of 8.2%.

The LR motor internal Power Factor was 40%, lagging.

The LR motor internal Power input was 15,008 watts.

The LR motor internal winding currents percent unbalance was 2.8 times the voltages percent unbalance. This is normal.

The LR Semi-HexTM line current was 75.4 amperes.

XVIII STARTING CONTACTOR SC

The Starting Contactor SC is a Square D Model 8910DP12, 2 poles, 20 amp. inductive, 30 amp. resistive, Grainger Stock 2CF80, coil 208/240 volts.

The coil in-rush current is 56 volt-amperes (va). The electrical transient time delay in the coil after energization is 6 milliseconds (ms) and the armature motion closure or physical time delay is an additional 8 milliseconds. The total turn-on delay time is 14 milliseconds. The factory-measured total pick-up time was 13.9 ms. Altogether, the total delay time to fully-closed contacts was less than one cycle of a 60-Hertz applied voltage.

The open initial coil in-rush current is 56 va.

The sealed coil input is 6 va.

The drop-out time is 11.8 ms measured at the factory.

The 240-volt coil d-c resistance is 725 ohms.

References: Square-D, 1(800)634-2003. Grainger Stock 2CF80, Square D Model 8910DP12, \$13.09.

The starting capacitors are inserted and removed by this Starting Contactor SC which closes in less than one cycle immediately upon application of the 230-volts power, and opens after a set time delay for acceleration of the shaft up to full speed. The acceleration time delay was adjustable for between 0.4 seconds and 2.6 seconds. Operation was satisfactory within this range.

XIX CONNECTION OF A THREE-WINDING COMPRESSOR TO A 230-VOLT SINGLE-PHASE ELECTRICAL SUPPLY.

The measured electrical conditions for the standard ARI calorimeter tests and 230 volts balanced three-phase voltage supplied are listed below:

Power = 5,264.25 watts.

Volts, Line-to-Neutral = 132.79 volts --- Or Volts per winding.

Current, each phase = 14.92 amperes --- Or Current per winding.

Volt-Amperes = 5,970.024 va

Power-Factor = 0.881,78 lagging

Lagging Phase Angle = -28.142° degrees lagging in each winding.

$(P - j Q)_M = 5,264.25 - j 2,815.83$ motor watts - j vars.

The Injected current of 14.92 amperes into T6 by capacitor C1 with 265.6 volts in the circuits of Figures 2 and 3 could be achieved with a capacitor C1 of 149.0 mfd. Because of integer values of available run capacitors, I used $(60 + 92.5) = 152.5$ mfd for C1 in Figure 3.

The compressor motor being tested has an ARI rated load power-factor of 88.8%, and a current lagging phase angle of $\Phi = -27.4^\circ$ This can be called a "high-power-factor" motor.

XX HERMETIC INSULATED TERMINAL BUSHINGS.

The FUSITE DIVISION, Emerson Electric Company, 6000 Fernview Avenue, Cincinnati, OH 45212-1399, sells bushings made in Japan. The common FUSITE bushing for a single-phase single-voltage motor has three conductors. The common FUSITE bushing for a three-phase wye-wound single-voltage motor has three conductors. Figure 12 is a photograph of a single Fusite bushings with four conductors which is readily available for dual voltage motors. Figure 13 shows dimensional drawings of a four-terminal bushing. We suggest that a four-conductor bushing be used for the Semi-HexTM connections. In this present case, the four conductors will be designated T2, T6, T13 and T45.

For a compressor of 60,000 btu/h and 5.5 kW electrical input, it is desirable to have all electrical power leads terminated with screw fittings, not quick disconnects. Loose connections

can cause heating on starting currents. Attention can be given to starting capacitor terminals, which carry these high starting currents.

VITRUS, Inc., 881 Main Street, Pawtucket, RI 02860, are an alternate supplier of hermetic electrical bushings and we will use their 4-terminal hermetic bushing in a Heat Pump for Oregon State University Malheur Experiment Station. They are at Tel. 1(401)724-9350. FAX (401)728-4620.

XXI COMMENTS

20-ton and 60-ton chillers and heat pumps are larger than the unit studied in this report.

When the supply is 460 volts, Double-Star and Double-Delta connections are more symmetrical, the components have lower costs, and these Y-Y and Δ - Δ circuits can be used for 9-lead and 12 lead motors.

This method has been used for a submersible motor in the bottom of a well, with only three electrical terminals brought to the well-head, driving a submersible pump through shaft connections between motor and pump. Single-Phase Efficiency was the same as the three-phase efficiency, which was much higher than from available single-phase submersible motors.

XXII AVAILABILITY

A suitable **Time Delay Relay**, (TDR), to control the Starting Contactor SC, is an IDEC Model GT5Y - 4SN1 - A200. This has a "coil" rated 200-240 volts ac. The contacts are DPDT (Double Pole, Double Throw). Contacts are rated 5 amperes resistive load, 2 amperes inductive load. Delay is adjustable from minimum 0.1 sec. to full scales between 1 second and 10 minutes. This has an 8-spade rectangular base.

This has much greater capability than needed. This is expensive for small systems, but reasonable in cost for systems from 10 KW through 100 KW.

For residential air conditioners, a SPDT time-delay relay or single-pole NC contact could be sufficient.

The Artisan Interval Timing Module, Model 4300, is rated 0.1-seconds to 4-seconds, load current one ampere inductive. We tested this timer. The oscillographic traces of the applied ac voltage and the resultant ac voltage across the load are shown in Figure 6A. The lower trace is the applied power starting at time $t = 0$ on the left and showing a 60-hertz sine wave.

The upper trace is the voltage across the load. This is five cycles of a 60-hertz sine wave. These five cycles are the interval time set to 83 milliseconds.

For our Bristol compressor, the starting contactor SC coil input is less than 100 va. Our SC contactor inserts the starting capacitors. The purpose of the interval timer is to insert the starting capacitors instantly when the power is applied, so that the motor locked-rotor currents and voltages are balanced for optimum accelerating torque.

Figure 6A shows that this Artisan interval timer would have a dead time or dead lag or dead delay of 50 milliseconds between the application of power, and before the timer would apply voltage to the SC contactor. This is three full cycles of dead time during which the three-phase motor would have full single-phase voltage and power applied. The only current into the D

winding at terminal T6 would be run-capacitor current. There would be insufficient or no starting current into D at T6.

With this “single-phasing” of a 3-winding motor, the power-line current could be several hundred amperes. The circuit-breaker should open instantly, and the motor would not start. “Single-phasing” a three-phase motor is known to destroy one winding quickly.

This destructive dead time is the interval between $t = 0$ and the beginning of the timing. This destructive dead time makes all interval timers of the type in Figure 6A unusable for our controls.

A satisfactory Interval Timer must have a solid contact closed before or at the instant of the application of power.

Another feature of this interval timer which we tested is that there are only three external contacts. Terminal 3 is Common to both power and load. Terminal 2 is for the input power. Terminal 1 is for the load. Even an experienced electrician might assume, without looking at the accompanying instruction sheet, that Terminal 1 and 2 are the input power, and Terminal 3 is the load. This experienced electrician connected power to Terminal 1, and the Interval timer was destroyed by being miswired by an experienced electrician. This cost us \$61.72 to replace by purchasing a new unit.

A satisfactory engineering product should have four terminals: Terminals 1 and 2 for the power, and terminals 3 and 4 for the load. There could also be internal protection against misconnections.

XXIII AC INTERVAL TIMER WITH NO TURN-ON DELAY

An independent manufacturer and supplier has a new unique ac interval timer Model 21 which has no turn-on delay. The adjustable delay time is between 0.3 seconds and 9 seconds. The cost is much less than available unsatisfactory timers. This promises to be a satisfactory product at low cost. Oscillograms of this unique timer are in Figure 6B and show its superiority compared to the available interval timers, one of which was shown in Figure 6A.

Figure 6B for Model 21 shows the power application trace at the bottom, and the timed interval trace at the top which is the voltage applied to the load. There is a dot at the beginning of the power trace at the bottom left that shows the exact instant of application of power at $t = 0$. There is a similar dot on the load trace at the left which shows that it too starts at exactly $t = 0$. There is no delay time in the start of the timed interval. The electrical **phase** of the timing at $t = 0$ is also exactly the same on the two traces. Figure 6B shows an acceleration time setting of 250 milliseconds, which is 0.25 seconds, applicable for a small motor. Five kilowatt motors could have an acceleration timed interval of 500 milliseconds. A typical 10 horsepower 4-pole motor could have a timed interval for acceleration of 800 milliseconds.

A typical 40 horsepower 4-pole motor could have a timed interval for acceleration of 1.5 seconds. A high-inertia band-saw might need six seconds to come up to 80% of synchronous speed.

This AC interval timer Model 21 is adjustable up to 9 seconds of acceleration time. One second is sufficient for the Bristol compressors.

The input power is ac voltage between 100 volts and 300 volts.

The time setting is a potentiometer.

The actual time matches the potentiometer setting for all input voltage values in the range between 50 volts and 300 volts.

The maximum load can be one-half ampere at any ac voltage less than 400 volts.

This new product is rated for an SC coil load of one-half ampere or less, which is sufficient for many contactors or small loads.

Figure 6C is a photograph of the circuit board of a Model 21 before potting. The complete system packaged for sale lists for \$29.00. The profit margin for the manufacturer is sufficient for satisfying OEM purchasers and their discounts. The company that makes the Model 21 is 123Phase Incorporated.

This Model 21 can replace the IDEC Model GT5Y - 4SN1 - A200 in paragraph 4A. The Allied list price for the IDEC is \$38.32; the Model 21 list price is \$29.00, a saving of \$9.32.

A 60,000 Btu/Hr compressor had the starting capacitors designed for optimum locked-rotor conditions. On testing with an acceleration setting of 0.4 seconds on an interval timer, the Bristol compressor started perfectly. With 0.7 seconds timing, the compressor started perfectly. With timings of 1.1, 1.7, 2.3, and 2.6 seconds, the compressor started each perfectly.

XXIV THREE-ELEMENT WATTMETER CONNECTION.

The purpose of this analysis is to anticipate and predict the unusual readings in a three-phase wattmeter connected to measure the power input to a 4-terminal SemiHex™ connection of the three windings of a 3-winding motor. These are the winding connections in Figures 3 and 4, with the wattmeter connection in Figure 10.

For one of these tests, the measured three-phase values for the standard ARI test were:

Power = 5,264.25 watts

Volts, Line-Line = 230.88 volts

Volts, Line-Neutral = 133.53 volts --- Or Volts per winding.

Current, each phase = 14.922 amperes --- Or Current per winding.

Volt-Amperes = 5,970.024 va

Power-Factor = 0.88178 lagging

Lagging Phase Angle = -28.1421° degrees

Magnetic vars = -j 2,815.823 vars lagging

$(P - j Q)_M = 5,264.25 - j 2,815.823$ motor watts - j vars.

In Figure 2,

Run Cap C1 =	152.5 mfd, @ 267 volts	I = 15.35 a
Run Cap C2 =	300 mfd, @ 133.5 volts	I = 15.099 a
Run Cap Vars, C1	+j 4,098.583	vars leading
Run Cap Vars, C2	+j 2,015.696	vars leading
Sum Run Cap Vars	+j 6,114.279	vars leading

The 3-element 4-wire wattmeter from the Semi-Hex™ Circuit to the compressor has a voltage neutral connection selected at T13.

The injection by C2 of 300 microfarads of current I2 into T45 is the value of
 $I_2 = 14.922 \angle -117.341^\circ$ amperes.

The 3-element wattmeter is connected with Phase A voltage from T2 to T13 of 230 $\angle 0.0^\circ$ volts and element phasor current of $14.922 \angle +2.659^\circ$ amperes. The complex power in Phase A is
 $(P + j Q)_A = (3,428.365 + j 159.22)$, watts - j vars. The wattmeter element A reads 3,428.37 watts.

Phase B voltage is from T45 to T13 of $133.53 \angle -30^\circ$ volts. The B-element current is $14.922 \angle -117.34^\circ$ amperes. The B-element complex power is $(P - j Q)_B = (92.472 - j 1,990.39)$ watts - j vars. The wattmeter element B reads 92.47 watts, for this injection.

Phase C voltage is from T6 to T13 of $133.5 \angle +90^\circ$ volts. The C-element current is $14.922 \angle +62.659^\circ$ amperes. The C-element complex power is $(P - j Q)_C = (1,769.55 - j 914.94)$ watts - j vars. The wattmeter element C reads 1,769.55 watts.

In this analysis, the total watts is the sum of the three wattmeter elements, which is 5,290.39 watts. Wattmeter element for Phase C reads 33.4% of the total watts. Wattmeter element for Phase A reads 64.8% of the total power. Wattmeter element for Phase B reads 1.75% of the total power. Phases A and B sum to 66.5% of the total power. The calculated sum of 5,290.39 watts is slightly more than the measured sum of 5,264.25 watts.

For Figures 3 and 4, the injected currents into T6 and T45 should be the full-load 14.922 amperes listed above. These currents are injected by Capacitors C1 and C2. The voltage across C1 is approximately 266 volts, and the voltage across C2 is approximately 133 volts.

Capacitor C1 should be $(14.922)(10^6) / [(377)(266)] = 148.8$ microfarads.

Capacitor C2 should be $(14.922)(10^6) / [(377)(133)] = 297.6$ microfarads.

The run capacity vars of these two are:

$VAR_{C1} = (14.922) (266) = +j 3,969.25$ varc leading

$VAR_{C2} = (14.922) (133) = +j 1,984.63$ varc leading

Sum Cap Vars = +j 5,953.88 varc leading

The single-phase power line will see the sum of the motor power and the capacitor vars.

$(P + j Q)_L = 5,264.25 - j 2,815.823 + j 5,953.88 = 5,264.25 + j 3,138.06$ line (watts - j vars).

$(P + j Q)_L = 6,128.60 \angle +30.8^\circ$ line va

PF = $\cos (+30.8^\circ) = 0.859$

Power-factor is 85.9% and the current leads the voltage by the angle of 30.8°

$(P + j Q)_L = (6,128.60) [\cos 30.8 + j \sin 30.8] = [5,264.25 + j 3,138.1]$

The line current is $6,128.6 / 230$ volts = 26.65 amperes.

The 26.65 amperes of the SemiHex circuit in Figure 2 contributes 3,138 leading vars to the power company. This reduces or eliminates the Voltage "SAG" or change in line voltage between no load and full load.

XXV DESIGNS AND TESTS FOR SEMI-HEX CIRCUITS IN FIGURES 3 AND 4.

The actual run capacitors used were slightly different from the numbers used in the calculation for nominal values. In Figure 2 tests,

$$(P + j Q)_L = 5,264.25 - j 2,815.823 + j 6,114.28 = [5,264.25 + j 3,298.46]$$

$$(P + j Q)_L = (6,212.26) [\cos 32.07 + j \sin 32.07]$$

$$\text{Line amps} = 6,212.26 / 230 = 27.0 \text{ amperes.}$$

$$\text{Power factor} = \cos 32.07 = 0.8474 \text{ leading.}$$

In Figure 3, Semi-Hex, 4 terminals:

Run Cap Vars, C1 = 150 mfd	+j 3,989 vars lead	15 amps	265.6 volts
Run Cap Vars, C2 = 300 mfd	+j 1,994 vars lead	15 amps	132.8 volts
Total	+j 5,983 vars leading		

In Figure 3, Single-Phase Line:

$$(P + j Q)_L = (5,357.5 - j 2,770.0 + j 5,983) = (5,357.5 + j 3,213.) \text{ watts} + j \text{ vars leading}$$

$$(P + j Q)_L = 6,247.09 \angle +30.952^\circ \text{ va and leading phase angle.}$$

$$\text{Power Line} = (6,247.09 / 230) = 27.16 \text{ amperes, at } \mathbf{85.76\%} \text{ Power-Factor, } \mathbf{leading.}$$

In Figure 4 with transformer, Semi-Hex, 4 terminals:

Run Cap Vars, C1 = 60 mfd	+j 1,595.7 vars lead	6.01 amps	265.6 v
Run Cap Vars, CTT = 117 mfd	+j 2,873.1 vars lead	11.25 amps	255 v
Run Cap Vars, C2 = 300 mfd	+j 1,994.6 vars lead	15.04 amps	132.8 v
Total	+j 6,463.4 vars leading		

Calculations of Nominal Performance for Fig. 4 are as follows:

$$\text{Motor } (P - j Q)_M = 5,357.5 - j 2,770.02 \text{ watts} - j \text{ vars}_M$$

CTT = 117 mfd	VTT = 255 vac	ITT = 11.248 a	VAR _{CTT} = +j 2,873.1
C1 = 60 mfd	V1 = 266.	I1 = 6.02 a	VAR _{C1} = +j 1,595.7
C2 = 300 mfd	V2 = 133.	I2 = 15.04 a	VAR _{C2} = +j 1,994.6

Figure 4, with transformer and CTT, Single-Phase Line:

$$\text{Single-Phase Line } (P + j Q)_L = 5,357.5 + j 2,873.1 + j 1,595.7 + j 1,994.6 - j 2,770.0 =$$

$$\text{Single-Phase Line } (P + j Q)_L = 5,357.5 + j 3,693.4 = 6,507.23 \angle +34.582^\circ$$

$$\text{RLA} = 6,507.23 / 230 = 28.29 \text{ amperes. Power-Factor} = \cos (34.582) = 0.8233 \mathbf{leading.}$$

XXVI SAG

The power-line current leads the power-line voltage by 31° in Figure 3 and by 35° in Figure 4. This leading current times the impedance in the power company distribution transformer is a transformer IZ voltage drop whose phasor is essentially orthogonal to the power line voltage and whose magnitude is a few percent. The voltage on the load is essentially the same magnitude as the no-load voltage from the power company. This eliminates the “**VOLTAGE SAG**” usually associated with high load currents.

XXVII SINGLE-PHASE MOTOR

The same ARI load conditions with the same compressor and with a **single-phase** motor had tests reported of

Watts input of 5,580.25 watts, with a

Current of 24.6 amperes,

Volt-Amperes = 5,677.8 va

Power-Factor = 98.3% lagging

EER = 10.2

Factory specifications for this Single-Phase Bristol Model H29A623-CBCA, York Part No. 015-032-54001 were Quadrature winding voltage of 270 volts; Run Capacitor, 60 mfd, 370 vac.; and Electrolytic Starting Capacitor (270-324) mfd, 330 vac. The starting capacitor has 325 volts maximum at the instant of 85% speed and pull-up of the **Potential Relay (PR)**.

XXVIII POWER COMPANY POWER LINES

Power Companies do not deliver precision balanced 230 volts. Several power companies that we know have published values for their expected voltages. For example, the target voltage is 240 volts, with a permitted variation of plus or minus 5%. This makes the range of permitted voltages to be from a minimum of 228 volts up to a maximum of 252 volts.

In remote agricultural areas, the target voltage is 480 volts for 3-phase motors, with a minimum of 456 volts (close to motor rated voltages of 460 volts) and a maximum of 504 volts.

At minimum voltage, motors will have approximately rated starting torque, and at maximum voltage, motors may have improved efficiency, if the core losses are less than the copper losses.

In residential areas, for this Bristol single-phase compressor for an air conditioner, at the 228 volts minimum, the potential relay might fail to pull-up, either opening a “slow-blow” circuit breaker, or welding closed the NC contacts in the PR, destroying it and the starting capacitor.

At the maximum applied voltage of 252 volts, the quadrature winding has 284 volts, and the starting capacitor has 341 volts across it at the instant of PR pull-up. This is 7% excessive power dissipated in the starting capacitor, above the factory value. In time, or after many starts, the starting capacitor may eventually fail. This is not a 40-year life which Dr. Smith aims for. This is beyond the borderline for reliability. A product should be reliable, robust, low-starting current, economic, and long life. The single-phase motor in paragraphs 6G and 9G is deficient in these respects. Dr. Smith prefers to use starting capacitors whose rated voltages are 30% higher than the expected maximum operating voltage.

The SemiHex™ system delivers a LR starting torque not less than 75% of the nameplate full Rated Starting Torque of the three-phase motor on balanced 230 volts, at less than half of the starting current ratio of the three-phase motor.

The SemiHex™ LR Ratio of LRA/RLA is 45.7% as much (half as much) as the single-phase motor on the same compressor. The owners and the neighbors of the SemiHex™ system both will benefit by improved power quality. There are less starting disturbances or flickers in the TV and computers, and less circuit-breaker trippings. The SemiHex™ system has reduced spike, pulse, and harmonic distortion.

The SemiHex™ LR Ratio of LRA/RLA is 3.6 times better than the catalog specification which lists a Locked-Rotor current of 150 amperes.

XXIX STARTING CONSIDERATIONS

LOCKED-ROTOR LOSSES.

Our SemiHex™ system uses a timer, not a Potential Relay, so that there are no large starting currents in the motor windings after one second.

Another advantage is that the SemiHex™ Locked-Rotor voltages and currents are **balanced** in the windings. The balance is achieved with electrolytic starting capacitors. These capacitors have internal watts (heating) losses, so that the air-gap flux magnitude is less than rated, and the starting torque is less than the nameplate locked-rotor torque for applied balanced full voltage. Another advantage is that the magnetic or out-of-phase SemiHex™ Locked-Rotor currents in the windings that produce flux and torque, are supplied by the starting capacitors, and not by the power-supply company.

The current that the power-supply company must provide is only the WATTS LOSS on locked-rotor. These watts losses are summarized in this Table A-XIII for Figure 3 below:

TABLE A-XIII
LOCKED-ROTOR LOSSES, FIGURE 3

Rotor watts	=	9,010. watts
Stator copper and iron watts	=	5,998. watts
Electrolytic Starting Capacitor losses	=	<u>2,334. watts</u>
Total Power-Line Input	=	17,342. watts

The watts loss in the rotor of 9,010 watts is delivered into the rotor by transformer action across the air-gap. These watts divided by the synchronous speed of the flux in the air gap, is the torque delivered to the rotor structure and shaft.

This synchronous torque or starting torque is $T = \text{Watts/RPM} = 9,010 \text{ watts} / 3,600 \text{ rpm} = 2.503 \text{ watts/rpm}$. Multiply by 7 to get pound-feet.

Torque = $7 \times 2.5 = 17.5 \text{ lb.-ft}$.

The power company needs to supply this torque and these 9,010 watts, and the copper losses in the stator winding, and the electrolytic capacitor losses of 2,334 watts. The total load on the power company is 17,342 watts, requiring a current of 75.4 amperes. The power company does not have to supply the magnetizing vars of 34,422 vars. If the power company had to supply the total locked-rotor input, the LR-VA load would be 37,551.5 va, and the current required would be 163.27 amperes. Our method is twice as good as the usual systems.

XXX STARTING-CURRENT CHANGES.

Interestingly, minimum LR starting current is not at unity power-factor. Consider this sequence of hypothetical design changes: The starting capacitor CX3 was 858 mfd, contributing + j 18,630 vars. The starting capacitor CX9 was 517 mfd, contributing + j 10,310 vars. Reducing the size of CX9 will linearly reduce its losses. Reduce CX9 by 10% to 465.3 mfd and + j 9,279 vars (a savings of 1,031 vars) which reduces its losses from 824.8 watts to 742.32 watts, a savings of 82.5 watts.

Now the new LR (P - j Q) is changed from the previous value of :

$$\text{(Previous) } (P - j Q)_L = (15,008 + 2,334 - j 34,422 + j 34,923) = (17,342 + j 501) =$$

$$(P - j Q)_L = 17,342 \angle +1.655^\circ$$

$$\text{SLA} = 17,342 / 230 = 75.4 \text{ amperes.}$$

The new value for 10% reduction in CX9 is:

$$(P - j Q)_L = (15,008 + 2,251.5 - j 34,422 + j 33,892.) = (17,259.5 - j 530) =$$

$$(P - j Q)_L = (17,267.636) \angle -1.75887^\circ$$

SLA = 17,267.6 / 230 = 75.08 amperes. This is a desirable lower line current. 10% savings in the CX9 cost causes a desirable 0.5% reduction in the starting current.

A 19% reduction in CX9 yields

$$(P - j Q)_L = (15,008 + 2,177.25 - j 34,422 + j 32,964.1) = (17,185.25 - j 1,457.9) =$$

$$(P - j Q)_L = (17,246.979) \angle -4.8490^\circ \quad \text{Power-Factor} = 0.99642$$

$$\text{SLA} = (17,246.979 / 230 = 74.9869 \text{ amperes}$$

This 74.987 amperes is very close to the minimum or optimum design. At the optimum, the rate of change of line current is zero, with respect to changes in CX9.

A full 20% reduction in CX9 down to 414 mfd yields

$$(P - j Q)_L = (15,008 + 2,169 - j 34,422 + j 32,861.) = (17,177 - j 1,561) =$$

$$(P - j Q)_L = (17,267.636) \angle -5.1926^\circ \quad \text{Power-Factor} = 0.9945$$

SLA = (17,247.8 / 230 = 74.99 amperes. This is slightly beyond the minimum current magnitude. The **20% savings in the CX9 cost** causes practically the same **0.5% reduction** in starting current as 19% savings.

The minimum-locked-rotor current electrolytic vars of 25,980 is 93% of the unity-power-factor locked-rotor electrolytic vars of 28,940. A reasonable trade-off would be a product design for less than the 92% electrolytic vars calculated for unity power-factor.

The design should aim for an angle of 5.15 degrees lag and a power-factor of 99.6% lagging.

A starting lagging angle of 5.15 degrees is close to the minimum current magnitude, and has lower current than unity power-factor. It also has a lower initial capital cost. In this range of power-factors between 99.5% and 100%, the electrolytic losses are dominant.

Smoothly reducing CX9 down to zero will smoothly reduce cost, smoothly increase the desirable LR - Torque but also smoothly increase the undesirable line current. These trade-offs are beyond the scope of this project.

XXXI COSTS

Capacitors are a major component of the Enabler cost.

These tests used several starting capacitors. A product for sale can use a single starting capacitor. The compressor will start perfectly with a much smaller value in microfarads, which would be sufficient for reliability and much less cost.

Figure 15 shows that the two run capacitors can be packaged in the same can, with four insulated bushings, at much lower cost than packaging individually. Figure 15 shows the voltage ratings, which reflect that often power-companies deliver 240 volts continuously, and with transients up to 250 volts at light loads. The voltage ratings for long life should be

VC1 = 300 volts. (T2 to T6).

VC2 = 150 volts. (T13 to T45).

Nominal Values of MFD:

C1 = 150. mfd.

C2 = 300. Mfd.

A reduction of -10% is possibly acceptable for a product. This might reduce the EER by 0.3%.

TABLE A-XIV
COSTS AND ECONOMY OF SCALE

When the production rate of three-phase units increases due to their increased uses in single-phase systems, the production cost will decrease perhaps 15% due to the higher factory run quantities of the three-phase units. For the three-phase units alone, this will decrease the listed price by perhaps \$ 200.00. This is a function of primarily the weight of the motor cast rotor and wound stator.

	<u>Single-Phase</u>	<u>Three-Phase Semi-Hex</u>
Bristol Model No.	H29A623-CBCA	H29A623-DBL
York Part Number	015-035-56001	015-032-54001
York List Price	\$1,445.00	\$1,425.00
Run Capacitors	60 mfd	450 mfd
Run Cap Cost	\$15.88 retail	\$88.65 retail
Start Capacitors	70 mfd	860 mfd
Start Cap Cost	\$26.65 retail	\$85.00 retail
Potential Relay	\$21.10 retail Steveco	
Time-Delay Relay + Contactor		\$42.00 list
Total List Prices, retail	\$1,508.63	\$1,640.65 list
LRA, Amperes	147 a	75.4 a

The Three-Phase Semi-Hex™ system will be more economic than the present single-phase system, with respect to initial capital cost. The old system is fractured into the compressor (Bristol) and the controls (York) of capacitors and starting relay. It is better to have the complete controls marketed with the compressor and guaranteed by the compressor manufacturer. This is customary with nearly all single-phase motors, who often have the necessary controls and capacitors bolted to the motor frame. The Three-Phase Semi-Hex™ system can avoid the PR problem shown in Figure 7.

XXXII COMPRESSORS

Bristol Model No. H29A623-DBL, York Part 015-032-54001, Three-Phase, 5.3 KW.
 Bristol Model No. H29A623-CBCA, York Part 015-035-56001, Single-Phase, 5.3 KW.
 Extra cost to use the Single-Phase motor is the

Run Capacitor, 60 mfd / 370 vac	\$ 15.88
Potential Relay,	\$ 21.10
Starting Capacitor, (270-324) mfd, 330 vac,	
Newark needs (216-259) + (53-64) mfd,	\$ 26.65
Grainger needs (189-227) + (88-106) mfd,	<u>\$ 28.01</u>
Retail sum, for single-phase motor,	\$ 63.63

XXXIII ENABLER RUN CAPACITORS.

	Retail cost
	<u>Rate \$ / mfd</u>
Allied, 1(800)433-5700:	
CDE Round 370 vac, 60 mfd, Stock 862-0351, \$11.83,	\$ 0.197 / mfd.
ASC, X386S Series, 330 vac, 60 mfd, Stock 225-5022, \$14.95,	\$ 0.249 / mfd.
Grainger:	
GE, Oval 370 vac, 80 mfd, Stock 3GA15, \$19.30	\$ 0.241 / mfd
Mallory, North American Capacitor Company, Type MPF,	
Round, 330 vac, 10 mfd, Cat. No. 23FD3310.	
Oval, 370 vac, 70 mfd, Cat. No. 38FD3770.	
OEM Run Cap estimated from 2001 quotes,	\$ 0.055 / mfd
C1, 150 mfd,	\$ 8.25
C2, 300 mfd,	<u>16.50</u>
Both Σ = 450 mfd,	\$ 24.75

OEM capacitor costs are approximately one-fourth of retail prices.

XXXIV STARTING CAPACITORS

Nueva Generacion Manufacturas, NG. Mallory Model 3534B7A0270A220A6.
 Grainger (270-324) mfd, 250 vac, Grainger Stock 4X662, \$12.91,
 CX3 = 858 mfd. Buy three. CX9 = 517 mfd. Buy two.
 Retail list, five x \$12.91 = \$64.55

Estimated OEM cost = 0.25 x Retail price.

Starting Capacitors CX3 and CX9, OEM = \$ 16.14

Run Caps from above, Σ both C1 and C2 = 450 mfd, \$ 24.75

Total Capacitor costs, Start plus Run, \$ 40.89

XXXV York catalog values

Item 1: Bristol Compressor Model H29A623-DBL, York Part Number 015-032-54001.
List, \$ 1,425.00. Three-Phase, 5.3 KW, 230 volts, 61,000 btu/hour, 17.68" high,
EER 11.4, RLA = 17.3, LRA = 150, 7/8" suction, 1/2" discharge.

Item 2: Bristol Compressor Model H29A623-CBCA, York Part Number 015-035-56001.
List, \$ 1,445.00. Single-Phase, 5.3 KW, 230 volts, 61,000 btu/hour, 17.6" high,
EER 11.4, RLA = 24, LRA = 147, 7/8" suction, 1/2" discharge.

Item 3: Required for the single-phase compressor above:

Run Capacitor, 60 mfd / 370 vac,

Starting Capacitor, (270-324) mfd / 330 vac.

Potential Relay with NC contacts and ac coil.

This is called a "Start Relay" GE 3ARR22-24-R.

Positive-Temperature Coefficient Thermistor PTCR Starting Device 305C9,
10 ohms cold resistance, 330 volts ac continuous.

XXXVI HALF-POWER DUAL-MODE SYSTEM

When a Half-Power Dual-Mode compressor reduces the desired power to save electricity by reversed phase-sequence on a reciprocating compressor which mechanically disconnects half of the pistons, then the reversing contactor can automatically change the run capacitor to 65% of the full-speed run-capacitor value. In the low-power mode, the efficiency can be optimized by the Enabler^R circuit values.

XXXVII ENGINEERING PHILOSOPHY

Our engineering philosophy is to make the entire system from readily-available standard components of low cost and high reliability, and standard motors. Only assembly, not manufacturing, is used. For example, GE motor-run capacitors and Mallory electrolytic starting-capacitors are available from Newark, 1(800)463-9275. Capacitor factories have suggested that they could provide the motor-run capacitors in a single can with four terminals, at a significant cost savings.

XXXVIII AIR-COOLING NEEDS

California Air Conditioning growth rate as measured by the electric usage.

Page 4 under Public Benefits.

Assume that with unprecedentedly increased documented air temperatures in the last several years, that the growth rate of new installations is now 1.5% per year. Applied to the EIA estimates, the growth value in 2006 would be 676 million dollars annually. Assume market penetration of 50%. Assume average Enabler savings of 7% for all sizes. The Enabler savings in 2007 year would be 23.66 million dollars. This first year savings is 23.66 million dollars.

The second year savings would be $24.015 + 23.66 = 47.675$ million dollars.

The third year savings would be $24.375 + 47.675 = 72.050$ million dollars.

The fourth year savings would be $24.7406 + 72.050 = 96.7906$ million dollars.

The fifth year savings would be $25.112 + 96.7906 = 121.902$ million dollars.

The sixth year savings would be $25.489 + 121.902 = 147.391$ million dollars.

The seventh year savings would be $25.871 + 147.391 = 173.262$ million dollars.

The eighth year savings would be $26.2591 + 173.262 = 199.5214$ million dollars.

The ninth year savings would be $26.653 + 199.5214 = 266.1744$ million dollars.

The tenth year savings would be $27.053 + 266.174 = 293.227$ million dollars.

The sum of all ten-year savings would be 1,430.654 million dollars.

This is 1.4 billion dollars of electricity savings in California due to 50% market penetration of the Enabler method.

This assumes that each electric load saves at the original electric rate.

Appendix to Page 4, Introduction: In the week of July 22 to July 28, 2006, in the County of Stanislaw, California, there were 18 confirmed deaths due to the heat wave. David Jones, Office of Emergency Services, Modesto, CA, 95354. Tel.1(209)525-4494.

XXXIX

Design and measurements of starting capacitors and starting currents for Figures 2, 3, and 4. Power-Line to Locked-Rotor.

With CX3 and CX9, Amperes Vars Phasor Current with respect to supply voltage.

CX3 77.6 + j 18,630 67.20 + j 38.80 amps.

CX9 44.8 + j 10,310 44.8 + j 0.00 amps.

Electrolytic Capacitor Losses,

Assume watts loss = 8% of vars = 2,334 watts.

LR Cap Vars, CX3 plus CX9, + j 28,940. + j vars

Run Cap Vars, C1 of 150 mfd, + j 3,989 + j vars

Run Cap Vars, C2 of 300 mfd, + j 1,994 + j vars

Total all Cap vars, + j 34,923 + j vars

XXXX SINGLE-PHASE POWER LINE

At 230 volts, 75.4 amperes, unity power factor, LR Line input is 17,342 watts input.

Assume Electrolytic Losses at 8% of vars = 2,334 watts. With 8% losses, Line $(P - j Q)_L$ is:

$$(P - j Q)_L = (15,008 + 2,334 - j 34,422 + j 34,923) = (17,342 + j 501) =$$

$$(P - j Q)_L = 17,342 \angle +1.655^\circ$$

$$\text{Supply Line Amperes} = \text{SLA} = 17,342 / 230 = 75.4 \text{ amperes.} \quad (\text{Calculated.})$$

Actual measured line current, LR-SLA = 75.4 amperes. (Near unity power-factor.)
XXXXI # Note: Our Locked-Rotor Torque of 17.6 lb.-ft. is approximately 25% less than the nameplate 3-phase torque at full rated balanced voltage because of the 2.3 KW of electrolytic losses in the starting capacitors. Reducing CX9 will increase the torque, due to higher winding voltage, and slightly reduce the line current due to less in-phase electrolytic losses.

XXXXII ADDRESSES OF PROFESSIONAL CONTACT PERSONS

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<p>California Energy Commission Energy Innovations Small Grant (EISG) Program PROJECT DEVELOPMENT STATUS</p>	<p>Questionnaire</p>
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Answer each question below and provide brief comments where appropriate to clarify status. If you are filling out this form in MS Word the comment block will expand to accommodate inserted text.

Please Identify yourself, and your project: PI Name Dr. Otto J. M. Smith, RPE California E666 Grant # 53828A/04-08 High-Efficiency Air-Conditioner on Single-Phase Electricity.	
Overall Status	
Questions	Comments:
1) Do you consider that this research project proved the feasibility of your concept?	<i>Both kinds of Air-Conditioner Controls worked excellently. The Semi-Hex control should be marketed. It can save almost 10% of the electricity cost of a customer.</i>
2) Do you intend to continue this development effort towards commercialization?	<i>I hope to license Bristol and Carrier to use this in their air-conditioners and heat pumps.</i>
Engineering/Technical	
3) What are the key remaining technical or engineering obstacles that prevent product demonstration?	<p><i>Presently the obstacles for improvement are that the motor components are made by one company, the compressor is made by a different company who only assembles the motor, and a third company makes the control cabinet and complete system. There is only slight collaboration and coordination between these three companies.</i></p> <p><i>The compressor factory does not have expert motor design and electrical engineers. It has thermodynamic and refrigeration engineers.</i></p> <p><i>Presently, the cabinet manufacturer makes the controls.</i></p> <p><i>It would be better if all three steps were in the same factory.</i></p> <p><i>The Enabler controls should be incorporated with the single-phase system and marketed as a combined unit,</i></p>

	<i>integral with the 3-phase compressor. No company has competent modern electrical engineers. They have refrigeration engineers.</i>
4) Have you defined a development path from where you are to product demonstration?	<i>I would like to sign licenses immediately. I have installed much larger and much smaller systems that have been operating for many years.</i>
5) How many years are required to complete product development and demonstration?	<i>To set up the production line at a factory to use 4-terminal Fusite bushings will be at least two months. The electrical controls can be provided in weeks. No manufacturing is required, only assembly. The interval timers can be provided in weeks.</i>
6) How much money is required to complete engineering development and demonstration?	<i>In-house tooling can be the responsibility of Bristol (York) and Carlyle (Carrier). Dr. Smith can provide consulting assistance.</i>
7) Do you have an engineering requirements specification for your potential product?	<i>The specifications are the units tested in this report: motor metallized polypropylene run capacitors, Square-D contactors, and interval delay timers.</i>
Marketing	
8) What market does your concept serve?	<i>Motels, residential and light commercial heat pumps and air-conditioners.</i>
9) What is the market need?	<i>The market need is for high efficiency "energy star" air-conditioners in response to the new federal requirements of significantly increased EER, energy efficiency ratio.</i>
10) Have you surveyed potential customers for interest in your product?	<i>I will after this report is published. I wish to persuade Amana, American Standard, Airtemp, Bryant, Carrier, Coleman, Fedders, Goodman, Janitrol, Lennox, Payne, Quaker, Trane, Tappan, Whirlpool, A.O. Smith, and York. All of them need this. This is the most economical method of obtaining higher efficiency.</i>
11) Have you performed a market analysis that takes external factors into consideration?	<i>Some other new technologies employ expensive larger radiators, grills, fans, and ducts. Part load controls have also been considered. I have not studied these. Variable-frequency variable-shaft-speed has also been proposed, but it is expensive, and produces unacceptable harmonic distortion of the electrical currents and undesirable spikes and pulses in the voltage.</i>

	<i>The industry has been lax in considering new electrical motor designs and controls and in measuring the present designs.</i>
12) Have you identified any regulatory, institutional or legal barriers to product acceptance?	<i>NO</i>
13) What is the size of the potential market in California for your proposed technology?	<i>Extrapolating the EIA estimates to include motels, light commercial, and residential, the new annual installation electrical load costs in California are \$676 M\$ (million dollars). Assume market penetration of 50%. Assume average Enabler savings for all sizes of 7%. The Enabler saving is 23.66 M\$ in the first year. Assume an annual growth rate of 1.5%. The second year savings is 47.67 M\$. The tenth year savings would be 293.23 M\$. The sum of all ten-year savings would be 1,431 M\$. This is 1.4 billion dollars of electricity savings due to the Enabler method. Converted to KWH at 30 cents per KWH, this is 4.8×10^9 KWH savings, or 4.8×10^6 MWH (Mega-Watt-Hours) of generation saved in ten years.</i>
14) Have you clearly identified the technology that can be patented?	<i>YES. The technology is a 3-winding motor with a specified injected current at a specified phase angle at each terminal not connected to a single-phase supply. I have six issued patents over the interval 1988 to 2006, and two patent applications pending. 123phase Inc. has a patentable invention of an interval timer which is beneficial.</i>
15) Have you performed a patent search?	<i>I do all my own technical work for each patent, and use patent attorneys for the legal steps. My patents never infringe and are exceptionally unique.</i>
16) Have you applied for patents?	<i>Six issued patents and two pending applications. My methods will be the best for the next one hundred years.</i>
17) Have you secured any patents?	<i>U.S. Patent Numbers: 4,792,740; 5,300,870; 5,545,965; 6,025,693; 6,049,188; and 7,023,167, all issued to Otto J. M. Smith.</i>
18) Have you published any paper or publicly disclosed your concept in any way that would	<i>I have published many papers before and after patents have issued. I do not intend to put my intellectual property into the public domain.</i>

limit your ability to seek patent protection?	Web Site http://phaseable.com has list of published references.
Commercialization Path	
19) Can your organization commercialize your product without partnering with another organization?	<i>I do not have an "organization". My product is ready to be incorporated in heat pumps and air conditioners immediately. All air-conditioner companies can manufacture my product. These companies would have non-exclusive licenses.</i>
20) Has an industrial or commercial company expressed interest in helping you take your technology to the market?	<i>Bristol gave me four compressors and I purchased one special compressor for the tests for this project.</i>
21) Have you developed a commercialization plan?	NO
22) What are the commercialization risks?	NONE THAT I KNOW OF.
Financial Plan	
23) If you plan to continue development of your concept, do you have a plan for the required funding?	<i>I have invested several million dollars of my own money and many years of my research and development time for designs, constructions, installations, and tests. Now I want the air-conditioning industry to take over. They have the capital, and their additional profit can reimburse them for their investments.</i>
24) Have you identified funding requirements for each of the development and commercialization phases?	NO
25) Have you received any follow-on funding or commitments to fund the follow-on work to this grant?	NO. <i>SDGE, SCE, PG&E, EPRI, EPA and CEC are logical potential sources of follow-on funding.</i>
26) What are the go/no-go milestones in your commercialization plan?	Not Identified.
27) How would you assess the financial risk of bringing this product/service to the market?	<i>This air-conditioner new model needs a million dollars for tooling, comprehensive testing, catalogs, spare parts inventory, finished product inventory, installation and repair instruction books, and training workshops for both factory and field technicians.</i> <i>A young professor should give lecture demonstrations to many technical institutes, universities, and professional societies and ASHRAE and ARI national meetings.</i>

28) Have you developed a comprehensive business plan that incorporates the information requested in this questionnaire?	NO
Public Benefits	
29) What sectors will receive the greatest benefits as a result of your concept?	<ol style="list-style-type: none"> 1. <i>Motels, residential and light commercial will save electricity costs.</i> 2. <i>Air-conditioning companies can make and market this product at less cost and higher profit compared to the single-phase systems now sold.</i> 3. <i>The power companies will benefit from increased distribution efficiency from the leading power-factor load.</i> 4. <i>These higher-efficiency loads will produce less pollution and less global warming than the displaced single-phase motors of low efficiency and undesirable lagging power-factor current.</i>
30) Identify the relevant savings to California in terms of kWh, cost, reliability, safety, environment etc.	<p><i>Paragraph 13 above shows 4.8×10^6 MWH (Mega-Watt-Hours) of generation saved in ten years, which is 1.4 billion dollars of savings for new customers. Saved generation means less air pollution and less global warming.</i></p> <p><i>Our Enabler systems are much more reliable than existing single-phase systems. We aim for a 40-year life, less vibration, less noise, and less voltage and current harmonics.</i></p>
31) Does the proposed technology reduce emissions from power generation?	YES. <i>That study is beyond the scope of this report.</i>
32) Are there any potential negative effects from the application of this technology with regard to public safety, environment etc.?	NO.
Competitive Analysis	
33) What are the comparative advantages of your product (compared to your competition) and how relevant are they to your customers?	<p><i>My customers are the air-conditioning companies and factories.</i></p> <p><i>My product comparative advantage to customer companies is less initial cost and higher profit in the factory. Another advantage is higher reliability of the control components.</i></p>

	<p><i>The factory customers are the retail buyers supplied by Atlas, Bryant, Sears, Carrier, Trane, Johnstone, York, etc.</i></p> <p><i>York customers' retail advantage is lower electricity bills, lower disturbance to lights and electrical equipment, less vibration, and lower auditory sounds.</i></p>
34) What are the comparative disadvantages of your product (compared to your competition) and how relevant are they to your customers?	<i>NONE.</i>
Development Assistance	
<p>The EISG Program may in the future provide follow-on services to selected Awardees that would assist them in obtaining follow-on funding from the full range of funding sources (i.e. Partners, PIER, NSF, SBIR, DOE etc.). The types of services offered could include: (1) intellectual property assessment; (2) market assessment; (3) business plan development etc.</p>	
35) If selected, would you be interested in receiving development assistance?	<p><i>YES, direct and personal marketing approach to the vice-presidents for new products of each and every air-conditioning company In the USA.</i></p> <p><i>Royalty and licensing decisions are made in the corporate offices of the president and vice-president, with the advice of the engineering staff.</i></p> <p><i>My licensing of Hewlett-Packard for my synthesized wave-forms and function generators was directly with Bill Hewlett, and this is typical.</i></p>