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ELECTRICAL ENERGY SAVING
EQUIPMENT AND PRACTICES IN
A TYPICAL AIR SEPARATION FACILITY

by

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Professor in Charge

Chairman of Department

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ABSTRACT

The objective of this thesis was to review current practices in designing and operating air separation facilities as they relate to energy conservation. This review was conducted using electrical energy as one criterian, due to the air separation industry being very large electrical energy consumers. The actual process efficiency was not treated in this survey, instead the electrical equipment (motors, controls etc.) was the main focus. New concepts and ideas, as well as current practices and design philosophies were evaluated. The review ascertained that the current plant design criterian produces an extremely efficient as well as cost effective facility. This design philosophy did not develop by accident, but was necessitated by the large volume of electrical energy used. Over the years the energy usage has grown as product demand became larger. Operating procedures were also reviewed, and the outcome recommended no major changes be initiated. Any major operating change would prove detrimental to improved efficiency as a key factor in the system's success is similarity in operating procedures as well as in equipment and facility design.

A. Introduction to Air Plant Design

Air separation for the production of industrial gases (oxygen, nitrogen, argon) is normally carried out by compressing air from atmospheric pressure to its liquid state. The liquid air (at cryogenic temperatures) is than passed through a distillation column, ("cold box") which allows the different gases to boil off at different levels. Each of the gases which comprises normal air has its own unique boiling point. A gas that boils off is then either boosted in pressure (by a product compressor) which is then supplied to a customer by pipeline or sent to a recycle compressor to be re-liquified and then put into liquid storage tanks. This liquid is then re-distributed by tanker trucks or rail cars to other locations and users. The size of an air separation plant is determined by the volume of product desired. For gas plants, the ratings are standard cubic feet per hour (SCFH) and tons per day (T/D) with 1000 SCFH approximately equal to 1 T/D. For liquid plants, the ratings are tons per day of liquid (T/D).

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Typical power requirements for air separation plants for a given rating are:[1]

SIZE	POWER REQUIREMENTS
40 T/D Gas Plant	.55 MVA
250 T/D Gas Plant	2 MVA
200 T/D Liquid Plant	5.6 MVA
300 T/D Liquid Plant	10 MVA
700 T/D Gas Plant	15 MVA
1000 T/D Gas Plant	20 MVA

The above values are not exact, as customer requirements and final plant design (machinery and process) change from facility to facility.

Although the power requirements are high, the physical layout of the facility is usually very compact. The typical 300 T/D

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[1] The size versus power requirements is not a one-to-one relationship. The reason being plant size and associated capital expenditure may not be in line with customer needs. For example, according to the given table, three-250 T/D gas plants would consume less power, 6 MVA, than one-750 T/D gas plant, 15 MVA. In this case the cost of 3 separate plants and associated compression equipment would constitute a much higher cost per unit product to the customer. Typically the smaller plants only produce one industrial gas, nitrogen. The larger plants produce nitrogen, oxygen and argon requiring additional equipment and energy consumption.

liquid plant is located on approximately 3 acres of land, for plant, buildings, offices, parking areas, etc. The plant is generally not staffed with a large number of personnel, and it obtains technical advise and expertise from a centrally located group. The maintenance functions are also handled from a centrally located group of mechanics and other trained technicians.

This type of support function is possible due to the fact that the plant process is in continuous operation which minimizes equipment breakdown. The breakdowns and planned plant maintenance outages are than handled by assembling the people with the proper skills necessary for the particular problem. Due to plant design simularity, this centrally controlled operation affords an excellent exchange of information to correct defects at other locations before breakdowns occur. This is important since the plant is in continuous operation, 24 hours a day, 365 days a year, with typical on-stream times of 97.5%. The plant is generally operated at its full production rating. All machinery, motors and compressors, generally run at full load for maximum efficiency. The loading varies slightly to "fine tune" the process to achieve the lowest cost of power unit versus unit of product. The loading is somewhat determined by ambient conditions, however, downtime and inefficiencies in process and machinery must be minimized to have an economically profitable facility.

This blending of maintenance and operating procedures results in a mobil work force which handles problems on an emergency 24-hour basis. It benefits from the in-house technical expertise that has developed over the years, and has a good working relationship with the various equipment vendors.

In a previous paragraph, some typical electrical loads for various plant sizes were given. A breakdown of these electrical loads would prove too narrow for a given plant to effectively be used as a good example. To provide a better understanding of the electrical equipment at air separation facilities, a single line diagram has been developed with all major aspects of a typical air separation plant included. The single line diagram is shown as Fig. 1, 2, 3. The various elements will be discussed in the following sections.

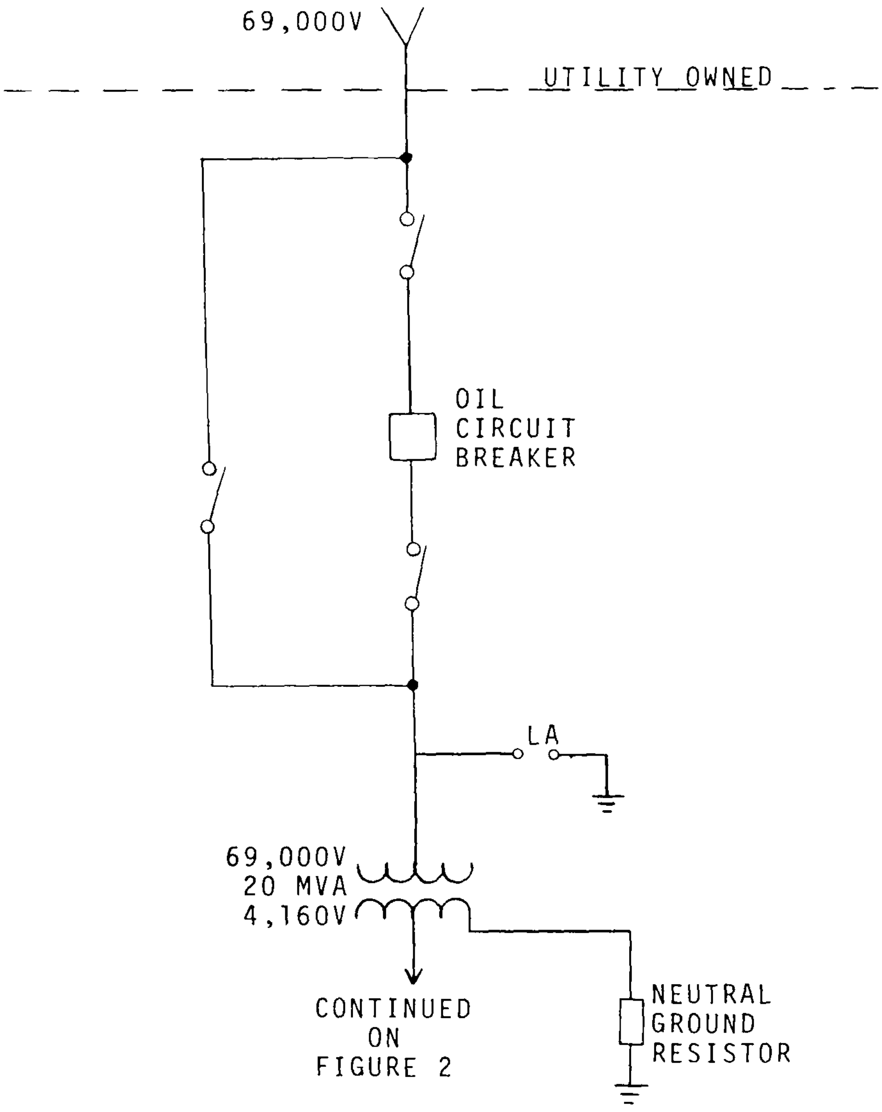

FIGURE 1

TYPICAL AIR SEPARATION PLANT SINGLE LINE

DIAGRAM - INCOMING VOLTAGE

CONTINUED FROM FIGURE 1

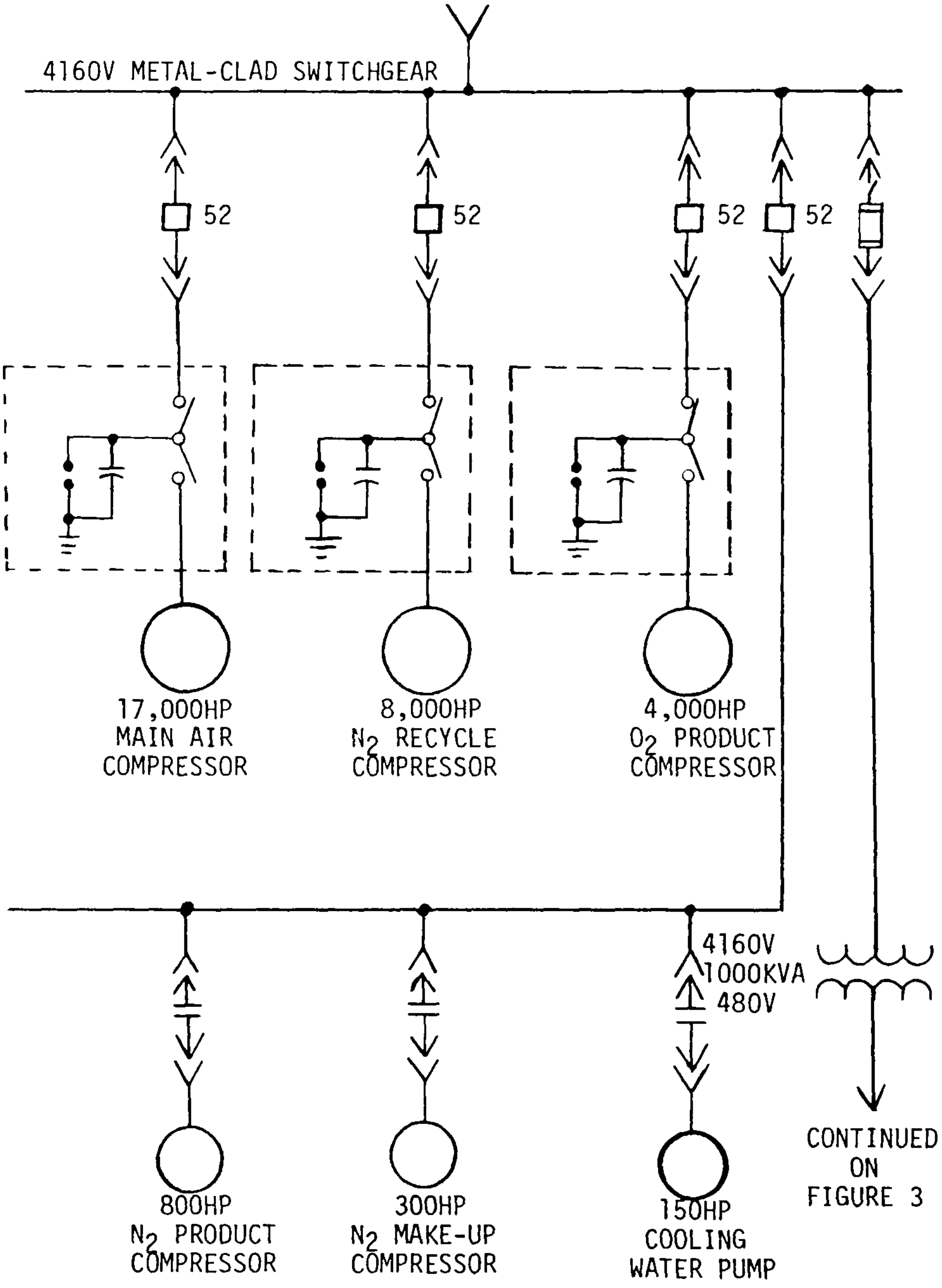

FIGURE 2

TYPICAL AIR SEPARATION PLANT SINGLE LINE

DIAGRAM - HIGH VOLTAGE EQUIPMENT

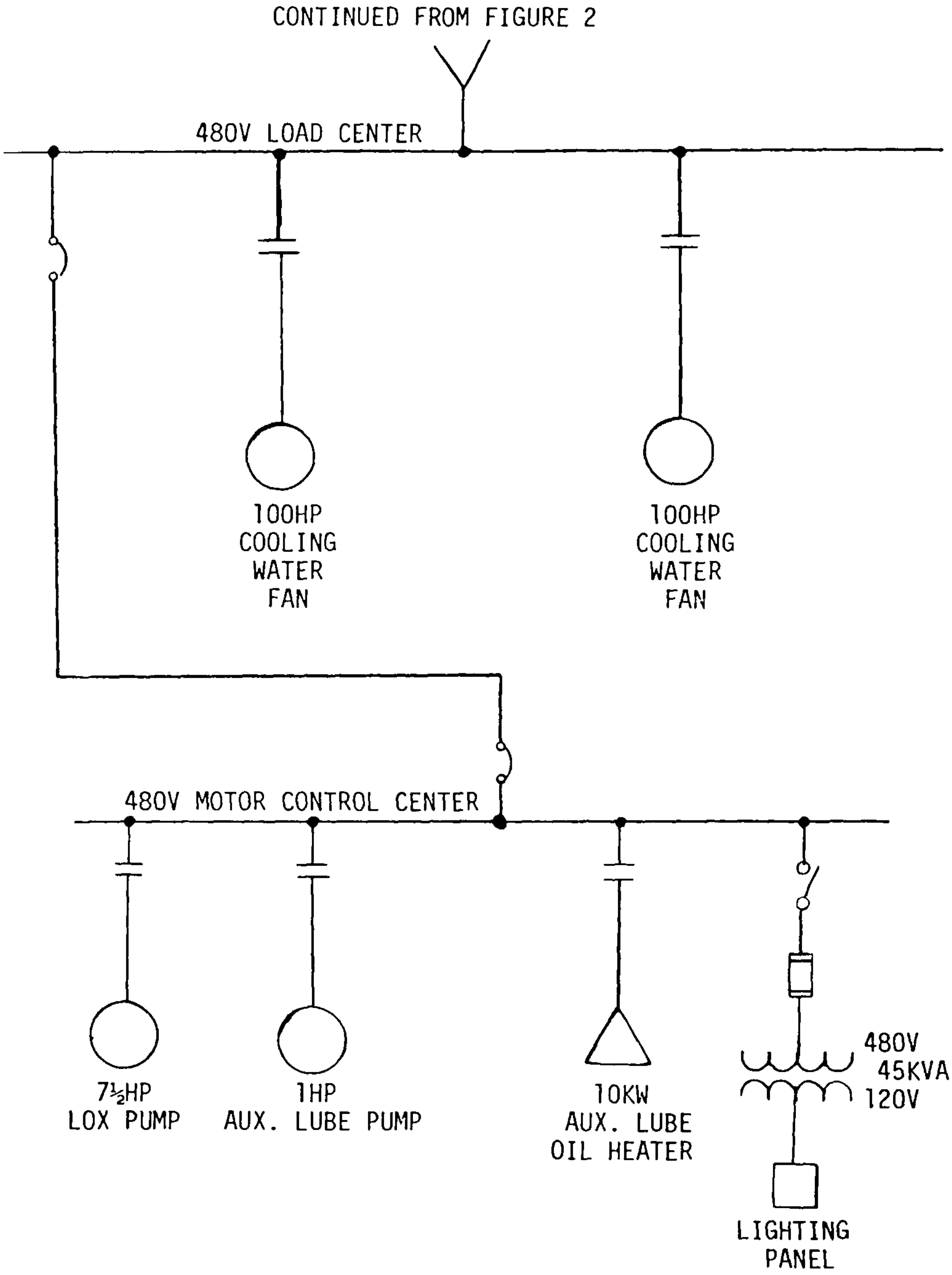

FIGURE 3

TYPICAL AIR SEPARATION PLANT SINGLE LINE

DIAGRAM - LOW VOLTAGE EQUIPMENT

B. Large High Voltage Motors

B.1 Synchronous Machines

As outlined earlier, the typical air plant utilizes electric motors for prime drivers of compression equipment. Synchronous motors comprise 50% of these main drivers. Generally synchronous motors are used in two areas. Large highspeed motors (5000 HP and above, 1200 and 1800 RPM speeds) driving centrifugal compressors and low speed motors (all HP ratings, 277 to 600 RPM speeds) driving reciprocating compressors. The synchronous motors are attractive for 2 reasons in the ratings stated. 1.) Initial costs are less. 2.) Control of power factor (power factor = $\frac{\text{KW (Actual Power Doing Work)}}{\text{KVA (Apparent Power Used)}}$) by external excitation. In some instances, over exitation is used to supply reactive power to the plant increasing the overall plant power factor. This is a significant point as almost every utility penalizes non-unity power factor. For a 20MW plant and $.03/KWH average industrial electric power costs, a monthly power bill is approximately $400,000.00. A power factor improvement of 1.0% is worth approximately $5,000.00 per month.

The synchronous motor, being a motor that synchronizes with power system frequency, must have its rotating magnetic field produced from an external source. This is generally done by supplying the rotating portion of the motor (the rotor) with electrically definitive north and south magnetic poles. These poles are than magnitized with external power to lock on to the power systems' rotating magnetic field which is developed in the stationary part of the motor (the stator). As the load on the motor changes, the external excitation to the rotor field can be varied to increase or decrease the attractive forces. If there is a deficiency of magnetic forces, reactive power (less than unity power factor) is supplied by the power system through the stator. If the force is greater than needed, reactive power is pumped back to the power system through the stator. If the magnetic forces are correct, unity power factor exists.

The supplying of external power to the rotor is accomplished by two methods: slip-ring excitation and brushless excitation. Slip-ring excitation was the original system developed and is accomplished by bringing the rotor field coil leads to a ring, made of brass, steel, or stainless steel and attached to the non-drive end of the motor shaft. The ring's outer diameter is generally a flat, polished surface. The rings are insulated from one another and the shaft. Mounted on the stationary frame of the motor is a brush holder which contains a number of carbon brushes which make pressure contact to the ring surface. Electrical energy is transfered by the brush-to-ring contact. The DC power is supplied to the brushes by means of a DC generator (usually driven by an AC or DC motor), batteries, or an AC to DC solid state rectifier. As the carbon to metal contact can't be properly lubricated (this would increase contact resistance), brushes must be changed frequently and rings re-polished (turned) occasionally. If DC generators are used for a DC source, their brushes and commutator must also be maintained.

The original slip-ring excitation system has been supplemented, since the 1960's by the development of the brushless excitation system. This system develops the field power in the following manner. Low power DC, 125 Volts at 4 amps, for example, is fed to a exciter stator which is located on the non-drive end of the actual motor. The exciter stator fits over an exciter rotor which is pressed on the end of the motor shaft. The exciter rotor is a wound rotor in three phase configuration. On start-up of the motor, the exciter rotor begins to turn, the DC power is then applied to the exciter stator creating a permanent magnetic field in which the exciter rotor is turning. This field induces power into the rotor which then develops three phase power at the rotor's output leads. This inducing of power, of course, is brushless.

The three phase power is then put to a three phase full wave diode bridge which develops the DC for the motor rotor. The only remaining components are control components to switch on the DC to the motor rotor. This switching system is made up of silicon controlled rectifiers (SCR's) and a sensing module (usually called a synchronizing module) which measures the optimum time to energize the motor field.

This technique results in a virtually maintenance free excitation system, as the semiconductor control components are extremely reliable.

The initial increased cost for this type of system is generally offset by the savings on maintenance and energy costs of a slip-ring type system in a very short time.

Since the rotor's magnetic field is produced externally in the synchronous machine, the motor can be operated at unity power factor. While operating at unity power factor, all the input power (KVA) is being converted to shaft horsepower (KW) with the exception of the losses within the machine (efficiency). These are both electrical and mechanical losses.

Of course the losses are designed to be a minimum but accurate determination of the losses is a critical factor in keeping the manufacturer striving to gain higher and higher efficiencies. Efficiency calculations are carried out by industry accepted test methods. An example of these tests is given in Appendix I contained on page 56.

From the results obtained in Appendix I, the overall efficiency of the synchronous motor with brushless excitation system is listed below. This efficiency is valid only for operation at 6600 volts, 1132 amps, and 1.0 power factor.[1]*

LOSSES	KW
Stray Load	15.77
Armature Copper	43.22
Core	62.92
Field Copper	26.88

*The bracketed numbers refer to a list of references located on Page 55.

Friction and Windage	50.00
Brushless Excitation System	2.72

Total Losses 201.51 KW

Total Output (KW) = 17000 HP x .746 x 1.0 = 12,682 KW

$$\text{Efficiency in Percent} = \frac{12{,}682 - 201.51}{12{,}682} \times 100 = 98.41\%$$

As a user of motors such as above, a typical air separation plant has little to do with the actual motor design. It is apparent that the efficiency is a critical factor in operating the plant over a 10 year contract. At $.03/KWH, a load of 12,682 KW and efficiency of 98.41%, the inefficiency of this motor costs $6.05 per hour of operating time; $52,998.00 per operating year. A .1% increase in efficiency saves $.38 per hour of $3,328.80 per operating year. With the efficiencies impacting in such a manner, a pressure point a user can use against a manufacturer, is to impose an efficiency evaluation against the quoted price.

This efficiency evaluation is generally carried out in the following manner. An actual example of an evaluation of a 1250 HP motor will be used. The cost per KW in use today is $1,200.00 per KWH. This is obtained by looking at the price of a KWH over a 10 year life of the facility.

Motor Output 1250 HP x .746 = 932.5 KW

Manufacturer Number	Output / Quoted Full Load Efficiency	Actual KW
1	$\frac{932.5}{.953}$	978.49
2	$\frac{932.5}{.953}$	978.49
3	$\frac{932.5}{.950}$	981.58
4	$\frac{932.5}{.944}$	987.82
5	$\frac{932.5}{.953}$	978.49

The lowest KW, 978.49, manufacturer number 1, 2, and 5 will be used as a base of $0.00 Penalties wll be as follows:

Manufacturer Number 3 (981.58 - 978.49) x $1,200.00 = $ 3,708.00

Manufacturer Number 4 (987.82 - 978.49) x $1,200.00 = $11,196.00

The total evaluation is then carried out.

Manufacturer Number	Quoted Cost	Efficiency Penalty	Evaluated Cost
1	$37,105	0	$37,105
2	$41,453	0	$41,453
3	$40,700	$ 3,708	$44,408
4	$26,750	$11,196	$37,946
5	$28,950	0	$28,950

Manufacturer #5 received the order, even though #4 had a lower quoted price.

In addition to the above efficiency evaluation, once a vendor is selected additional bonuses or penalties can be added to the order. Typically, the efficiencies are not guaranteed efficiencies. A bonus/penalty situation can occur when the manufacturer is held to the stated efficiencies. An actual example was on the 17,000 HP motor described in the test procedure of Appendix I. Once this manufacturer received the order, an efficiency of 98.10% was guaranteed. An offer was agreed upon by vendor and user to a $10,000 per 0.1% bonus over the guaranteed efficiency and a penalty of the same amount per 0.1% below guaranteed efficiency. This added extra incentive to increase efficiency once the order was received.

There are different parameters a motor designer has the option to change in order to increase efficiency. In almost every case, one factor affects many others. For some examples:

1. Higher grade stator lamination steel being used to reduce core losses - increased stator lamination steel costs increase the total cost to manufacture machine.
2. Reducing or removing cooling fans from rotor to reduce windage losses - increases temperature rise in motor causing greater copper losses due to increased conductor resistance per given value of current.
3. Increasing bearing diameter to reduce bearing temperature rise due to lower bearing surface speeds - increases friction losses, due to increased surface contact.

It is common procedure with almost all motor manufacturers to use computer programs to minimize losses by optimizing these critical variables. Since material costs continue to fluctuate, this optimizing process must be performed for each motor designed at a given time. Of course, market variables also have a definite input into the decision. Market inputs such as past and projected future business with that customer; the customers industry growth potentital, etc.

The customer also must look at the vendor with several areas of concern:

Expertise in Design - Can the vendor provide quality state-of-the-art equipment?
Service - Does the vendor have a service organization?
Reliability - Is the equipment able to withstand constant use and remain functioning throughout its designed life?
Convenience - Is the vendor readily available when questions need to be answered?

These factors are considered after the economic evaluation is made and can influence the machine purchase. This can result in purchasing a machine that is not the lowest economically evaluated cost.

The synchronous motors outlined in this section generally have overall rated efficiencies of 96.0% to 98.8%. In general, any higher efficiencies most likely cannot be obtained and moderate increases in efficiencies tend to be cost prohibitive. The general trend has been to increase capacity with existing materials by utilizing tighter design tolerances, thereby, essentially making the same machine smaller.

B.2 Induction Machines

Large induction motors are used in driving centrifugal compressors (3500 HP and lower, 1800 and 3600 RPM) and in some cases reciprocating compressors (1000 HP and lower, 600 to 900 RPM). For the ratings stated, the induction motor is attractive for two reasons.

A. Initial costs are less.

B. No auxiliary equipment or accessories are necessary.

Compared to synchronous machines, the power factor and efficiencies of induction motors are generally less. Those power factor and efficiency penalties are generally offset by the lower initial costs. Since synchronous machines are not built to operate at 3600 RPM, expensive gear boxes must be included in the overall evaluation.

An induction machine is one whose magnetic field in the rotor is developed by magnetic induction from the rotating magnetic field in the stator. The rotor cannot ever achieve synchronous speed, for if it did, the magnetic inductive force would go to zero. This then causes the rotor to slip behind the stator magnetic field. This slip is known as slip speed or slip frequency. An example would be a 4 pole motor (synchronous speed 1800 RPM) may have a full load speed of 1785 RPM or a frequency of .5 cycles for a 60 cycle system. The rotor must be built to withstand much more thermal loading than a synchronous rotor. The most common construction is a copper bar in a steel lamination design known as a squirrel cage rotor.

There is also another type of induction rotor which is built with wire instead of bars. It is known as a wound rotor. The wound rotor wires can be brought out to slip rings and then to a rheostat. By adding or subtracting resistance, the motor speed and torque characteristics can be changed. Since this feature is seldom needed in an air separation plant, squirrel cage motors are almost exclusively used.

Due to the rotor's magnetic field being produced by induction from the rotating stator magnetic field, the reactive power necessary must come from the power system. This then gives a fixed power factor for a given load. Obviously, it can never by unity or leading. The system must supply the magnetic field through the stator and this causes the electrical losses to increase.

Efficiency calculations are carried out by industry accepted test methods. An example of these tests is given in Appendix II contained on page 60.

From the results obtained in Appendix II, the overall efficiency of this induction motor for operation at 4000 volts, 419 amps, and .9378 power factor is as follows:

LOSSES, KW	
Stator Copper	21.88 KW
Rotor Copper	22.93 KW
Stray Load	21.25 KW
Core	27.57 KW
Friction and Windage	17.00 KW
TOTAL LOSSES	110.63 KW

$$\text{Total Output (KW)} = \frac{4000 \times 419 \times 3 \times .9378}{1000} = 2722.356$$

$$\text{Efficiency in Percent} = \frac{2722.356 - 110.63}{2722.356} \times 100 = 95.94\%$$

The evaluation procedure for the purchase of induction motors is essentially the same as for synchronous outlined in an earlier section. The power factor value must be included in the calculations. The same penalty/bonus for guaranteed vs actual efficiencies can be applied to add additional incentive to manufacturing and market considerations for induction motors as in the case of synchronous motors.

An added constraint is increased competition. The sizes discussed above comprise the bulk of motor applications. This may further influence the marketing approach to a user and willingness to attempt to gain lower efficiencies.

The induction motors outlined in this section generally have overall rated efficiencies of 95% to 97.5% and overall power factors of 88% to 94%. The lower evaluated costs generally overcome the lower power factors and efficiencies over the operating life of the machine in the ratings outlined.

C. Small Low Voltage Motors

C.1 3Ø 460 Volt Motors

3Ø 460 volt motors are utilized by air separation in the following manner:

1. Cooling Water Pumps
2. Cooling Tower Fans
3. Lube Oil Pumps
4. Product Pumps
5. Vent Fans
6. Blowers
7. Small Instrument Air Compressors, etc.

They are typically bought as a package with the device they drive. An example would be a plant cooling tower with fans and pumps. The motor sizes range from 1 HP to 150 HP with some going up to 500 HP. Speeds are typically 1800 and 3600 RPM. Since bought as a package, they are not normally specified by the user as the main drives are. The package vendor chooses the motors used in this application.

An exception to the above is in the case of smaller sized air separation plants, 50 T/D or less. The main drive can be as large as 1000 HP and it is specified and evaluated in the same manner as the high voltage machines outlined in the preceeding section. At these smaller sized plants the remaining motors are usually under 25 HP.

Since this equipment serves to support the main drives, they are known as plant auxiliaries. The cost of this equipment is generally a very small percentage of the total investment and it is not uncommon to have spare units, including motors, on hand. For motors not spared, local service shops can rewind such motors usually overnight for about 1/2 of the cost of a new one.

All 460 volts motors under 200 HP conform to NEMA (National Electric Manufacturers Association) standards as far as frame sizes, general electrical characteristics, etc. All manufactures must conform to NEMA specs. For example, any NEMA frame motor of a given horsepower and manufacturer is interchangeable, physically, with the same rating of another manufacturer.[2]

This standardization offers flexibility in that there are many vendors that manufacture the same basic motor. "Off-the-shelf" availabilities are generally experienced, making the need for spare parts less critical. There is one drawback to a small motor user in that the competition among manufacturers for this type motor is extremely great. Up until the past few years this competition resulted in less then optimum design. Cost was the main consideration in manufacturing NEMA frame motors.

Motors of this type are tested in the same manner as large induction motors. Since the motors are manufactured in a production line assembly method (cost competitiveness dictates this), the first motor of a type is tested. Motor electrical characteristics do not normally change unless there is a design or material change usually due to cost or availability.

Typical efficiencies and power factors of some 4 pole motors are listed in Table 1.[3]

HORSEPOWER	FULL LOAD RPM	AMPS AT 460 VOLTS	EFFICIENCY	POWER FACTOR
10	1745	13.0	85.0	85.0
20	1760	24.6	88.5	87.0
30	1770	35.0	90.0	89.0
40	1775	47.5	91.0	87.0
50	1775	58.5	91.5	87.0

TABLE 1

TYPICAL EFFICIENCIES AND POWER FACTORS OF 4 POLE MOTORS

These efficiencies have been accepted until the last 5 years in which energy costs have been climbing drastically. This has been due in the United States to increased imported oil costs, and a high rate of inflation. In an attempt to improve the poorer efficiencies, there have been several "black box" devices developed. One of the first of these concepts is the Wanlass motor.

The Wanlass concept is quite simply to take a motor and add a capacitor in series with the run winding of an existing capacitor start motor circuit. The effect is to add some of the reactive power for magnitizing the core and raise the motor voltage to near motor magnetic saturation. These conditions drives the power factor towards unity and raises the motor efficiency. The following are some examples of a conventional and converted motor.[4]

	HP	VOLTS	AMPS	WATTS	POWER FACTOR	EFFICIENCY
1/4	Conventional	120	5.2	365	.53	.51
	Converted	120	2.6	300	.97	.61
1/3	Conventional	120	6.0	425	.53	.55
	Converted	120	2.3	335	1.0	.69
1/2	Conventional	120	7.7	605	.62	.61
	Converted	120	4.7	500	.87	.72

The above results were obtained by test. The motors up to 1 HP which are single phase and prime candidates for this type of conversion number about 500 million. The drawback lies in the cost to convert versus letting the motors remain inefficient. The majority of motors in this rating are not on continuously driven equipment (washers, dryers, dishwashers, air conditioners, dehumidifiers, etc.). The cost to convert may typically cost as much as operating the motor over the life of the driven equipment. Capacitor sizing is very critical, for improper sizing can cause the core to be driven into saturation, which will cause the power factor to drop drastically. Motor size and mounting location have a deciding factor as to converting a motor to the Wanlass configuration.

The above discussion and examples are all concerned with single phase motors up to 1 HP. Larger single phase and three phase motors (the types used in air separation facilities) unfortunately do not lend themselves to being converted. The capacitor sizing and cost becomes prohibitive on larger single phase motors and on three phase motors. In addition to sizing problems, means for shorting out the capacitors for starting duty must also be added, increasing costs and complexity. As a rule, the larger a motor becomes in size, the smaller the inefficiencies become and closer to unity power factors result.

In summary for the typical air separation plant, or any continuous driven equipment, the Wanless type motor is not practical or cost beneficial. Due to the lack of benefits gained, this type motor has not grown in popularity with vendor or user. The Wanless type motor most fits the application of the small or residential user, but at this point in time is still cost prohibitive.

Another recent device which lends itself to 3 phase motors of larger than NEMA size is the NOLA device.[5] This is a power factor control system which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement between current and voltage. It provides less power to the motor as loading is reduced. When the motor is running lightly loaded, most of the current (and input power) goes to magnetize the core. The power factor is low. The control device lowers the applied voltage, reducing magnetization in the core, thus reducing the power needed to supply core losses. The method in which the power factor controller works is to take the voltage waveform and "chop" it using solid stage devices. By increasing or decreasing the chopping rate, the effective magnitude is increased or decreased.

The drawback is, although iron loss decreases, the shaft load will draw current which produces I^2R loss in the stator and rotor. A voltage reduction will increase that current and those losses. The other more serious drawback is the harmonic content of the "chopped" voltage waveform. These harmonics can cause excessive overheating especially in the rotor. The problem is further complicated by the inability to calculate these harmonics or their effects.

This lends itself to the fact that economic justification for a controller of this type may not always exist, and an exact calculation is extremely difficult. The most likely candidates for this type controller are machine tool drives, vacuum pumps, and office machines. Basically, any drive in which the motor runs mostly at little or no load but cannot readily be shut down when not needed. The typical air separation plant generally does not have this type of load, thereby, making this type controller even more unattractive.

The third most significant type of "add-on" energy saving device is a variable frequency, variable voltage inverter. This inverter utilizes solid-state devices to take the sinusoidal AC power supply waveform apart and put it together again as a different frequency. This variable frequency can be used on a motor that runs at less than full load most of the time. A varying pump load, for example, could operate efficiently over a wide range of both horsepower and speed. A 3 to 1 difference in RPM is likely. This allows a 1800 RPM motor to operate at half load, half rated frequency and speed (900 RPM) almost as efficiently as carrying rated horsepower at full speed. Another possibility of variable frequency is wider use of higher frequency motor designs, smaller and more efficient for steady speed operation on as much as 1000 Hz.

There have been some 6 and 12 step inverters which have outputs resembling a sine wave when the higher number of steps are used. The result in any case is far from a smooth sinusoid. This means the motor voltage contains a high harmonic content, which produces additional motor winding heat losses, generates negative torques, and can alter the shape of the motor's speed-torque curve. Standard motors have been tested to show 20% higher temperature rise with a 12 step inverter and as much as 35% more temperature rise with a 6 step unit. Motors on this type of service must be designed for extra cooling or sized larger than the normal brake horsepower, would dictate.

The main drawback to using this type of system in a typical air separation plant is, in addition to the inherent problems, the air plant equipment is driven at constant load making the variable speed feature unnecessary.

The only other option to gain increased motor efficiency is to re-design the existing motor type to gain higher efficiency. As noted earlier, there is little effect one user can exert on a vendor to increase efficiency in this highly competative range of motors. However, due to government regulations on minimum efficiency criteria for this type motor soon to be initiated, many manufacturers are developing a market for these motors. To date almost every NEMA frame motor manufacturer offers some sort of "high efficiency" or "energy saver" type of motor. These motors are essentially the same motors designed to a tighter criteria and using better grade materials to achieve the higher efficiencies. Thi of course involves higher costs to the user.

The typical air separation plant has small motors that operate at near full load year round. However, there are approximately 45% that are installed spares, operate at start-up conditions, operate during outages, or operate at approximately 3/4 load. This diversity dictates there are many approaches to the question of purchasing "high efficiency" motors versus standard motors. The approach taken in this section will be to use the sizes outlined in the beginning and assume the following:

1. Using same manufacturer (with vendor supplied equipment not likely to happen)
2. Operating at full load (as explained does not always occur)
3. Operating year round (may be true depending on service)

The above assumptions obviously favor the "high efficiency" type motor.

HORSEPOWER	FULL LOAD RPM	STANDARD EFFICIENCY	STANDARD COST	HIGH EFFICIENCY	HIGH EFFICIENCY COST
10	1745	.87	$ 412.00	.88	$ 522.00
20	1755	.885	$ 690.00	.895	$ 808.00
30	1770	.895	$ 988.00	.910	$1,159.00
40	1765	.895	$1,318.00	.914	$1,527.00
50	1770	.905	$1,676.00	.917	$1,915.00

The evaluation on the above data is carried out below using the following formula for watts saved.[6]

$$\text{WATTS SAVED} = \text{HP} \times 746 \times \left(\frac{1}{\text{Standard Efficiency}} - \frac{1}{\text{High Efficiency}}\right)$$

KWH Costs Based on 8760 Hours/Year at $.03/KWH

$$\text{Payback Ratio in Years} = \frac{\text{Cost of Premium Motor}}{\text{Energy Cost Saved/Year}}$$

HORSEPOWER	WATTS SAVED	ENERGY/COSTS SAVED/YEAR	COST OF PREMIUM MOTOR	PAYBACK RATIO
10	97.44	$ 25.61	$110.00	4.30
20	188.37	$ 49.50	$118.00	2.38
30	412.18	$108.32	$171.00	1.58
40	693.08	$182.14	$209.00	1.15
50	539.35	$141.74	$239.00	1.69

The average payback ratio is 2.22 years, however, the assumptions made and the larger numbers of the smaller sizes (typical, four 10 HP for each 40 HP) used makes this factor very optimistic. A more detailed study would have to be conducted to determine the ratio at a specific facility, but indications are this ratio to be in excess of 5 years. With today's economic situation, typical payback periods of anywhere from 2 to 5 years are required.[7]

Moreover with the typical 20 MW air separation facility the low voltage (480 volt) motor load is less than 750 KW. Using 750 KW as the low voltage load, this represents approximately 3.8% of the total load. Using the average efficiency increase for the motors listed, 1.015%, the low voltage motor load drops to 738.92 KW or 3.7% of the total load. The 11 KW savings results in about $240.00 per operating month in a $400,000/month bill.

The above information indicates any current means to attempt to improve the efficiency of the low voltage motor load is both relatively noneffective and not economically justifiable at a typical air separation facility.

C.2 10 120 Volt Motors

This type of motor is used in air separation plants in the following manner:

1. Small Chemical Feed Pumps
2. Small Chemical Mixers
3. Hand and Shop Tools
4. Small Office/Shop Area Vent Fans

The use of 10 120 volt motors as indicated above consist of loads that have very low load factors and are very few in number. The typical efficiencies and power factors of these type motors tend to be in the 50% to 70% range. The "black box" methods of increasing efficiencies and the problems associated with these methods also exist for the 10 120 volt motors.

The operating costs versus efficiency study for this type of motor category is not normally done on a typical air separation facility as the load is negligible. In other industries, however, where this type of motor is the mainstay, this type of study is critical. As stated earlier, it is estimated that the number of 10 120 volt motors in service today exceeds 500 million units.

D. Power System Power Factor

1. Typical Power Factors

Due to the generally high synchronous motor load at the larger (20 MW size) air separation facilities the power factor of the power system is usually not of main concern. Power factor is defined as the actual power doing work (watts) divided by the apparent power consumed (volt-amperes). The 20 MW air separation facility has approximately 80% of its total horsepower as synchronous load. It is a generally accepted utility practice to penalize customers who have a power factor lower than 90% and offer a credit to those greater than 90%. These penalties or credits can be as high as $100.00 per 0.1% over or under the nominal. This of course must be weighed against the pay back ratio of credit earned versus cost of correction equipment.

The power utilization at a typical air separation plant tends to have a varied supply depending on the customer's resources or liabilities. Some examples of power supply contracts are as follows:[8]

TYPE OF SUPPLY	COMMENTS
Air separation plant owned owned substation	Power bought from utility

TYPE OF SUPPLY	COMMENTS
Customer pays portion of power bill of air separation plant owned substation	Utility costs to customer are reflected in cost of industrial gases supplied. Where customer is extremely large electric power user, this arrangement may afford lower air separation power costs.
Power is purchased from customer to air separation plant owned substation	Customer may have generating capabilities which would make costs lower and reflect in lower industrial gas costs to customer. Customer may be large user of electric power which would command a lower power rate. This would reflect in lower industrial gas costs to customer.

TYPE OF SUPPLY	COMMENTS
Power is supplied by customer to air separation plant	Customer may have generating capabilities which would make costs lower and reflect in lower industrial gas costs to customer.
	Customer may have a large electric power load which would result in lower energy costs and lower industrial gas costs.

With the above types of power arrangements being utilized, a survey was conducted at a number of air separation plants to determine if power factor correction equipment could be justified. The plants listed below have primarily synchronous loads or only induction loads.

Plant #1 (Induction Load)
No credit for power factor improvement.
Plant #2 (70% Synchronous Load)
Plant now operating at 98.5% power factor.
Plant #3 (85% Synchronous Load)
Plant now operating at 98.4% power factor.

Plant #4 (90% Synchronous Load)

Plant now operating at 99% power factor.

Plant #5 (70% Synchronous Load)

Plant now operating at 97% power factor.

Power contract calls for 90% minimum power factor.

Plant #6 (90% Synchronous Load)

Plant now operating at 99% power factor.

Power contract calls for 95% minimum power factor.

Plant #7 (90% Synchronous Load)

Plant now operating at 100% power factor. Power factor credit of $3,828.00 per year in effect.

Plant #8 (Induction Load)

Plant now operating at 92% power factor. Power factor credit of $1,164.00 per year in effect.

Plant #9 (Induction Load)

Plant now operating at 89% power factor. Power factor credit not applicable.

Plant #10 (Induction Load)

Plant now operating at 84.5% power factor.

Power factor penalty of over $5,000,00 per year in effect.

Power contract calls for 90% minimum power factor.

In the case of Plants #1, #2, #3, #4, and #9, the cost to increase the power factor cannot be justified because of no credit offered by the utility.

In the case of plants #5 and #6, the power contract minimum has been met and there is no justification to increase power factor.

For plants #7 and #8 there is a credit already in effect. Any attempts to improve the credit will be offset by power factor correction equipment costs. The power factor (and credit enjoyed) is obtained with only normal equipment used for the air separation process. No power factor correction equipment has been added.

Plant #10 will have power factor correction equipment installed (capacitors) costing approximately one years penalty. The power factor will be corrected to approximately 92%. This value will meet the power contract's 90% power factor minimum.

There were two other plants which had a power factor limitation placed on them in the initial design. In both cases, the customer was supplying the power requirements. This stipulation was handled in the design stages and power factor correction equipment was designed into the facilities.

2. Types of Correction[9]

As seen above, unity power factor synchronous motors are by far the easiest means to help correct power factor. Even though the power factor for the motor is 1.0, the large motor requires substantial KW to operate. This unity power factor KW load makes the overall plant KW high but does not require reactive power to run. For example, if the induction load of a facility was 1000 KVA at 90% power factor, the KW would be 900. If a 10,000 HP unity power factor synchronous motor were added, the new load would be:

$$1000 \text{ KVA} + 7460 \text{ KVA} = 8460 \text{ KVA}$$

$$900 \text{ KVA} + 7460 \text{ KW} = 8360 \text{ KW}$$

The over all plant power factor would now be:

$$\frac{8360 \text{ KW}}{8460 \text{ KVA}} = .988$$

98.8% Power Factor

It is obvious that the larger the synchronous motor load to induction load ratio is, the closer to unity the power factor will be. This is evident in most of the plants listed on the previous page.

The second most common means of power factor correction is by use of capacitors. They are generally connected to the load side of a motor starter and are switched on and off with the motor load. In some cases, capacitors are placed at the incoming power service to correct overall power factor for the facility.

When applied to motor circuits or plants with a large amount of motor load, they have a limit as to the capacity that may be applied. This is especially critical when the motors are connected to high inertia loads. Centrifugal compressors, found extensively in air separation plants, are such loads. The motor will run a relatively long time at quite a high speed after power is removed. When the power is initially removed, the capacitor serves as an excitation source for the induction motor. This can cause very high induced voltages. This high induced voltage can breakdown cable and motor coil insulation, as well as presenting a potential safety hazard. Another danger occurs if the power should be reclosed in a relatively short period of time after power removal, and the induced voltage is out of phase with the line voltage. This out of phase situation can cause extremely high transient torques which can damage shafts, bearings, couplings, gears, etc. To prevent the problems listed above by over sizing the capacitor, motor manufacturers will indicate the maximum allowable power factor correction capacity permissible on a given type size and voltage motor. This indication generally must come directly from the manufacturer if the motor is above the NEMA frame sizes.[2]

A last method of power factor correction is a synchronous condenser. A synchronous condenser is essentially a synchronous motor that is built to operate without a mechanical load. This results in a smaller size, since there is no inertia to overcome except that of the synchronous condensers' own rotor. The condenser is operated only to supply reactive power. It is continuously adjustable due to the excitation system being the same as that which is on a synchronous motor. This type of device is usually used on a system where there is a large amount of reactive power needed. A large manufacturing plant or a utility would be prime examples.

As can be seen from above, the power factor at a typical air separation facility tends to be very good, and there is very little economic incentive to add capacitors and not enough correction needed to justify a synchronous condenser. The synchronous motor load is usually large enough to give the plant good power factor. On the smaller facilities, where there is only inductive load, in some cases, capacitors have been added, and in the case of plant #10 listed in the section earlier, capacitors will be added in the near future.

E. Control Systems for Motors

In general, the control systems used on motors tend to be simple. Most breakers and starters are operated by 120 volt control relays. The protective devices used are highly efficient and require very little power to operate and seldom need maintenance. In the past control components were all of the electro-mechanical type. These units were built for heavy duty industrial use, being able to withstand lightning and voltage surges, extreme ambient temperature conditions, and extremely dirty and corrosive environment. Recent advances in electronic technology and the need to reduce manufacturing costs have brought about a shift from electro-mechanical components to solid-state devices. At the outset, 5-8 years ago, these solid-state units were unreliable. Large ambient temperature swings and high moisture conditions were fatal. The dirty and corrosive atmospheres also affected this type of relay. Once the moisture and temperature problems were solved (this required the industry 5 years to resolve), the units became more reliable. The effect of lightning and voltage surges now became significant. A voltage spike (whatever the source) tends to degrade the electronic components associated with a unit's internal power supply. These deficiencies are still a prime concern of manufacturers and users of solid state control devices.

There are more and more solid state control devices being marketed that have proper surge protection engineered into them. This is due in part to new standards being developed to aid manufacturers in design parameters. These were not initially available due to the developmental work on solid state devices was carried out in ideal laboratory conditions, rather than using the "dirty" electrical environment of an industrial installation.

Although control devices themselves are energy efficient, their reliability is of prime concern when it comes to saving energy. Start up time in most industrial situations is very energy inefficient in terms of excessive power usage and in not producing a marketable product. Even with the state-of-the-art devices becoming more and more adaptable to the industrial environment, most industrials favor the electro-mechanical devices over the solid state units. Air separation facilities are no exception to this preference.

F. Miscellaneous Loads

This section will briefly deal with typical miscellaneous electrical loads. These loads consist of the following:

1. Office and workshop area space heating
2. Domestic water heating
3. Plant area lighting
4. Office and workshop area lighting

The total loading of these loads on a typical 20 MW Air Separation Facility is approximately 60 KW, or 0.3% of the total plant load. This load, with an estimated 40% duty factor, results in about $500.00 per month in a $400,000 per month power bill. As in the case for 1 Ø 120 volt motors the load is essentially negligible and is ignored.

The domestic water heating and space heating are, of course, 100% efficient. The only improvements possible come from better building insulation and building design. Due to the relatively inexpensive heating energy costs, inovative building designs are not used. The building design is only tempered by the local weather conditions at a given facility.

Plant area lighting is now accomplished by either mercury vapor or high pressure sodium lamps. This method of lighting is much more efficient on a Watts per Lumen basis than incandescent lighting. The main consideration, however, in choosing this type of lighting source in <u>not</u> efficiency but safety and ease of maintenance. The life expectancy of a metalic vapor system is far greater then that of an incandescent system. This translates into ease of maintenance which enhances safety due to these areas remaining illuminated. An example of this is the average life of a 100 watt incandescent light bulb is 750 hours. A similar mercury vapor bulb has a life expectancy of 24,000 hours. An increased life expectancy of over 30 times.[10]

Office and workshop area lighting is accomplished by regular flourescent lighting. There is no appreciable benefit to design for maximum efficiency in this area.

It is obvious from the above that all loads that fall under this category are most cost effective when the equipment remains reliable, and as maintenance free as possible. Therefore, the necessity for purchasing the most energy efficient equipment available is reduced.

G. Process Computer Control

The ultimate objective of a computer system is to improve the performance of the plant through better monitoring and control. The monitoring system provides the capability of continuous evaluation of plant and equipment performance at the plant site in order to detect and correct any deviation from the target optimum plant operating conditions. The control system is designed to operate the plant in a "rock-steady"[1] fashion so that plant operation can be optimized. The improvement in performance results in the decrease in power consumption for a fixed amount of production.

The improvement in plant performance through a computer is achieved by a program of monitoring, control, and optimization. The computer implements a "best operator" philosophy stored in its memory. One of the most significant aspects of this computer control system is its capability to monitor the plant. The monitoring of plant performance can guide an operator towards optimum operation of the plant. This can be readily achieved only if the plant operation is "rock-steady" so that the operator can make small and frequent changes that are

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[1] The term "rock-steady" is used to define the plant operation as stable in terms of temperatures, pressures and flows necessary to produce the product demand. The time required to reach this condition depends on method of previous shutdown and length of time the plant was out of production.

necessary for optimum performance. The objective of the control system is to establish this steady plant operation. Once the monitoring and control functions are achieved, the plant operating conditions are then expected to be changed to optimum operating conditions. These optimum operating conditions are affected by ambient changes and production demand changes.

All the benfits that can be achieved from computer control arises from the computer's capability of carrying out two master functions. One is measuring continuously a very large number of process and equipment data and carrying out instantaneous calculations to provide any desired results. The second is its capability of performing closed loop control on calculated or measured process variables, thereby replacing many manual control loops. These two functions enable the computer system to monitor the plant operating condition and then adjust the operating conditions as close to any desired constraints. Significant power savings can be achieved at the plant turndown conditions. Plant turndown is defined as any period where the full production capacity of the plant is not needed. For example only 75% production is demanded. Turndown conditions generally increase the plants production inefficiency. Since at turndown there are additional operating variables and their interactions are compounded, the computer can effectively handle these changes and optimize the turndown.[11]

Process computers have been installed at some typical Air Separation Liquid Plants with the preliminary reports indicating increased efficiency of at least 3%. A typical 300 T/D Liquid Plant, with a 10MVA load, and 3% increase in efficiency can reduce a $216,000/month power bill by approximately $7000. With a typical computer system costing $150,000 to install, pay out can be achieved in 2.5 years.

H. Conclusions

With the concept of air separation plants as a criterion, the needs for cost effective production, and very high efficiency equipment are obvious for very good (97% or higher) on-stream times. In the case of large motors it is shown that the current design specifications and testing procedures are producing highly efficient machines. It is also apparent that most competitive manufactures are producing equipment which is as efficient as possible without becoming cost prohibitive. In contrast to the larger machine, manufacturers have many options open to them in the small motor area. Higher grade design, higher grade material, frequency and voltage controllers, and improved motor winding connections have been proven to be effective in increasing efficiency in certain applications. However it is shown that the application of small motors at a typical air separation plant have such load and duty factors, that these energy saving ideas are not cost effective at this time. This accounts for the continued purchase of these types of motors based on low cost as opposed to operating characteristics.

The power factor survey resulted in the power factor correction of just one facility. The modification has been carried out and was successful. The close-to-unity power factors enjoyed are a result of large synchronous loads and continued full load operation. Control systems while not energy intensive in themselves can have an influence on plant performance from a dependability standpoint.

Start-up costs (due to control component failures or shut-downs) are lost production costs and although do not reflect on the efficiency of the equipment, impact on the facilities financial profitability. As is the case with small motors, many improvements are possible with miscellaneous plant loads (heating, lighting, etc.). However these loads are negligible and low cost and availability are the prime purchasing considerations. Due to the large volume of electrical energy consumed, the impact of a process control computer saving power is large. This concept, however, is in actuality a process efficiency improvement tool and is not discussed in detail. There is no effect by the computer on the equipment efficiency.

In conclusion it is noted that current air separation plant design and operating procedures are producing extremely efficient facilities. These practices have been in effect for many years. This energy conservation philosophy has been developed over the years since the infancy of the air separation industry. As the plants became larger, so did energy consumption and the size of the equipment. This necessitated the need for efficient energy use prior to the energy "crises" and concern for energy conservation which came to light in the mid 1970's. Continued air separation industry growth and profitability depend on "fine tuning" and continuing these energy saving attitudes.

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Appendix I

The following data is the efficiency calculation from an actual motor used in an air separation facility.

SYNCHRONOUS MOTOR

Horsepower - 17,000
Power Factor - 1.0
Phase - 3
Frequency - 60 Cycles
Volts - 6600
Amps - 1132
Speed - 1200 RPM

The motor is rotated at a constant speed of 1200 RPM by a direct coupled DC drive motor. With this DC motor driving the motor under test, an open circuit test for the determination of core loss and a short circuit test for the determination of stray load loss can be made. The mechanical output of the drive motor, determined by subtracting the drive motor losses from the electrical power input to the drive motor, is equal to the losses of the synchronous motor.[11]

The open circuit test provides data from which the core loss is determined. Under open circuit conditions, the output power of the DC drive motor equals the sum of the friction and windage loss and the core loss of the synchronous motor. The DC drive motor output with no excitation applied to the synchronous motor is 49.26 KW. The DC drive motor output with excitation on the synchronous motor adjusted to obtain rated terminal voltage is 112.60 KW. Core loss is 112.60 - 49.26 = 63.34 KW. This value must be corrected to show the core loss for 110% load by using the per unit voltage behind armature resistance. In this case it is .9967. The core loss is assumed proportional to the square of the armature resistance. For this machine $63.34 \times (.9967)^2 = 62.92$ KW core loss. The short circuit test provides data from which the stray load loss is determind. Under short circuit conditions, the output power of the DC drive motor equals the sum of the friction and windage loss, the armature copper (ohmic) loss, and the stray load loss of the synchronous motor.[13]

The friction and windage loss as measured above was 49.26 KW. The armature copper (ohmic) loss is calculated by the following formula.

$$I_A^2 \; R_A \; (\mathrm{KW}) = 3 \; R_F\left(\frac{234.5 + T \text{ (Test Level °C)}}{234.5 + 25}\right) \frac{I_A^2}{1000}$$

R_F = Armature Resistance per Phase at 25°C = .008855

The test was conducted with the following results:

Current = 1132.5 amps (Rated Current)

Temperature of Armature = 55.1°C

$$I_A^2 \; R_A \text{ (KW)} = 3\ (.008855)\ \frac{(234.5 + 55.1)}{234.5 + 25}\ \frac{(1132.5)^2}{1000} = 38.02$$

Output Power from DC Drive Motor = 103.05 KW

Stray Load Loss (KW) = 103.05 - 38.02 - 49.26 = 15.77 KW

A friction and windage test is then conducted on completely assembled motor. This test is the same as conducted for the core loss test. The friction and windage loss was measured to be 50.00 KW.

The calculation of the synchronous motor field excitation was done by the Potier reactance method. Using this method on six data points, the field amps at 100% load was determined to be 340 amps.

The armature and field windage copper ohmic losses are calculated at full load conditions and corrected to 95°C.

$$I_{\text{Field}}^2 \; R_{\text{FIELD}} \text{ (KW)} = I_F^2 \; R_F \left(\frac{234.5 + 95}{234.5 + 25}\right) \left(\frac{1}{1000}\right)$$

For I_F = 340 A and R_F Measured at .18311 at 25°C

$$I_F \;\; R_F \text{ (KW)} = 26.88 \text{ KW}$$

$$I^2_{\text{Armature}} \; R_{\text{Armature}} \text{ (KW)} = 3\ I_A^2 \; R_A \; \frac{234.5 + 95}{(234.5 + 25)} \;\; \frac{1}{1000}$$

For $I_A = 1132$ A and $R_A = .008855$

$$I_A^2 R_A \text{ (KW)} = 43.22 \text{ KW}$$

The brushless excitation system consists of an exciter rotor, exciter stator and a diode bridge with semi-conductors. The unit placed on the synchronous motor under test is of a standard design. The losses for the total exciter have been determined by similar test methods when the exciter was initially built. This is the loss figure that will be used. The brushless excitation system losses are 2.72 KW.[1]

Appendix II

The following data is for the efficiency calculation from an actual motor used in an air separation facility. The test method was the input measurement type with a coupled load.[14]

INDUCTION MOTOR

Horsepower - 3,500
Phase - 3
Frequency - 60 Cycles
Volts - 4,000
Amps - 419
Synchronous Speed - 1,785
Temperature Rise - 80°C

The motor stator DC resistance is measured. It is used in the following formula to calculate stator I^2R (copper ohmic) loss.

$$I^2R \text{ Stator} = 3/2\ I^2R \text{ at } 105°\text{C } (25°\text{C Plus Rise Temperature})$$

$$R \text{ (Corrected to } 105°\text{C)} = .0831$$

$$I = 419 \text{ A (Measured at Full Load)}$$

$$I^2R \text{ Stator} = \frac{3}{2}(419)^2\ .0831 = 21.88 \text{ KW}$$

The rotor copper ohmic loss is determined from the data gained in the above test at full load conditions, in addition to measuring the slip and the input power to the motor.

Stator Input Power = 2774.58 KW

$$\text{Slip} = \frac{1800 - 1785}{1800} = .00833$$

The formula used for the rotor I^2R loss is:

Rotor I^2R Loss = (Measured Stator Input - Stator I^2R Loss) x Slip

Rotor I^2R Loss = (2774.58 - 21.88) .00833 = 22.93 KW

The stray load loss can be determined by measuring the input to the stator with the rotor removed and subtracting the I^2R stator loss. During this test, bearing brackets and other structural parts in which current might be induced are to be in place.

Stray Load Loss = Input to Stator - I^2R Stator Loss

Stray Load Loss - 43.13 KW - 21.88 KW = 21.25 KW

The friction and windage and core losses for the induction motor are determined by a no-load test. The no-load input power is a summation of the following losses:

Friction and Windage

Core

Stator I^2R

The input power minus the stator I^2R is then plotted on a no-load KW vs line volts curve given on Figure 4. Separate determination of the core loss is not necessary for usual performance calculations. The separation may be made by reading volts, amps, and watts input at rated frequency and at voltages ranging from 125 percent of rated voltage down to the point where further voltage reduction increases the current (usually about 15 percent of rated voltage). The curve is extended to zero volts. The KW curve intercept with zero voltage axis is the core loss valve. The rated voltage point minus the core loss valve is the friction and windage valve. The valves for this machine read from the attached cure are:

Core Loss = 27.57 KW

Friction and Windage Loss = 17.00 KW

The power factor for the machine is measured at full load using the following formula:

$$PF = \frac{\text{Watts}}{\text{Line Volts} \times \text{Line Amps} \times 1.732}$$

For this motor:

Volts = 4000

Amps = 419

Watts = 2,722,355

$$PF = \frac{2,722,355}{4000 \times 419 \times 1.732} = .9378$$

INDUCTION MOTOR

HORSEPOWER 3500

VOLTS 4000

AMPS 419

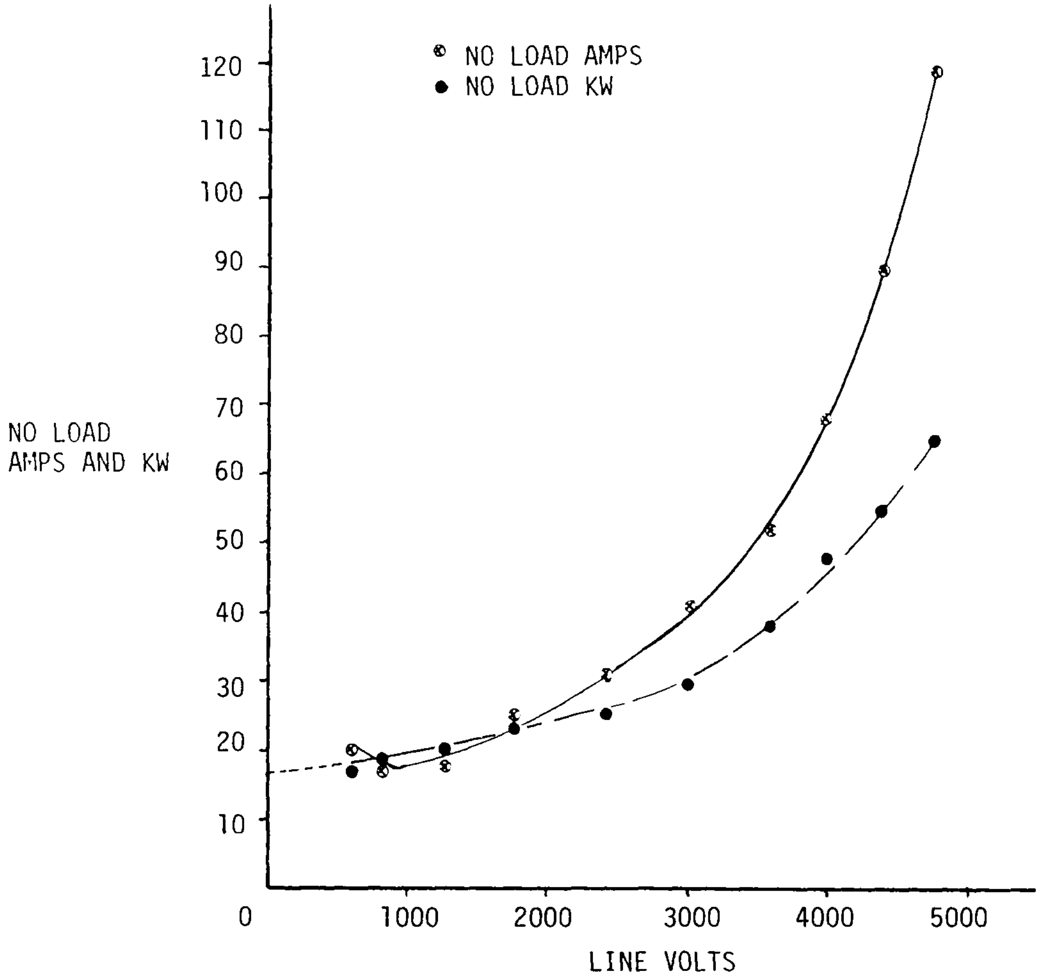

FIGURE 4

NO LOAD POWER VERSUS LINE VOLTS

BIOGRAPHICAL DATA

Name: John Michael Mitroka

Place and Date of Birth: Allentown, Pennsylvania June 20, 1952

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Mother's Name: Mildred J.

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Societies: Institute of Electrical and Electronics Engineers

Professional Experience: Employed by Air Product since 1974 as an Operations Electrical Engineer. Responsibilities include troubleshooting problems at existing operating facilities, recommending and specifying modifications to improve operating on-stream times, and reviewing new projects to ensure integrity of design is carried through.