

# Baldor Motor Basics — Part 9

## Amps, Watts, Power Factor and Efficiency

### Approximate Load Data from Amperage Readings

### Power Factor Correction on Single-Induction Motors

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(A continuing series of articles, courtesy of the Baldor Electric Co., dedicated primarily to motor basics; e.g. — how to specify them; how to operate them; how — and when — to repair or replace them, and considerably more.)

#### Introduction

There seems to be a great deal of confusion among the users of electric motors regarding the relative importance of power factor, efficiency and amperage, as related to operating cost. The following information should help to put these terms into proper perspective.

At the risk of treating these items in reverse order, it might be helpful to understand that in an electric bill, commercial, industrial or residential, the basic unit of measurement is the kilowatt hour. This is a measure of the amount of energy that is delivered. In many respects, the kilowatt hour could be compared to a ton of coal, a cubic foot of natural gas, or a gallon of gasoline, in that it is a basic energy unit. The kilowatt hour is not directly related to amperes, and at no place on an electric bill will you find any reference to the amperes that have been utilized. It is vitally important to note this distinction. You are billed for kilowatt hours: you do not necessarily pay for amperes.

**Power factor.** Perhaps the greatest confusion arises due to the fact that early in our science educations, we were told that the formula for watts was amps times volts. This formula,  $\text{watts} = \text{amps} \times \text{volts}$ , is perfectly true for direct current circuits. It also works on some AC loads such as incandescent light bulbs, quartz heaters, electric range heating elements, and other equipment of this general nature. However, when the loads involve a characteristic called inductance, the formula has to be altered to include a new term called power factor. Thus, the new formula for single phase loads becomes,  $\text{watts} = \text{amps} \times \text{volts} \times \text{power factor}$ . The new term, power factor, is always involved in applications where AC power is used and inductive magnetic elements exist in the circuit. Inductive elements are magnetic devices such as solenoid coils, motor windings, transformer windings, fluorescent lamp ballasts, and similar equipment that have magnetic components as part of their design.

Looking at the electrical flow into this type of device, we would find that there are, in essence, two components. One portion is absorbed and utilized to do useful work. This portion is called the real power. The second portion is literally borrowed from the power company and used to magnetize the magnetic portion of the circuit. Due to the reversing

nature of AC power, this borrowed power is subsequently returned to the power system when the AC cycle reverses. This borrowing and returning occurs on a continuous basis. Power factor then becomes a measurement of the amount of real power that is used, divided by the total amount of power, both borrowed and used. Values for power factor will range from zero to 1.0. If all the power is borrowed and returned with none being used, the power factor would be zero. If on the other hand, all of the power drawn from the power line is utilized and none is returned, the power factor becomes 1.0. In the case of electric heating elements, incandescent light bulbs, etc., the power factor is 1.0. In the case of electric motors, the power factor is variable and changes with the amount of load that is applied to the motor. Thus, a motor running on a work bench, with no load applied to the shaft, will have a low power factor (perhaps .1 or 10%), and a motor running at full load, connected to a pump or a fan might have a relatively high power factor (perhaps .88 or 88%). Between the no load point and the full load point, the power factor increases steadily with the horsepower loading that is applied to the motor. These trends can be seen on the typical motor performance data plots which are shown (Fig. 1).

**Efficiency.** Now, let's consider one of the most critical elements involved in motor operating cost. This is efficiency. Efficiency is the measure of how well the electric motor converts the power that is purchased into useful work. For example, an electric heater such as the element in an electric stove, converts 100% of the power delivered into heat. In other devices such as motors, not all of the purchased energy is converted into usable energy. A certain portion is lost and is not recoverable because it is expended in the losses associated with operating the device. In an electric motor, these typical losses are the copper losses, the iron losses, and the so-called friction and windage losses associated with spinning the rotor and the bearings and moving the cooling air through the motor.

In an energy efficient motor, the losses are reduced by using designs that employ better grades of material, more material and better designs, to minimize the various items that contribute to the losses in the motor.

For example, on a 10 hp motor, a Super-E energy efficient design might have a full load efficiency of 92.4%, meaning that, at full load (10 hp), it converts 92.4% of the energy it receives into useful work. A less efficient motor might have an efficiency of 82%, which would indicate that it only converts 82% of the power into useful work.

Typical performance - not guaranteed values.

15 HP 3 PH 60 HZ 1765 RPM 460 V 0936M  
 TORQUES (LB-FT): P0=165 PU=68.2 LR=79.1 LRA=122.9

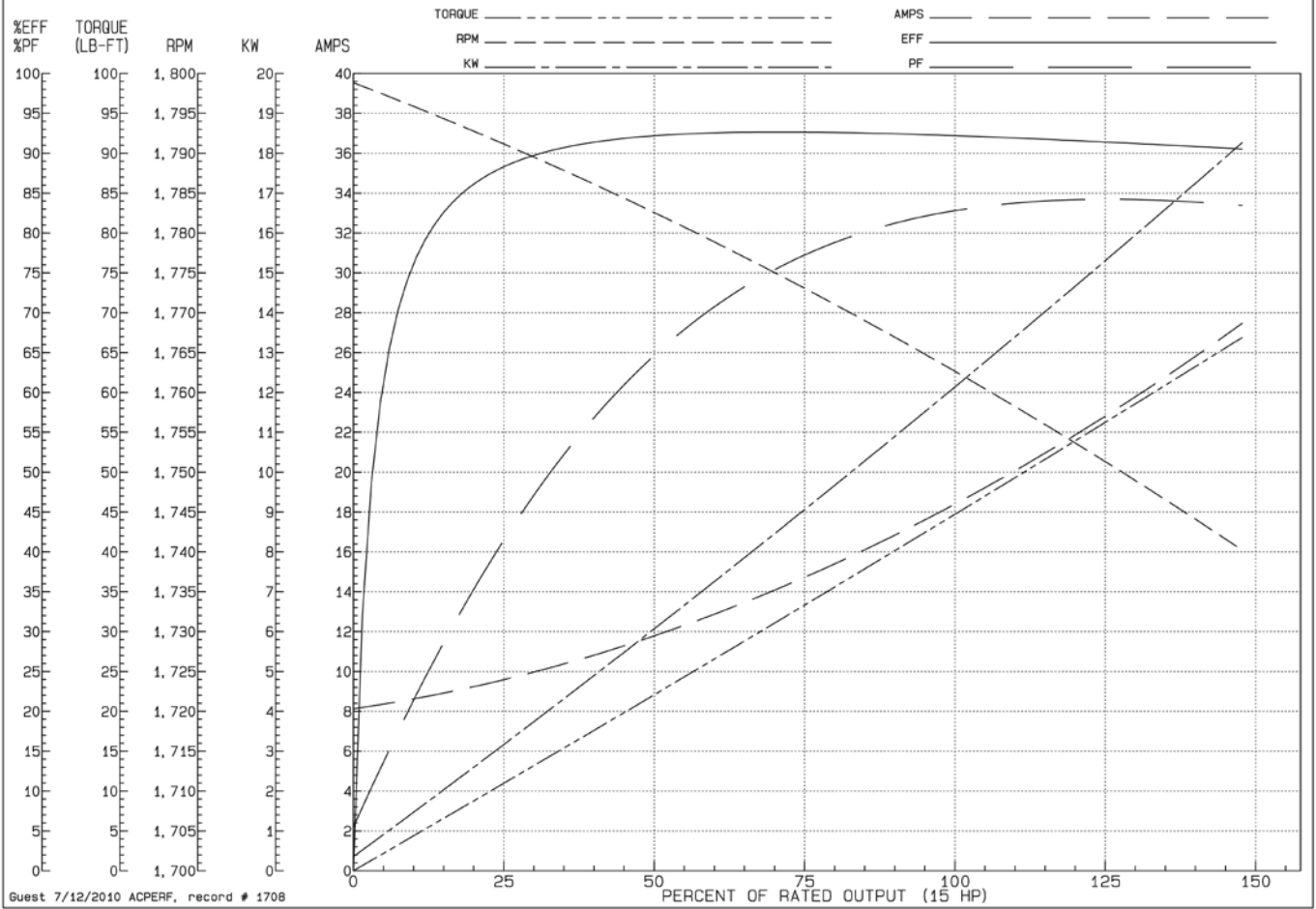


Figure 1 Typical — not guaranteed — motor performance data plots.

In general, the efficiency of motors will be relatively constant from 50% to 100% of rated load.

**Amperes.** Now, let's discuss amperes. Amperes are an indication of the flow of electric current into the motor. This flow includes both the borrowed as well as the used power. At low load levels, the borrowed power is a high percentage of the total power. As the load increases on the motor, the borrowed power becomes less and less of a factor and the used power becomes greater. Thus, there is an increase in the power factor as the load on the motor increases. As the load continues to increase beyond 50% of the rating of the motor, the amperage starts to increase in a nearly straight line relationship (Fig. 1).

### Summary

Figure 1 shows significant items that have been discussed as plots of efficiency, power factor and watts, as they relate to horsepower. The most significant factor of all these is the watts requirement of the motor for the various load levels because it is the watts that will determine the operating cost of the motor, not the amperage.

The customer that has an extremely low power factor in

the total plant electrical system, may be penalized by his utility company because he is effectively borrowing a great deal of power without paying for it. When this type of charge is levied on the customer, it is generally called a power factor penalty. In general, power factor penalties are levied only on large industrial customers and rarely on smaller customers regardless of their power factor. In addition, there are a great many types of power customers such as commercial establishments, hospitals, and some industrial plants that inherently run at very high power factors. Thus, the power factor of individual small motors that are added to the system will not have any significant effect on the total plant power factor.

It is for this reason that the blanket statement can be made, that increasing motor efficiency will reduce the kilowatt hour consumption and the power cost for all classes of power users, regardless of their particular rate structure or power factor situation. This same type of statement cannot be made relative to power factor.

The following basic equations are useful in understanding and calculating the factors that determine the operating costs of motors and other types of electrical equipment. **PTE**

## Operating Cost Calculations

### Motors

$$\text{Kilowatt Hours} = \frac{\text{hp}^{**} \times .746 \times \text{Hours of Operation}}{\text{Motor Efficiency}}$$

\*\* Average Load hp (May be lower than Motor Nameplate hp)

General Formula      All Loads

$$\text{Kilowatt Hours} = \frac{\text{Watts} \times \text{Hours of Operation}}{1000}$$

Approximate Operating Cost\* = Kilowatt hours × average cost-per-kilowatt-hour

\* Does not include power factor penalty or demand charges which may be applicable in some areas.

### Useful Constants

Average Hours per Month = 730

Average Hours per Year = 8,760

Average Hours of Darkness per Year = 4,000

Approximate Average Hours per Month (single shift operation) = 200

## APPROXIMATE LOAD DATA FROM AMPERAGE READINGS

### Conditions

1. Applied voltage must be within 5% of nameplate rating.
2. You must be able to disconnect the motor from the load (by removing V-belts or disconnecting a coupling).
3. Motor must be 7½ hp or larger — 3,450; 1,725; or 1,140 rpm.
4. The indicated line amperage must be below the full load nameplate rating.

### Procedure

1. Measure and record line amperage with load connected and running.
2. Disconnect motor from load. Measure and record the line amperage when the motor is running without load.
3. Read and record the motor's nameplate amperage for the voltage being used.
4. Insert the recorded values in the following formula and solve.

$$\% \text{ Rated hp} = \frac{(2 \times \text{LLA}) - \text{NLA}}{(2 \times \text{NPA}) - \text{NLA}} \times 100$$

Where:

LLA = Loaded Line Amps

NLA = No Load Line Amps (Motor disconnected from

load)

NPA = Nameplate Amperage (For operating voltage)

**Note:** This procedure will generally yield reasonably accurate results when motor load is in the 40 to 100% range and deteriorating results at loads below 40%.

### Example and Calculation:

A 20 hp motor driving a pump is operating on 460 volts and has a loaded line amperage of 16.5. When the coupling is disconnected and the motor is operated at no load the amperage is 9.3. The motor nameplate amperage for 460 volts is 19.4.

Therefore we have:

Loaded line amps (LLA) = 16.5

No load amps (NLA) = 9.3

Nameplate amps (NPA) = 19.4

$$\% \text{ Rated hp} = \frac{(2 \times 16.5) - 9.3}{(2 \times 19.4) - 9.3} \times 100 = \frac{23.7\%}{29.5\%} = 80.3\%$$

Approximate load on motor slightly over 16 hp.

## POWER FACTOR CORRECTION ON SINGLE-INDUCTION MOTORS

### Introduction

Occasionally we are asked to size power factor correction capacitors to improve the power factor of a single motor. Usually, the requested improved power factor level is 90 or 95%. The necessary calculations to get the proper capacitor KVAR (kilovolt ampere reactive) value are straightforward, but since we don't do it often it is nice to have the method in writing.

**Procedure.** The first thing needed is the full load power factor and efficiency information for the motor. On Baldor motors this can be found on the internet at [www.Baldor.com](http://www.Baldor.com). Next, since most power factor tables are worked in terms of kilowatts, it is necessary to convert the motor output rating into kilowatts. The procedure for doing this is to take the motor hp multiplied by the constant for kW per hp (0.746). This will give Output kW. Then it is necessary to divide this by the efficiency of the motor (as a decimal) to get the input kW at full load. Next, refer to power factor correction (Table I) going in from the left with the existing power factor and coming down from the top with the desired power factor. Where they intersect find the multiplier needed.

Next, multiply the motor input kilowatts by the appropriate

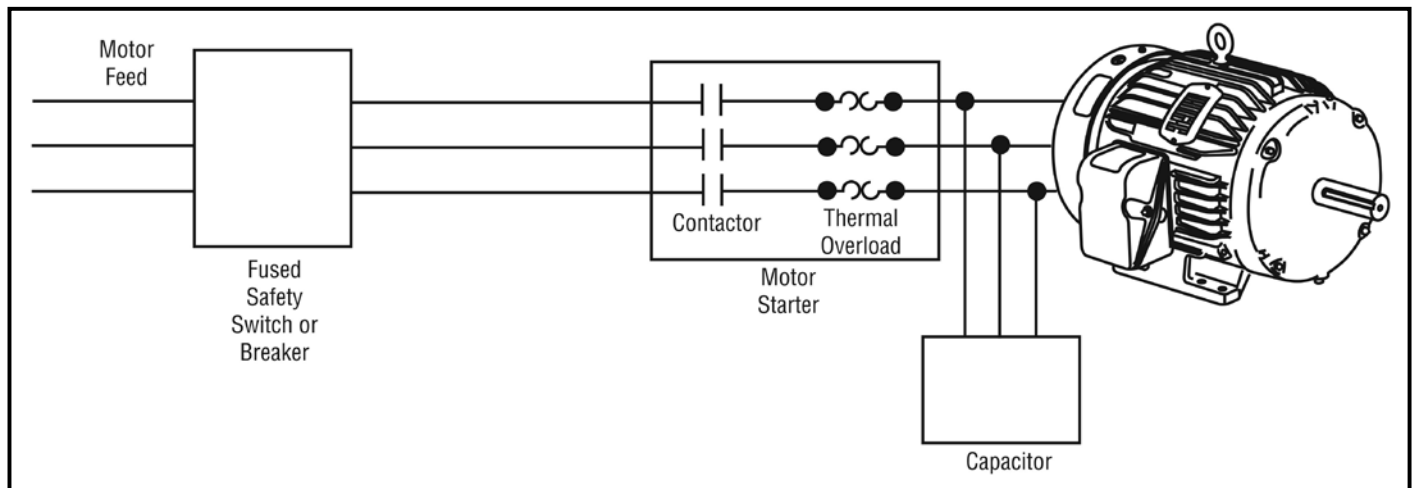


Figure 2 For single-motor correction, capacitors are connected between motor starter and motor at the motor terminals.

ORIGINAL FACTOR %	DESIRED POWER FACTOR		
	85	90	95
60	0.713	0.849	1.004
62	0.646	0.782	0.937
64	0.581	0.717	0.872
66	0.518	0.654	0.809
68	0.458	0.594	0.749
70	0.400	0.536	0.691
72	0.344	0.480	0.635
74	0.289	0.425	0.580
76	0.235	0.371	0.526
77	0.209	0.345	0.500
78	0.182	0.318	0.473
79	0.156	0.292	0.447
80	0.130	0.266	0.421
81	0.104	0.240	0.395
82	0.078	0.214	0.369
83	0.052	0.188	0.343
84	0.026	0.162	0.317
85	0.000	0.136	0.291
86		0.109	0.264
87		0.083	0.238
88		0.056	0.211
89		0.028	0.183
90		0.000	0.155
91			0.127
92			0.097
93			0.066
94			0.034
95			0.000

3-PHASE STANDARD CAPACITOR RATINGS KVAR (Kilovolt Amperes Reactive)		
1.0	20.0	70.0
1.5	22.5	75.0
2.0	25.0	80.0
2.5	27.5	85.0
3.0	30.0	90.0
4.0	32.5	100.0
5.0	35.0	120.0
6.0	37.5	140.0
7.5	40.0	150.0
8.0	42.5	160.0
9.0	45.0	180.0
10.0	50.0	200.0
11.0	52.5	225.0
12.5	55.0	250.0
15.0	60.0	300.0
17.5	65.0	350.0

multiplier from Table 1 to get the required KVAR of power factor correction. This value would be rounded out to match commercially available power factor correction capacitor ratings shown in Table 2.

**Example.** To illustrate the procedure an example is worked as follows:

What is the KVAR of power factor correction capacitors needed to improve the power factor of a catalog number M2555T, 100 hp motor, to 95% at full load?

Step 1: Look up the existing power factor and efficiency.

$$\text{Efficiency} = 94.1\%$$

$$\text{Power factor} = 85\%$$

Step 2: Convert the hp to kilowatts *output*.  $100 \text{ hp} \times 0.746 = 74.6 \text{ kW}$

Step 3: Convert kilowatts *output* to kilowatts *input* by dividing by the full load efficiency.

$$\frac{74.6}{.941} = 79.3 \text{ kW input}$$

Step 4: Look in Table 1 to find the multiplier to achieve the desired 95% corrected power factor.

The multiplier is 0.291.

Step 5: Multiply input kW by this multiplier.  $79.3 \times 0.291 = 23.1 \text{ KVAR}$

This gives the required capacitor KVAR.

Step 6: Select closest value from Table 2. 22.5 KVAR

The voltage of the capacitor would also have to be specified; in this case it would be 480 volts.

**Current correction.** In many cases when a single motor is being corrected, the capacitors are connected between the motor starter and the motor at the motor terminals (Fig. 2). With this being the case, the effect of the correction is to reduce the current flowing through the starter and overload relay. Since the overload heaters are selected (or adjusted) on the basis of the motor at full load current, this means that the overloads will not correctly protect the motor unless the ampacity is reduced to reflect the reduced current now flowing as a result of the power factor improvement.

The motor itself will draw the same number of amps at full load as it would without the power factor correction. However, the power factor correction capacitors will be supplying a portion of the current, and the balance will be coming through the starter from the power line.

The new value of current passing through the overloads is given by the following formula:

$$\text{Current}_{\text{new}} = \text{Motor full load (nameplate) amps} \times \frac{\text{Power factor original}}{\text{Power factor corrected}}$$

For example, in the case of the 100 hp motor in the example, the heater size — which would normally be selected from the motor nameplate current at 118 amps — would have to be adjusted as follows:

$$\text{Current}_{\text{new}} = 118 \times \frac{.85}{.95} = 118 \times .895 = 105.6 \text{ or approximately } 106 \text{ amps } .95$$

## Summary

A few words of caution might be appropriate here. Usually it is desirable to “under correct” rather than “over correct.” If the capacitors chosen are too large, there can be a number of problems — including high transient torques and overvoltage. Thus it is usually not desirable to attempt to improve power factor beyond 95%; it also usually becomes uneconomical to attempt improvements beyond 95%.

**Please note:** This type of power factor improvement *should not be used* in any situation where the motor is being controlled by a solid state device such as a soft start control or a variable frequency drive.

(See Figure 2 for Convenient Motor and Energy Formulas.) **PTE**

