ECONOMIC COMPARISION OF POWER FACTOR CORRECTION BY CAPACITORS AND HIGH POWER FACTOR/HIGH-EFFICIENCY MOTORS

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ABSTRACT

The traditional approach to power factor correction in a facility is to add capacitors to individual loads such as motors and fluorescent lighting circuits to add a capacitor !ank with switching to a ma"or distri!ution panel or to add a capacitor !ank with switching to the power input panel from the utility lines. #ecently it has !een shown that careful selection of high$efficiency motors for a facility can result in new motors with a significantly higher power factor than the motors they replaced. This paper compares and discusses the cost$effectiveness of installing capacitors on individual motors with the cost$effectiveness of installing high$efficiency high power factor motors.

INTRODUCTION

%acilities with a low power factor sometimes pay a utility rate penalty. #ecently it has !een shown that careful selection of high$efficiency motors with high power factors can improve the economic !enefit of replacing standard$efficiency motors with high$efficiency motors !y as much as &' ( )1*. The com!ination of an energy cost savings from improved efficiency and a power factor penalty cost savings from improved power factor makes the economics of selecting high$efficiency motors even more attractive. +n some cases the economic !enefit from a reduced power factor penalty provides enough incentive to choose a high$efficiency high power factor motor as a via!le approach to power factor correction.

There are two conventional approaches to power factor correction in facilities, one is installing capacitors on motors motor circuits fluorescent lighting circuits and other inductive loads- the other is installing capacitors at the entrance of the main power lines in the facility. The cost of the capacitors is repaid through the savings from the utility penalties that would have !een charged for the poor power factor. .owever to the present authors/ knowledge no one has compared the cost$effectiveness of using high$efficiency high power factor motors with the cost$effectiveness of installing capacitors on motors.

This purpose of this paper is to descri!e the conditions under which one of the following techni0ues should !e employed to reduce power factor penalty charges,

1. #eplace failed standard$efficiency motors with premium$efficiency high power factor motors

1. #eplace failed standard$efficiency motors with new standard$efficiency motors and install capacitors on the new motors.

DATA COLLECTION

Motor Power Factor and Efficiency

+nformation a!out the performance of motors was o!tained from a valua!le and user$friendly resource called 2otor2aster availa!le from the 3ashington State 4nergy 5ffice)1*. 2otor2aster contains a data!ase of over 11 ''' motors and has data on motor models costs efficiencies at different loads and power factor at different loads. 3e used the 2otor2aster data!ase !y taking a sample of ten standard$efficiency motors and ten high$efficiency high power factor motors for each horsepower rating. The efficiency and power factor were recorded for load factors of 1'' (67 (7' (and 17 (.

3e have compiled a list of motor si8es and their efficiency at different loads in **Table 1**. The ta!le was constructed !y computing the average efficiency of a standard$efficiency motor 94%s: and the average efficiency of a high$efficiency or premium efficiency motor 94%p:. ; similar ta!le was developed for motor si8es and their power factor at different loads. **Table 2** lists the average power factor for a standard$efficiency motor 9<%s: and the average power factor of specific high$ efficiency motors with high power factors 9<%p:. Both ta!les list the cost premium 9C<: for high$efficiency motors. The cost premium is defined as the difference in the cost of a high$efficiency motor and the cost of a standard$efficiency motor. +n the economic analysis of correcting power factor !y replacing a standard$efficiency motor with a high$efficiency motor the implementation cost is the cost premium. 3e have used this data to evaluate the cost$effectiveness of correcting power factor. 3e hope that energy and plant managers as well as energy analysts and consultants will use these ta!les as another data resource to utili8e when selecting or specifying motor types and si8es.

Capacitor Cost

3hen selecting a capacitor to correct the power factor of a motor the capacitor must !e properly si8ed to meet the desired level of power factor correction. The si8e of the capacitor in k=;#s will increase su!stantially with the desired power factor. Since power factor is descri!ed !y the cosine function incremental improvements in power factor demand increasingly more capacitance. %or instance a motor circuit with total k3 input of 1'' k3 at >'(power factor would need a capacitor rated at 16 k=;# ?1.7 k=;# and 67.' k=;# to improve the power factor to @'(@7(and 1''(respectively. ;lthough increasingly more capacitance is needed for !etter power factors the cost of installing a capacitor on a certain si8e motor increases slowly since large capacitors cost less per k=;# than small capacitors.

3e compiled list prices of 17' capacitors from national manufacturers and distri!utors. Based on that data we constructed a 0uadratic function to estimate the cost of a capacitor descri!ed as

y9A: B 1@?.C@ D 11.'''A $ '.''?A 1

where A is the desired k=;# rating of the capacitor and y is the cost of the capacitor. **Graph 1** shows the predicta!ility of costing capacitors. 2anufacturers of capacitors must recover setup costs regardless of a capacitor/s si8e. Thus the average cost of a capacitor is higher for smaller capacitors. .owever the cost of capacitors rated 7' k=;# and a!ove can !e linearly estimated since the average cost sta!ili8es at a!out E1& per k=;#.

MOTOR LOADS

2otor loads are usually specified in terms of horsepower efficiency and load factor. Since the load factor varies greatly with the motor/s application load factor is often the leading factor for correct energy cost analysis. .owever power factor has !ecome one of the emergent energy measurements for facility managers as utility companies move away from traditional k3 !illing to newer rate structures such as direct k=; !illing. The relationships of real power 9k3: apparent power 9k=;: and reactive power 9k=;#: are descri!ed as follows,

k=;# B √ 9k=; 1 $ k3 1 :

where

k3 B L% F .< F C G 4%

k=; B k3 G <%

and

L% B load factor

.< B horsepower

C B conversion '.6?C k3 G hp

4% B efficiency

<% B power factor

; motor with a higher power factor re0uires less total current and less reactive current for an e0ual amount of useful work. That is less reactive power is needed to generate the fluA for the magnetic field of the motor in order to produce the same amount of real work. ; motor with a higher efficiency rating re0uires less electric power for an e0ual amount of useful work. ;n improvement in efficiency reduces the total power re0uirement which can mean a reduction in power factor penalties as well as a reduction in energy costs.

Because the power factor and efficiency of a motor vary with the load of the motor the e0uations a!ove must !e calculated with the power factor and efficiency ratings at the given load factor. 2otor power factors !egin to erode as motor operation drops !elow 67(of rated load and decline sharply !elow 7'(of rated load)&*. Ta!le 1 shows that power factors of all motors deteriorate markedly at load factors of

7' (and especially at load factors of 17 ($ regardless of whether the motors are standard$ efficiency or premium$efficiency. 4fficiencies often peak at 67 (load and deteriorate noticea!ly at lower load factors. %rom Ta!le 1 we can see that efficiency drops 7$6 (in smaller motors and 1$? (in larger motors. +t is clear from this data that it is not very cost$effective to run motors at low load factors.

UTILITY POWER FACTOR CHARGES

There are three principal methods !y which utilities charge for a customer/s poor power factor. These are direct k= ; charges !illing demand ad"ustments for low power factor and charges for eAcess k= ; #s. +n the economic analysis of power factor cost savings in this paper the following three eAample utility rates were used 9see #eference 1 for a further eAplanation of these rates:. The economic penalty from poor power factor varies significantly depending on the particular utility rate structure. Billing on k= ; is !y far the most severe penalty and offers the most incentive for correcting facility power factors.

Htility #ate 5ne, E6.'1Gk= ;
Htility #ate Two, E7.''Gk3 9!illed demand $ ad"usted for power factor:
Htility #ate Three, E7.''Gk3 plus E'.67 for eAcess k= ; # a!ove C' (of real demand

A COMPARISON OF ECONOMICS UNDER THREE DIFFERENT UTILITY RATES

2otors are manufactured in nominal horsepower ratings such as 7 .< and 17 .<. 5ur study evaluates the power factor cost savings for a typical motor of every si8e in the market from 1 .< to 17' .<. 3e evaluated three common levels of power factor correction, @' (@7 (and 1'' (. 5ne measure of cost$effectiveness is the simple pay!ack period 9S<<:. 3e have chosen to use this measure since it is easy to calculate and most plant engineers and managers use it in practice. Cost effective is defined as a S<< less than two years. Iot cost effective is defined as a S<< greater than three years.

Utility Rate One

There are two important conclusions to !e drawn. %irst correcting the power factor of small motors should !e done !y replacing failed standard$efficiency motors with new premium$ efficiency motors. Second correcting the power factor of a large motor should !e done !y installing a capacitor on the motor. 3e have constructed a power factor correction guide !elow that plant engineers and managers can use to Ouickly determine which method of power factor correction to use.

POWER FACTOR CORRECTION GUIDE

Hse . igh$4fficiency 2otors Hse Capacitors
when the motor is, when the motor is,

1' .< or less Jreater
than 1' .<
at 7'$1'' (load at 7'$1'' (load

Less than 7 .< 7 .< or more
at a!out 17 (load at a!out 17 (load

Utility Rate Two

Hnder the second rate structure our analysis reveals that installing capacitors on standard$ efficiency motors or replacing standard$ efficiency motors with high$efficiency motors are cost$effective only for motors rated less than 7 .< at 17 (load. The simple pay!ack period varies from 1.& years to 1.C years. 2ost facilities that employ either method of power factor correction for motors rated less than 7 .< at 17 (load will o!serve a pay!ack period of less than two years. Ieither method is an economically attractive approach to power factor correction for any motor rated at 7 .< or a!ove. %or capacitor power factor correction the S<< declines slightly as the level of power factor correction increases from @'(to @7(and from @7(to 1''(. Kam looking to clean this paragraph up suggestions welcomeL

Utility Rate Three

%or facilities that are penali8ed under the third utility rate structure installing capacitors is cost$ effective for 1''(power factor correction of motors rated at 1'' .< and a!ove. ; facility that fits these conditions can eApect the power factor penalty cost savings to repay the cost of the capacitors in a!out 1.6 years. The simple pay!ack period varies from 1.? years to 1.1 years depending on the si8e of the motor a!ove 1'' .< and the load factor at which the motor operates. Cbalde\SJT dinstalLing capacitors is not cost$ effective for @'(power factor correction @7(power factor correction and motors rated !elow 1'' .<. %urthermore replacing standard$ efficiency motors with high$efficiency motors is not cost$effective under any circumstances for a facility with this utility rate. Kam looking to clean this paragraph upL

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ECONOMIC INSIGHTS TO CORRECTING POWER FACTOR

The SPP of correcting power factor with high-efficiency motors increases as the motor size increases. **Graph 3** shows that the cost$ effectiveness for installing high$efficiency motors decreases in general as the horsepower of the motor increases. There are three reasons that eAplain this o!servation,
1: The difference !etween the power factor of a standard$ efficiency motor and the power factor of a premium$efficiency motor decreases as the si8e of the motor increases- 1: The difference !etween the efficiency of a standard$efficiency motor and the efficiency of a premium$efficiency motor decreases as the si8e of the motor increases- and &: The cost of a motor increases as the si8e of the motor increases.

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ADDITIONAL BENEFITS

There are additional !enefits to consider !efore choosing a power factor correction techni0ue for a facility. 5ne of the !enefits of correcting power factor with capacitors is that the capacitor can !e installed any time during the life of the motor. Correcting power factor in this way can !e cost$effective whether or not the motor has failed.

;n additional !enefit to correcting power factor with a high$efficiency motor is the energy cost savings that come from improved efficiency of the motor. %acilities that have a policy of !uying high$efficiency motors should purchase high$efficiency high power factor motors to reduce energy consumption costs and to reduce possi!le power factor penalty charges. Since the design of a motor and its efficiency primarily determine the cost a high power factor motor often costs no more than its low power factor counterpart.

CONCLUSION

%or facilities with power factor penalties in their utility rate the economic !enefit of improving power factor often leads to the installation of capacitors to correct the poor power factor of electric motors. +n this paper we have demonstrated that replacing standard$efficiency motors with carefully selected high$efficiency high power factor motors is a !etter alternative to power factor correction for certain smaller$si8ed motors. <lant engineers and managers at this type of facility should use high$efficiency motors to correct the power factor of small motor loads and use capacitors to correct the power factor of large motor loads.

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