**ELECTRIC MOTORS AND VOLTAGE**

**Effects of low and high voltage on motors and the related performance changes**

There are many undesirable things that happen to electric motors and other electrical equipment as a result of operating a power system in an over voltage manner. Operating a motor beyond its nominal range of its voltage requirements will reduce its efficiency and cause premature failure. The economic loss from premature motor failure can be devastating. In most cases, the price of the motor itself is trivial compared to the cost of unscheduled shutdowns of the process. Both high and low voltages can cause premature motor failure, as well as voltage imbalance.

So the best life and most efficient operation occur when motors are operated at voltages close to the nameplate ratings. This is where POWER OPTIMISA can beneficially impact a whole site, not only by reducing the cost of the electricity bill, but also by extending the life of the electrical motors while preventing unexpected failures.

**EFFECTS OF HIGH VOLTAGE***

One of the basic things that people assume is, that since low voltage increases the amperage draw on motors, then by the same reasoning, high voltage would tend to reduce the amperage draw of the motor. This is not the case [see graph below]. High voltages on a motor tends to push the magnetic portion of the motor into saturation. This causes the motor to draw excessive current in an effort to magnetize the iron core beyond the point to which it can easily be magnetized. This generally means that the motors will tolerate a certain change in voltage above the design voltage, but extremes above the designed voltage will cause the amperage to go up with a corresponding increase in heating and a shortening of motor life. For example, many motors are rated at 220/230 volts and had a tolerance band of plus/minus 10%. Thus, the actual voltage range that they can tolerate on the high voltage connections would be at least 207 volts to 253 volts. Even though this is the so-called tolerance band, the best performance of larger motors would occur at or near the rated voltage. The extreme ends, either high or low, would be putting unnecessary stress on the motor.

Generally speaking, these voltage tolerance ranges are in existence, not to set a standard that can be used all the time, but rather to set a range that can be used to accommodate the normal hour-to-hour swings in received voltage. An operation of a motor on a continuous basis at either the high extreme or the low extreme will shorten the life of the motor.

Although this paper covers the effects of high and low voltage on motors, the operation of other magnetic devices is often affected in similar ways. Solenoids and coils used in relays and starters are punished by high voltage more than they are by low voltage. This is also true of ballasts in fluorescent, mercury, and high pressure sodium light fixtures. Transformers of all types, including welding transformers, are damaged in the same way. Incandescent lights are especially susceptible to high voltage conditions. A 5% increase in voltage results in a 50% reduction in bulb life. A 10% increase in voltage above the rating reduces incandescent bulb life by 70%.

Overall, it is definitely in the equipment’s best interest to have incoming voltage close to the equipment ratings. High voltage will always tend to reduce power factor and increase the losses in the system which results in higher operating costs for the equipment and the system.
The graph shown in Figure 1 is widely used to illustrate the general effects of high and low voltage on the performance of “T” frame motors. It is okay to use the graph to show “general” effects but, bear in mind that it represents only a single motor and there is a great deal of variation from one motor design to the next. For example, the lowest point on the full load amp line does not always occur at 2-1/2% above rated voltage. On many motors it might occur at a point 2% to 3% below the rated voltage. Also the rise in full load amps at voltages above the rated, tends to be much steeper for some motor winding designs than others.

**LOW VOLTAGE**

When electric motors are subjected to voltages below the nameplate rating, some of the characteristics will change slightly and others will change more dramatically. A basic point to note is that to drive a fixed mechanical load connected to the shaft, a motor must draw a fixed amount of power from the power line. The amount of power the motor draws is roughly related to the voltage x current (amps). Thus, when voltage gets low, the current must get higher to provide the same amount of power. The fact that current gets higher is not alarming unless it exceeds the nameplate current rating of the motor. When amps go above the nameplate rating, it is safe to assume that the buildup of heat within the motor will become damaging if it is left unchecked. If a motor is lightly loaded and the voltage drops, the current will increase in roughly the same proportion that the voltage decreases. If voltages go too low Power Optimisa have a model that will tap them up.

For example, say a 10% voltage decrease would cause a 10% amperage increase. This would not be damaging if the motor current stays below the nameplate value. However, if a motor is heavily loaded and a voltage reduction occurs, the current would go up from an already fairly high value to a new value which might be in excess of the full load rated amps. This could be damaging. It can thus be safely said that low voltage in itself is not a problem unless the motor amperage is pushed beyond the nameplate rating. I.e/ it must be controlled in a safe range.
Aside from the possibility of over-temperature and shortened lifespan created by low voltage, some other important items need to be understood. The first is that the starting torque, pull-up torque, and pull-out torque of induction motors, all change based on the applied voltage squared. Thus, a 10% reduction from nameplate voltage (100% to 90%, 230 volts to 207 volts) would reduce the starting torque, pull-up torque, and pull-out torque by a factor of .9 x .9. The resulting values would be 81% of the full voltage values. At 80% voltage, the result would be .8 x .8, or a value of 64% of the full voltage value. In this case, it is easy to see why it would be difficult to start “hard-to-start” loads if the voltage happens to be low. Similarly the motor’s pull-out torque would be much lower than it would be under normal voltage conditions.

To summarise: low voltage can cause high currents and overheating which will subsequently shorten motor life. Too low voltage can also reduce the motor’s ability to get started and its values of pull-up and pull-out torque. On lightly loaded motors with easy-to-start loads, reducing the voltage will not have any appreciable effect except that it might help reduce the light load losses and improve the efficiency under this condition. The Power Optimisa helps protect in this circumstance.

Some general guidelines might be useful:
1. Small motors tend to be more sensitive to over-voltage and saturation than large motors.
2. Single phase motors tend to be more sensitive to over-voltage than three phase motors.
3. Older U-frame motors are less sensitive to over-voltage than newer “T” frames.
4. Premium efficiency Super-E motors are less sensitive to over-voltage than standard efficiency motors.
5. Two pole and four pole motors tend to be less sensitive to high voltage than six pole and eight pole designs.
6. Over-voltage will drive up amperage and temperature even on lightly loaded motors. Thus, motor life will be shortened by high voltage.
7. Full load efficiency drops with either high or low voltage.
8. Power factor improves with lowering voltage and drops sharply with lowering from high voltage levels.
9. Inrush current goes up with higher voltage.


** Baldor Electric Company is global renowned designer, manufacturer and marketer of industrial electric motors, power transmission products, drives and generators. It is listed in the New York Stock exchange

POWER OPTIMISA’s effect on an AC motor

Induction motors (single phase or 3 phases) account for most of the industrial, commercial and residential appliances like refrigerators, air conditioning, air compressors, and pumps among others. These motors have five major components of loss; Iron loss, Copper loss, Frictional loss, windage loss and sound loss. All these losses add up to the total loss of the induction motor. Frictional loss, windage loss and sound loss are constant, independent of shaft load, and are typically very small. The major losses are Iron loss and Copper Loss. The iron loss is essentially constant, independent of shaft load, while the copper loss is an I2R loss which is shaft load dependent. The iron loss is voltage dependent and so will reduce with reducing voltage. For a motor with a 90% full load efficiency, the copper loss and iron loss are of the same order of magnitude, with the iron loss typically amounting to 25 - 40% of the total losses in the motor at full load. If we consider for example, an AC motor with a full load efficiency of 90%, then we could expect that the iron loss is between 2.5% and 4% of the motor rating.

By optimizing the voltage on a motor, which was operating at less than maximum efficiency, the POWER OPTIMISA effects result in a reduction of the iron loss of the motor. In a case where the motor has a very high magnetizing current, there can be a reduction in copper loss also. By managing the voltage and voltage balance, the motor efficiency will be improved.

POWER OPTIMISA will thus reduce the stress and losses on motors so they operate at their maximum efficiency (close to their nameplate rating), and assuring steady power output. This will reduce
maintenance costs for the lifetime of the motor. Through the more efficient operation of the motors, there will also be a reduction in the amount of reactive power (kVAr) consumed which will improve the power factor. POWER OPTIMISA manages to save the energy that is being wasted while proving the best power to power to the motor.

**POWER OPTIMISA’s effect on motors with inverter drives or variable speed drives**

As with AC motors, the POWER OPTIMISA will reduce the stress on VSDs (inverter drives) by delivering an optimized voltage. There will be no effect on speed or torque of the motor as it is buffered by the inverter. The life span of these types of drive will be shortened considerably if the supply voltage is too high or fluctuating, and many sites report the need to replace such expensive drives frequently. By correcting this problem, the POWER OPTIMISA will significantly reduce equipment replacement costs. VSDs and inverter drives are also notorious for generating harmonics, which can damage sensitive equipment. As the POWER OPTIMISA is able to attenuate THD’s via filter harmonics, the damaging effect of these drives can be limited.