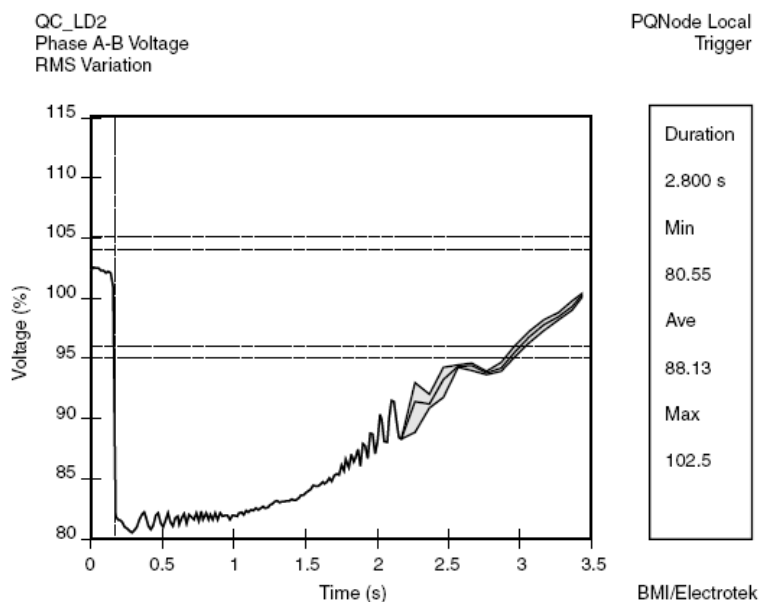# Motor-Starting Sags

Motors have the undesirable effect of drawing several times their full load current while starting. This large current will, by flowing through system impedances, cause a voltage sag which may dim lights, cause contactors to drop out, and disrupt sensitive equipment.

The situation is made worse by an extremely poor starting displacement factor usually in the range of 15 to 30 percent. The time required for the motor to accelerate to rated speed increases with the magnitude of the sag, and an excessive sag may prevent the motor from starting successfully. Motor starting sags can persist for many seconds, as illustrated in Fig. 2.6.

2.3.1 Motor-Starting Methods

Energizing the motor in a single step (*full-voltage starting*) provides low cost and allows the most rapid acceleration. It is the preferred method unless the resulting voltage sag or mechanical stress is excessive.

Figure 2.6 Typical motor-starting voltage sag

Autotransformer starters have two autotransformers connected in open delta. Taps provide a motor voltage of 80, 65, or 50 percent of system voltage during start-up. Line current and starting torque vary with the square of the voltage applied to the motor, so the 50 percent tap will deliver only 25 percent of the full-voltage starting current and torque. The lowest tap which will supply the required starting torque is selected.

Resistance and reactance starters initially insert an impedance in series with the motor. After a time delay, this impedance is shorted out. Starting resistors may be shorted out over several steps; starting reactors are shorted out in a single step. Line current and starting torque vary directly with the voltage applied to the motor, so for a given starting voltage, these starters draw more current from the line than with autotransformer starters, but provide higher starting torque. Reactors are typically provided with 50, 45, and 37.5 percent taps.

Part-winding starters are attractive for use with dual-rated motors (220/440 V or 230/460 V). The stator of a dual-rated motor consists of two windings connected in parallel at the lower voltage rating, or in series at the higher voltage rating. When operated with a part-winding starter at the lower voltage rating, only one winding is energized initially, limiting, starting current and starting torque to 50 percent of the values seen when both windings are energized simultaneously.

Delta-wye starters connect the stator in wye for starting and then, after a time delay, reconnect the windings in delta. The wye connection reduces the starting voltage to 57 percent of the system line-line voltage; starting current and starting torque is reduced to 33 percent of their values for full-voltage start.

2.3.2 Estimating the Sag Severity During Full-Voltage Starting

As shown in Fig. 2.6, starting an induction motor result in a steep dip in voltage, followed by a gradual recovery. If full-voltage starting is used, the sag voltage, in per unit of nominal system voltage, is

$$V_{Min(p.u)} \square \frac{V(pu).kVA_{SC}}{kVA_{LR} \square kVA_{SC}}$$

Where V (pu) = actual system voltage, in per unit of nominal.

kVA_{LR} = motor locked rotor kVA

kVA_{SC} = system short-circuit kVA at motor

Figure 2.7 illustrates the results of this computation for sag to 90 percent of nominal voltage, using typical system impedances and motor characteristics. If the result is above the minimum allowable steady-state voltage for the affected equipment, then the full-voltage starting is acceptable.

If not, then the sag magnitude versus duration characteristic must be compared to the voltage tolerance envelope of the affected equipment. The required calculations are fairly complicated and best left to a motor-starting or general transient analysis computer program.

The following data will be required for the simulation:

- Parameter values for the standard induction motor equivalent circuit: $R1$, $X1$, $R2$, $X2$, and XM.
- Number of motor poles and rated rpm (or slip).

- WK^2 (inertia constant) values for the motor and the motor load.
- Torque versus speed characteristic for the motor load.
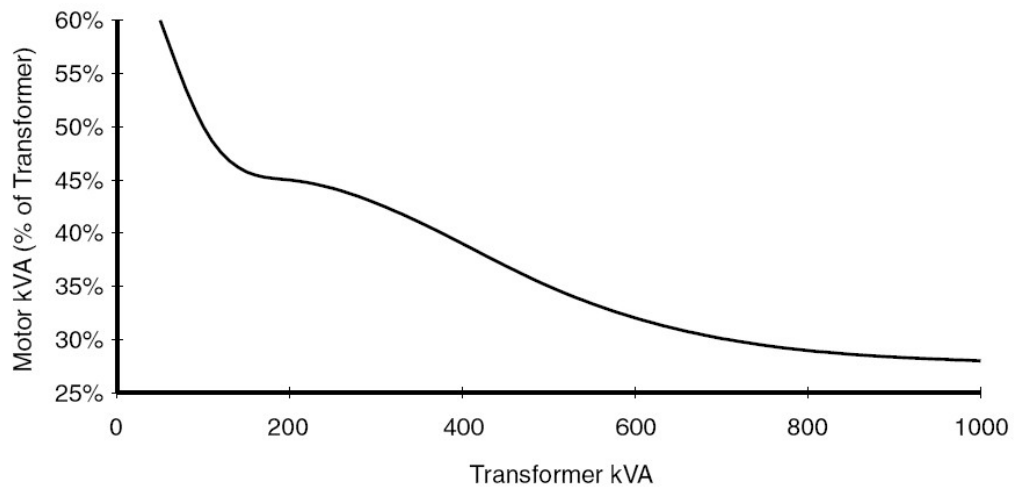
Figure 2.7 Typical motor versus transformer size for full-voltage starting sags of 90 percent