



# Introduction to Motor Starting Analysis

An Online Continuing Education Course for Engineers

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# Introduction to Motor Starting Analysis

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## Introduction

This course discusses the benefit obtained from motor-starting studies and examines various types of computer-aided studies normally involved in motor-starting studies. Data or information required for these studies as well as the expected results of a motor-starting study effort is also reviewed.

## Need for Motor-Starting Studies

### Problems Revealed

Motors on modern industrial systems are becoming increasingly larger. Some are considered large even in comparison to the total capacity of large industrial power systems. Starting large motors, especially across-the-line, can cause severe disturbances to the motor and any locally connected load, and also to buses electrically remote from the point of motor starting. Ideally, a motor-starting study should be made before a large motor is purchased. A starting voltage requirement and preferred locked-rotor current should be stated as part of the motor specification. A motor-starting study should be made if the motor horsepower exceeds approximately 30% of the supply transformer(s) base kVA rating, if no generators are present. If generation is present, and no other sources are involved, a study should be considered whenever the motor horsepower exceeds 10–15% of the generator kVA rating, depending on actual generator characteristics. The study should also recognize contingent condition(s), i.e., the loss of a source.

It may be necessary to make a study for smaller horsepower sizes depending on the daily fluctuation of nominal voltage, voltage level, size and length of the motor feeder cable, amount of load, regulation of the supply voltage, the impedance and tap ratio of the supply transformer(s), load torque versus motor torque, and the allowable starting time. Finally, some applications may involve starting large groups of smaller motors of sufficient collective size to impact system voltage regulation during the starting interval.

A frequent problem has been failure to start when the motor coupled to its load is energized for the first time. Typically the motor appears to start smoothly, and then is tripped off line by relay action before it reaches full speed. When the starting time is prolonged enough to exceed the permissible locked rotor time, the relay can operate even though its time current curve is at all points above the motor starting curve. Some of the effects of starting a large motor are presented below.

Motor terminal voltage - During the starting, the motor terminal voltage should be maintained at approximately 80% of the rated voltage for type B motors having a standard 150% starting torque at full voltage with a constant torque load applied. An 81.6% rated voltage will develop a

torque  $T = 0.8162 \times 150\% = 100\%$ . Also, in every case the starting time has to be evaluated for the damage limit of the motor.

Effect of motor starting on other running motors - Motors that are running normally on the system will slow down in response to the voltage drop occurring when a large motor is started. The running machines must be able to reaccelerate once the machine being started reaches the operating speed. If the voltage drop is very severe, the loading on the running machines may exceed the breakdown torque at the reduced voltage. The decelerating machines may impose heavy current demand to produce excessive voltage drop.

Heavy starting currents - In the case of design B motors, the pullout torque is 200% of the rated torque. If the motor terminal voltage falls below 71% of the rated voltage the motor may stall. This is based on the assumption that the developed torque is proportional to  $V$ . If other than design B motors are used on the system, a similar criterion can be established to evaluate re-acceleration following a motor starting.

Flicker - Power system loads such as computer equipment, power electronic equipment and sensitive control devices may be affected during motor starting. There is a wide variation in the magnitude of the voltage drop by electronic equipment. Voltage fluctuations may also cause objectionable light flicker in domestic applications. For much of the new electronic equipment, the allowable voltage drop data has to be obtained from the manufacturer.

Effect on control devices - The control devices are not required to pick up at voltages below 5% of the rated name plate value. The DC control devices can operate at 80% of the rated voltage. Critical control operations can therefore encounter difficulty during the motor starting period if the voltage drop is excessive. The actual drop out voltage of industrial contactors is 60% - 70% of the rated system voltage.

A brief discussion of major problems associated with starting large motors, or groups of motors, and therefore, of significance in power system design and evaluation follows.

### **Voltage Dips**

Probably the most widely recognized and studied effect of motor-starting is the voltage dip experienced throughout an industrial power system as a direct result of starting large motors. Available accelerating torque drops appreciably at the motor bus as voltage dips to a lower value, extending the starting interval and affecting, sometimes adversely, overall motor-starting performance. Acceptable voltage for motor-starting depends on motor and load torque characteristics. Requirements for minimum starting voltage can vary over a wide range, depending on the application. (Voltages can range from 80% or lower to 95% or higher.)

During motor-starting, the voltage level at the motor terminals should be maintained, as a minimum, at approximately 80% of rated voltage or above. This value results from examination of speed-torque characteristics of motor type (150% starting torque at full voltage) and the desire to successfully accelerate a fully loaded motor at reduced voltage (that is, torque varies with the square of the voltage  $T = 0.8^2 \times 150\% \approx 100\%$ ). When other motors are affected, or when lower shaft loadings are involved, the minimum permissible voltage may be either higher or lower, respectively. The speed-torque characteristics of the starting motor, along with any other affected

motors and all related loads, should be examined to specifically determine minimum acceptable voltage. Assuming reduced voltage permits adequate accelerating torque, it should also be verified that the longer starting interval required at reduced torque caused by a voltage dip does not result in the  $I^2t$  damage limit of the motor being exceeded.

Several other problems may arise on the electrical power system due to the voltage dips caused by motor-starting. Motors that are running normally on the system, for example, will slow down in response to the voltage dip occurring when a large motor is started. The running machines must be able to reaccelerate once the machine being started reaches operating speed. When the voltage depression caused by the starting motor is severe, the loading on the running machines may exceed their breakdown torque (at the reduced voltage), and they may decelerate significantly or even stall before the starting interval is concluded. The decelerating machines all impose heavy current demands that only compound the original distress caused by the machine that was started. The result is a “dominoing” voltage depression that can lead to the loss of all load.

The speed-torque characteristics (200% breakdown torque at full voltage) should prevent a stall, provided the motor terminal voltage does not drop below about 71% of motor nameplate voltage. This is a valid guideline to follow anytime the shaft load does not exceed 100% rated, since the developed starting torque is again proportional to the terminal voltage squared ( $V^2$ ), and the available torque at 71% voltage would thus be slightly above 100%.

Other types of loads, such as electronic devices and sensitive control equipment, may be adversely affected during motor-starting. There is a wide range of variation in the amount of voltage drop that can be tolerated by static drives and computers. Voltage fluctuations may also cause objectionable fluctuations in lighting. Tolerable voltage limits should be obtained from the specific equipment manufacturers.

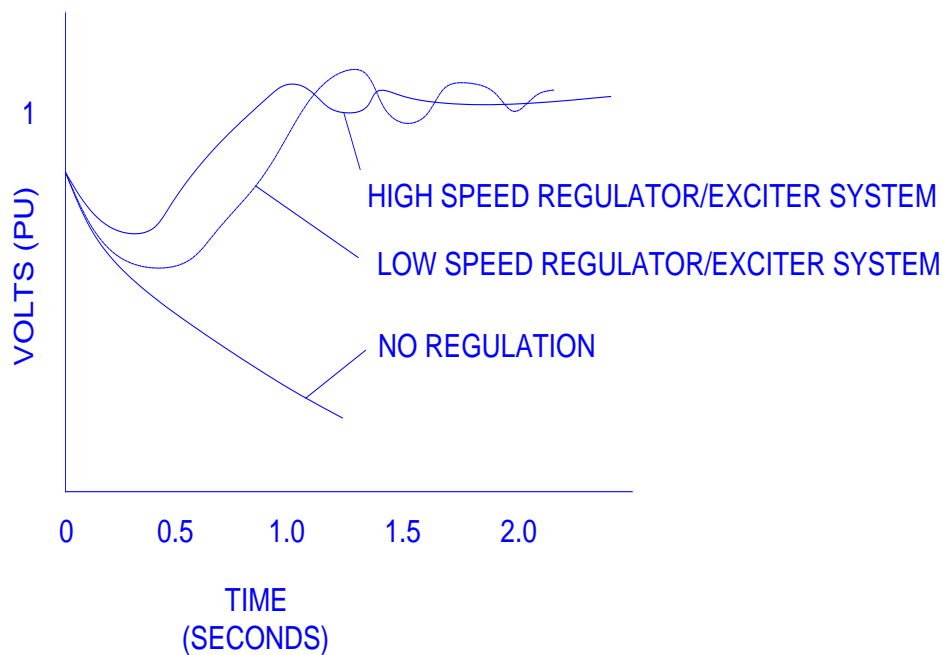
By industry standards, AC control devices are not required to pick-up at voltages below 85% of rated nameplate voltage, whereas DC control devices must operate dependably (i.e., pick-up) at voltages above 80% of their rating. Critical control operations may, therefore, encounter difficulty during motor-starting periods where voltage dips are excessive. A motor-starting study might be required to determine if this is a problem with thoughts to using devices rated at 110 V rather than the normal 115 V nominal devices. Contactors are required to hold-in with line voltage as low as 80% of their rating. The actual dropout voltages of contactors used in industrial applications commonly range between 60–70% of rated voltage, depending on the manufacturer. Voltages in this range, therefore, may be appropriate and are sometimes used as the criteria for the lower limit that contactors can tolerate. Depending on where lighting buses are located, with respect to large starting motors, this may be a factor requiring a motor-starting study. Table 1 summarizes some critical system voltage levels of interest when performing a motor-starting study for the purpose of evaluating the effects of voltage dips.

**Table 1. Summary of representative critical system voltage levels when starting motors**

Voltage drop location or problem	Minimum allowable voltage (% rated)
At terminals of starting motor	80% a
All terminals of other motors that must reaccelerate	71% a
AC contactor pick-up (by standard) (see 9.8, NEMA standards)	85%
DC contactor pick-up (by standard) (see 9.8, NEMA standards)	80%
Contactor hold-in (average of those in use)	60–70% b
Solid-state control devices	90% c
Noticeable light flicker	3% change

### **Weak Source Generation**

Smaller power systems are usually served by limited capacity sources, which generally magnify voltage drop problems on motor-starting, especially when large motors are involved. Small systems can also have on-site generation, which causes an additional voltage drop due to the relatively higher impedance of the local generators during the (transient) motor-starting interval. The type of voltage regulator system applied with the generators can dramatically influence motor-starting as illustrated in Figure 1. A motor-starting study can be useful, even for analysing the performance of small systems. Certain digital computer programs can accurately model generator transient behaviour and exciter/regulator response under motor-starting conditions, providing meaningful results and conclusions.



*Figure 1—Typical generator terminal voltage characteristics for various exciter/regulator systems*

### **Special Torque Requirements**

Sometimes special loads must be accelerated under carefully controlled conditions without exceeding specified torque limitations of the equipment. An example of this is starting a motor connected to a load through gearing. This application requires a special period of low-torque cushioned acceleration to allow slack in the gears and couplings to be picked up without damage to the equipment. Certain computer-aided motor-starting studies allow an instant-by-instant shaft output torque tabulation for comparison to allowable torque limits of the equipment. This study can be used for selecting a motor or a starting method, or both, with optimum speed-torque characteristics for the application. The results of a detailed study are used for sizing the starting resistors for a wound rotor motor, or in analyzing rheostatic control for a starting wound rotor motor that might be used in a cushioned starting application involving mechanical gearing or a coupling system that has torque transmitting limitations. High-inertia loads increase motor-starting time, and heating in the motor due to high currents drawn during starting can be intolerable. A computer-aided motor-starting study allows accurate values of motor current and time during acceleration to be calculated. This makes it possible to determine if thermal limits of standard motors will be exceeded for longer than normal starting intervals. Other loads have special starting torque requirements or accelerating time limits that require special high starting torque (and inrush) motors. Additionally, the starting torque of the load or process may not permit low inrush motors in situations where these motors might reduce the voltage dip caused by starting a motor having standard inrush characteristics. A simple inspection of the motor and load speed-torque curves is not sufficient to determine whether such problems exist. This is another area where the motor torque and accelerating time study can be useful.

## Recommendations

### Voltage Dips

A motor-starting study can expose and identify the extent of a voltage drop problem. The voltage at each bus in the system can, for example, be readily determined by a digital computer study. Equipment locations likely to experience difficulty during motor-starting can be immediately determined.

In situations where a variety of equipment voltage ratings are available, the correct rating for the application can be selected. Circuit changes, such as off-nominal tap settings for distribution transformers and larger than standard conductor-sized cable, can also be readily evaluated. On a complex power system, this type of detailed analysis is very difficult to accomplish with time-consuming hand solution methods.

Several methods of minimizing voltage dip on starting motors are based on the fact that during starting time, a motor draws an inrush current directly proportional to terminal voltage; therefore, a lower voltage causes the motor to require less current, thereby reducing the voltage dip.

Autotransformer starters are a very effective means of obtaining a reduced voltage during starting with standard taps ranging from 50% to 80% of normal rated voltage. A motor-starting study is used to select the proper voltage tap and the lower line current inrush for the electrical power system during motor start. Other special reduced-voltage starting methods include resistor or reactor starting, part-winding starting, and wye (Y)-start delta ( $\Delta$ )-run motors. All are examined by an appropriate motor-starting study, and the best method for the particular application involved can be selected. In all reduced voltage starting methods, torque available for accelerating the load is a very critical consideration once bus voltage levels are judged otherwise acceptable. Only 25% torque is available, for example, at 50% reduced voltage applied at the motor terminals. Any problems caused by the reduced voltage imposed by special starting methods are a

Another method of reducing voltage dip on starting motors is a capacitor starting system. This method, the high inductive reactance of the motor is offset by the addition, during the starting time, of a capacitor in parallel with the motor. This differs from the practice of using capacitors for power factor correction.

A motor-starting study can determine the effect of the starting capacitors and determine whether the motor will be energized. The study can also establish whether the motor will be energized because of an excessive voltage drop that occurs during starting. The study can also determine if the motor will be energized because of an excessive voltage drop that occurs when added to the motor starting current. The switching of the capacitor bank must be done momentarily ahead of the motor starting current to avoid a voltage dip during motor installation.

Use of special starters or capacitors is an alternative method of maintaining voltage at acceptable levels during motor starting. Off-nominal tap settings for distribution transformers and larger than standard conductor-sized cable are also a solution for voltage dips. By raising no-load voltage in areas of the system experiencing difficulties during motor-starting, the effect of

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