DESIGN GUIDE TO LIMIT OBJECTIONABLE VOLTAGE DROP (FLICKER)

System Reliability and Power Quality Subcommittee

Transmission and Distribution Engineering Committee

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CONTRIBUTORS

The System Reliability and Power Quality Subcommittee of the Transmission and Distribution Engineering Committee (TDEC) provided invaluable assistance in preparing this document.

DISCLAIMERS

- **DISCLAIMER**

  This guide provides technical information for understanding, measuring and mitigating voltage fluctuations on the electric distribution systems to ensure power quality and customer satisfaction. It is meant to provide a general understanding of the substation power transformer testing process. Since testing requirements and applications will vary, a test procedure that is appropriate in one situation may not be appropriate in another and strict adherence to the guidance presented here is not a guarantee of transformer performance. The TDEC does not assume any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information contained in this guide. Reference herein to any specific commercial product, process or service by trademark, name, manufacturer, or otherwise does not necessarily constitute or imply endorsement, recommendation, or favoring of same by the TDEC.

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  References included in this document were accurate at the time of publication, but there is no guarantee of future applicability.

LEGAL NOTICE

ABBREVIATIONS

A/C	Air conditioning
ANSI	American National Standards Institute
ASD	Adjustable-speed drive
CSI	Current-source inverter, a basic ASD
CSP	Concentrated solar power
hp	Horsepower
IEC	International Electrotechnical Association
IEEE	Institute of Electrical and Electronics Engineers
kVA	Kilovolt-amperes (1000 volt-amperes)
kVAR	Kilovolt-amperes reactive (1000 volt-amperes reactive)
LRA	Locked rotor amps of a motor
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
Plt	A measure of long-term perception of flicker obtained for a two-hour period, or 12 consecutive Pst values
PQ	Power Quality
Pst	A measure of short-term perception of flicker obtained for a ten-minute interval
PWM	Pulse-width modulated, a basic ASD
RLA	Running load amps of a motor
RTO	Regional transmission organization
STATCOM	Static synchronous compensator
SVC	Static VAR compensation
VAR	Volt-amperes reactive
VFD	Variable-frequency drive
VSI	Voltage-source inverter, a basic ASD

INTRODUCTION

The primary purpose of this guide is to provide technical information to understand and limit load-driven voltage fluctuations on the electric distribution system that are considered objectionable to end-use customers. Voltage fluctuation, also known as voltage flicker, was traditionally the result of starting large induction motors, therefore drawing significant inrush current, therefore causing system voltage to drop.

Today, voltage flicker is still caused by starting the traditional induction motor; however, other causes, and other induction motor applications, have surfaced over the years. Some examples include welding equipment, rotary phase converters, rock crushers, woodchippers, electric drilling rigs, and the introduction of distributed generation.

Proposed motor, distributed generation, and other rapid fluctuating load installations must be appraised for any possible adverse effect on neighboring electric consumers. The starting of a motor causes a voltage dip, which may cause light flicker, electronic equipment to turn off or, in an extreme case, may cause other motors to drop offline.

These considerations make it very important that the probable voltages during running and starting conditions be determined prior to the installation of service facilities. This publication discusses flicker standards, policy considerations, induction motors, air conditioning loads, and other potential problem loads. It also includes information on motor control and provides methods for calculating voltage and voltage flicker during starting and running conditions.

In addition to the introduction, this guide is divided into five sections titled Flicker Standards, Policy Considerations, Induction Motors, Air Conditioning Loads, and Other Potential Problem Loads. References and Appendices providing supporting data can also be found towards the end of this document.

FLICKER STANDARDS

What is the definition of flicker, lamp flicker, and voltage flicker? On a basic level, flicker is a voltage fluctuation on an electric power system resulting in a noticeable change in illumination as perceived by the human eye. Voltage flicker has always presented design challenges for engineers, with one major factor influencing the design criteria—human perception. Every person has a different awareness and tolerance for flicker, making flicker design requirements inherently difficult to define.

SOURCES OF FLICKER

There is a wide range of sources of flicker; one of the more common offenders is an induction motor starting. When an induction motor starts, the motor must draw enough current to begin spinning the rotor as well as the load; this current can be 5–7 times normal running current. Many other electrical loads—including arc furnaces, woodchippers, metal shredders, and compressors—can cause significant and frequent voltage fluctuations and begin to irritate nearby members receiving electric service.

In today's environment of distributed generation, power generation plants can go offline unexpectedly, causing voltage flicker. For example, wind farms that experience an abrupt change in wind speed or direction often separate from the utility system, causing a sudden voltage drop. Sudden voltage drop also occurs when a distributed generator on a distribution feeder separates from the utility system during a faulted condition and the utility system performs a successful reclose on the load.

HISTORICAL FLICKER DESIGN CRITERIA

Historically, "flicker" curves, as shown below in Figure 1, have been used to determine acceptable voltage fluctuations or lamp flicker conditions during motor starting. The curves were developed to relate a member's irritation level to magnitude and frequency of the flicker or voltage fluctuations. These curves are often referred to as the GE flicker curves.

The curves work in the following manner: the frequency of the lamp flicker run along the "x" axis with voltage changes running vertically along the "y" axis. As the frequency of the flicker increases, so does the likelihood that a member will call in a complaint. The same is true for the magnitude of the flicker. When the magnitude of the voltage fluctuation increases, it is likely the irritation level of the member will also increase. This results in an increased chance of receiving a power-quality complaint. These flicker curves are still used in IEEE Std. 141-1993.

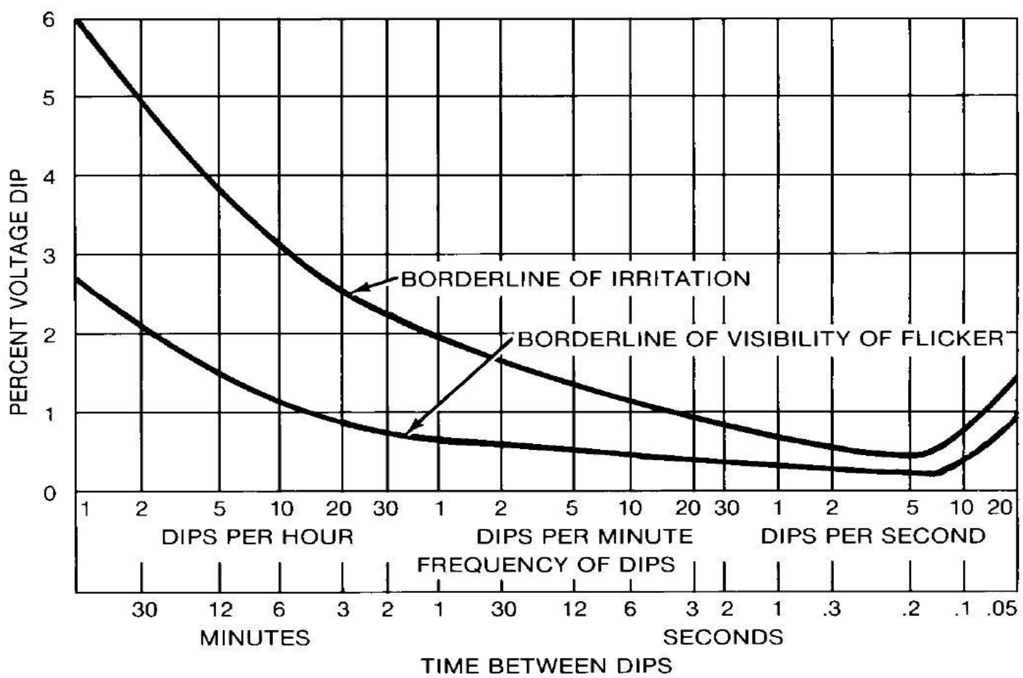


Figure 1. Range of Observable and Objectionable Voltage Flicker Versus Time.
(IEEE Std. 141-1993)

CURRENT FLICKER DESIGN STANDARDS

As electrical loads have evolved and become more complex, there has been a movement to address lamp flicker through other standards. IEC 61000-4-15:2010 is one such standard. This standard has been adopted by IEEE as IEEE Std. 1453-2011.

This standard presents a different concept for working with voltage fluctuations. Two new measurements of flicker are introduced, Pst and Plt:

- **Pst.** A measure of short-term perception of flicker obtained for a ten-minute interval. This value is the standard output of the flickermeter.

- **Plt.** A measure of long-term perception of flicker obtained for a two-hour period. This value consists of 12 consecutive Pst values.

For existing installations and for planning purposes, IEEE recommends the following Pst and Plt be maintained:

	Existing Installations	Planning Levels	
Voltage	MV	MV	HV-EHV
Pst	1.0	0.9	0.8
Plt	0.8	0.7	0.6

Calculating Pst and Plt values poses a difficult task and is best done with a special power quality meter capable of measuring each value. This works well for existing installations but causes problems for defining design requirements as new electric loads are brought online. Figure 2 below compares the two different flicker standards when rectangular voltage fluctuations are used in IEC calculations.

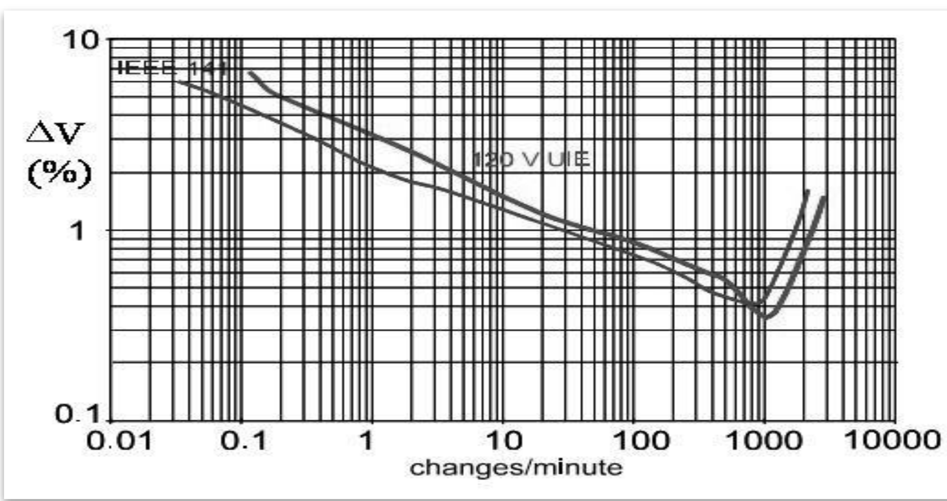


Figure 2. Comparison of IEC 61000-4-15 and IEEE Std 141-1993 for Irritation.
(IEEE 1453-2004, Figure A.2, Chart Pg. 7)

For this design guide, IEEE Std. 141-1993 will be used because this standard is more practical from a planning standpoint. IEEE Std. 1453-2011 requires a special flicker meter and complex calculations not easily performed for planning purposes.

POLICY CONSIDERATIONS—REQUIREMENTS TO SERVE CONSUMER EQUIPMENT

Because of the potential for induction motors, distributed generation, and other loads to adversely impact the service quality to not only the member with the equipment but also to other members in the area, it is incumbent upon the cooperative to have policies in place to serve these loads. These policies should provide guidelines for providing service to customer equipment that can be administered by the cooperative in a fair manner. The policies should require the member requesting service to provide adequate documentation about the equipment such that the cooperative can ensure that the electric distribution system is adequate to accommodate the proposed equipment. In the event the system is found to be inadequate, service can be denied or the requesting member can propose alternative equipment—such as reduced voltage start—or fund system improvements through a contribution in aid of construction.

Additionally, the policies should protect the cooperative from damage claims in the event the equipment fails. This policy should put the burden of protecting the equipment installation from variations in electric service on the member. Additionally, cooperatives should require members to provide notice prior to installing equipment that may have an adverse impact on the system.

Finally, a cooperative should outline what it considers to be an adverse effect and the cooperative's remedy if the member is found to be creating adverse effects on the system. Sample language for such a policy is given below.

Example Policy

> *The power and energy taken by the member shall not be used in such a manner as to cause, in the sole opinion of the cooperative, unreasonable fluctuations or disturbances, including, without limitation, harmonic distortion, on the cooperative's or the cooperative's power supplier's system. Member shall provide, at its expense, suitable apparatus which will reasonably limit such fluctuations. Member agrees to refrain from starting or running motors or other equipment which, in the view of the cooperative, results in excessive voltage drop or voltage disturbances to the power system. Further, the member agrees to refrain from starting motors simultaneously on equipment containing multiple motors when practicable to do so.*
>
> *In the event that, in the sole opinion of the cooperative, unreasonable fluctuations or disturbances—including, without limitation, harmonic distortion, excessive voltage drop, or voltage disturbances—are caused by member's facilities, the cooperative shall immediately notify member of the circumstances, and the cooperative shall then have the right, after reasonable notice, to discontinue the delivery of power and energy until the condition causing such fluctuations, voltage drops, or disturbances is corrected by member. cooperative shall give member written notice of these circumstances in addition to the*

above-mentioned notice, but the requirement of providing such written notice shall not limit or delay the cooperative's right to discontinue service to the member. Despite such discontinuance of service, the member shall be obligated to pay the cooperative the amounts due for power and energy, including the minimum bills for such power.

INDUCTION MOTORS

VOLTAGE DURING RUNNING CONDITIONS

During running conditions, an induction motor has less effect on voltage than during a locked rotor condition. However, the induction motor still can have an adverse effect on voltage if the service designed to serve the induction motor is not specified to the conditions of the motor's operating characteristics. One of the key indicators concerning the induction motors running characteristics is the running load amps of the motor (RLA). The RLA is specified on the nameplate of the motor along with the locked rotor amps (LRA). The other key indicators are the NEMA Rating of the motor, the motor's efficiency, and the power factor, all of which are contained on the motor's nameplate. The nameplate data is the key information needed to specify the transformer and service wire necessary to effectively serve the induction motor under running conditions.

EFFECT OF SUPPLY VOLTAGE ON MOTOR PERFORMANCE

Voltage variation from nominal voltage and voltage unbalance for three-phase motors has an effect on the operation of the motor. Induction motors may operate successfully under most conditions with an applied voltage that varies plus or minus ten percent from the rated nominal voltage; however, the performance of the motor will be degraded and the motor will not operate according to its designed characteristics.

Either low voltage or high voltage can cause some increase in temperature of the motor. This, together with other conditions that may exist—such as poor ventilation or unbalanced voltage—could cause a motor to overheat even though any one of the conditions alone could be tolerated.

VOLTAGE DROP CALCULATIONS

Prior to installing supply facilities, it should be determined that adequate terminal voltage will exist under running conditions. In calculating voltage drop, it is important that full load motor current be used. Due to the use of submersible pump motors, horsepower rating may not be a true indication of the full load current needed to operate. Based on their depth in the earth, a submersible pump will require more current than an electric pump motor installed above ground. In the case of single-phase motors that are used with farm equipment, horsepower rating may not be an effective value for calculating full load current since most of the single-phase motors are phase-replication motors used to create three-phase power.

Voltage drop through consumer-owned wiring should be checked against the limits allowed by the National Electrical Code because the voltage drop in feeders and branch circuits may be excessive, causing low-voltage conditions at the terminals before the induction motor even operates.

For determination of primary voltage, the maximum and minimum voltage can usually be obtained from engineering reports, created by engineering analysis software, or found in voltage recordings from PQ meters. Approximate voltage drop in transformers and services can be determined from the equation:

$$V = I\,(R \cos \theta + X \sin \theta)$$

Where:

V	=	voltage drop in volts
I	=	full load current of motor in amperes
R and X	=	resistance and reactance, respectively, of transformer or service conductors in ohms
θ	=	full load power factor angle of motor current

In the absence of more specific information, a full load power factor of 85% to 95% may be assumed for typical squirrel cage motors. If for example, 90% is assumed, the equation becomes:

$$V = I\,(0.9R + 0.435\,X)$$

Single-Phase Motors

For single-phase 230-volt motors, the impedance (resistance and reactance) of transformers and services on a 120-volt base can be obtained by use of Equations 3 and 4 of the Calculating Form of Appendix II. The current on the 120-volt base will be 230/120, or about 1.9 times the rated full load current. The voltage drop on a 120-volt base is approximately:

$$V = 1.9\, I_{\text{rated}}\,(0.9R + 0.435X)$$

Where R and X are on a 120-volt base.

Three-Phase Motors

For three-phase motors on three-phase banks, the impedance (resistance and reactance) on a 120-volt phase to neutral base for transformers and services is given by Equations 3 and 4 of the Calculating Form of Appendix IV. The current on the same base will equal (I rated) (V rated) where V rated is the rated line-to-line voltage of the motor.

Voltage drop on a 120-volt phase to neutral base is approximately:

$$V = (I \text{ rated}) \left(\frac{V \text{ rated}}{208}\right) (0.9R + 0.435X)$$

VOLTAGE UNBALANCE (THREE-PHASE SERVICE)

A small percent unbalance in three-phase supply voltage causes a considerable increase in induction motor heating. The heating increases rapidly with unbalance and motor damage can occur if unbalance is high enough or if it is coupled with low or high voltage, motor overload, poor ventilation, high ambient temperature, or some combination of these conditions. In the operation of an induction motor, it is generally recommended that the percent imbalance should not exceed 5% because the heat generated from an unbalance in excess of 5% may damage the motor.

A small amount of line voltage unbalance is unavoidable; however, this can be minimized with properly adjusted single-phase regulators on all three phases. Where there is excessive unbalance, low voltage, high ambient temperature, or poor ventilation, it may be necessary to derate motors.

Since V-phase transformer banks and wye-delta banks supplying both single-phase and three-phase load inherently cause some unbalance, three-phase squirrel-cage induction motors supplied by these banks should generally be derated 10% to 20%.

VOLTAGE DIP DURING STARTING

Since squirrel-cage induction motors normally draw five to six times or more starting current, depending on the NEMA Code of the motor, reference Figure 3 below for appropriate starting current based on NEMA Code. When starting the motor across the line, an appreciable voltage dip may be expected depending on motor size and location on the line. Primary line voltage dip is particularly important since it affects many consumers.

Figure 3. NEMA Code Letters for Locked Rotor KVA.
(NEMA MG 1-2011, Paragraph 10.37.2)

LETTER DESIGNATION	KVA PER HORSEPOWER*	LETTER DESIGNATION	KVA PER HORSEPOWER*
A	0.0 – 3.15	K	8.0 – 9.0
B	3.15 – 3.55	L	9.0 – 10.0
C	3.55 – 4.0	M	10.0 – 11.2
D	4.0 – 4.5	N	11.2 – 12.5
E	4.5 – 5.0	P	12.5 – 14.0
F	5.0 – 5.6	R	14.0 – 16.0
G	5.6 – 6.3	S	16.0 – 18.0
H	6.3 – 7.1	T	18.0 – 20.0
J	7.1 – 8.0	U	20.0 – 22.4
		V	22.4 & UP

Appendices I and III provide charts that show the voltage dip caused by starting current flowing through each system component. Examples are given to illustrate the use of these charts.

Where the results obtained by using the charts show the voltage dip to be marginal in acceptability or for motors with starting currents greater than shown on the charts, the voltage dip should be calculated using the best data available. Appendices II and IV give the equations needed to calculate voltage dip in a convenient Calculating Form and a sample problem to illustrate the use of the Forms. Voltage dip can be calculated for all size motors using an engineering analysis software package.

Note that the Voltage Dip Charts and the Calculating Forms identify motors in terms of starting current rather than horsepower.[1] While there is a specific relationship between starting current and horsepower for NEMA standard motors, there are many nonstandard motors used for which there is no definite relationship.

Starting current may be obtained from the motor nameplate code letter (see Appendix VI) or from the manufacturer. In the absence of any better information, the starting current may be assumed to be six times the full load running current.

Magnitude of Permissible Voltage Dip

Once the magnitude of the expected voltage dip for a particular motor application is calculated, it is necessary to determine whether this level is acceptable. As discussed previously, the use of "flicker curves" is a common approach to making this determination. While the flicker curves are useful as a guide, they should not be applied indiscriminately; it is typical to find that the curves suggest it is desirable to limit the voltage dip of motors to about 3% on the primary distribution system.

The difficulty with defining a fixed limit for voltage dip is that it permits consumers located nearer the source to connect larger motors than would be permitted for consumers located further from the source. For this reason, it is recommended that a maximum starting current limit be defined that would apply without penalty to all consumers regardless of location. This would mean that the voltage dip would increase with distance away from the substation. This is generally acceptable, since the larger dip is seen by fewer consumers. However, even near the end of a line, about a 6% primary voltage dip should be considered as the absolute maximum.

The starting current limit would depend on the characteristics of the system, considering the legitimate needs of the motor-using consumers and the rights of other consumers to receive quality service. An IEEE working group has recommended that a minimum starting current of 260 amperes at 230 volts be permitted for single-phase motors anywhere on the system. This is equivalent to a NEMA 10 horsepower motor started across-the-line and is a common threshold for the application of single-phase motors.

Effect of Large Voltage Dips

It is probable that exceptions to the permissible starting current limitation will have to be made on occasion. For these larger motors, a more detailed study of the effects of the voltage dip is required together with possible ways of reducing its magnitude in the event that it is not tolerable.

a. Lighting and Television. A severe limitation on voltage dip is imposed by the requirements of loads such as lighting, computers, televisions, and other digital equipment. The magnitude of dip or flicker which will not cause irritation is dependent on its frequency of occurrence. Reasonable levels can be determined by referencing Figure 1 above.

[1] Note that ANSI C84.1-2016 provides that "the voltage ratings in each class of utilization equipment should be either the same as the nominal system voltages or less than the nominal system voltages by the approximate ratio of 115 to 120." These examples are shown using this ratio.

b. Other Motors. If the voltage dip is too large, motor-starting contactors or under-voltage relays used in control of other motors may drop out. At least a 20% dip (on the primary line) is usually required before this difficulty arises, however.

c. Starting Torque. Occasionally, the voltage dip may be so large that the motor causing the dip will not start or, if it does start, it will not come up to speed. Starting torque requirements vary widely, depending on the driven equipment. For instance, a reciprocating pump requires much more starting torque than a rotary pump. The available motor torque must be well above that required by the load at all points up to full speed.

The torque developed by an induction motor at any speed is approximately proportional to the square of the voltage. A motor with 90% of its rated voltage, for example, will have 81% of its rated torque. Excessive voltage dip will, therefore, greatly reduce the motor torque available during starting and acceleration. Even if the motor comes up to full speed, it may overheat if the acceleration time is too long or if it does not have enough time between starts to sufficiently cool.

Where both the motor and driven equipment are supplied by the same source, the minimum terminal voltage required to start the motor under load may be obtained from the manufacturer. The magnitude of motor terminal voltage on starting can then be calculated using the methods of Appendices II and IV.

REMEDIAL MEASURES WHEN PRIMARY VOLTAGE DIP IS EXCESSIVE

The best way to prevent excessive voltage dip is to perform voltage-dip calculations prior to the installation of service facilities and the purchase of the motor, but sometimes remedial or corrective steps may be required when existing motors or end-use facilities are upgraded.

Reduced voltage starters and solid-state "soft-start" devices are widely used in industries where voltage flicker is a common consideration; many end users prefer their use to extend the service life of large motors and associated power trains. This is the first consideration when confronting objectionable voltage dip. This equipment is discussed later in Section IV. For situations in which the motor has not yet been purchased, the consumer may be required to use a motor that draws a lower starting current or to use two or more smaller motors to drive the load. One type of motor available with lower starting current is the soft-start or two-step part-winding motor. It must be determined, however, that the motor will provide sufficient starting torque for the load.

It should be noted that line voltage regulators do not respond rapidly enough to be effective in preventing voltage dip due to motor starting current.

Other options for reducing either the motor's inrush current or the magnitude of voltage dip include, but are not limited to the following.

Wound-Rotor Motor

A wound-rotor motor in lieu of a squirrel-cage induction motor is particularly advantageous where frequent starting is required since such motors provide relatively high starting torque with low starting current without excessive temperature rise. Starting current of the wound-rotor motor with control can usually be limited to 200% of rated full load current. Because a wound-rotor motor and its control are more expensive than a squirrel-cage induction motor, it will seldom be used if the consumer makes the decision.

Written-Pole Motor

For single-phase feeder lines, the single-phase written-pole motor may be used to limit startup current inrush to 2 or 3 times full-load running currents. This may allow the utility to serve a remote load that normally would require costly installation of three-phase power. Irrigation wells and remote oil pumping sites, from 10 to 75 horsepower, can benefit from this technology. The utility engineer should review current policies; limitations on load sizes served from single-phase lines may need to be adjusted to allow the use of this type of motor. In any case, individual line conditions should be reviewed before installing this type of application.

Series Capacitors

Series capacitors may be used to reduce the effect of motor starting current on those consumers located on the line beyond the capacitor relative to the source. However, consumers who are on the same line and located closer to the source will experience no improvement in voltage dip.

Motor current flowing through the series capacitor causes a voltage rise, which is a function of line current and power factor. The series capacitor acts, therefore, as an instantaneous voltage regulator and is most effective when applied on a line servicing pulsating loads, such as rock crushers or sawmills. (Note: Such loads are, however, more effectively controlled by requiring the consumer to balance the motor mechanically.)

Series capacitors must be specifically engineered and, after they are installed, the engineer must be certain that changes in load current or fault current does not endanger the installation. Where series capacitors are used, prediction of circuit performance during transient conditions—such as motor starting and switching—is difficult. Problems which may be encountered include self-excitation of motors during starting and ferroresonance in transformers.

Switched Shunt Capacitors

Shunt capacitors connected to the line during the time that the motor is started may be used to reduce the magnitude of voltage dip. The capacitor current cancels all or a part of the reactive component of the motor starting current, with the result that the line current and, hence, the voltage dip will be reduced. This method requires the use of a rather large amount of capacitors (approximately three to six times the motor kilowatt rating) and is most effective when the reactance component is the predominant part of the line conductor impedance.

MOTOR CONTROL AND PROTECTION

In general, induction motor controls provide motor short-circuit and ground fault protection, motor-running overcurrent protection, and a means for starting and stopping the motor.

Motor Starters

Motor controllers or starters may provide for either full voltage (across the line) or reduced voltage starting. Across the line starting is generally employed unless the inrush current would cause objectionable voltage dip.

Running overcurrent protection is generally incorporated into the starter. Combination starters, which include both running overcurrent protection and short-circuit protection, may also be obtained. The starter may be either manual or magnetic. Some manual starters do not disconnect the motor from the line on low voltage or loss of voltage. Magnetic starters, however, are responsive to low voltage and the contactors usually drop at 50% to 70% of rated voltage unless time delay hold-in is employed. If under-voltage protection is used, the dropout point is likely to be set to approximately 80%.

Depending on the control scheme used with the contactors, the motor may either restart automatically on restoration of voltage or it may be restarted only by operation of the start button. Automatic restart is generally not advisable since it is hazardous in many situations and, with large motors, it may cause difficulty with cold load pickup. Article 430-43 of the NEC contains Code requirements for automatic restarting.

Because A/C contactors with A/C coils drop open on loss of voltage or extreme low voltage, motors may sometimes drop off the line due to under voltage during system disturbances. Although this may be a nuisance, it will permit a controlled reapplication of load on the system.

For critical loads, time delay hold-in may be employed. This holds the motor on the line for a selected time period (usually about two seconds). Motors that remain on the line during recloser operations may draw an excessively large inrush current upon re-energization, which is undesirable from the power supplier's viewpoint. In addition, the possibility of motor damage may exist and protection against out-of-phase re-energization is sometimes applied, particularly on motors larger than 200 horsepower.

a. <u>Reduced Voltage Starters.</u> Larger motors started across the line can momentarily cause objectionable system voltage drops due to high starting current requirements. Reduced-voltage starters avoid this problem by reducing a motor's terminal voltage and starting current and then applying full voltage at a point at nearly rated speed. Reduced-voltage starters are a specialized type of magnetic contactor.

   Motor torque is proportional to the square of the voltage. Reduced-voltage starting reduces torque and causes less mechanical shock on shafts, belts, gears, and other mechanical parts. On the other hand, if the load is a high inertia load, the reduced torque may not be enough to accelerate the motor and its load, resulting in the motor's stalling. The motor must be capable of developing enough torque at the reduced voltage to accelerate a load to full speed or a special motor designed for this purpose should be used.

   Reduced-voltage starters adjust the motor terminal voltage during starting through the following methods:

   - Primary Resistor or Reactor Type
   - Autotransformer Type
   - Wye-Wye Type
   - Part-Winding Type
   - -Solid State Type ("Soft-Start")

b. <u>Adjustable Speed Drives.</u> Solid-state or electronic speed drives for larger, low-voltage (less than 600-volt) motors have greatly increased the application of speed control. Solid-state drives provide more energy-efficient operation than traditional speed control and can be more accurately applied for precise control of a load.

Digital microprocessor- controlled drives, called adjustable-speed drives (ASDs) or variable-frequency drives (VFDs), have a large array of features, including motor protection and operating diagnostics. A disadvantage of ASDs is their sensitivity to terminal voltage fluctuations that may cause artificial ASD outages in the rural environment. Another disadvantage to consider with ASDs is that they are a source of harmonics that will be transmitted to the utility distribution system. Limits for harmonic distortion should be as published in the latest issuance of ANSI/IEEE 519, "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems." When there is reasonable cause for concern, the utility should consider requiring the installation of a monitoring system to permit ongoing assessment of compliance with ANSI/IEEE 519 criteria.

These drives use diodes or silicon-controlled rectifiers (or thyristors) to convert ac to dc voltage. The dc section uses an inductor, a capacitor, or both to "smooth out" the dc. The inverter converts the dc voltage and current back to ac to selected frequency and voltage levels. The motor terminal frequency and voltage are controlled to obtain the desired motor output for a given application.

ASD design assumes a maximum length of the motor supply circuit of typical wire size. The maximum motor circuit length differs with each manufacturer. Therefore, the manufacturer's instructions must be consulted for the restriction for a given ASD. Motor cable length limitations must be considered in the application where the motor will be some distance from its drive. If multiple motors are supplied from the same drive, the total circuit length is applicable. If the length and size are out of limit, the continuous output of the drive decreases.

One of the side effects of ASD operation is the potential for very fast voltage transients (see Section 4) being produced in the motor cable. When this occurs, the motor winding insulation may be damaged. New motor installations should utilize inverter duty motors. Where needed, an optional motor filter is available for installation in the output of the drive or at the motor. Three basic ASD types are manufactured:

- Current-Source Inverter (CSI) Drive
- Voltage-Source Inverter (VSI) Drive
- Pulse-Width Modulated (PWM) Drive

Short Circuit and Ground Fault Protection

Short circuit and ground fault protection is intended to protect the motor branch circuit conductors, motor control apparatus, and motors against overcurrent due to faults as specified in Article 430, Part IV, of the NEC. Either fuses or circuit breakers may be used for this purpose; however, such devices cannot protect against all types of faults.

The device must be capable of interrupting the maximum available fault current and be as sensitive as possible to low values of fault current. Also, its speed of operation should be such that it opens the circuit before serious damage can occur. Table 430.52 of the NEC provides more detail of maximum allowable ratings of these devices.

Running Overcurrent Protection

Motor running overcurrent protection is intended to protect motor control apparatus and motors from damage due to motor overload or failure to start. This protection may be obtained by means of overcurrent devices responsive to excessive current or thermal protectors integral with the motor.

Motor branch circuit overcurrent protection may be obtained from the same device that furnishes running overcurrent protection if the rating or setting of the device provides the protection specified in Article 430, Part III, of the NEC. In all cases, the sensors must cause interruption of current to the motor on excessive overload.

a. Type of Control Usually Applied. Probably the most frequently used starters for single-phase motors are lever-operated, dual-element fused switches. These devices may not offer adequate protection for motors used for many farm applications. Silo unloader motors, for example, are quite susceptible to damage since they may operate overloaded and under very adverse conditions. For motors 5 horsepower and larger, and especially in applications where damages have been experienced, consumers should be encouraged to use magnetic motor controllers with an undervoltage release.

   The degree of protection justified for three-phase motors is related to motor size and application. On rural systems, protection for three-phase motors is often provided by a motor starter consisting of magnetic contactors with heat coils which approximately sense motor temperature as a function of motor current. It is important that the heat coils be carefully selected so that they are properly coordinated with the motor characteristics. Improperly applied coils may either prevent using the full horsepower of a motor or they may allow it to operate overloaded, resulting in motor damage.

b. Number of Overcurrent Units Required. The National Electrical Code requires that running overcurrent protection for unattended three-phase motors be installed in all three phases. However, motor controllers are normally furnished with only two thermal protection units and provisions for the third one. These two units provide protection against a stalled condition or an overload condition; however, unless the third unit is also installed, the motor is likely to be damaged by overheating if one phase of the primary line is opened. NEC Table 430.37 governs the minimum allowable overload units for various motor supply voltages.

c. Limitations of Heat Coils. Heat coils cannot protect motors from overheating due to inadequate ventilation or excessive voltage unbalance with all phases energized. Motors which may be subject to unbalanced voltage include those on open delta transformer banks, those on three-phase banks supplying both single-phase and three-phase load and those supplied through phase converters.

   For motors operating near rated load, protection from overheating may be obtained with control schemes utilizing temperature sensing elements built into the motor or embedded within the motor windings. The range of heating rate for which protection can be obtained is dependent on the characteristics of the temperature-sensing element used. Some devices, for example, have such large mass or such poor motor winding contact that they do not act fast enough to prevent damage on rapidly rising temperature conditions such as a stalled rotor.

Other Motor Relay Protection

A variety of relays are available to monitor single- and three-phase motor voltage or current. In all cases, the relay opens the starter contacts, which de-energizes the motor. The need for this protection depends on the specific system problem and on the type of load. Relays provide the protective functions singly or in combination with other functions and are available from many vendors:

- Phase Unbalance Relays
- Loss of Phase and Phase Reversal Relays
- Underload Relays
- Long Acceleration Time Relays
- Undervoltage Relays
- Overvoltage Relays
- Short Cycle Timers
- Digital Motor Protection and Display Relays

AIR CONDITIONING LOADS

Many residential customers today have either a central air conditioner or heat pump for space cooling or heating purposes. When an air conditioner or heat pump starts, a momentary dimming of the lights may occur. This dimming occurs because the large starting current required by the compressor motor causes a voltage drop in the transformer and service drop. This voltage drop is typically referred to as “flicker.” Flicker is the perceived change in light intensity. Since it is a perceived value, each customer has a slightly different threshold of perception. Historically, utilities have used the curves in Figure 1 as a guideline for voltage fluctuations.

A typical air conditioner or heat pump may start 2–3 times per hour. This translates to a voltage fluctuation of 4.5% to 5% on the Border Line of Irritation curve. However, the graph also shows some customers may actually see flicker as low as 1.75% on the Border Line of Visibility curve. For design purposes, the Border Line of Irritation curve should be used. In using this curve, a good design criteria would be to limit transformer and service drop to a total of 5% to minimize flicker complaints. Flicker is not known to be harmful to the customer’s equipment unless the flicker or voltage drop is so severe the air conditioner will not start.

The flicker or voltage drop is the sum of the voltage drop in the service transformer plus the voltage drop in the service conductors. This voltage drop occurs when the air conditioner compressor starts. The current drawn by the compressor at this time is called locked rotor amps (LRA). The LRA is listed on the air conditioners outdoor unit name plate. There are numerous software programs available for calculating the voltage drop based on air conditioning unit size or LRA.

The following charts could be used to provide a quick estimate of voltage flicker from typical air conditioners or heat pumps.

Table 1. Voltage Flicker Overhead Service Transformers.

		% Voltage Flicker in Service Transformer						
A/C Tons	LRA	25 KVA	50 KVA	37.5 KVA	50 KVA	75 KVA	100 KVA	167 KVA
1	32	0.71	0.47	0.35	0.24	0.18	0.11	0.19
1.5	48	1.06	0.71	0.53	0.35	0.26	0.16	0.29
2	64	1.41	0.94	0.71	0.47	0.35	0.21	0.38
2.5	80	1.77	1.18	0.88	0.59	0.44	0.26	0.48
3	96	2.12	1.41	1.06	0.71	0.53	0.32	0.58
3.5	112	2.47	1.65	1.24	0.82	0.62	0.37	0.67
4	128	2.83	1.88	1.41	0.94	0.71	0.42	0.77
5	160	3.53	2.36	1.77	1.18	0.88	0.53	0.96

Table 2. Voltage Flicker Table Overhead Triplex Per 100 Feet.

		% Voltage Flicker in Service Conductor Per 100 Ft.					
A/C Tons	LRA	#2	1/0	4/0	250	350	500
1	32	0.85	0.54	0.28	0.24	0.18	0.13
1.5	48	1.28	0.81	0.42	0.36	0.27	0.20
2	64	1.71	1.08	0.55	0.48	0.35	0.27
2.5	80	2.13	1.35	0.69	0.60	0.44	0.33
3	96	2.56	1.62	0.83	0.71	0.53	0.40
3.5	112	2.98	1.89	0.97	0.83	0.62	0.47
4	128	3.41	2.16	1.11	0.95	0.71	0.54
5	160	4.26	2.70	1.38	1.19	0.89	0.67

Table 3. Voltage Flicker Table Padmount Service Transformers

		% Voltage Flicker in Service Conductor Per 100 Ft.					
A/C Tons	LRA	#4	#2	1/0	2/0	3/0	4/0
1	32	1.35	0.85	0.54	0.43	0.34	0.28
1.5	48	2.03	1.28	0.81	0.64	0.51	0.41
2	64	2.71	1.70	1.08	0.86	0.68	0.55
2.5	80	3.38	2.13	1.35	1.07	0.86	0.69
3	96	4.06	2.56	1.61	1.29	1.03	0.83
3.5	112	4.73	2.98	1.88	1.50	1.20	0.96
4	128	5.41	3.41	2.15	1.71	1.37	1.10
5	160	6.76	4.26	2.69	2.14	1.71	1.38

Table 4. Voltage Flicker Table Underground Al Triplex Per 100 Feet.

		% Voltage Flicker in Service Transformer							
A/C Tons	LRA	10 KVA	15 KVA	25 KVA	37.5 KVA	50 KVA	75 KVA	100KVA	167 KVA
1	32	1.92	1.28	0.77	0.51	0.38	0.26	0.19	0.11
1.5	48	2.88	1.92	1.15	0.77	0.58	0.38	0.29	0.17
2	64	3.84	2.56	1.54	1.02	0.77	0.51	0.38	0.23
2.5	80	4.80	3.20	1.92	1.28	0.96	0.64	0.48	0.29
3	96	5.76	3.84	2.30	1.54	1.15	0.77	0.58	0.34
3.5	112	6.72	4.48	2.69	1.79	1.34	0.90	0.67	0.40
4	128	7.68	5.12	3.07	2.05	1.54	1.02	0.77	0.46
5	160	9.60	6.40	3.84	2.56	1.92	1.28	0.96	0.57

When performing flicker calculations, loading of the transformer has little effect on flicker.

For performing flicker calculations, the cooperative may want to develop a standard or policy on maximum air conditioner starting current (i.e., LRA >32 amp per ton). This would allow the cooperative to have a standard design and inform the customer of this requirement. Then the customer could be aware of this requirement when purchasing an air conditioner. Today the higher efficiency compressors typically have higher locked rotor amps and newer "scroll" type compressors are available that have significantly higher starting currents.

Even with the best practices and intentions, occasionally a customer comes along who has a slightly higher LRA or a lower threshold of perception. The most readily available and economical solution is the addition of a "hard start" kit. The kit consists of a larger starting capacitor and is usually successful in eliminating marginal flicker.

OTHER POTENTIAL PROBLEM LOADS

The most common objectionable voltage fluctuations occur when large motors start. Most of this guide has been focused on the starting issue. However, there are other loads involving high in-rush currents that also cause objectionable voltage fluctuations. These in-rush currents are associated with normal continuous operation of the load and are not confined to start-up. This section will define some of the more typical problem loads and offer some precautions and solutions the cooperative may need to consider when serving such loads.

WOODCHIPPER

Woodchippers typically consist of two different types of chipping methods. One involves chipping entire tree trunks to develop wood chips for paper processing or boiler feedstock. The chipper motor in these instances can be as large as 1,000 horsepower. The other chipping operation involves chipping smaller logs to produce mulch, typically for landscaping. These chipper motors are often smaller, in the 500-horsepower range. However, both loads can cause objectionable voltage fluctuations on the primary distribution system. Chipping operations typically employ some type of fly wheel application to facilitate the chipping operation, but the cooperative should still expect to see current in-rush of 2–3 times full load current when the chipping of an individual tree or log starts. This in-rush current cycling can occur 10–20 times per hour.

Current in-rush of this magnitude could cause objectionable voltage flicker on the distribution feeder serving the chipper facility.

There are numerous solutions to this flicker problem. The cooperative should evaluate all options and determine the best solution. The cooperative also should determine if the customer should supply the solution or pay an aid-to-construction contribution for cooperative-furnished solutions. In some instances, the cooperative may decide to supply the solution at no cost to the customer.

Solutions the cooperative may investigate are described below.

1. Variable speed conveyor belts are becoming more popular in wood chipping operations, especially in smaller establishments. High in-rush current is often the result of too much wood product being fed into the chipper too quickly. Newer controllers monitor the chipping motor current and, when the controller senses an increase in current, the controller stops or slows the conveyor belt feeding the wood, allowing the chipper motor to chip the wood product without high in-rush current.

2. Upgrade the distribution feeder. Often a cooperative can solve the flicker problem by reconductoring or increasing the primary voltage on the distribution feeder. A 25-kV distribution feeder with large conductors can often fix the problem. Cooperatives need to make sure they are using accurate, current in-rush data when pursuing this solution.

3. When neither of the above solutions work, the cooperative may investigate the use of static var compensation (SVC). SVCs have increased in popularity recently. The SVC fundamentally is a three-phase controlled shunt capacitor. It monitors the bus voltage continuously, switching shunt capacitors in or out as needed to raise or lower bus voltage. These SVCs are typically three-phase and are installed on the cooperative's primary distribution feeder.

4. An alternative to the SVC is a static synchronous compensator (STATCOM). The STATCOM is fundamentally a controlled voltage source. The STATCOM monitors the three-phase bus voltage and, by using a voltage source converter, provides a three-phase set of output voltage with desired amplitude and frequency. The STATCOM can mitigate flicker as well as limit unbalances between phases and control power factor. The STATCOM is typically faster than

the SVC and, thus, is better at mitigating serious flicker problems on the primary distribution bus.

MINING LOADS

Mining facilities typically utilize a substantial number of motors in their operations. Motors are used to operate conveyor belts, ventilation fans, pumps, and the mining machines themselves. The majority of the motors used are typically operated for long periods of time once they are started (e.g., conveyor belts, ventilation fans, and pumps are left running for an entire shift or, in some cases, at all times) and, thus, do not contribute as much to voltage flicker concerns due to their infrequent starts. The largest of these motors, though, may still require some sort of voltage flicker mitigation measures to be employed, such as soft starters or VFDs.

Voltage flicker concerns stemming from mining operations are typically created by the mining machines themselves. These motors can be quite large (multiple 200+ hp motors per machine is not uncommon) and are frequently started and stopped. Additionally, the motors can bog down when the cutters are applied to the rock face being mined and the current drawn by these motors can in some cases approach locked rotor amps. Therefore, normal operation of mining machines can yield repeated and varying voltage fluctuations on the cooperative's primary distribution facilities feeding the mine. To complicate matters, several mining machines can be operated simultaneously at a mining site, compounding the problem.

Solutions to mitigate objectionable voltage flicker due to mining operations can be limited. In many cases, the mining machines do not have the capability to utilize soft starters or VFDs. Due to this limitation and the potentially large number of motors located at a mining site, a centralized solution is generally found to be the most cost-effective approach. Shunt capacitors installed as part of a static VAr compensator (SVC) is a common solution employed. SVCs continually monitor the reactive requirements of the load and switch in/out the required capacitance on a very fast basis (response times measured in cycles are common). There are several advantages to this solution:

1. One SVC can be used to mitigate the voltage flicker concerns at an entire mining operation.
2. The shunt capacitors in the SVC not only mitigate voltage flicker but also correct power factor levels on a continual basis.
3. The SVC is typically installed on the cooperative facilities and owned/operated by the cooperative, giving the cooperative control of the solution to ensure adequate power quality to all of its other members.

Rock crushers, lumber mills, and gas industry related loads all have similar characteristics regarding voltage flicker concerns as those mentioned for mining operations. In many cases, though, soft starters and VFDs can be used at small to mid-size operations (up to 1 MW) to mitigate voltage flicker. Larger installations may require a centralized solution such as an SVC.

Another dimension that factors into whether the voltage flicker is perceived by members to be a problem is the length of time that the condition persists. In some cases, existing mining operations that have created voltage flicker outside of normal industry standard tolerances have sensitized members such that no amount of reasonable mitigation is enough to eliminate their perception of a problem existing. Detailed study prior to these types of loads commencing operations is needed to ensure any potential voltage flicker concerns are identified and addressed up front.

DISTRIBUTED ENERGY RESOURCES (DER)

In recent years, distributed generation in the form of wind generators, solar panels, biomas, energy storage systems, and microgirds have grown in the generation capacity supplied to a utility's distribution systems. Distributed energy resources can pose risks to power quality on the utility distribution system. It may cause issues for other loads connected to the distribution systems, such as reverse power flow, harmonic distortion and voltage fluctuations resulting from reactive power (kVAR) variability.

In the case of some distributed generation, harmonics and KVAR issues can be mitigated by equipment supplied by the manufacturer of the distributed generation equipment. When distributed generation is providing generation capacity to the utility's distribution system, it can provide KVAR support to the interconnected distribution system. This KVAR support can cause a voltage rise that may be helpful to a utility distribution system. However, the fluctuation of KVAR must be taken into consideration by the utility when any distributed generation is interconnected to the utilities distribution system. For example, rapid changes due to passing clouds can cause abrupt shifts in power output, resulting in voltage flicker. In some instances battery energy storage systems (BESS) may be deployed alongside DER to buffer output fluctuations, reduce flicker and enhance load balancing efficiency.

The fluctuation of KVAR can have an effect on induction motors connected to the utility distribution system that can be both positive and negative. When the distributed generation is contributing KVAR to the system, it can help the utility in providing some mitigation of the locked rotor effect during a motor start. However, with the diversity of design of distributed generation, harmonics and KVAR contributed by the generation equipment can cause an issue with induction motors during motor start and running conditions, including the low-voltage ride-through capabilities of a motor's relay. Modern DER systems increasingly rely on inverters equipped with advance grid support functions to mitigate these issues. Examples include:

- Volt-Watt and Volt-Var control to manage voltage rise and reactive power flow.
- Frequency-Watt response to support frequency stability.
- Ride-through capabilities to maintain operation during voltage or frequency disturbances.

These features are now mandated by updated standards such as IEEE 1547-2018 and UL 1741, which define interoperability and performance requirements for DERs.

When distributed generation is interconnected with a utility's distribution system, the utility must evaluate equipment settings—such as regulators, capacitors, and protection schemes—to ensure there are no adverse impacts on the system. Particular attention should be given to the utility's protection and control schemes to guarantee proper fault clearing, prevent conflicts, and maintain stable voltage profiles.

Some states and regional transmission organizations (RTOs) have established criteria for the interconnection of generation facilities. State regulatory standards addressing distributed generation interconnection may define:

1. The maximum size of generation that can be interconnected
2. The operating conditions that distributed generation equipment must maintain
3. The actions a utility may take in response to adverse conditions affecting its distribution system

In cases where state regulatory bodies do not provide interconnection standards, utilities can reference the criteria set by their RTO as a template for developing their own interconnection requirements.

APPENDIX I. VOLTAGE DIP ESTIMATING CHARTS FOR 230-VOLT SINGLE-PHASE MOTORS

These charts provide the approximate voltage dips resulting from across-the-line starting of single-phase, 230-volt motors. They are based on average values of transformer impedance and a motor starting current power factor of 60%. Results are given in volts on a 120-volt base.

Where the voltage dip obtained by the use of these charts is considered marginal in acceptability, greater accuracy may be obtained by the use of actual transformer and motor data and the method of Appendix II.

PROCEDURE FOR USING CHARTS

1. Determine starting current at 230 volts.
   a. Use NEMA Code Letter from motor nameplate and equations of Appendix VI-A.
   b. Where nameplate data is not available, assume starting current is five to six times full load current, except that for certain nonstandard motors it may be necessary to obtain information from motor manufacturer.
2. Using starting current at 230-volts, enter charts and read voltage dip for each of the following:
   a. Substation
   b. Primary line
   c. Service transformer
   d. Service
3. Determine percent voltage dip from the following:

$$\% \text{ dip} = \frac{(100)\ (\text{Voltage dip on 120-volt base})}{120}$$

4. Add voltage dip of substation and primary line.   This is the maximum voltage dip seen by other consumers on the same phase.
5. Add voltage dip of all system components. This is the voltage dip at the motor terminals.
6. To evaluate the acceptability of dip or need for corrective measures, refer to the text.
7. Where voltage dip is marginal, obtain more exact data, if possible, and use the calculating method of Appendix II.

EXAMPLE

Determine voltage dip caused by across-the-line starting of a NEMA standard, single-phase, 10 hp, 230-volt motor located 17 miles from the substation.

Known Data

Substation size – 3750 kVA or 1250 kVA/phase

Primary line – 17 miles of #2 ACSR

Service transformer – 15 kVA

Service run - #1 A1. triplex, 100 feet long

Starting current – 260 amperes

Solution

Enter all charts at 260 amperes starting current.

Chart I-A Substation. Proceed vertically to1250 kVA/phase line, then left horizontally. Read 0.3-volt dip.

Chart I-B Primary Line. Proceed vertically to #2 ACSR line, then left horizontally. Read 0.27 volts per mile. Multiply by 17 miles to obtain 4.7 volts dip.

Chart I-C Service Transformer. Proceed vertically to 15 kVA line, then left horizontally. Read volts dip.

Chart I-D Service. Proceed vertically to #1 aluminum triplex line then left horizontally. Read .035 volt per foot. Multiply .035 by 100 to obtain 3.5 volts dip. (Note that we used the one-way distance from the transformer to the motor.)

Voltage dip seen by other consumers at or beyond the motor location is
0.3 + 4.7 = 5 volts on 120-volt base. Percent primary dip = (5) (100)/120 = 4.2%.

Voltage dip at motor terminals = 5 + 7.3 + 3.5 = 15.8 volts on 120-volt base.

Percent dip = (100) (15.8)/120 = 13.2%.

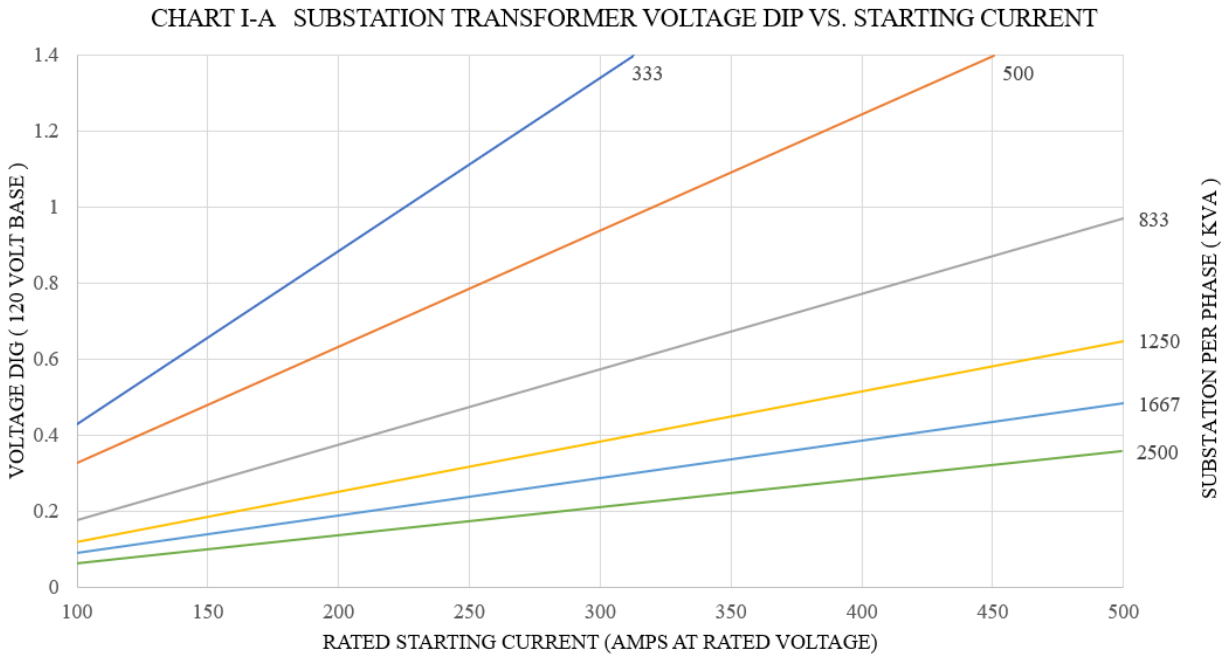


CHART I-A SUBSTATION TRANSFORMER VOLTAGE DIP VS. STARTING CURRENT
VOLTAGE DIG (120 VOLT BASE)
RATED STARTING CURRENT (AMPS AT RATED VOLTAGE)
SUBSTATION PER PHASE (KVA)
333
500
833
1250
1667
2500
0
0.2
0.4
0.6
0.8
1
1.2
1.4
100
150
200
250
300
350
400
450
500

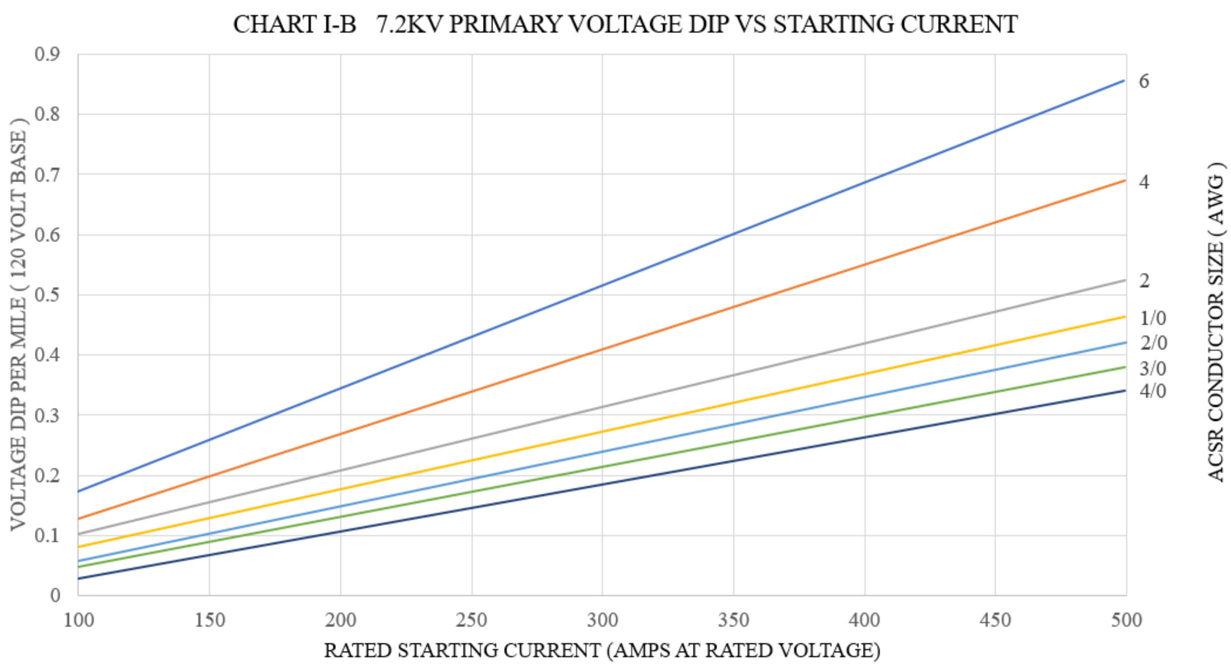


CHART I-B 7.2KV PRIMARY VOLTAGE DIP VS STARTING CURRENT
VOLTAGE DIP PER MILE (120 VOLT BASE)
RATED STARTING CURRENT (AMPS AT RATED VOLTAGE)
ACSR CONDUCTOR SIZE (AWG)
6
4
2
1/0
2/0
3/0
4/0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
100
150
200
250
300
350
400
450
500

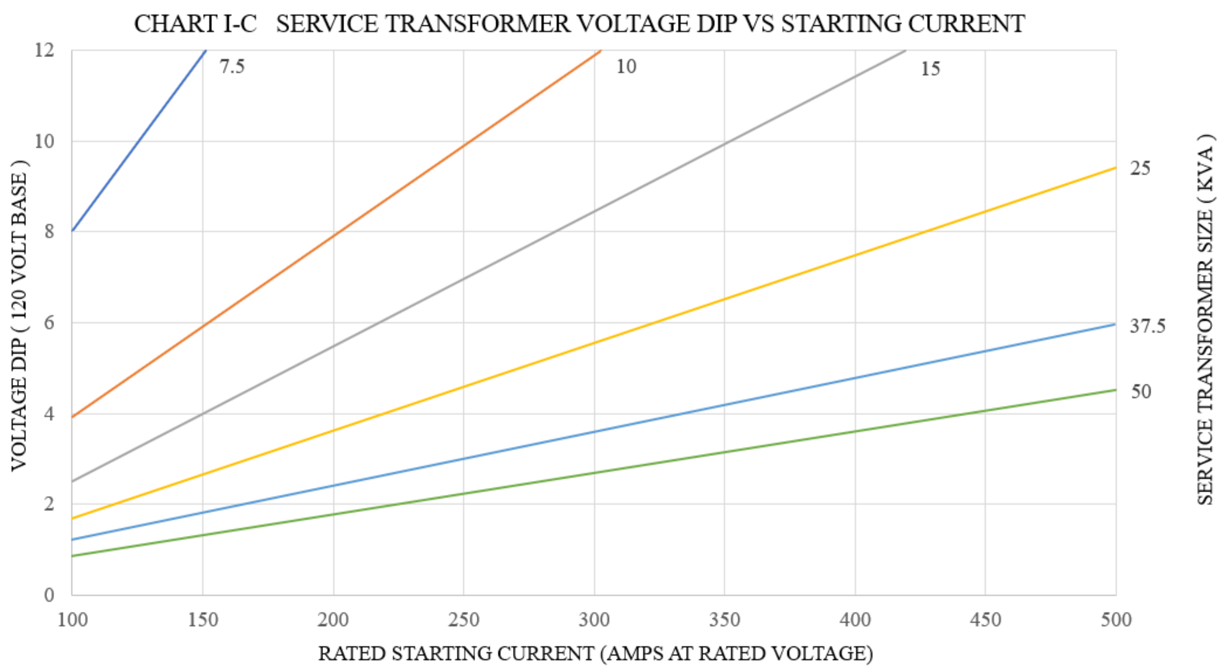


CHART I-C SERVICE TRANSFORMER VOLTAGE DIP VS STARTING CURRENT
VOLTAGE DIP (120 VOLT BASE)
SERVICE TRANSFORMER SIZE (KVA)
RATED STARTING CURRENT (AMPS AT RATED VOLTAGE)
0
2
4
6
8
10
12
100
150
200
250
300
350
400
450
500
7.5
10
15
25
37.5
50

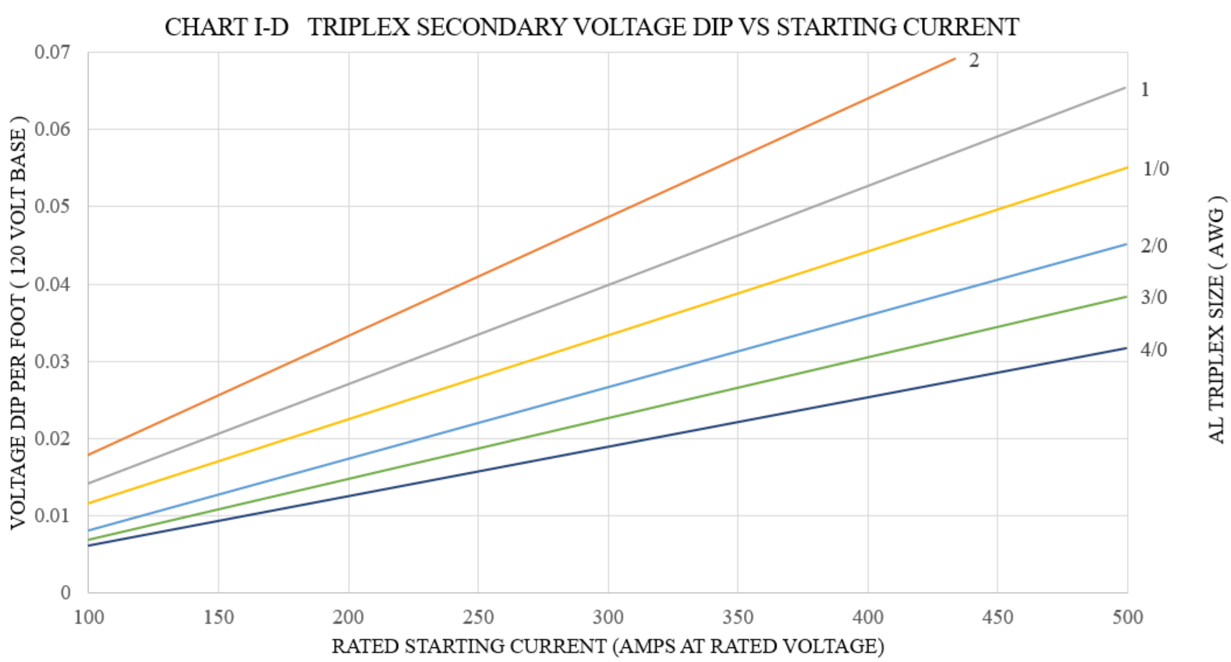


CHART I-D TRIPLEX SECONDARY VOLTAGE DIP VS STARTING CURRENT
VOLTAGE DIP PER FOOT (120 VOLT BASE)
AL TRIPLEX SIZE (AWG)
RATED STARTING CURRENT (AMPS AT RATED VOLTAGE)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
100
150
200
250
300
350
400
450
500
2
1
1/0
2/0
3/0
4/0

APPENDIX II. VOLTAGE DIP CALCULATING FORM FOR 230-VOLT SINGLE-PHASE MOTORS

This form provides a procedure for calculating voltage dip resulting from across-the-line starting of single-phase, 230-volt induction motors. Since the effect of other system loads is not considered in this method, the voltage dip values obtained will be somewhat higher than will actually exist. From this viewpoint the results are conservative.

However, in using this method to determine whether the voltage at the motor terminals is sufficient to start the motor and bring it up to speed, the voltage drop on the primary line due to other loads must be taken into account. It is considered sufficiently accurate to use the voltage drop at the point of motor location due to these other loads by the level shown in the most recent Construction Work Plan using RUS Bulletin1724D-101B and subtract this voltage drop arithmetically from the motor terminal voltage obtained using this voltage dip calculating form.

This method requires that the user have actual nameplate data for substation transformer, service transformer, and motor, and be proficient in the use of complex algebra.

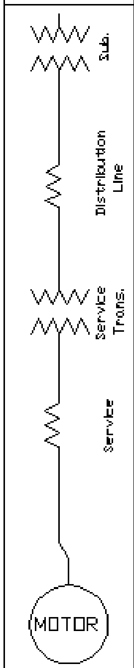
1 Schematic Diagram	2 Impedence Diagram	3 Applicable Z Equation 120 v. base, single phase, 230 v. motor	4 Calculated Z, (R+jX)	5 Approximate Voltage dip I_S (Rcos θ + Xsin θ)	6 Cumulative Voltage dip	7 Affected Consumers
	(1) Z_{Sub}	$Z_{Sub} = \frac{\%Z \times .144}{KVA/Phase} \times (.2+j.98)$ (%Z and KVA from nameplate)		V1	(V1)	
	(2) Z_L	7.2 KV L-G primary $Z_{Line} = .000278 \times Z_L \times Miles$ 14.4 KV L-G primary $Z_{Line} = .0000695 \times Z_L \times Miles$ (Z_L from Appendix VI)		V2	(V1)+(V2)	All on same phase
	(3) Z_T	$Z_T = \frac{\% Z \times 144}{KVA} \angle \theta_T$ (% Z and KVA from nameplate) θ_T from Mfg. or Appendix VI)		V3	(V1)+(V2)+(V3)	All on same distribution transformer
	(4) Z_S	$Z_{Service} = \frac{(2)Z}{1000} \times Length(ft.) \times .25$ (Z from Appendix VI)		V4	(V1)+(V2)+(V3)+(V4)	All on same service
	(5) Z_M	$Z_M = \frac{E \text{ rated} \times 0.25}{\text{Starting I}} \angle \theta_N$ — or — $Z_M = \frac{E^2 \text{ rated} \times 0.25}{\text{Starting VA}} \angle \theta_N$ (Starting I or VA and θ_N from motor Mfg., or approximate value from Appendix VI)		V5	125-[(V1)+(V2)+(V3)+(V4)] — or — $\frac{Z_N}{Z_{Total}} \times 125$	
			$I_S = 125/Z_{Total}$			

Exhibit II-A: Voltage Dip Calculating Form for 230-Volt, Single-Phase Motors.

PROCEDURE FOR USING FORM

1. Obtain the following data:

   a. Substation transformer kVA/Phase.

   b. Percent impedance of substation transformers.

   c. Line impedance in ohms per mile (see Appendix VI-B).

   d. Percent impedance of service transformer.

   e. Service conductor impedance in ohms/1000 feet (see Appendix VI-E).

   f. Nameplate voltage of the motor.

   g. Motor starting current at rated voltage.

2. Using the above data and the equations of Column 3 of the Voltage Dip Calculating Form, calculate the impedance on a 120-volt base for each system component and insert the result in Column 4.

3. Add all impedances in Column 4 to obtain Z_{Total}.

4. Calculate starting current on a 120-volt base:

$$I_s = \frac{125}{Z_{Total}}$$

5. Determine the power factor (cos θ) and reactive factor (sin θ) of starting current I_S.

6. Calculate voltage dip due to starting current, I_S, attributable to each component of system impedance:

   Voltage dip = I_S (R cos θ + X sin θ)

   Where R and X are obtained from Column 3.

   Insert these values in Column 5.

7. Determine cumulative voltage dip as indicated in Column 6.

8. Evaluate the effect of voltage dip in accordance with the discussion in the text.

SAMPLE PROBLEM

Determine the maximum voltage dip caused by across-the-line starting of a 10hp, 230-volt, single-phase motor located 12 miles from the source.

Known Data

Regulated bus voltage at substation: 125 volts on 120-volt base

Substation: 1500 kVA, 3-phase, $Z_t = 7.5\%$, $R_t = 0.2Z_t$, $X_t = 0.98Z_t$

Primary line: 12 miles of No. 2 ACSR at 7.2 kV

Service Transformer: 15 kVA, 7.2 kV to 120/240 volts, 1.7% Z, $\theta = 40^\circ$

Secondary: 125 feet off 1/0 aluminum triplex

Single-phase NEMA standard induction motor: 10 hp, 230-volt,

Starting current: 260 amperes, locked rotor power factor = 0.6

Solution

Using the equations of column 3, the impedance, Z, for each system component is calculated on a 120-volt base.

Substation Impedance $Z_s = \frac{\% Z \times .144}{\text{kVA/phase}} (0.2 + j\ .98)$

Using above data $Z_s = \frac{7.5 \times .144}{500} (0.2 + j\ .98) = .000431 + j\ .00212$ ohms

Other impedances are then calculated as shown below using data from Appendix VI and inserted in Column 4 as shown in Exhibit II-B.

$Z_l = (.000278)(1.64 + j\ 1.47)\ (12)$

$Z_t = [\ (1.7)\ (.144)\ (.766 + j.644)\ ]\ /15$

$Z_s = [(2)\ (.1644 + j.02588)\ (125)\ (.25)]\ /\ 1000$

$Z_m = [(230)(.25)(.6 + j.8)]\ /\ 260$

1 Schematic Diagram	2 Impedence Diagram	3 Applicable Z Equation 120 v. base, single phase, 230 v. motor	4 Calculated Z, (R+jX)	5 Approximate Voltage dip I_S (Rcos θ + Xsin θ)	6 Cumulative Voltage dip	7 Affected Consumers
Sub.	(1) Z_{Sub}	$Z_{Sub} = \frac{\%Z \times .144}{KVA/Phase} \times (.2+j.98)$ (%Z and KVA from nameplate)	.000431+j.00212	V1	(V1)	
Distribution Line	(2) Z_L	7.2 KV L-G primary $Z_{Line} = .000278 \times Z_L \times$ Miles 14.4 KV L-G primary $Z_{Line} = .0000695 \times Z_L \times$ Miles (Z_L from Appendix VI)	.00547+j.0049	V2	(V1)+(V2)	All on same phase
Service Trans.	(3) Z_T	$Z_T = \frac{\% Z \times 144}{KVA} \angle \theta_T$ (% Z and KVA from nameplate) θ_T from Mfg. or Appendix VI)	.0125+j.0105	V3	(V1)+(V2)+(V3)	All on same distribution transformer
Service	(4) Z_S	$Z_{Service} = \frac{(2)Z}{1000} \times$ Length(ft.)x.85 (Z from Appendix VI)	.01028+j.00162	V4	(V1)+(V2)+ (V3)+(V4)	All on same service
MOTOR	(5) Z_M	$Z_M = \frac{E \text{ rated} \times 0.25}{\text{Starting I}} \angle \theta_N$ —or— $Z_M = \frac{E^2 \text{ rated} \times 025}{\text{Starting VA}} \angle \theta_N$ (Starting I or VA and θ_N from motor Mfg., or approximate value from Appendix VI)	.1328+j.177	V5	125-[(V1)+ (V2)+(V3)+ (V4)] —or— $\frac{Z_N}{Z_{Total}} \times 125$	
			$I_S = 125/Z_{Total}$			

Exhibit II-B. Voltage Dip Calculating Form for 230-Volt, Single-Phase Motors.

Z_{Total} = .1615 + j.1961
= .254 /50.527

Cos 50.527º = .635

Sin 50.527º = .7719

I start = (125)/Z_{Total}

I start = $\frac{125}{.254}$ = 492.1 on 120-volt base

Using the equation of column 5, the voltage dip on a 120-volt base is calculated for each component and inserted in column 5, as shown in Exhibit II-C.

V1 = 492.1 [(.000431) (.635) + (.00212) (.773)] = 1 volt (rounded for ease of use)

V2 = 492.1 [(.00547) (.635) + (.0049) (.773)] = 3.6 volts

V3 = 492.1 [(.0125) (.635) + (.0105) (.773)] = 7.9 volts

V4 = 492.1 [(.01028) (.635) + (.00162) (.773)] = 3.8 volts

1 Schematic Diagram	2 Impedence Diagram	3 Applicable Z Equation 120 v. base, single phase, 230 v. motor	4 Calculated Z, (R+jX)	5 Approximate Voltage dip I_S (Rcos θ + Xsin θ)	6 Cumulative Voltage dip	7 Affected Consumers
Sub.	(1) Z_{Sub}	$Z_{Sub} = \frac{\%Z \times .144}{KVA/Phase} \times (.2+j.98)$ (%Z and KVA from nameplate)		V1 1.0	(V1)	
Distribution Line	(2) Z_L	7.2 KV L-G primary $Z_{Line} = .000278 \times Z_L \times$ Miles 14.4 KV L-G primary $Z_{Line} = .0000695 \times Z_L \times$ Miles (Z_L from Appendix VI)		V2 3.6	(V1)+(V2)	All on same phase
Service Trans.	(3) Z_T	$Z_T = \frac{\% Z \times 144}{KVA} \angle \theta_T$ (% Z and KVA from nameplate; θ_T from Mfg. or Appendix VI)		V3 7.9	(V1)+(V2)+(V3)	All on same distribution transformer
Service	(4) Z_S	$Z_{Service} = \frac{(2)Z}{1000} \times Length(ft.) \times .25$ (Z from Appendix VI)		V4 3.8	(V1)+(V2)+(V3)+(V4)	All on same service
MOTOR	(5) Z_M	$Z_M = \frac{E\ rated \times 0.25}{Starting\ I} \angle \theta_N$ —or— $Z_M = \frac{E^2\ rated \times 0.25}{Starting\ VA} \angle \theta_N$ (Starting I or VA and θ_N from motor Mfg., or approximate value from Appendix VI)		V5	125-[(V1)+(V2)+(V3)+(V4)] —or— $\frac{Z_N}{Z_{Total}} \times 125$	
			$I_S = 125/Z_{Total}$			

Exhibit II-C. Voltage Dip Calculating Form for 230-Volt, Single-Phase Motors.

Primary voltage dip = 1.0 + 3.6 = 4.6 volts on 120-volt base

Percent primary dip = (100) (4.6)/120 = 3.8%

Voltage dip at motor = 4.6 + 7.9 + 3.8 = 16.3 volts on 120-volt base

Percent dip at motor = (100) (16.3)/120 = 13.6%

If the motor is to be started often, or if there are many consumers beyond the motor location, the primary dip of 3.8% might be considered excessive. If, however, the motor will be started infrequently and the maximum primary dip of 3.8% will not be seen by a large number of consumers, it would generally be considered acceptable.

The voltage at the motor terminals will be that which existed prior to the motor starting less the 13.6% dip. If prior to the motor starting the voltage were 240, the starting voltage would be 240 minus 32.6, or approximately 207 volts. Since this is 90% of the 230-volt motor rating, 81% of the rated starting torque would be available during acceleration. If, however, the motor terminal voltage prior to motor starting were 230 volts, only about 74% of rated starting torque would be available during acceleration. Whether or not this is adequate would depend on the torque requirements of the load.

APPENDIX III. VOLTAGE DIP ESTIMATING CHARTS FOR 230-VOLT, THREE-PHASE SQUIRREL CAGE MOTOR ON THREE-PHASE BANK

These charts provide the approximate voltage dip (120-volt phase to neutral base) resulting from across-the-line starting of 230-volt, three-phase induction motors supplied from three-phase distribution banks.

The charts are based on the following assumptions:

1. Motor starting power factors of 0.4 to 0.3. (This range of values is generally applicable for 30 through 100 hp. Squirrel cage motors.)
2. Substation transformer impedance of 7%.
3. Distribution line impedance as given in typical of RUS Construction.
4. Service transformer impedance of 1.7% for 10- through 37.5-kVA transformers, and 1.8% for 50- through 167-kVA transformers.

More accurate results can be obtained by using specific data for a particular installation, and the calculating method of Appendix IV. If the dips are critical, such calculations are recommended.

These charts may also be used to estimate voltage dip due to starting 460-volt motors. In this case, enter charts at actual motor starting current and apply the following corrections to the results obtained from the charts:

Charts III-A, III-B, III-C. For 460-volt motors, voltage dip will be two times that indicated.

Chart III-D. For 460-volt motors, voltage dip will be one-half of that indicated.

Further, Chart III-B may be used with 14.4/24.9-kV primary line voltage. In this case, the voltage dip will be one-fourth of that indicated for 7.2/12.5-kV lines.

CHART III-A SUBSTATION TRANSFORMER VOLTAGE DIP VS. STARTING CURRENT

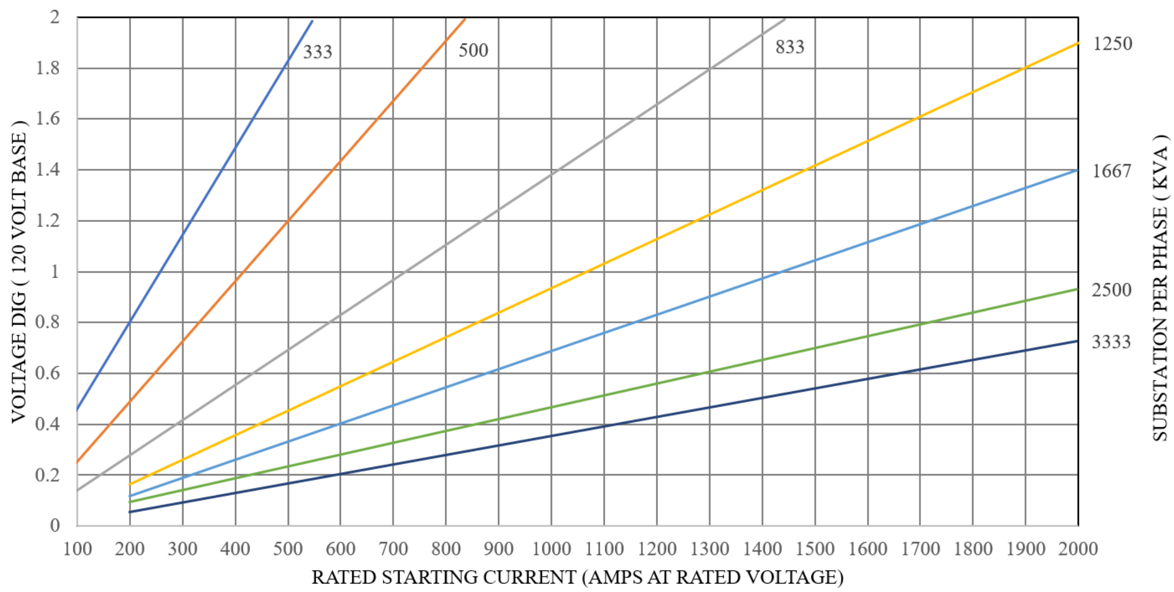
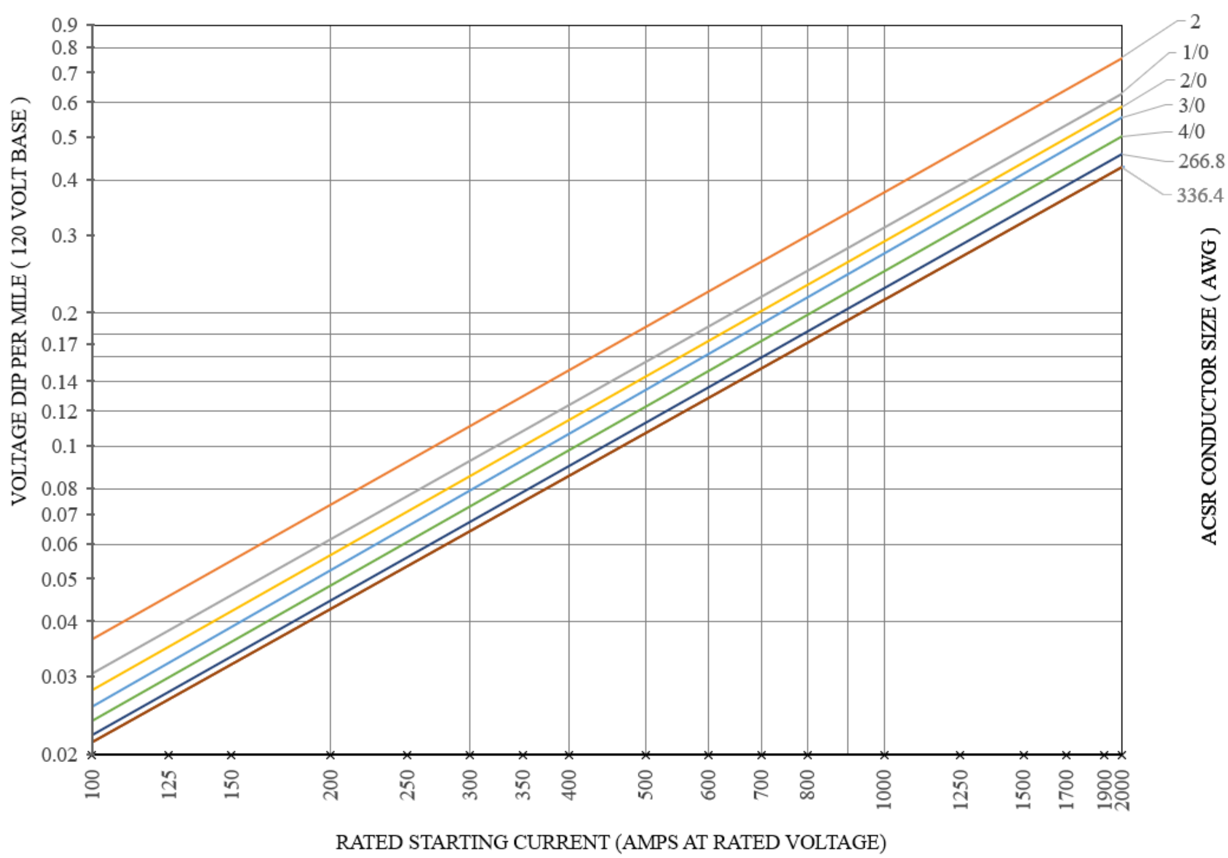
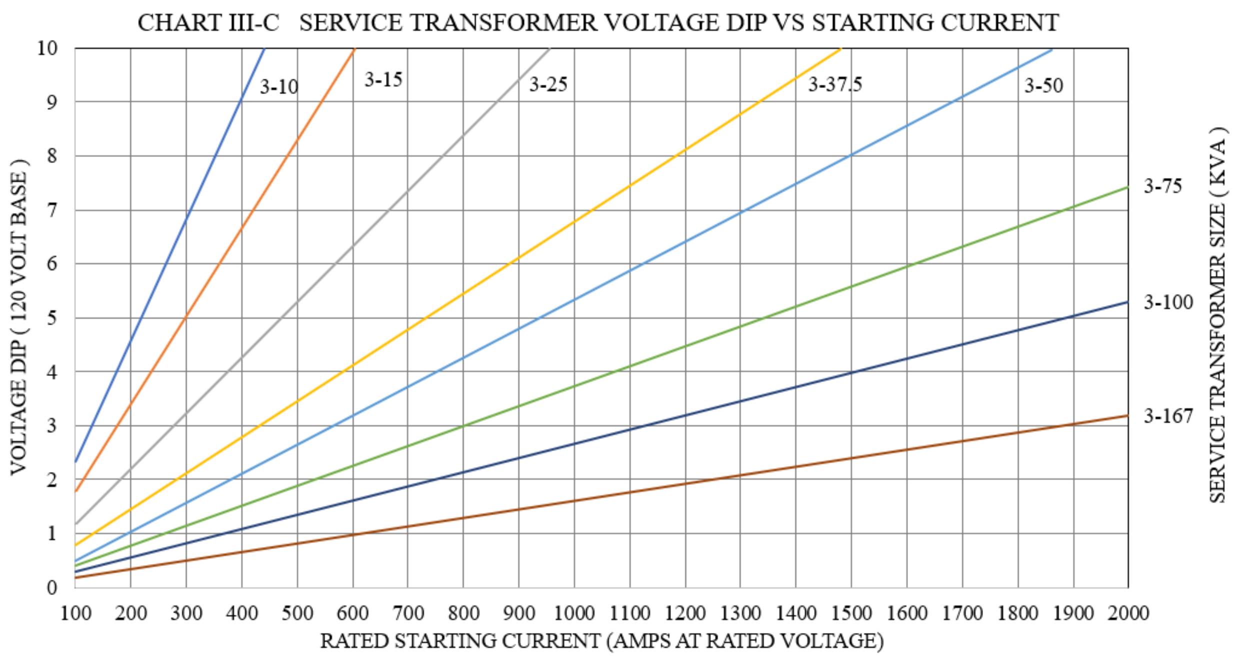
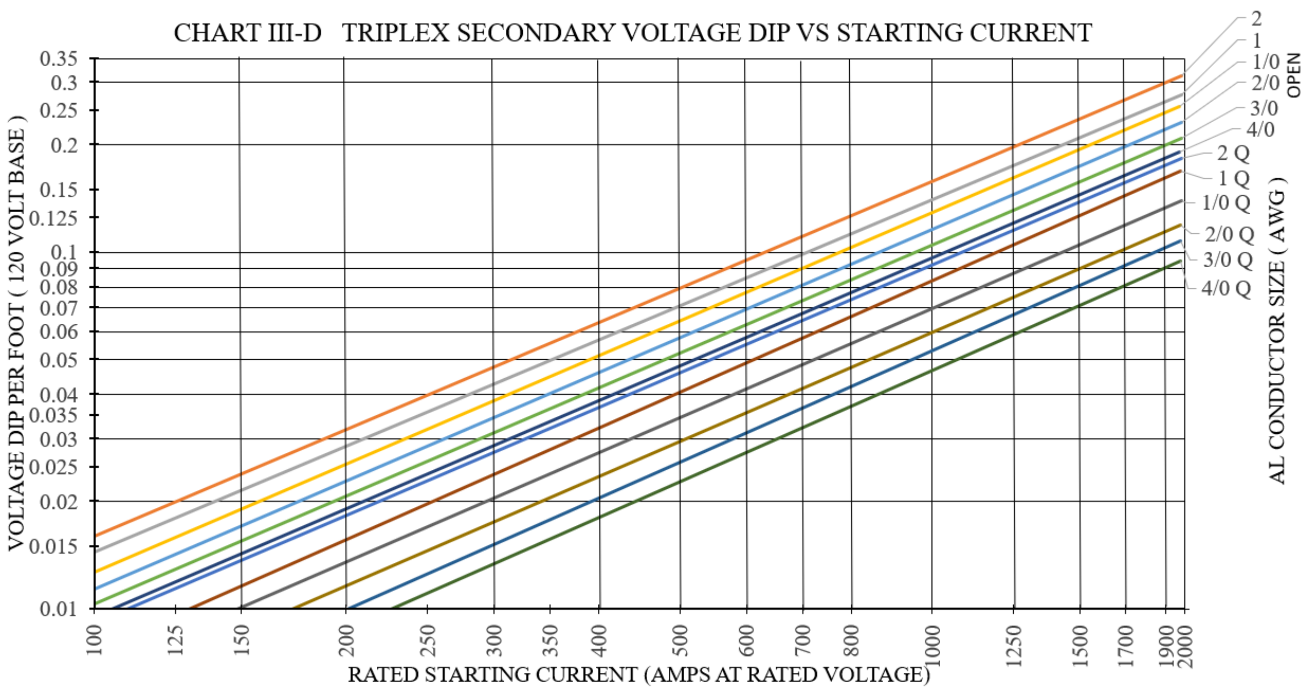


CHART III-B 7.2KV PRIMARY VOLTAGE DIP VS STARTING CURRENT







The procedure for using these charts is the same as that outlined for single-phase motors in Appendix I.

EXAMPLE

Determine the voltage dip caused by across-the-line starting of a 460-volt, 50hp, three-phase code letter F induction motor with the following known data.

Substation size: 7500 kVA or 2500 kVA per phase

Primary Line: 14 miles of 1/0 ACSR at 14.4/24.9kV

Service Transformer: three 15 kVA units

Secondary: 70-foot run of 1/0 aluminum conductor at one foot spacing

Solution (From Appendix VI-A)

Use 5.5 starting kVA per horsepower for code letter F motor.

Starting current = [(1000) (50) (5.5)] / [(1.73) (460)] = 345 amps

Enter all charts at 345 amps starting current.

Chart III-A Substation: Proceed vertically to 2500 kVA per phase line, then left horizontally. Read 0.35 volts dip. Since the motor is rated 460 volts instead of 230, we must now multiply by two:

(0.35)(2) = 0.7 volts dip.

Chart III-B Primary Line: Proceed vertically to 1/0 line, the left horizontally. Read 0.11 volts dip. This must be multiplied by 2 because the motor is rated 460 volts, and by one-fourth because the distribution voltage is 14.4/24.9 kV.

(0.11 volts per mile) (2) (1/4) (14 miles) = 0.8 volts dip.

Chart III-C Service Transformers: Proceed vertically from 345 amperes to 3-15 kVA line, then left horizontally. Read 6 volts dip. Since the motor is rated 460 volts, this must be multiplied by two.

(6) (2) = 12 volts dip.

Chart III-D Service: Proceed vertically from 345 amperes to 1/0 line, then left horizontally. Read .045 volts per foot. Since the motor is rated 460 volts, this must be multiplied by one-half.

(.045) (1/2) (70) = 1.6 volts dip.

(Note that 70 feet is the *one-way* distance from the transformer to the motor.

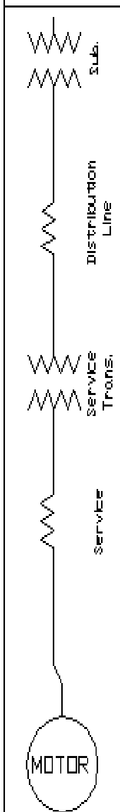
Primary voltage dip (that seen by other consumers at or beyond the motor location) is:

0.7 + 0.8 = 1.5 volts on 120-volt phase to neutral base

Voltage dip at the motor terminals is:

$$1.5 + 12.0 + 1.6 = 15.1 \text{ volts on 120-volt phase to neutral base}$$

Percent dip at motor = (100)(15.1)/120 = 12.6%



1 Schematic Diagram	2 Impedence Diagram	3 Applicable Z Equation 120 v. base, single phase, 230 v. motor	4 Calculated Z, (R+jX)	5 Approximate Voltage dip I_S (Rcos θ + Xsin θ)	6 Cumulative Voltage dip	7 Affected Consumers
	(1) Z_{Sub}	$Z_{Sub} = \frac{\%Z \times .144}{KVA/Phase} \times (.2+j.98)$ (%Z and KVA from nameplate)		V1	(V1)	
	(2) Z_L	7.2 KV L-G primary $Z_{Line} = .000278 \times Z_L \times Miles$ 14.4 KV L-G primary $Z_{Line} = .0000695 \times Z_L \times Miles$ (Z_L from Appendix VI)		V2	(V1)+(V2)	All on same phase
	(3) Z_T	$Z_T = \frac{\% Z \times 144}{KVA} \angle \theta_T$ (% Z and KVA from nameplate) θ_T from Mfg. or Appendix VI		V3	(V1)+(V2)+(V3)	All on same distribution transformer
	(4) Z_S	$Z_{Service} = \frac{(2)Z}{1000} \times Length(ft.) \times .85$ (Z from Appendix VI)		V4	(V1)+(V2)+(V3)+(V4)	All on same service
	(5) Z_M	$Z_M = \frac{E \text{ rated} \times 0.25}{\text{Starting I}} \angle \theta_M$ —or— $Z_M = \frac{E^2 \text{ rated} \times 0.25}{\text{Starting VA}} \angle \theta_M$ (Starting I or VA and θ_M from motor Mfg., or approximate value from Appendix VI)		V5	125-[(V1)+(V2)+(V3)+(V4)] —or— $\frac{Z_M}{Z_{Total}} \times 125$	
			$I_S = 125/Z_{Total}$			

Exhibit IV-A: Voltage Dip Calculating Form for 230-Volt, Three-Phase Motors.

APPENDIX IV. VOLTAGE DIP CALCULATING FORM FOR THREE-PHASE SQUIRREL CAGE MOTORS

This form has been prepared to organize and simplify the calculation of voltage dip due to across-the-line starting of three-phase induction motors on three-phase transformer banks. The method requires actual nameplate data for the motor, service transformer, and substation transformer, plus knowledge of complex algebra.

The results obtained will not be exact due to the effect of other system loads and the use of an approximate equation. If, however, the effect of other system loads is taken into account—by calculating the voltage drop due to these loads using the level shown in the most recent Construction Work Plan using RUS Guide 1724D-101B—the results should be sufficiently accurate. The voltage drop due to other system loads must be subtracted from the motor terminal voltage obtained by the use of this calculating form.

This procedure for using this form is the same as that outlined for the form of Appendix II.

SAMPLE PROBLEM

Regulated bus voltage at substation: 125 volts on 120-volt base

Substation: 5000 kVA, 3-phase, Z_t = 7%, $R_t = 0.2\ Z_t$, $X_t = 0.98\ Z_t$

Primary line: 10 miles of 3-phase 1/0 ACSR at 7.2/12.5 kV

Service Transformer: 3-37.5 kVA, 7.2 kV to 480 volts, 1.7% Z, $\theta_t = 45^o$

Secondary: 50 feet of 1/0 A1. at one foot spacing

Three-phase induction motor: 100 hp., 460-volt, starting current = 666 amperes, locked rotor power factor = 0.32.

Solution

Using the equations of Column 3, the impedance, Z, for each system component is calculated on a 120-volt phase to neutral base.

Substation impedance $Z_{sub} = \frac{(\%Z)(.144)}{kVA/phase}(.2 + j.98)$

Using above data, $Z_{sub} = \frac{(7)(.144)(.2 + j.98)}{1667} = .000121 + j.000592$ ohms.

Other impedances are then calculated as shown below and inserted in Column 4 as shown in Exhibit IV-B.

Z_1 = (.000278)(.885 + j.756) (10)

Zt = (1.7) (.144) (.707 + j.707) / 37.5

Z_s = (.1644 + j.1033) (50) (43.2) / 480^2

Z_m = (460)(24,950)(.32 +j.948) / (666) (480^2)

1 Schematic Diagram	2 Impedence Diagram	3 Applicable Z Equation 120 v. base, single phase, 230 v. motor	4 Calculated Z, (R+JX)	5 Approximate Voltage dip I_s (Rcos e + Xsin e)	6 Cumulative Voltage dip	7 Affected Consumers
Sub.	(1) Z_{Sub}	$Z_{Sub} = \frac{\%Z \times .144}{KVA/Phase} \times (.2+j.98)$ (%Z and KVA from nameplate)	.000121+ j.000592	V1	(V1)	
Distribution Line	(2) Z_L	7.2 KV L-G primary Z_{Line} =.000278 × Z_L × Miles 14.4 KV L-G primary Z_{Line} =.0000695 × Z_L × Miles (Z_L from Appendix VI)	.00246+ j.0021	V2	(V1)+(V2)	All on same phase
Service Trans.	(3) Z_T	$Z_T = \frac{\% Z \times 144}{KVA} \angle\theta_T$ (% Z and KVA from nameplate, θ_T from Mfg. or Appendix VI)	.00462+ j.00462	V3	(V1)+(V2)+(V3)	All on same distribution transformer
Service	(4) Z_S	$Z_{Service} = \frac{(2)Z}{1000} \times Length(ft.) \times .25$ (Z from Appendix VI)	.001543+ j.00097	V4	(V1)+(V2)+ (V3)+(V4)	All on same service
MOTOR	(5) Z_M	$Z_M = \frac{E\ rated \times 0.25}{Starting\ I} \angle\theta_N$ —or— $Z_M = \frac{E^2\ rated \times 0.25}{Starting\ VA} \angle\theta_N$ (Starting I or VA and θ_N from motor Mfg., or approximate value from Appendix VI)	.0239+ j.0709	V5	125-[(V1)+ (V2)+(V3)+ (V4)] —or— $\frac{Z_N}{Z_{Total}} \times 125$	
			$I_S = 125/Z_{Total}$			

Exhibit IV-B. Voltage Dip Calculating Form For Three-Phase Squirrel Cage Motors

Z_{Total} = .0326 + j.0792 = .0856/<u>67.6º</u>

Cos 67.6º = .381

$\sin 67.6^\circ = .925$

$I_{start} = 125/ Z_{total} = 125/.0856$

$I_{start} = 1460$ on 120-volt base

Using the equation of Column 5, the voltage dip on a 120-volt base is calculated for each component, and inserted in Column 5 as shown in Exhibit IV-C.

$V_1 = 1460[(.000121)(.381) + (.000592)(.925)]$

$V_2 = 1460 [(.00246)(.381) + (.0021)(.925)]$

$V_3 = 1460 [(.00462)(.381) + (.00462) (.925)]$

$V_4 = 1460 [(.001543) (.381) + (.00097) (.925)]$

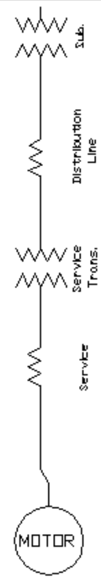
1 Schematic Diagram	2 Impedence Diagram	3 Applicable Z Equation 120 v. base, single phase, 230 v. motor	4 Calculated Z, (R+jX)	5 Approximate Voltage dip I_S (Rcos θ + Xsin θ)	6 Cumulative Voltage dip	7 Affected Consumers
 Sub.	(1) Z_{Sub}	$Z_{Sub} = \frac{\%Z \times .144}{KVA/Phase} \times (.2+j.98)$ (%Z and KVA from nameplate)		V1 0.9	(V1)	
Distribution Line	(2) Z_L	7.2 KV L-G primary Z_{Line} =.000278 × Z_L × Miles 14.4 KV L-G primary Z_{Line} =.0000695 × Z_L × Miles (Z_L from Appendix VI)		V2 4.2	(V1)+(V2)	All on same phase
Service Trans.	(3) Z_T	$Z_T = \frac{\% Z \times 144}{KVA} \angle \theta_T$ (% Z and KVA from nameplate) θ_T from Mfg. or Appendix VI)		V3 8.8	(V1)+(V2)+(V3)	All on same distribution transformer
Service	(4) Z_S	$Z_{Service} = \frac{(2)Z}{1000} \times$ Length(ft.)×.25 (Z from Appendix VI)		V4 2.2	(V1)+(V2)+ (V3)+(V4)	All on same service
MOTOR	(5) Z_M	$Z_M = \frac{E \text{ rated} \times 0.25}{\text{Starting } I} \angle \theta_N$ —or— $Z_M = \frac{E^2 \text{ rated} \times 0.25}{\text{Starting VA}} \angle \theta_N$ (Starting I or VA and θ_N from motor Mfg., or approximate value from Appendix VI)		V5	125-[(V1)+ (V2)+(V3)+ (V4)] —or— $\frac{Z_N}{Z_{Total}} \times 125$	
			$I_S = 125/Z_{Total}$			

Exhibit IV-C. Voltage Dip Calculating Form For Three-Phase Squirrel Cage Motors

Primary voltage dip = 0.9 + 4.2 = 5.1 volts on 120-volt base

Percent primary dip = (100)(5.1)/120 = 4.25%

Total voltage dip = 16.1 volts on 120-volt base

Percent total dip = (100)(16.1)/120 = 13.4%

APPENDIX V. VOLTAGE DIP ESTIMATING CHARTS—THREE-PHASE SQUIRREL CAGE MOTOR ON V-PHASE BANK

The following two charts may be used to estimate voltage dip in substations and 7.2/12.5-kV distribution lines due to across-the-line starting of three-phase, 230-volt motors on open wye-open delta distribution banks. The charts are based on:

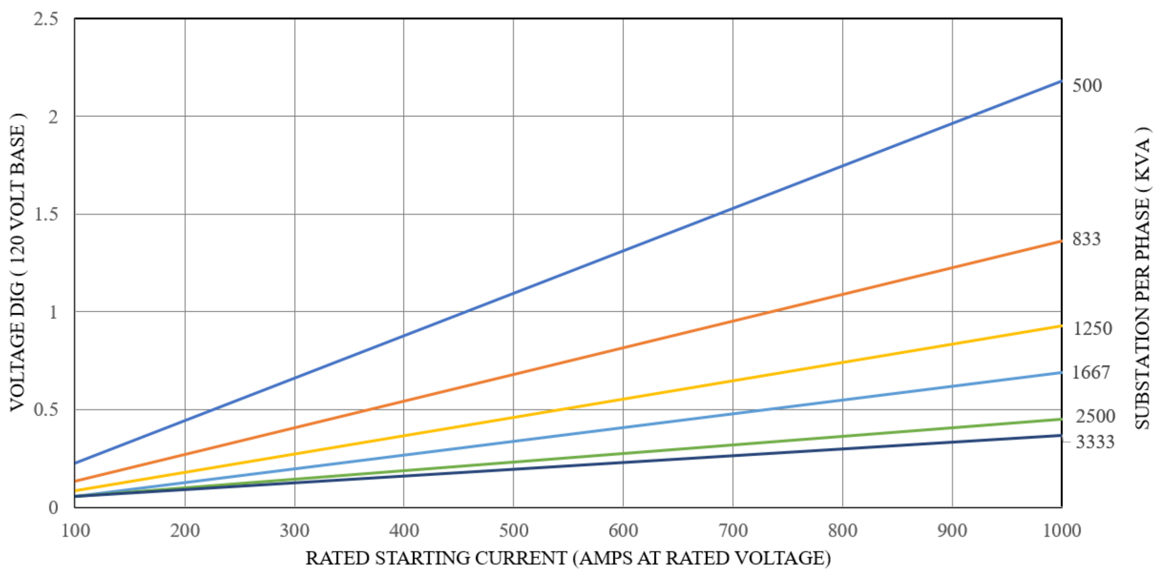
1. Substation transformer impedance of 7%.
2. Distribution line impedance typical of RUS Construction.
3. Motor starting power factor of 0.5 (generally applicable to squirrel cage motors rated less than 25 hp).

It will be noted that only the primary voltage dip can be estimated with these charts. It is this dip, however, that is most important since it will be seen by other consumers on the distribution line. The number of variables makes it impractical to show transformer and secondary voltage dip in graphic form for V-phase banks.

The procedure for using these charts is the same as that outlined for single-phase motors in Appendix I.

The charts may also be used for 460-volt motors. In this case, the results obtained from the charts must be multiplied by two. Also, Chart V-B may be used for 14.4/24.9-kV lines. In this case, the voltage dip will be one-fourth of that indicated for 7.2/12.5-kV lines

CHART V-A SUBSTATION TRANSFORMER VOLTAGE DIP VS. STARTING CURRENT



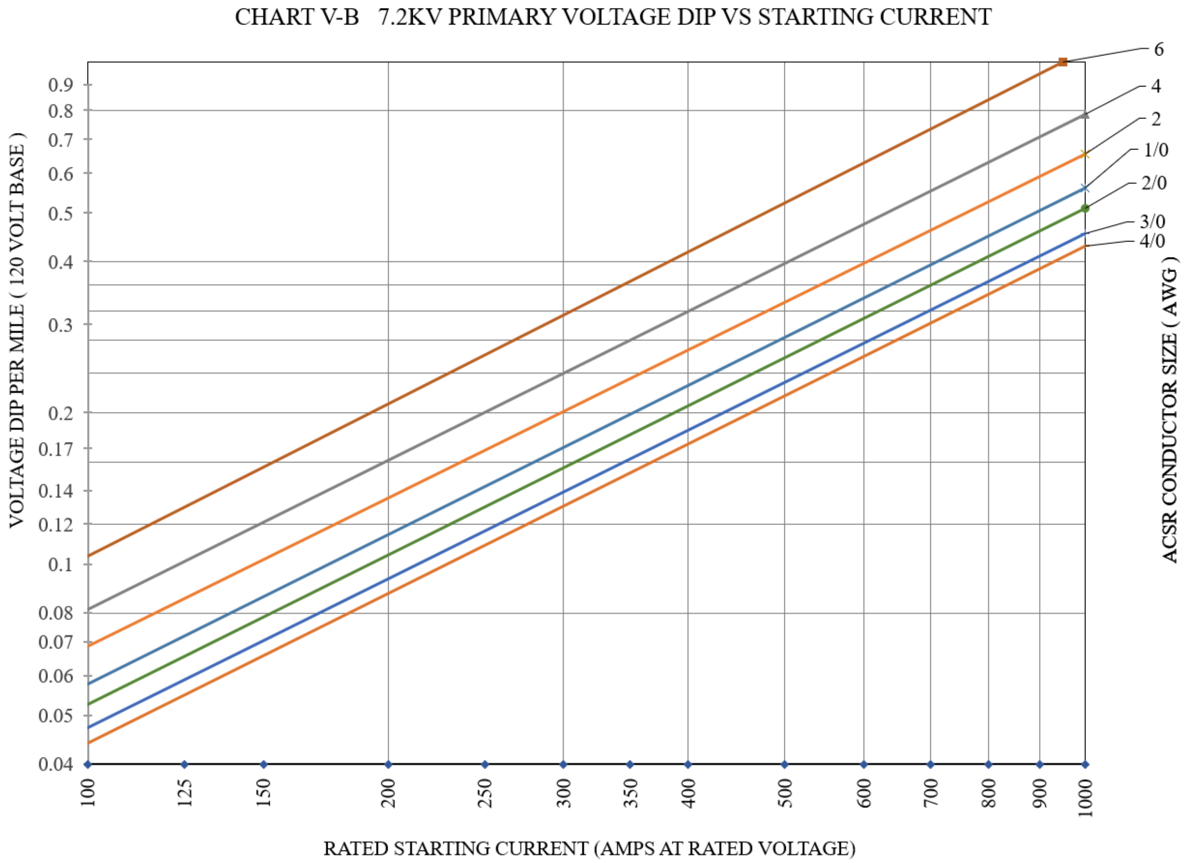


CHART V-B 7.2KV PRIMARY VOLTAGE DIP VS STARTING CURRENT
VOLTAGE DIP PER MILE (120 VOLT BASE)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.17
0.14
0.12
0.1
0.08
0.07
0.06
0.05
0.04
100
125
150
200
250
300
350
400
500
600
700
800
900
1000
RATED STARTING CURRENT (AMPS AT RATED VOLTAGE)
6
4
2
1/0
2/0
3/0
4/0
ACSR CONDUCTOR SIZE (AWG)

APPENDIX VI. MISCELLANEOUS ESTIMATING INFORMATION

NEMA CODE LETTER

Starting kVA standards for induction motors have been established by NEMA. On standard motors (many are nonstandard) this is identified by a code letter stamped on the motor nameplate. The following formulae can be used to determine rated starting current when the code letter is known:

$$\text{1-phase motor starting current} = \frac{(1000)\,(hp)\,(\text{Code Letter kVA})}{\text{rated voltage}}$$

$$\text{3-phase motor starting current} = \frac{(1000)\,(hp)\,(\text{Code Letter kVA})}{(1.73)(\text{rated voltage})}$$

Common code letters and corresponding starting kVA per horsepower are:

Code Letter	SkVA/hp
D	4.00–4.40
E	4.50–4.99
F	5.00–5.59
G	5.60–6.29
H	6.30–7.09

LINE IMPEDANCE/RESISTANCE/REACTANCE

Line impedance, resistance, and reactance for standard REA distribution lines may be obtained from the following table.

Line impedance, Z_L, Resistance, and Reactance of REA Lines:					
Conductor Size		Single Phase Ohms per Mile		Three Phase Ohms per Mile	
Cu Equiv.	ACSR	R	X	R	X
4/0		.43	1.04	.278	.633
3/0		.498	1.07	.350	.653

2/0	4/0	.64	1.22	.441	.712
1/0	3/0	.76	1.27	.556	.728
1	2/0	.94	1.37	.702	.742
2	1/0	1.12	1.45	.885	.756
4	2	1.64	1.47	1.41	.780
6	4	2.47	1.46	2.24	.806
8	6	3.72	1.54	3.51	.853

SERVICE TRANSFORMERS PHASE ANGLES

The phase angle of service transformers varies considerably. However, the following approximate values may be used when actual data is not available.

Approximate Angle, θ_T, for Single Phase, 7.2 KV Service Transformers	
Transformer KVA	θ_T
5 and 10	30º = .866 + j.5
15	40º = .766 + j.644
25 and 37.5	45º = .707 +j .707
50 and 75	52.5º = .609 +j .794
100 and 167	60º = .5 +j .866

STARTING POWER FACTOR

The following table lists the approximate starting power factor for three-phase induction motors.

Approximate Starting Power Factor (Cos. θ), and Sin θ For Three Phase Induction Meters		
Motor Hp.	Cos. θ	+ j sin θ
10	.54	.843
15	.50	.866
20	.47	.883
30	.42	.908
50	.38	.925
100	.32	.948
200	.25	.968

SERVICE CONDUCTOR IMPEDANCE

The impedance of the service conductor is given in the following table. The open wire impedance is based on 1-foot spacing.

Impedance, Z, Ohms/1000 Feet of Conductor				
AL	Cu. Equiy.	Open Wire (20ºC.)	Triplex (20º C.)	Quadruplex (20ºC.)
6	8	.6813 + j .194	.6482 + j .03035	.6613 + j .0361
4	6	.4157 + j .140	.4157 + j .02925	.4157 + j .0350
2	4	.2615 + j .1087	.2616 + j .02823	.2616 + j .0336
1	3	.2074 + j .1060	.2074 + j .02784	.2074 + j .0335
1/0	2	.1644 + j .1033	.1644 + j .02588	.1644 + j .0328
2/0	1	.1305 + j .1007	.1305 + j .02541	.1305 + j .0323
3/0	1/0	.1035 + j .09803	.1035 + j .02495	.1035 + j .0317
4/0	2/0	.08213 + j .09536	.08218 + j .02459	.08219 + j .0313
250 MCM	157.2 MCM	.06956 + j .0922		
266.8 MCM	3/0	.06520 + j .09145		
336.4 MCM	4/0	.0518 + j .08877		

REFERENCES

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