PDHonline Course E242 (4 PDH)

Primary Electric Distribution for Industrial Plants

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2020

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Primary Electric Distribution for Industrial Plants

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Course Content

Introduction

My other Course E208, “Electric Power Distribution for Industrial Plants”, is a low voltage system (under 600 volts) suitable for small and medium sized industrial plants with relatively light electrical loads. When a sizable plant expansion program is contemplated, modernization of the existing distribution system would be a necessary preparatory step. Electric load growth and increased wiring distances would encounter voltage drop problems with a low voltage (under 600 volts) system, making it imperative to go to a higher voltage distribution system.

This Course on **Primary Electric Distribution** is concerned with medium voltage levels at 2.4Kv to 15Kv. The text will cover the plant electrical system with respect to design, reliability, safety and voltage selection. Initially, the course was initially sponsored by West Penn Power Company for industry personnel. The course now has been modified to meet current requirements of National Electric Code (NEC) and is designed especially for Engineers, Inspectors and others concerned with electric power distribution for industrial plants.

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An industrial plant operation to be good requires a safe and reliable electrical power distribution system. Otherwise production suffers. In growing operations where new processes, equipment and new buildings are expanded, the electric load invariably increases so that sooner or later circuits become overloaded. Wires may overheat causing insulation deterioration resulting in short circuits. Then, fuses blow or breakers trip causing the factory to shut-down. Stop-gap emergency measures taken to get production rolling may cause breakers and switches to be patched or oversized, heedless of the fact that conductors are overheating and insulation deteriorating. Ground faults occur and production again must wait until repairs are made. Finally, the voltage drop on overextended circuits results in poor voltage regulation causing motors to burnout. The tangled electrical distribution system has gotten a strangle hold on the operation. Needless to say that something must be done to restore adequate wiring so that the plant can enjoy the flexibility and reliability not possible otherwise.

Selection of Proper Plant Voltages

Advantage should be taken of decreased circuit investment, lower electrical losses, and better voltage regulation by carrying power as close to actual loads as possible at relatively higher voltages.

When low-voltage feeder lengths are short so that voltage drops are not excessive and when foreseeable loads do not exceed approximately 1,000 Kva at 480 V(1200 Amps) or 500 Kva at 240 V (1200amps), the system can be supplied direct from the power company service. However, 240 V is not desirable as indicated below.

240 Volts Versus 480 Volts

Probably the two most common secondary voltages to compare are 240 and 480. A majority of smaller industries and larger plants with small or medium size motor loads can utilize either 240 or 480 systems.

The economics favor selecting a 480 V system over a 240 V system in a typical plant. Motor costs are the same, however, starters and wiring favor the 480 V system. This indicates that a 480 V system is the most economical system to select in case of low-voltage distribution. A 600 V system would probably show a greater economy. However, 550 or 575 V equipment is not as readily available as 480 V, thus it is seldom used except in certain industries. As a result, equipment manufacturers have standardized more on 480 V.

Shifting from 240 Volts to a 480-Volt System

Some plants now with 240 V systems are faced with the question of shifting to 480 V. Before converting or modernizing a system, consideration should be given to existing and obsolete equipment, plant processes, and possible expansion. A study may indicate changing only a portion of a plant to 480 V while maintaining 240 V until such time as the conversion can take place. In this case, the 240 V. equipment can be supplied through step-down transformers. (This is especially true where primary distribution is involved.)

If the 240 V motors are recent, they are re-connectable for 440 V. In general, motor starters can be converted by the installation of new thermal trips and new operating coils on the contactor as long as the horsepower rating is unchanged.

Shifting to 480 V is a good time to replace overloaded motors and to change the under-loaded motors which contribute to poor system power factor.

If the plant has 120 V lighting, then, 4/1 transformers would be required. If the lighting were 240 V then a decision would have to be made whether to use 2/1 transformers or the center tap of the 480 V power transformer.

Heating loads create another problem. Sometimes 240 V heating elements can be placed in series for 480 V. Otherwise, 2/1 step-down transformers are required.

Conductors, safety switches, and breakers can utilize 480 V without change and it will be possible to carry twice the load thus permitting expansions at no additional costs. This saving will help offset a portion of the motor control cost.

The major reason for converting to the 480 V is to reduce future costs of equipment such as unit substations, controls, wiring, and improved voltage regulation at minimum cost.

Voltage Regulation

Industrial distribution systems and utilization equipment are designed on the basis of a nominally constant voltage. Lamps, motors, and heating equipment are designed to give the most economical combination of characteristics at rated voltage which is the voltage nominally provided by the distribution system. See Table #1. Voltage variation affects various equipment differently:

1. Induction Motors

The most significant effects of low voltage are reduction in starting torque and increased full load temperature rise. The most significant effects of high voltage are increased torque, increased starting current, and decreased power factor. The increased torque may cause couplings to shear off or damage driven equipment. Increased starting current causes greater voltage dip and increases light flicker.

2. Synchronous Motors

The effect of voltage variation on the performance of synchronous motors is similar to that on induction motors. However, while the starting torque varies as the square of the voltage, maximum or pull-out torque varies directly with the voltage.

3. Incandescent Lamps

A 10% reduction in incandescent lamp voltage results in a 30% reduction in light output. In other words, when the voltage is 10% low, 30% of the investment in the lighting system is lost. With an over-voltage of 10%, lamp life is reduced to less than one-third.

4. Fluorescent and Mercury Lamps

Fluorescent and mercury lamps operate satisfactorily over a rather wide voltage spread. In general, 10% variation in line voltage changes light output only about 10%. The life of these lamps is affected less by circuit voltage variation than incandescent lamps.

5. Heating Devices

Output of heating devices varies with the square of the voltage. Thus, a 10% reduction in voltage means a 19% reduction in heat.

6. Electronic Equipment

For satisfactory service, it is important that the voltage be kept near the rating of electronic devices. In many cases, this necessitates a regulated power source such as a regulating transformer having constant output voltage.

7. Capacitors

The kilovar output of capacitors, like heating devices, varies with the square of the voltage.

8. Solenoid Operated Devices

The pull of alternating current solenoids varies approximately with the square of the voltage. However, solenoids are designed liberally and can operate satisfactorily on 10% over-voltage and 15% under-voltage.

9. Light Flicker

The effect of sudden changes in voltage repeated at short intervals is termed “light flicker”, and flicker may be an annoying problem. It is caused primarily by resistance welders, arc furnaces, and fluctuating motor loads.

Fluorescent lamps are less subject to flicker during voltage changes than incandescent lamps, provided that the lower limit of voltage remains above the value at which the fluorescent lamps will be extinguished.

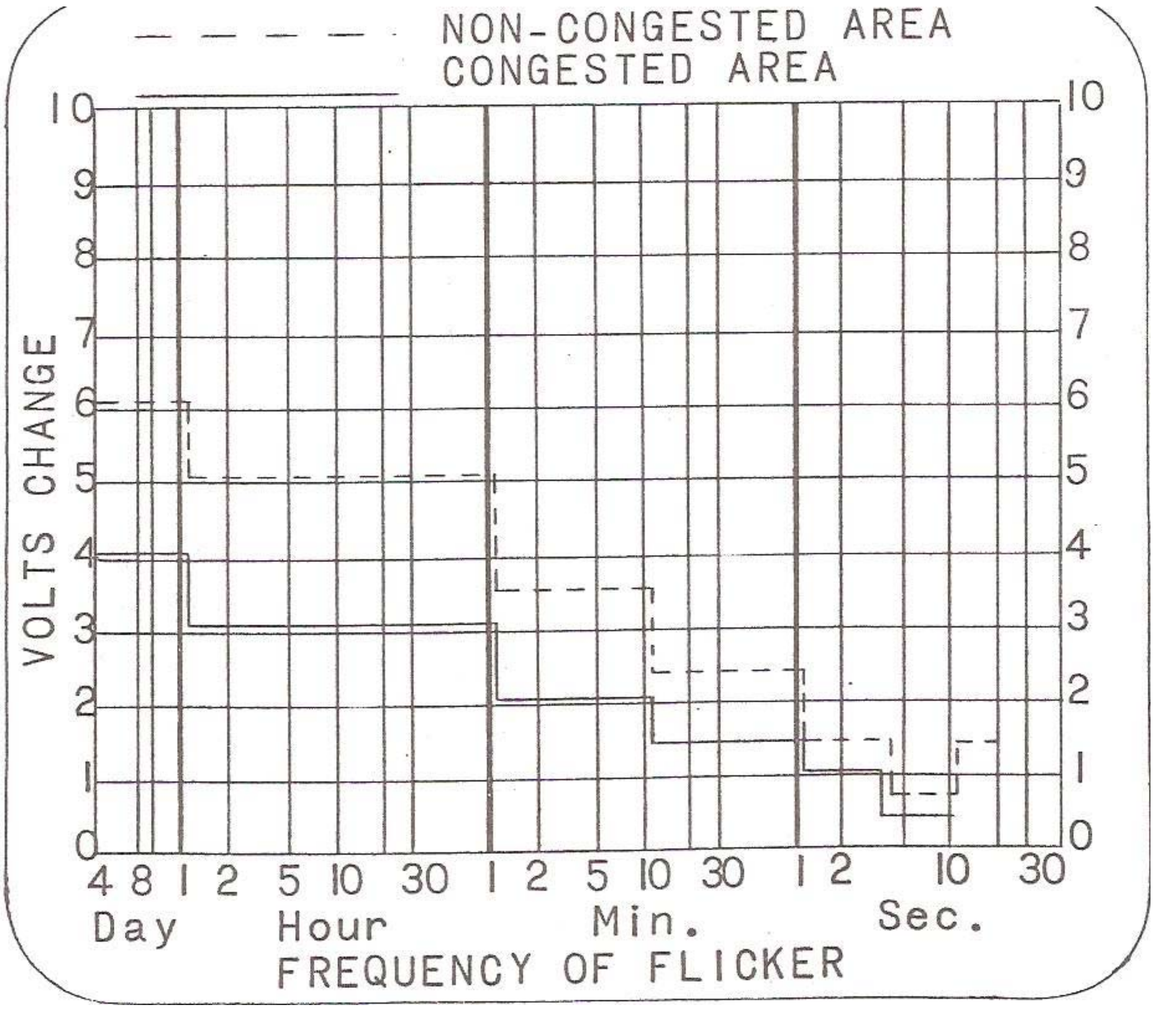

Figure 1

To eliminate objectionable light flicker, the design of the system should be such that the voltage variation of Figure 1 is adhered to.

Methods of Reducing Voltage Drop

* Steady Loads

The first consideration of voltage drop is with steady loads where certain fixed methods can be applied to reduce these voltage drops. Since drop is affected by current and impedance, the following suggestions may tend to reduce the drop:

1. Used closely spaced conductors. For instance, use cable instead of widely separated single conductors.

2. Use low voltage bus-way or multi-bar interleaved construction.

3. In some cases, two smaller cables in parallel may have lower impedance than one large cable.

4. Keep low voltage feeder lengths as short as possible.

5. Change circuits to higher voltage.

6. Improve the operating power factor of a circuit.

7. Change transformer taps and use lower impedance transformers.

* Fluctuating Loads

One way to reduce light flicker is to install a separate service for the flicker producing load. This is the normal way to handle arc furnaces which are normally placed on a separate primary circuit. However, even when impedances and currents have been kept to a minimum, and where voltage feeders are as short as possible, and it still is not possible to achieve the required voltage, voltage regulation equipment may be necessary. For example, a voltage regulator would be appropriate when the voltage on a feeder is satisfactory for most equipment such as motors, but not satisfactory for electronic equipment such as an IBM machine. In that case, a voltage stabilizing transformer may be placed on the circuit serving the electronic equipment.

Voltage Drop Calculations

One method of calculating drop in a conductor was covered in Course #208, “Electric Power Distribution for Industrial Plants”. There are also charts and tables available which give the voltage drop for a given conductor.

A second consideration for steady load is the drop through transformers. As a general rule of thumb, the voltage drop of 3% can be used for the average secondary transformer. The actual voltage drop varies with the power factor as shown in Figure 2. Accurate figures on a particular transformer can be obtained from the manufacturer.

Voltage drops created by fluctuating loads such as motors, welders, and arc furnaces occur in both the conductor and transformer. The conductor drop is calculated by using the formula: $E = IZ$, where “I” is the starting current of the motor and “Z” is the impedance of the circuit.

Power Factor Improvement

Power factor is very important for efficient operation of electrical systems and a high power factor is best. The ratio of actual power (watts) to apparent power (volt-amperes) expressed as a percentage determines the power factor.

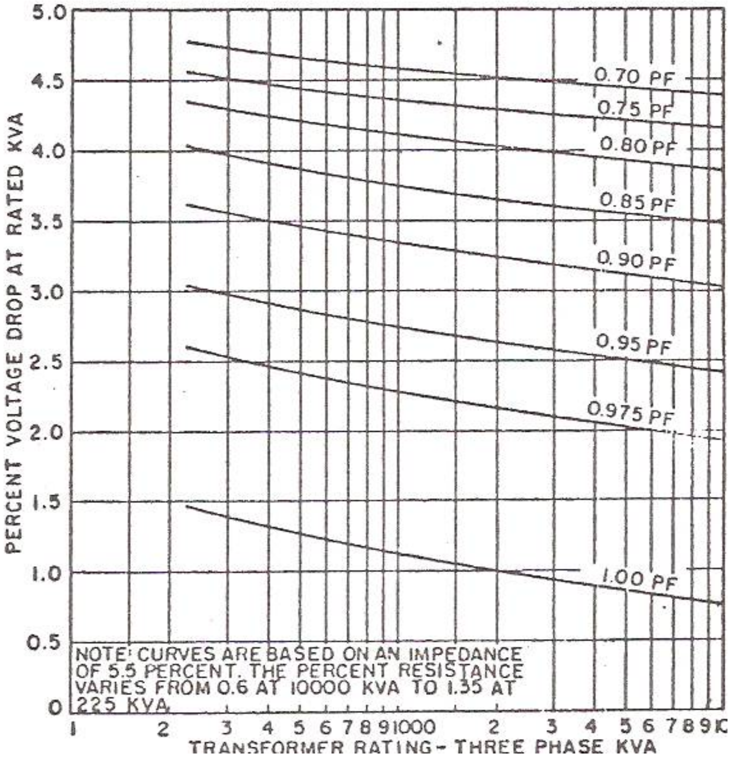

Figure 2

System power factor improvement may be obtained by installing equipment that operates at unity power factor or installing devices which supply leading current to the system. One method commonly used for supplying leading current, as described in Course #208, is the installation of capacitors. Capacitors can be applied at various points throughout the system. The most effective location is at the motor or point of use. Installing capacitors at a central location may lead to over-voltage when the load drops and should be guarded against.

The capacitor is a device without moving parts and has the property of supplying magnetizing current to the load. Efficiency of capacitors is high, having losses less than one-half of 1 % of their Kva rating.

ystem Planning

The determination of the voltage level and the power wiring layout comes under the subject called System Planning. The planning should include how the basic components should be supplied with power and how they should be tied together.

During the past 50 years, industry has experienced a tremendous advance in process and production methods which make liberal use of electrical and electronic equipment. Too often it is not recognized that the more complex production machinery requires a more reliable power system.

Determination of Load

To properly plan and design a plant power distribution system, a close estimate of the location and magnitude of the electrical load is very necessary. The magnitude of the load includes not only an estimate of the electrical size of the individual loads, but also the load growth, as well as information about the diversity factors for the various loads and groups of loads. Correct use of the proper factors will enable one to work back from the connected loads through all of the load centers to the main supply.

Load Estimating

In new installations, the task of load estimating is one of making an estimate of the loads from what little information is available on the proposed plant and of supplementing this with data from similar existing plants. General data on similar plants can be obtained from discussions with personnel of those plants. Another good source of information is the Power Engineer from the local electric utility.

Estimating Lighting Loads

The lighting load may be roughly estimated by considering two factors-- intensity of the illumination desired, and the type of lighting, id. est. whether it is incandescent, mercury, or fluorescent. If the lighting system is to be incandescent, 1 va per sq.ft gives about 10 FC. When using mercury or fluorescent lamps 1 va per sq ft gives about 20 FC. For more accurate figures a lighting layout should be made. For outdoor lighting, an allowance of 10% of the indoor lighting should be more than sufficient.

Lighting requirements vary greatly by industry. Table 2 shows how the foot-candle level changes with the seeing task involved. After estimating the lighting load, the effect of this load on the distribution system must be determined. This is done by applying the diversity factor, 80%, for lighting loads unless it is known that all the lights are on at one time, such as in an office.

Estimating Air Conditioning Loads

The cooling requirements for any space depends on the building exposure, amount of insulation, and the internal heat load—such as lights, people and power equipment. For normal conditions, a rough rule would be 400 sq ft of floor space/ton of cooling. Small air cooled units have a power requirement of 1.5 Kva/ton and larger units would be lower. In order to compensate for high levels of lighting and for motor and heat loads, add 0.4 Kva to the air conditioning for each additional Kw of such load.

Estimating Power Load

Major components such as large motors or furnaces exert the maximum influence on the power demand and are often decided early in the preliminary stages of planning.

As a "rule of thumb" for large induction motors and for .8 power factor synchronous motors, the Kva demand may be considered to be the same as the horsepower rating; for unity power factor synchronous motors, use a Kva demand of .8 times the horsepower rating. Quite often larger machines will operate alternately rather than together. So, it is important to consider diversity factors to prevent over-designing the system. Table 3 shows some representative load densities for different types of industries. The figures are average for a number of plants and should be used for preliminary estimating only since there could be a fairly wide variation.

Table 4 may help you estimate the power requirements of a new industrial plant. This shows the kilowatt-hours used per unit of product and again is the general average of many plants making the same product. Because this is an average, the figures should be used for rough estimating or checking only.

The tables are for preliminary or rough estimating only. To get a more accurate figure, work from the actual loads. After the loads of individual machines have been determined, apply the diversity factors for this equipment to get a total demand on the feeders. Include, of course, the 50% growth factor to size the feeders. (See Course #208)

These feeder demands, including growth, are then combined to give the substation size by using the diversity factor (100%) for multiple feeders. Normally, individual substations are then combined using a diversity factor of 90% to determine the main substation.

As an example, let's consider a plant having fours feeders loaded similarly. The connected load, including growth for four feeders, is 1350 Kva. After applying the load diversity factors (from Table 5), the sum of the feeder sizes is 1000 Kva. Assuming a diversity factor of 100% for multiple feeders, the substation size then is 1000 Kva. However, the demand meter might show only 600 Kva, so there would actually be a diversity factor of 60 % (600/1000). This is because we have allowed for growth in sizing our equipment.

Using the diversity factor between substations of 90%, the size of the main substation would be 3600 Kva (4000 Kva x 90%). A main substation of 3750 Kva would probably be selected because this is the next standard size.

If the 50% growth were not expected for 5 years or more, it could be eliminated when sizing the main transformer. In this case 3600 Kva divided by 1.5 equals 2400 Kva. A 2500 Kva transformer would then be selected. This size could handle the near-term growth as outdoor transformers can be overloaded.

The decision to reduce the size of the main transformer depends on the load growth and the economics of each installation. However, the 1000 Kva indoor unit substation should still be sized for load growth.

Selection of Primary Voltage

The medium primary voltages contemplated in this Course are in the range of 2.4 Kv to 15 Kv. In choosing a system voltage, a plant's electrical growth should be considered, as today's 10,000 Kva plant may be 15,000 Kva, 20,000 Kva or more in a few years.

Primary voltages, like low voltages, have nominal ratings for both system and equipment ratings as shown in Table 6. The selection of primary voltages depends on:

1. Voltage Supply from the utility company.
2. The total plant load.
3. Distance power must be transmitted.
4. Voltage of large motors and or other equipment.

If the incoming supply voltage is greater than 15,000 volts, it is normally economically and technically desirable to step this voltage down in a transformer station to a lower voltage for primary distribution within the plant. However, some industries find that 25 Kv distribution is feasible.

The most popular primary voltages distributed to secondary unit substations for step-down are 4160 and 13,800 volts. Others are 2400, 4800, 6900, 12,000 and 13,200 volts.

It is nearly always less expensive to use a primary voltage higher than 2400 volts and to operate all motors 200 hp and less on 480 volt circuits. Larger motors should be served at the primary voltage.

2.4 Kv Versus 4.16 Kv.

When a plant's supply transformer capacity totals less than about 10,000 Kva, the cost of substations, primary switchgear, and cable feeders tends to favor a primary voltage of 2400 V to 4160 V. Step-down transformer costs are just about the same for both voltages but switchgear cost for 2400 V may be higher depending on the short-circuit duty. A 1200 Amp, 4160 V breaker or cable will serve as much load as a 2000 Amp, 2400 V breaker or cable at less cost.

Motors at 2300 volts are generally cheaper than 4 Kv motor for any size. Motor control prices are just about the same for both voltages. However, the savings in breaker and cable costs may still outweigh the savings in motor costs unless a large number of motors are involved.

Generally, the 4160 V system will have a lower cost with greater expansibility than the 2400 V system.

4.16 Kv to 13.8 Kv

Between 10,000 and 20,000 Kva, either 4160 or 13,800 volts might be more economical. However, unless the load is concentrated, it usually is desirable to go to 13,800 V. In this load range, 13.8 Kv substations cost less than 4160 V. The 13.8 Kv metal-clad switchgear is available in higher interrupting ratings that 4160 V switchgear. Also, 13.8 Kv may reduce the number of circuits required and, therefore, very appreciably reduce the system cost.

The intermediate step of 6900 V could have been selected if a portion of the plant equipment were rated at 6900 V. Motor costs at 6600 V are less than at 13.2 KV. Transformer costs are about the same for either voltage while switchgear and cable costs are higher at 6900 V. In general, 6900 V and 13.8 Kv systems will have approximately the same costs. However, “when in doubt, choose the higher voltage” is a cardinal rule for selecting voltages.

Plants with loads greater than 20,000 Kva should use 13.8 Kv. The savings in switchgear and cable will more than offset the extra costs of motors and controls plus step-down substations.

Factors in Selecting a Distribution System

One standard distribution system is not adaptable to all industrial plants. Each plant is different, load requirements are never the same. For this reason, we must have some method of evaluation which we can follow when choosing the best system for any one case. Here is a check list for evaluation of a system:-

1. **Safety**: Never make a compromise where safety is concerned. When good equipment is properly installed, safety to personnel, building and equipment is inherent.

2. **Reliability:** The degree of reliability which must be designed into the system is dependent upon the type of manufacturing or process operation of the plant.

3. **First Cost:** While first cost is important, it is often minimized if the system is reliable and the operation is satisfactory. Cost should not be the determining factor in the plant wiring design since the actual distribution cost represents only from 2 to 10% of the plant investment.

4. **System Voltage and Voltage Regulation**: Use the proper system voltage for the distances and equipment involved. The uniformity of voltage throughout the system is also becoming increasingly important due to the increase in automatic and electronic equipment.

5. **Operating and Maintenance Cost**: In a well-designed system with proper equipment, emergency maintenance will be reduced to a minimum. Accessibility for inspection and repair should be carefully considered. Keep the system simple so that the electricians have an easier job when and if trouble does occur.

6. **Flexibility**: Make certain when the system is chosen that plant voltages, rating of equipment available, space for additional equipment, and capacity for increased loads are considered. Another important factor to consider is the ability of the system to accommodate changes of load within the plant.

7. **Influence of Building Construction on Design**: Remember that the design of the building plays an important part in the choosing of a distribution system. Is it an office building? -- multi-storied? -- single floor? -- plant with high bay?

Now, let's see just what systems are available and how some of the foregoing factors apply.

Circuit Arrangements

Of the many possible circuit arrangements, five major types will be considered:

1. Radial

In the simple radial system, one primary feeder and one transformer bank for each secondary bus is utilized as shown in Figure 4. In the widely-used unit substation distribution type of radial system, power is distributed at primary voltages to substations located close to the centers of electric load. From these substations, the voltage is

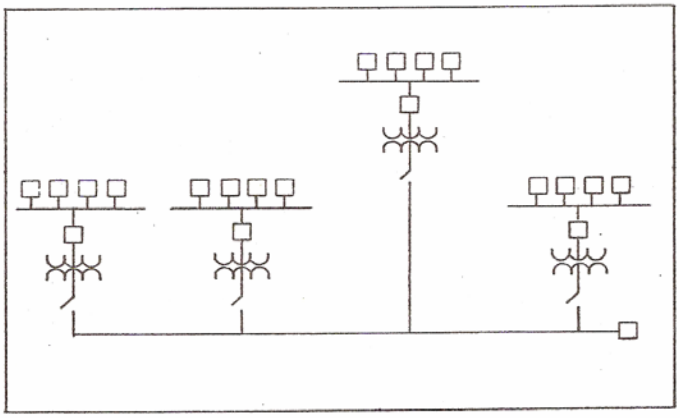

Figure 4

stepped-down to utilization voltages of 600 V or less and delivered by short secondary feeders to points of use.

The radial system has the lowest investment cost of the systems we will discuss, low maintenance and operating cost, and is quite flexible. It makes it easy to add or extend a primary feeder and install another secondary unit substation.

Based on rates of failure, the service reliability of this system is high. For example, if a plant had five dry-type unit substations and one mile of primary cable, we could expect, on the basis of averages, one transformer failure every 500 years and one primary cable failure every 100 years. Somewhat greater reliability can be obtained however, by using two or more feeders to supply the secondary substations. The radial system is basic to the other systems in discussions that follow.

2. Secondary Selective

Second in popularity to the radial system is the Secondary Selective System shown in Figure 5. Essentially, it consists of the simple radial system changed to a secondary selective arrangement by installing a normally open tie between pairs of substations. The tie can be a cable between an extra breaker on each bus of two distant stations or a tie breaker between the buses of two substations “back to back”. A further step for greater selectivity would be the use of two radial systems with one of each pair of substations fed from a different primary circuit.

Because the secondary selective system is in effect two radial systems with a

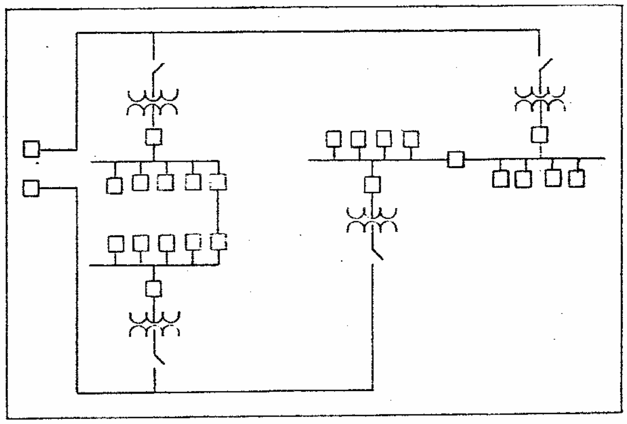

Figure 5

secondary tie between them, it has all the appealing qualities of a radial system: low cost, safety, ease of operation, simplicity, good voltage regulation, and can be cared for by the average electrician. This system permits taking any part of the system, down to the feeder breakers out of service for maintenance or servicing and yet have power available at every secondary bus. Cost is increased about 10 to 30%, depending largely upon the relative substation sizes and locations.

The secondary selective system has been used in about every kind of manufacturing plant and meets exacting requirements of critical processes in chemical plants, paper mills, steel mills, petroleum refineries, and drug manufacturing plants.

The most common way to design a secondary distribution system is to approach it on the basis of sizing the transformer to the load just as in the case of a radial distribution system. This provides little if any reserve transformer capacity for emergency operation except that to care for normal load growth. This approach keeps the system investment to a minimum and yet provides the most basic and important advantage of a secondary selective circuit arrangement, that is to have emergency power available at every important secondary bus from another substation bus through the normally open tie breaker in the event that a transformer or a primary feeder is out of service. If essential load is greater than the usual 25% to 50% of total load, or if it is desired for any other reason, transformer capacity may, of course, be increased over that determined by sizing on a radial system basis.

However, it is important to not parallel the transformers unless the secondary breakers have enough interrupting capacity.

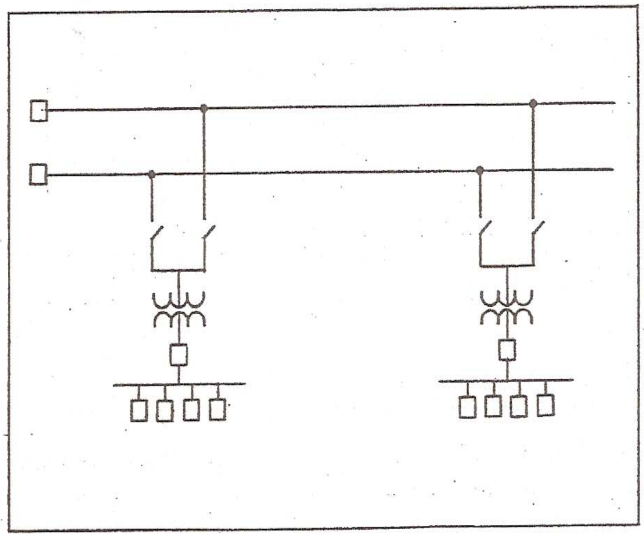

Figure 6

3. Primary Selective

The primary selective system shown in Figure 6 above differs from the radial and the secondary selective arrangements in that two primary feeders are brought to each substation.

It entails additional cost over the radial and secondary selective systems for primary cable and for switching means to select the desired feeder at each substation and to transfer one substation from its existing source to another.

Interrupter switches are normally used in place of more costly circuit breakers for this switching. However, interrupter switches can only break normal load currents up to 600 A. Thus, it would be well to have feeders de-energized before switching to eliminate the hazard of transferring a faulty transformer to an energized feeder.

The sole reason for using a primary selective system instead of a radial or secondary selective load center system is to provide service to the load center substation primary in the event of a primary failure.

4. Looped Primary

If the primary selective system is altered by tieing together the ends of the primary feeders and installing switching means at the substations, we have a looped

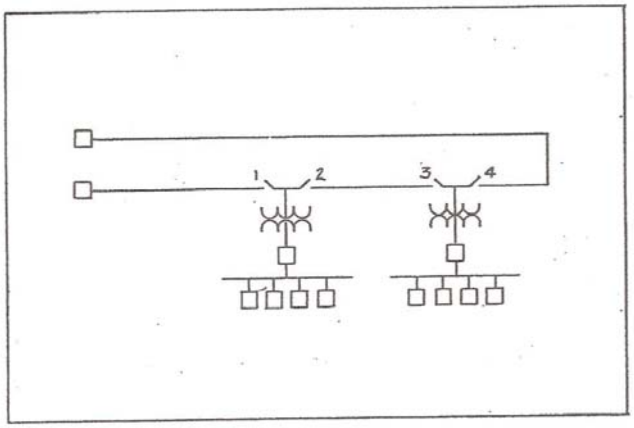

Figure 7

primary system as shown in Figure 7. Sectionalization of the loop requires switching means at the points indicated numerically on the sketch. When low cost interrupter switches are used, reliability and safety are reduced. The only really safe way to sectionalize an energized looped primary is with properly applied power circuit breakers at these points.

The looped primary system is usually relatively expensive when compared to the radial system, but is somewhat lower in cost than a primary selective system due to reduced conductor costs. However, the reliability and flexibility are somewhat greater.

5. Secondary Network

The last but most reliable system presented here is the secondary network as shown in Figure 8. By secondary network, it is meant that all of the secondary substations have their low voltage buses tied together in a loop or network.

The main purpose of having a secondary loop is to provide an alternate supply to any load bus when, for any reason, a primary supply is taken out of service. Other important advantages to a secondary network are:

(1) Less transformer capacity is needed because the load is shared by all transformers on the circuit.

(2) There is a saving in secondary circuit conductors because load buses may be inserted in the loop near the point of maximum loads.

(3) System losses are lower because of the short secondary circuits, just as in a radial system.

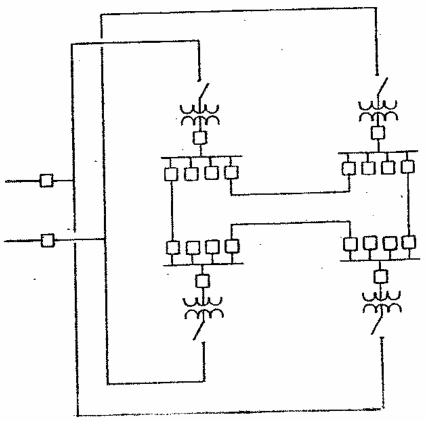

Figure 8

(4) The system provides greater flexibility. After proper study, new or relocated loads may be placed anywhere on a properly installed system.

(5) This is a "stiff" system and voltage drop associated with motor starting and welding may be less.

The secondary network is complicated and therefore more difficult to operate and maintain. It has long runs of secondary conductors to form the interconnections, relatively elaborate protective equipment, and high interrupting ratings. Its cost is relatively high—twice as much as a radial and 25 to 50% higher than a comparable secondary selective system where service continuity is of utmost importance. However, it has a place in industry.

Combinations of these systems are also used, such as a looped primary with a secondary selective or, perhaps one section of a plant may use a radial system and another section the secondary network, for example.

Transformers

In many ways the power transformers for most types of industrial service have similar requirements. This has resulted in standardization of characteristics, so wherever possible, it is suggested that transformers conforming to these standards be specified. Transformers with special ratings or characteristics can be built, but the cost will be higher and the delivery time longer.

Points to Consider in Transformer Selection

1. Kva Rating

The minimum size would be the Kva rating to handle the immediate load required. Of course, consideration should be given to possible future load growth as pointed out previously. This will naturally indicate a transformer size larger than is needed originally. However, where a company has a large number of various size transformers, they may be able to install them with a rating close to the actual load requirements, then change the bank when the load grows.

2. **Voltage Ratings and Ratios**

The transformer should be selected to give the proper voltages at the load terminals. This voltage is the system voltage desired, not the equipment utilization voltage. This allows for voltage drop through the transformer and in various feeders to the point of use. The ratio of the transformer naturally should be such that the secondary voltage may be obtained from the available primary voltage.

3. **Voltage Taps**

Most modern transformers have taps in the windings that make it possible to change the turn ratio slightly. These taps do not materially affect the voltage drop through the transformer, they merely change the voltage level. The standard for the taps in transformers used in industrial systems is to have two 2 ½% taps both above and below rated voltage. Thus, if the voltage at the point of use were too low, the plant voltage level could be raised by using the 2 ½% below tap. Then with 2400 V 2 ½% higher or 494.4 volts.

4. **Type of Construction**

Liquid-filled transformers may be filled with either transformer oil or askarel. This liquid actually performs two separate jobs:- it serves as a heat transfer medium, and serves as insulation. Dry-type transformers are available in either a ventilated or sealed enclosure.

In general, askarel-filled and sealed dry-type transformers are suitable for both indoor and outdoor locations. Oil-filled transformers are suitable only for outdoor locations and may not be used indoors unless located in a fire-proof vault due to the flammability of oil.

Ventilation and atmospheric conditions are important factors in locating ventilated dry-type transformers which are designed for installation in dry locations having a clean, dry, cooling air supply.

Atmospheric conditions are not critical in the location of liquid-filled or sealed dry-type transformers since their core and coils are sealed.

6. **Impedance**

Transformers are generally designed to conform with the following minimum impedance values:

Up to 300 Kva……………………2.0%
300 – 500 Kva……………………4.5%
Over 500 Kva…………………….5.75%

These values are subject to standard tolerances of + or – 7 ½%, and apply to transformers with high voltage windings rated 25 Kv and below. Manufacturers will design transformers to meet your own impedance requirements if the standard values do not fit into your plans, but this naturally adds to the cost. Transformers with low impedance will give less voltage drop, but will also give higher available fault currents.

7. Single Phase or Three Phase Transformers

The recent trend in industry is to use transformers of 3-phase construction rather than using three single phase transformers to make a 3-phase bank. Three-phase transformers have an excellent service record, cost less, and require less space. If three single phase transformers are used, the bank can still operate at reduced capacity in open delta in the event one of the transformers fails.

Switchgear

Metal clad switchgear is an assembly consisting of metal enclosed units and auxiliary compartments. All parts are completely contained within grounded metal enclosures. Secondary control devices and their wiring are isolated from all primary devices by grounded metal barriers or shielding. Major parts of a primary circuit such as circuit breakers, transformers, and braces are also isolated by grounded metal barriers. The circuit breaker is removable and equipped with self-coupling primary and secondary disconnecting contacts. It has a disconnecting mechanism to physically move it between connected and disconnected positions. All buses, connections, joints, and connections to joints are insulated and the stationary structures consist of self-supporting steel frames.

Metal-clad switchgear should not be confused with metal-enclosed switchgear. In this type the switchgear is also enclosed with a protective cabinet but the individual components are not isolated from one another.

Since safety is of prime importance in the selection of any equipment, the use of metal-clad switchgear should be considered any place where there is a group of switches or breakers. All energized parts are completely enclosed and interlocks can be provided so that no compartment can be opened while the enclosed equipment is energized.

Unit Substation

Many transformers used in industrial plants are associated with unit substations. When the substation is indoors the transformers are usually askarel-filled or dry-type, and oil-filled when used outdoors. The unit substation shown in Figure 9 combines the transformer, primary switch or breaker, and secondary switchgear all in one factory assembled integrated unit.

Unit substations are divided into two classifications, primary and secondary types. A primary unit substation is one which has over 1500 volts on the low side. Secondary unit substations have low voltage ratings 600 volts and below. Also, the primary voltage on a secondary station is usually less than 15 Kv.

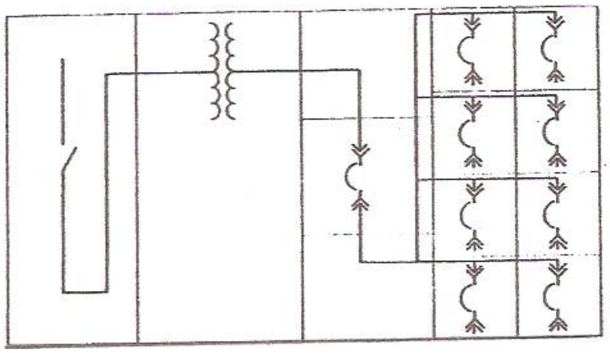

Figure 9

Advantages of Unit Substations

Probably the two biggest advantages of unit type substations over conventional field assembled types are lower installation and engineering costs. Installation is simplified to the extent that it is only necessary to supply a flat foundation for the unit, set the unit in place, and connect the leads. All of the internal wiring has been done by the manufacturer. Engineering time is saved because the manufacturer will coordinate all of the components of the substation, it is not necessary for the engineer to do all the tedious wiring details.

Unit substations can be constructed to be used with any distribution system. The radial type substation is the most common type in use today. The secondary selective type substation has a normally open tie breaker connecting the two buses.

Grounding

Proper grounding at a substation, whether it is the unit type or a field type assembled type, is very important. The object of grounding is to prevent dangerous potentials from existing between non-current carrying metallic objects and between these objects and the earth. Any metallic enclosure that holds wires or cables should be grounded. This includes transformer cases, switch, breaker and regulator cases, bus supporting structures, metal-clad switchgear housings, and the substation fence if there is one. Then all the grounds should be tied together to give the lowest possible ground resistance.

Circuit Arrangement Check List

After you have chosen the distribution system which you feel best accomplishes the solution to your problem it is sound engineering practice to "stand back" and take an overall look at the layout. As you look at the entire system, ask yourself these questions:

(1) Is the system as simple as reliability and flexibility require?

(2) Is working on energized conductors unnecessary?

(3) Will a fault in any location shut down only a portion of the entire system?

(4) Have you designed adequate capacity into the system for emergencies?

(5) Can the system be expanded for future growth?

(6) Is good voltage regulation obtained?

If the answer to all of these questions is yes, then you probably have a very good system. It is then possible to proceed with specifications and detailed design for the job.

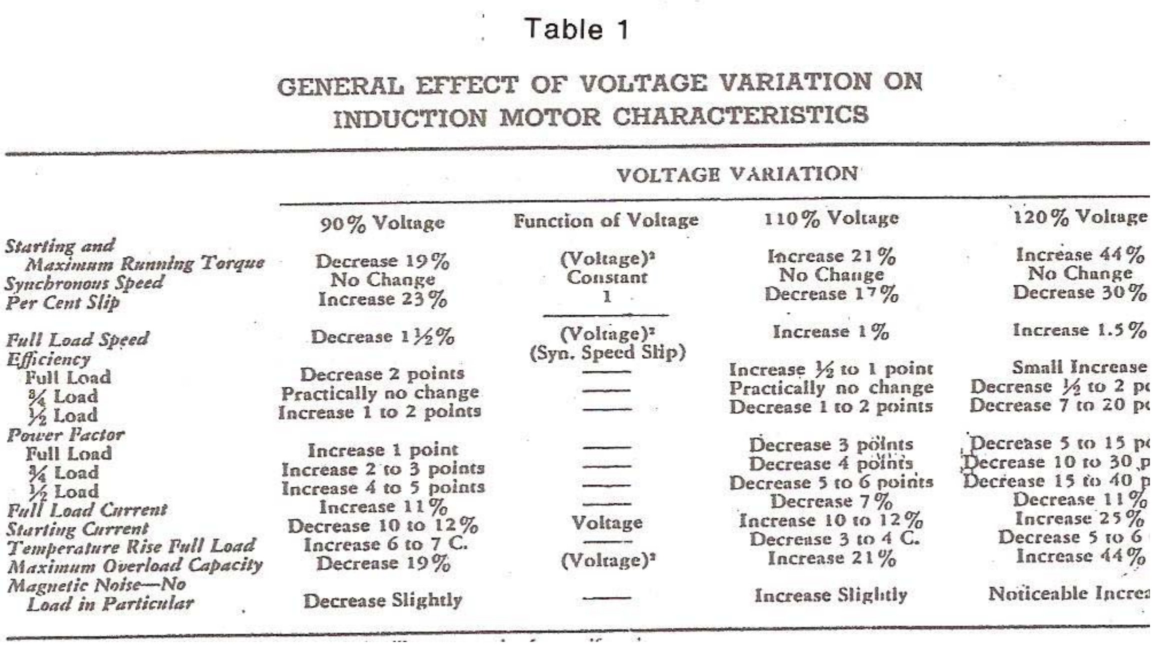

Table 1

GENERAL EFFECT OF VOLTAGE VARIATION ON INDUCTION MOTOR CHARACTERISTICS

	VOLTAGE VARIATION			
	90% Voltage	Function of Voltage	110% Voltage	120% Voltage
Starting and Maximum Running Torque	Decrease 19%	$(\text{Voltage})^2$	Increase 21%	Increase 44%
Synchronous Speed	No Change	Constant	No Change	No Change
Per Cent Slip	Increase 23%	$\frac{1}{(\text{Voltage})^2}$	Decrease 17%	Decrease 30%
Full Load Speed	Decrease 1½%	(Syn. Speed Slip)	Increase 1%	Increase 1.5%
Efficiency				
Full Load	Decrease 2 points	——	Increase ½ to 1 point	Small Increase
¾ Load	Practically no change	——	Practically no change	Decrease ½ to 2 p
½ Load	Increase 1 to 2 points	——	Decrease 1 to 2 points	Decrease 7 to 20 p
Power Factor				
Full Load	Increase 1 point	——	Decrease 3 points	Decrease 5 to 15 p
¾ Load	Increase 2 to 3 points	——	Decrease 4 points	Decrease 10 to 30 p
½ Load	Increase 4 to 5 points	——	Decrease 5 to 6 points	Decrease 15 to 40 p
Full Load Current	Increase 11%	——	Decrease 7%	Decrease 11%
Starting Current	Decrease 10 to 12%	Voltage	Increase 10 to 12%	Increase 25%
Temperature Rise Full Load	Increase 6 to 7 C.	——	Decrease 3 to 4 C.	Decrease 5 to 6
Maximum Overload Capacity	Decrease 19%	$(\text{Voltage})^2$	Increase 21%	Increase 44%
Magnetic Noise—No Load in Particular	Decrease Slightly	——	Increase Slightly	Noticeable Increa

(Note: This Table shows general effects, which will vary somewhat for specific ratings)

Table 2

ESTIMATED LIGHTING LOAD DENSITIES

Office	Foot-candles	Volt-Amp/Ft.^{2} Fluor.	Volt-Amp/Ft.^{2} Inc.
Designing, detailed drafting	200	10	-
Auditing, accounting, rough layout	150	7.5	-
Regular office work, active filing	100	5	10
Conferring, interviewing, washrooms	30	1.5	3
Corridors, elevators, stairways	20	1	2
Factories			
General fabrication and assembly, automatic machining, medium inspection	150	7.5	-
Rough bench and machine work, shearing foundry work, rough inspection	70	3.5	7
Washrooms, storage	30	1.5	3
Finishing and inspecting, engraving, alterations and repairs (tailoring), textile (sewing, grading dark goods), shoe manufacturing, extra fine bench work, toolmaking	1000	50	-
Proofreading, typesetting, machining, sewing (light goods), fine assembly, inspection, fine hand-painting	300	15	-

Table 3

ESTIMATED LOAD DENSITIES IN VARIOUS INDUSTRIES

Manufacturing	Volt-Amp/Ft.^{2}
Chemical	10-15
Electronics, industrial	6-10
Foundry (excluding large electric furnaces)	11-15
Glass	1.5-8.5
Heavy machinery	7-13
Light Machinery	11-15
Metal fabricating and assembly	3-8
Small device, industrial	4.5-10
Textile	12

Table 4

ESTIMATED POWER CONSUMPTION FOR VARIOUS INDUSTRIES

Unit Products	Kw-Hr. FOR EACH.	Unit
Butter	136	1000 lb.
Carpets and Rugs	1480	1000 sq. yd.
Cement	22	Barrel
Coal Preparation	2-5	Ton
Food, frozen	144	1000 lb.
Glass manufacturing		
Container	80-140	Ton
Fiber	500	Ton
Plate	600-1100	Ton
Pressed or blown	120-200	Ton
Window	75-120	Ton
Paper		
Pulp grinding	1850	Ton
Newsprint machine	400	Ton
Boxboard from waste paper	300	Ton
Kraft paper	1000-1100	Ton
Kraft board	600-700	Ton
Book and bond paper	1000	Ton
Refinery	3	Barrel
Rubber and Plastics	2400	Ton
Sewage*	.11	1000 persons (per hr.)
Municipal water pumping*	.36	1000 persons (per hr.)
STEEL	250	TON.

* Maximum demand.

Bulk Products

Bulk Products	Kw-Hr.	Unit
Aluminum	9.0	1 lb.
Electric Steel	0.330	1 lb.
Gasoline	0.0015	1 lb.
Phosphoric Acid (Elect. furnace)	1.80	1 lb.
Sodium	4.70	1 lb.

Process

Motor Drive Requirement

Motor Drive Requirement	Kw-Hr.		Unit
Blast furnaces	10	(pig iron produced)	Ton
Open-hearth	8	(of steel ingots)	Ton
Blooming or Slabbing Mill	20-25	of Product	Ton
Hot-strip Mill	80-90		Ton
Cold-strip Mill	80-100		Ton
Billet Mill	20-30		Ton
Structural and Rail Mills	30-60		Ton
Continuous Pickling	6-7		Ton

Thermal Requirement

Thermal Requirement	Kw-Hr.	Unit
Drawing (600 F.)	57-100	Ton
Galvanizing (850 F.)	91-133	Ton
Annealing (1500 F.)	182-286	Ton
Enameling Cast Iron (1350 F.)	182-333	Ton
Carburizing (1650 F.)	333-500	Ton

Table 5

Diversity Factors

Motors General Purpose	30%
Motors Semi-continuous Processes	60%
Motors Continuous Operations	90%
Resistance Heating	80%
Induction Furnaces	80%
Arc Furnaces	100%
Lighting	80%
Arc Welders	30%
Resistance Welders	20%

Table 6

MEDIUM VOLTAGE RATINGS

Nominal System Voltage	Other Designations of Identical Systems	No-Load Transformer Secondary Rated Voltage	Motors and Control	Capacitors
2400 Wye/Delta	2200, 2300, 2500	2400	2300	2400
4160 Wye	4000	4160	4000	4160
4800 Delta	4600	4800	4600	4800
6900 Delta	6600, 7200	6900	6600	6640
8320 Wye	-	8320	-	7960
12000 Wye/Delta	11000, 11500, 12470	12000	11000	12470
13800 Wye	13200	13800	13200	13800