EY-E - Electrical Substation and Switchyard Design

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Short Description

This manual demystifies the concepts of earthing/grounding as applicable to utility networks and industrial plant distribution systems as well as their associated control equipment. It contains sections on system earthing/grounding, protective earthing/grounding and surge/noise protection of power and electronics systems normally found in distribution networks.

A brief introduction to the design of substation earthing/grounding has been included. Detailed information on ground electrodes and measurement of earth/ground resistance is also available.

Description

Power distribution system needs to be planned with care. In any modern industry, the power system is an essential facility that keeps the industrial process functioning. It should be planned considering the need for trouble free service under various conditions the normal and not-so- normal. In this chapter we will discuss the different aspects of planning power distribution systems.

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First Chapter

Distribution System Planning

Power distribution system needs to be planned with care. In any modern industry, the power system is an essential facility that keeps the industrial process functioning. It should be planned considering the need for trouble free service under various conditions the normal and not-so- normal. In this chapter we will discuss the different aspects of planning power distribution systems

Learning objectives

- System planning-Why is it needed
- Approach to planning
- Data for planning and collection of data
- Planning process
- Studies needed
- Software packages and their use

1 The need for system planning

Power distribution systems form a significant portion of the capital investment in any industry and can vary between 7 to 15% of the total investment depending upon the type of industry. Operation and maintenance of a power system also entails significant costs. In order to make the industry profitable, it is necessary to plan the power system in such a way as to obtain the least total cost of ownership. This does not mean selecting/configuring systems with the lowest initial cost, but also consider the cost of operation, maintenance/upgrades and decommissioning the system. To give an example, the initial cost of certain piece equipment, say a transformer may seem lower in comparison to competition. However, the losses in the transformer may be high and when considered over the entire life time of the transformer can result in significantly higher cost of ownership. Another example may be that of a lower cost distribution system with no redundancy provisions, as discussed in the earlier chapter. A single failure in such a system may result in a significant loss of production which will offset the initial cost savings many times over.

Another aspect of planning is the need to design a system with optimum performance. While ensuring continuity of supply by appropriate redundancy is one of the major factors in system planning, the need to optimize the system losses, ensuring proper power quality and obtaining trouble free operation by correct selection and sizing of equipment based on environmental conditions are key factors which ensure lower ownership costs. For example, the performance of equipment and their life depend to a great extent on the quality of power. Variations in voltage beyond permissible limits and presence of significant harmonic voltage/current in a system can affect the equipment output and result in excessive temperatures and reduced insulation life. In some cases this can cause unscheduled interruptions and thus disrupt production. These have a direct bearing on the operation and maintenance costs.

Correct selection of equipment to withstand environmental factors such as high ambient temperature and humidity, harsh chemicals or conductive dust and variations of power supply parameters is thus an important consideration in system planning. Where environmental issues of power continuity or quality cannot be met by equipment design/sizing, a planner may also need to include equipment to bring the errant variables within acceptable range, examples being voltage regulation systems, uninterrupted power supplies, harmonic filters, etc. These not only apply to new systems but also those where modifications and addition of equipment are being planned.

2. Approach to system planning

Let us take the example of a new industrial facility and discuss as to how the power distribution system of such a facility will be planned. The basic approach can be summarized in the following essential steps:

- Collection of field level data
- Projection of future growth
- Analyzing the data for optimized location of key assets
- Decisions on basic system parameters
- Decisions regarding distribution configuration
- Finalizing equipment ratings/sizing
- Selection of appropriate equipment with proper maintainability and expandability We will discuss these steps in detail in the ensuing sections.

3 Data collection

This is the first step in planning any power distribution system and any incorrect data introduced at this stage will have serious consequences later which may be difficult, expensive and sometimes even impossible to correct. Also, the data collection approaches adopted for power system in an industry and in a utility system are somewhat different. We will discuss this in detail here.

1 Industrial system

Planning the power distribution system in an industry has to start with assessing the overall energy requirement and power demand. This can be computed by a planner based on industry information. Many industries have definite energy consumption norms in the form of specific energy consumption figures (kWh per unit output). While these form a good starting point, there is a need for tuning this information for a specific facility since each may have certain typical variations from typical figures depending on the process used even though the end product would be the same. For example, the electricity usage of an electrical arc furnace steel making facility (quantitatively and qualitatively) will be significantly different from a facility which uses a converter process. The energy requirement per unit of production and the production rate and knowledge of demand fluctuations (which can be very significant in some cases) will be adequate to freeze the capacity of major equipment and also form the basis of the contract to be entered into with the power utility.

This however is only an initial exercise before the facility is fully defined. As the processes and details of the equipment become clearly defined, a detailed estimation of electrical energy requirements and power demand will be undertaken using equipment/drive lists and their ratings. The initial figures need to be constantly reviewed and adjusted at different stages of the facility progress. The data required to be collected for estimation of energy and power demand are:

- List of connected loads and locations
- Pattern of loading (variations due to process requirements)
- Assessing the load factor, demand factor and diversity factor

- Separating critical loads from non-critical loads
- Loads with unusual demand patterns
- Loads with high harmonic content
- Load with special requirements
- Inclusion of future growth plans in the assessment
- Utility interfacing

From the above it may be noted that a list of loads and a plan showing their locations is the first step in starting a detailed planning exercise. Pattern of loading of different equipment and an entire subsystem will be helpful in the assessment of load factor, demand factor and diversity factor. Application of these factors is critical in fairly accurate estimation of energy requirement and power demand. These factors are defined in IEEE Red book (IEEE Std. 141) as follows:

Load factor: The ratio of the average load over a designated period of time to the peak load occurring in that period.

Demand factor:

The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system, or part of the system, under consideration. The resultant is always 1 or less and can range from 0.8 to 1 to as low as 0.15 to 0.25 for some plants with very low diversity.

Diversity factor:

The ratio of the sum of the individual non-coincident maximum demands of various subdivisions of the system to the maximum demand of the complete system. The diversity factor is always 1 or greater.

Information on these factors is useful in designing electrical systems. For example, the sum of the connected loads on a feeder, multiplied by the demand factor of these loads, will give the maximum demand that the feeder must carry. The sum of the individual maximum demands on the circuits associated with a substation or panel board, divided by the diversity factor of those circuits, will give the maximum demand at the substation or panel and on the circuit supplying it. The sum of the individual maximum demands on the circuits from a transformer, divided by the diversity factor of those circuits, will give the maximum demand on the distribution transformer and will thus decide the transformer rating. Deciding the values of these various factors that need to be used in the planning requires adequate knowledge about the specific industrial process. While existing facilities with similar processes may give an idea of the values to be assumed for planning purposes, any unique feature in the facility under consideration can cause the values to be different. As such, an element of judgment and conservative assumptions become inevitable in planning.

Unusual load behavior including high fluctuations and high harmonic content must be known while planning. Such behavior can adversely affect the rest of the system and sometimes even the nearby external consumers. This knowledge enables corrective equipment to be introduced to minimize such adverse influence. Similarly, any requirements of equipment such as voltage sag/frequency limits or harmonic limits expected must also be known in order to introduce required devices/components such as voltage correctors, emergency standby/uninterruptible power supply, voltage sag support equipment etc. or plan suitable redundancies.

Knowledge of growth plans in the immediate foreseeable future based on corporate planning studies will help in making a realistic system plan in the medium term. This will avoid the need for making major system changes after the facility becomes operational and goes into an expansion mode. Naturally caution needs to be exercised as such planning may give rise to high capital usage and delay in expansion plans may mean under-utilization of system capacity resulting in sub- optimal operation.

Once the complete data has been gathered and analyzed, the necessary interfacing with power supply utilities is the next step. Usually this goes together with planning in order to assess the type of power source point near the new facility, the voltage profile, daily and seasonal variation of voltage etc. This interfacing also gives adequate time for utility planners to examine additional capacity requirements and distribution configurations and synchronize their actions with the commissioning of the new facility.

Also, most facilities require substantial power for construction activities. If this power has to be extended by the power utility, the requirement for the same must be informed so that necessary equipment and power supply lines are established in time for the start of construction activities.

2 Utility System

The data requirements may differ somewhat with utility systems. Often utility systems have existing infrastructure where additional loads may be introduced by demographic changes (such as major commercial ventures, resorts etc., coming up in predominantly residential communities) and new developments in unoccupied green-field areas. Utilities are often privy to information on such changes quite early-on since the planners of such new facilities and developments need to interact with utility agencies to gather data required for their own planning and ensure electricity availability at their facility battery limits. A proactive utility thus needs to do the following on their own initiative:

- Check for new developments
- Make assumptions based on existing consumption patterns
- Assess new load requirements- example, an industry being planned in a community
- Check for any major changes in demographic patterns in the offing
- Assess seasonal change patterns
- Assess possible growth of loads
- Use economic indices for growth planning

These steps will ensure that the utility is in a state of constant preparedness for the demands they are likely to encounter and is in a position to advise and assist the new customers for planning their facilities effectively.

4 Projection of future growth of electricity demand

As discussed in an earlier section, knowledge of expansion plans in the medium-term future (say 5 years) is necessary in order to satisfactorily plan electrical systems. This is because any expansion in the electrical system of a running facility is difficult to carry out and can cause operational inconvenience and even disruption. Also, it may be possible to avoid addition of major equipment by going in for a small additional capacity in the beginning. For example, it may be easier (and often cheaper) to plan for a main incoming transformer of 20% additional capacity initially than adding a transformer of 20% capacity along with the required feeder arrangements and installation requirements later. Another possibility is going in for dual rating equipment (a common example being transformers with enhanced ratings for forced-cooling).

The above approach is ideal in those cases where the slightly higher initial expenditure does not affect the financial viability of the project. If this is not so, or if the facility owners are intent on keeping the initial costs lower, then the next best option may be to design a system which provides facilities for future addition of equipment, though such equipment may actually be purchased and installed at a later date. This may include earmarking feeders, providing additional capacity cables, providing space for installation of new equipment and cabling within existing electrical rooms and cable spaces. In addition, the equipment may be specified with the required provisions for expandability. In other words, the entire planning is done as though the additional equipment is there except that it will actually be purchased and installed at a future date. Doing so reduces the time and effort required to make such additions and also the consequent operational disruption.

Admittedly, such future planning is not an easy exercise, particularly in nascent industries with uncertain growth path or industries with uncertain market projections. In such cases, one must reconcile to planning for the facility on hand and establish future parts of the facility as independent entities with minimum interfaces to the already existing systems.

Location of key assets

In the context of electrical distribution systems, key assets refer to major installations such as plant incoming substation, step-down substations, MV switchboards, load center substations and power generating equipment for emergency/standby power. The general principle is to locate any distribution equipment ideally at the weighted center of the loads fed by it. This is an ideal location

from the electrical point of design and when the assets are placed in such locations, the benefits that accrue are:

- Shorter cable routes for internal power connections, particularly for major loads.
- Power flow in a uniform direction without taking a zigzag route
- Lower electrical losses and smaller cable sizing
- Avoiding excessive voltage drop (as a result of shorter paths, particularly useful for handling peak load currents such as motor starting)

It can thus be seen that correct locations result in reduced capital cost for cabling as well as lower operating expenses by way of lower losses. However a few points need attention.

- The most optimum location is not always the most convenient from access and other necessities and sometimes may call for an alternative solution. One of the considerations while planning a major facility is convenient entry and exit of incoming power lines/cables into the facility without the need to cut across any of the plant facilities. For example, an outdoor switchyard with overhead outgoing lines would require incoming and outgoing overhead lines with clearly demarcated power alleys for routing the lines. For this reason, incoming substations are often located at the periphery of a facility even though this location is not at the weighted-centre of loads.

- When competing for space with production equipment, there is a possibility that the most appropriate location for electrical equipment may pose problems for locating production equipment or for material flow. Here also a compromise often becomes necessary.

- The selected location must allow adequate space for maintenance and removal of equipment. An example:

  - Large transformers need to be moved sometimes for major repairs. As such, their location must be decided in such a way that it is possible to provide an approach road for removal of the transformer.

- Safety aspect must be reviewed while selecting appropriate locations. Locations with harsh or flammable environment may not be suitable even though otherwise ideal from a purely electrical point of view. Examples are:

  - Location of a generating facility using fuel oil must ensure that no unsafe situation will be created by the fuel storage tanks vis-à-vis the other nearby facilities.

  - Mineral oil-filled transformers can constitute a fire hazard. Locations of such transformers deep inside a facility may not be acceptable for this reason. Such transformers are therefore located at the periphery of a facility, though this location is not otherwise ideal.

- The selected location must also offer expandability. Selecting a location where expansion of equipment (additional panels, additional bays in outdoor stations etc.) is difficult may become a serious constraint at a later date when such expansion needs to be planned.

It must be remembered that a location once selected will often be impossible to change at a later date and more so after a facility is completed. Correct selection at the planning stage is therefore absolutely essential and must receive the utmost attention.

Selection of basic system parameters

The next step in the design is to plan the basic system parameters of the power distribution system. The parameters to be selected are:

- Environmental or ambient specification
- Voltage level/s to be adopted in the distribution system and system frequency
- Acceptable variations in power system parameters
- Fault interrupting/withstanding capacity

1 Environment

Environmental specifications will depend mostly on the location of the facility and will form the basis of design of the electrical equipment to be purchased and auxiliary facilities to be established (cabling, earthing, lightning protection, etc.). Temperature and relative humidity are the most important environmental parameters to be determined for the selection of electrical equipment. These are based on data available for the location of the facility from agencies dealing with weather-related information. Similarly the factors related to lightning flash density need to be obtained in order to determine the need and level of lightning protection of facilities.

Presence of dust in the environment, combustible gases and chemical pollutants must also be known. Dust concentration influences the type of insulators to be provided for outdoor equipment (higher levels call for increased creepage distances) and the IP degree of protection to be used for indoor equipment. Presence of combustible gases will determine the type of flameproof enclosures necessary for electrical equipment or alternatively they may have to be moved to areas where such hazard does not exist. Presence of chemicals in the atmosphere will decide the type of surface treatment needed for equipment enclosures. Chemicals present in the soil will determine the type of earth electrodes to be provided.

Another information required is the altitude of the location with reference to sea level. Altitudes higher than 1000m result in lower density of atmospheric air and makes cooling less effective. Thus such equipment will have to be selected with required derating.

2. Voltage and frequency

The next set of parameters to be decided is the voltage and frequency values to be used. Selection of frequency is a straightforward decision and is based on the standard adopted in the country of location. Care is required while using equipment purchased (usually second-hand plant and machinery) from countries where the voltage and frequency standards are different and in extreme cases these may require appropriate conversion equipment to match with the rest of the system.

Selection of voltage is more complex. The incoming equipment must naturally match with the voltage of the external utility system to which the facility needs to be connected. This in turn is decided by the total load anticipated as utilities have their own stipulations and limits of capacity that can be fed to individual consumers at different levels. A typical example is: if the connected load is less than 1 MVA, a system voltage level of 11 kV is acceptable and for 1 to 5 MVA a level of 33 kV is suitable. Beyond this capacity the voltage level must be higher at 100 kV+. These are largely determined by the transformer ratings that are normally manufactured for different primary voltage levels and the utility substation capacities at the busbars of different voltage levels. Such rules may vary from utility to utility.

Utilization voltages are fixed by equipment ratings. A bulk of the loads of most industrial facilities are LV ac motors, the exact voltage value varying from country to country, the standard voltages being 380, 415 or 460V. Again, there are capacity restrictions. LV motors are normally used up to a rating of 250 kW. Larger capacities will call for different voltage values; examples being 150 to 2000 kW at 3.3 kV, 200 to 3200 kW at 6.6 kV and 400 to 20000 KW at 11 kV. You may note that there is a overlap in these ratings, with the minimum and maximum values dependant on design constraints. Selection of voltage levels will call for careful examination of predominant groupings of high capacity drives and there is no single best solution. Other considerations such as standardization, inventories to be kept etc. will also determine the voltage levels to be selected. We had discussed various configurations of systems with multiple voltage levels in the previous chapter.

3 Acceptable variations in power system parameters

Frequency and voltage are closely controlled in utility systems within accepted limits. Normally, variations keep happening depending on system operating conditions and the load drawn by the facility itself but as long as the values stay within limits, there is no need for concern. Abnormal conditions such as a short circuit or earth fault and intermittent incidents such as large motors

starting occur frequently and can cause voltage/frequency excursions beyond the limit values. Equipment, in turn, are designed to withstand reasonable variations in voltage and frequency. In case it is found that the actual variations are likely to exceed equipment design limits, we have the following options:

- Control the extent of variations by configuration changes
- Provide automated interfaces to keep the variations within limits
- Specify equipment for enhanced variation levels

For example, changing of motor ratings (by opting for higher voltage or by providing more no. of smaller capacity drives) can reduce the voltage drop while starting a motor on a weak supply system. Another common method is the use of soft starter or starting variable speed drives for large motors.

Similarly, providing voltage regulators at the interface point may reduce variations to desired values and can be adopted where the external system exhibits large voltage excursions. Providing switchable capacitors or static VAR compensators may reduce voltage fluctuations in certain cases.

Most equipment can withstand a large variation for a small period. Specifying equipment capable of riding over a brief variation may sometimes provide an effective solution. Or, equipment can be specified for satisfactory operation over a wider operating band of voltage and frequency (up to a reasonable limit naturally).

4.1 Fault withstanding capacity

Another important parameter is the fault withstand capacity of equipment. Equipment subjected to high fault currents experience severe thermal and mechanical stresses and must be designed to withstand these effects. Similarly equipment designed to interrupt faults (fuses, circuit breakers, etc.) also have specific upper limits for interruption. Selection of equipment must be done so as to have ratings which are appreciably higher than the actual short circuit currents likely to occur in the circuits where they are installed. Method of evaluation of fault current in systems and their impact on equipment performance will be discussed in detail in a later chapter.

7 Planning of electrical system configuration

Once the basic system parameters have been finalized, the next task is to plan the overall distribution system configuration. This is a very important step and requires the planner to consider all the aspects and arrive at an optimal configuration. In the previous chapter we discussed several ways of ensuring redundancies in distribution system and these discussions offer useful guidance for planning. The configuration once finalized is extremely difficult if not impossible to modify at a later date. At the end of this step we will have finalized the following details:

- Overall configuration
- No. of incoming feeders
- Incoming and distribution voltage level
- Ratings of major equipment
- Redundancy planning
- Type of distribution (Radial, Ring, etc.)
- Type of redundancy including standby generation

- Integration of emergency/standby generation with the distribution system

- System Earthing and protective earthing (Local statutory requirements must be considered as the basis)

- Equipment for voltage/pf/harmonic control

The output of this step is an overall distribution single line schematic for the facility being planned. Some of the details may take several iterations before they can be considered frozen, since data inputs may undergo changes as the design of facility progresses. But a well-conceived system will require minimal changes later on, mostly affecting the ratings and not the basic configuration itself. Some of the configuration issues such as voltage levels, distribution arrangements and redundancy

options were discussed in the previous module and need not be repeated. Other aspects such as standby/emergency generation and integration with the distribution system, earthing options etc. will be discussed in later modules in detail.

Control of voltage is necessary for proper operation of the electrical and electronic equipment fed from the distribution system. Similarly, presence of harmonic-producing loads can create several problems for other connected systems and appropriate corrective measures need to be incorporated in the planning stage. We will discuss the issue of power quality and its impact and how problems arising from power quality incidents can be overcome in a subsequent module. Low power factor of loads results in under utilization of distribution equipment and also increases system losses. This aspect will be touched along with other power quality problems and solutions.

8. Equipment ratings/sizing

Deciding the ratings of distribution equipment is the next stage in system planning. The common ratings required to be finalized at this stage are:

- Rated voltage, current and frequency
- Variations of voltage and frequency
- Fault withstand current and time
- Fault breaking capacity
- Clearance and creepage
- IP ratings of enclosures

All except the nominal current rating of individual equipment will be arrived using the basic system parameters discussed in an earlier section. Permissible variation of voltage and frequency as well as voltage sag tolerance is specific to the equipment and it must be checked whether the limits of variations of the power system match with these individual equipment requirements. Where the expected variations are higher than what the equipment can accept, specific measures will have to be planned such as sag correctors, uninterrupted power supply systems with independent control of frequency and so on. Decision on enclosure IP categories and insulator creepage will depend on ambient conditions of the installation site. It may be worth mentioning that in large facilities, the ambient conditions may all not be uniform everywhere and care will be needed to select the appropriate specifications in each case independently.

Nominal current rating will be arrived at based on the expected maximum continuous load current for the concerned equipment. Care must be taken to compute the maximum load current under the worst case scenario, especially where the distribution system configurations may cause some of the circuits to draw more than usual load current. Abnormal system conditions such as sustained voltage sag (even though within permissible limits) may cause overloading due to higher current drawn by motor loads connected to it. If the ambient conditions (mainly temperature and altitude) at the installation site differ from the rated maximum ambient values of the equipment, derating factors recommended by manufacturers need to be considered while selecting ratings (the rated current will thus be higher than what otherwise would have been necessary). Switchgear and its components are generally manufactured in a few standard ratings and thus the selection would require the use of the next higher available rating to the value the computed after derating. For cables, bus bars, etc., sufficient extra capacity may also have to be considered for accommodating future load growth. Any sustained overload beyond rated current will cause heating of current carrying parts and their temperature will rise beyond values permissible for the insulation materials used. This will cause insulation failures and unscheduled outages. A margin of 10 to 20% is usually considered by planners while making initial selection of ratings and may be fine tuned as the information of the loads become more definitive.

Market availability may sometimes become a constraint for selection and may even cause changes to the planned configuration. Ratings of switchgear, transformers, interrupting capacity of circuit breakers etc. often become limiting factors and dictate the choice or may require additional equipment (such as current limiting reactors) to be introduced in the system.

While equipment sizing is the first step in finalizing the required distribution equipment, there are other factors which play an important role too,

- Cost factor
- Market reputation of the vendors who can supply such equipment
- Experience of other users (internal/external)
- Conformity to standards (national/international)
- Standardisation and variety reduction
- Maintenance requirements
- Status of technology
- Local statutory requirements being met

These factors are self explanatory and there is no need to elaborate all of them. However the following are worth noting:

- Cost comparison must be made on the Total Cost of Ownership (TCO) and not just the initial cost alone.
- Maintenance requirements can often dictate a choice. An example: For overhead distribution lines, use of oil circuit breakers is maintenance intensive and best replaced by vacuum circuit breakers which are virtually maintenance-free.
- Status of technology means considering mature technologies and reject both unproved as well as outdated technologies. Unproved technologies may fail in the market place and quickly become obsolete; the same thing can also happen with equipment whose technologies are on the way out. Distribution equipment will have to operate for a few decades and obsolescence will result in high costs for upgradation/replacement.

- Often local statutory authorities make specific stipulations for electrical installations and these may not be complied by the equipment of some of the manufacturers. This can pose a problem while obtaining approvals for commissioning.

10. Maintainability and expandability

Planning must be done with due regard to maintainability of the equipment in service. Space for maintenance and other requirements must be integrated into the facility while the planning process is going on. Also, equipment such as switchboards may undergo additions or changes during this process. The initial assumptions must be constantly reviewed and necessary changes must be made in the layout to ensure space adequacy. Some of the aspects to be taken care of are as follows.

- Adequate space for all equipment as planned
- Access for maintenance
- Clearances for safety and maintainability
- Removal of parts
- Special tackles used at site
- Buildings to be designed considering expandability

While the requirement of space, maintenance access and clearances are usually obvious, the other points may need careful attention. These may only be known after finalizing the exact equipment as they vary from vendor to vendor. Early discussions after order placement will be required to freeze requirements arising from equipment-specific aspects.

As stated in the previous chapter, any distribution system equipment must be expandable to accommodate changes or additions to the plant process without major changes to the distribution system. Apart from expandability of equipment, other requirements such as space for such additions must also be planned without which equipment expandability alone will not be of much use. Important aspects to be considered as a part of expandability of distribution equipment are:

- Building design loads as a result of additions to switchgear
- Lighting and HVAC system to cater to expansion of distribution equipment.

As stated earlier, the ratings of principal equipment should be selected adequately to accommodate near-term growth of the system.

1.1 System studies needed for planning

While the foregoing sections described the qualitative process of planning a distribution system, detailed calculations are needed to arrive at different system parameters and also to predict the behavior when abnormal conditions occur due to disturbances in the internal distribution system or in the external supply system. System studies start with a model of the power system. A good model should represent the system as accurately as possible and include as much detail as possible of the area to be studied. The rest of the system which is not of interest is usually reduced to the main elements only. For example, while studying a plant electrical distribution system, the internal system is shown in great detail right down to the LV feeders whereas the external utility system which is much larger and complex is reduced to an infinite source with the entire system represented as a single lumped equivalent impedance.

The typical studies needed for planning distribution systems are described briefly below.

1. Load estimation

Load estimation is the first step in the system study and involves calculation of the load currents of the tail-end distribution circuits. For an accurate estimate, it is usual to use recorded data in the case of existing systems or calculate the estimated loads using a combination of techniques and known indices.

2. Load flow

Load flow studies are usually important for mesh networks and help to arrive at the load current (active and reactive) in different branches. Since multiple paths are available, the calculation involves complex numerical methods. Since the system configuration in a mesh network can change continually and affect the load flow, a study will involve the calculations to be repeated for different operating conditions and assess the loads on individual feeders, transformers and busbars for these conditions and size the equipment for the worst case. Radial distribution systems normally used in industries are easier to analyze as the load flow is through a single designated route. Utility systems which use ring and mesh distribution as well as transmission systems which are invariably complex mesh type networks need detailed load flow studies. Such studies help in pinpointing line overload conditions and help to plan configuration changes in the system (by switching in/out some of the lines), load management or generation control to correct abnormal situations. The typical applications evaluate:

- Overloaded cables, overhead lines and transformers
- Voltage drop and regulation
- Tap position control on transformers or switching capacitor banks

Fault level

The current flowing in the system during short circuit faults and earth (ground) faults is an important study. This knowledge is a must for sizing of cables, specifying the interrupting capacity of circuit breakers and fuses, specifying the short time fault withstand capacities of switchgear and for protection setting and coordination. The value of short circuit current depends on the type of fault, location of the fault and supply system conditions (configuration at the time of fault). Value of earth fault current depends on the type of system earthing/neutral impedance, transformer connections in the faulted circuit as well as system impedances from source to fault point. We will discuss the calculation of fault levels in a later chapter in detail. Simple systems lend themselves to manual evaluation of fault currents while complex systems need computer software tools for calculating fault currents. Fault calculations are useful to study cases of:

- Switchgear being overstressed

- Underrated cables
- Switch transformers, lines or cables out to control fault level

4. Voltage profile/transformer tap position

The voltage at any point in a power system keeps changing constantly depending upon the system configuration and loading. The evaluation of the voltage profile at different points (usually buses) in the system is a sequel to the load flow study. With a dynamic system model, it is possible to evaluate the voltage in various buses for any given condition and check whether the calculated values are within the permissible limits. When there are deviations, corrective action may be required in the form of adding compensation capacitors, on-load tap changing of power transformers etc.

5. Motor Starting

Starting of large motors using direct-online method can cause appreciable voltage drop in the system and can interfere with other operating loads. In addition, the reduced voltage available at the motor will result in lower starting torque, particularly in LV systems and prolong the starting period or in extreme cases even failure to start. Care is required when the supply is being obtained from lower capacity standby plant generators as the system has much higher internal impedance in this condition and results in large voltage drops. The studies pertaining to motor starting are helpful in planning proper counter measures such as assisted starting.

6. Harmonic power flow

With increasing use of non-linear loads such as computers, variable speed drives, rectifiers etc. harmonic distortion of supply voltage and circulation of harmonic current in various parts of a distribution network has assumed importance. The effects of harmonic flow can affect circuits/equipment in different parts of a system and not limited to just those in the vicinity of harmonic producing loads. We will discuss in detail the problem of harmonics in alter chapter. A proper study of harmonic power flow helps in planning mitigation measures.

7. Relay coordination

Any distribution network is provided with extensive protective devices to avoid damage to equipment such as motors, transformers, generators and lines. The selection and setting of protective devices is important in order to ensure the basic requirements of sensitivity, selectivity, stability and speed. This is usually an extension of fault level calculation since the knowledge of the fault level at different points in a system is the main input for relay setting and coordination study.

8. Stability and transient performance

When any abnormal condition such as a

fault happens in a system, the stability of the system is affected. The conditions include:

- Lightning on power system
- Switching capacitor banks
- Transient torque pulses on motor shafts

In a system with large generators, synchronous motors and large induction motors, the sudden drop of voltage due to short circuits can lead to unstable conditions due to a sudden change in the torque conditions. This may cause machines to pull out of step and can cause the whole system to collapse. Fast operation of protective devices generally helps in preserving stability. But to evaluate the stability of a system under transient conditions, it is necessary to do a transient stability study. The applications include studies to determine:

- Unstable generators
- Inductors motors that don’t re-accelerate
- Faulty settings on power swing blocking relays
- Transient voltage recovery after dips

9. Arc flash studies (equipment specific)

The dangers of arc flash is currently receiving a lot of attention and several studies have been carried out in order to design appropriate personnel protective equipment (PPE) depending on the heat energy that a worker can be exposed to in the event of an arc. This energy is a function of the arc fault current (usually lower than a bolted short circuit current), the operating time of circuit protective device and the distance between the arc source and the body of the worker. The last factor is equipment-specific and may vary depending upon the construction of the equipment and the type of maintenance that the equipment calls for, and thus needs to be individually evaluated. Procedure for calculation of energy has been detailed in IEEE standard 1584 and is used for deciding upon the type of PPE.

12. Software packages used for system studies

Various software applications have been developed and are commercially available for conducting system studies. Some of these software packages specialize in studying industrial distribution systems (e.g. ETAP). Others are designed more with utility distribution in mind (e.g. CYMDIST, ERACS, PSS/E). The difference between them lies mostly in the specialized study modules available with the package which can be either tailored to industry or utility. The studies described in the earlier section are the basic ones and all the packages provide modules for these studies. The specialized modules however are added on depending on the application required to be study. For example, packages meant for industrial systems usually have the following add-on modules:

- Ground Grid design
    - Calculation of touch and step potentials
- Motor starting behavior
- Battery sizing
- Cable sizing
- Energy Management System

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Product Gallery