ELECTRIC POWER DISTRIBUTION SYSTEMS

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Keywords: Distribution system planning, Load characteristics, Subtransmission Lines, Distribution substations, Design of primary and secondary Systems, Distribution system operation.

Contents

Summary

This chapter provides an overview of electrical distribution network and systems. The primary substation is the load center taking power from the transmission or subtransmission network and distributes electricity to customers via the distribution network consisting of cables/OHL and customer substations. Various power system components, like Circuit breaker, OHL, cables, and secondary equipment like protection relay, distribution automation are presented. The distribution system from planning, design, implementation, operation and maintenance is also described. The performance features of the distribution systems in terms of a number of measurable indices are highlighted.

1. Introduction

The primary purpose of an electricity distribution system is to meet the customer's demands for energy after receiving the bulk electrical energy from transmission or subtransmission substation. There are basically two major types of distribution substations: primary substation and customer substation. The primary substation serves as a load center and the customer substation interfaces to the low voltage (LV) network. Customer substation is referred to a distribution room normally provided by the customer. The distribution room can accommodate a number of HV switchgear panel and the transformer to enable LV connection to the customer incoming switchboard.

Depending on the geographical location, the distribution network can be in the form of overhead lines or underground cables. Cables are commonly used in urban areas and overhead lines are adopted for rural areas. Different network configurations are possible in order to meet the required supply reliability. Protection, control and monitoring equipment are provided to enable effective operation of the distribution network.

Planning of the distribution network is essential to enable the required demand can be met based on various forecast loading figures and supply security/reliability. There are three categories of planning, namely the long-term planning, the network planning and construction planning. Long-term planning is to determine the most optimum network arrangements and the associated investment with consideration on future developments. Stage-by-stage development must be in line with the forecasted load growth so that electricity demands can be timely met. The construction planning or design is the actual design and engineering work when the required circuits and substations have been planned and adopted.

Design, installation, operation and maintenance are the basic engineering considerations for a typical power system, including distribution.

2. Distribution System Planning

One of the essential elements in distribution system planning is the location of the load centre where the primary substation is situated. Establishment of load centre or primary substation, particularly in a densely populated area, must be prepared in long-term plan, for example, in a 10-year plan. The outlets from the primary substation will then supply the required electrical energy to the nearby customer loads. Customer substations will then further transform the distribution high voltage to the LV. (LV refers to the voltage below 1000V).

2.1. Basic Design Criteria

Distribution network refers to those 22kV or 11kV network supplying electricity to customers through cable or Overhead Line (OHL). From primary substation to various customer substations, various types of network configurations are possible, for example, single-end fed, double-end fed and closed ring network arrangement. In the customer substation, it normally consists of the step down transformer to LV; it may also contain HV circuit breaker(s), ring main units. Additional consideration is the availability of remote control facilities to enhance the security of supply.

In transmission network, the typical design concept is the 'N-1' reliability application. 'N-1' is referred to as any single component failure in the supply network will not affect the electricity supply. Hence in the case of a failure of a transmission line, or a transformer connected to the distribution primary substation from the transmission source, the supply to the distribution network will not be affected. It is normally achieved with suitable protection and associated inter-tripping or switching scheme to the distribution incoming from the transmission network. Hence, the primary substation is thus designed to supply a firm load based on the calculation of 'N-1' criteria.

On the other hand, the distribution network connected from the primary source substation will depends on the geographical locations of the customer substations. There are three major types of distribution networking:

Single-end radial fed

Single-end radial fed refers to a number of customer substations or pole-mounted substations are connected to the primary substation. The supply security is the lowest as any single point failure will result in the loss of supply to the customer substation. Similarly, any single failure in the customer substation will result in loss of supply to the customer. In case of fault, the supply restoration will depend on the fault repair time.

Double-end fed with an NO point

To provide a higher supply security, the customer substations can be fed from two sources as shown in Figure 1.

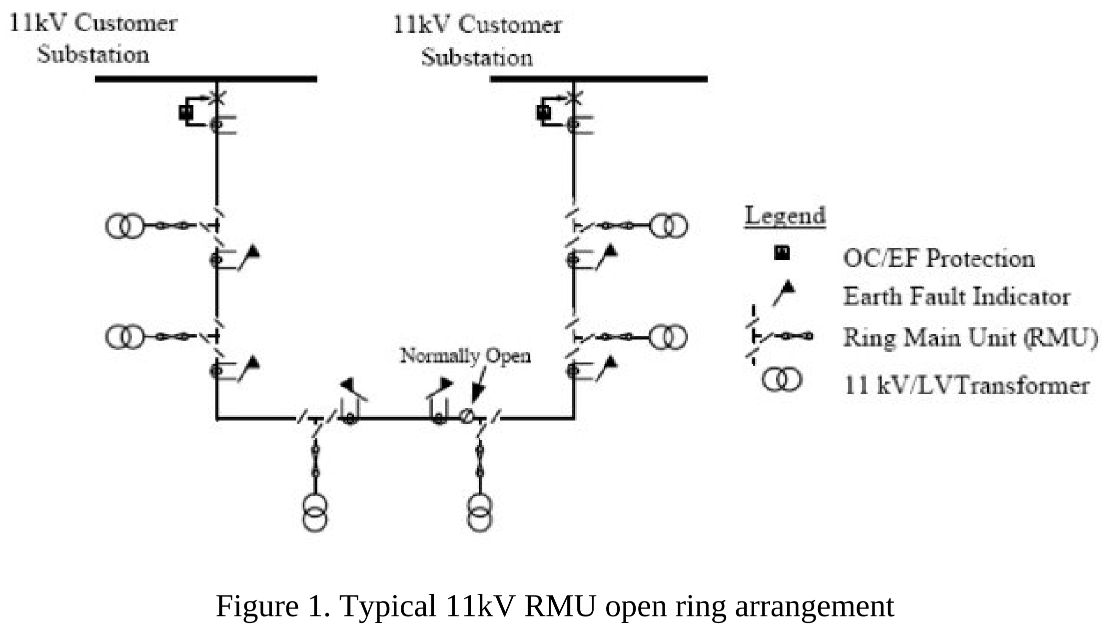

Figure 1. Typical 11kV RMU open ring arrangement

The customer substation is normally supplied from a single end and in the case of loss of supply from the one source end, for example due to a component failure, the NO (normally open) point can be closed to restore supply after the faulty portion of the component is isolated. The supply restoration will be quicker and is not directly depended on the fault repair time. The customer substation may consist of Rain Main Unit (RMU) and equipped with earth fault indicator as shown below. This configuration provides less secure supply since most of RMU only equipped with isolators which is unable to break fault current. This results in loss of supply in case of fault in the RMU circuit since the controlling circuit breaker at the controlling/customer substation will trip to isolate the faulty circuit.

Ringed network arrangement

A typical customer substation in a ring-configured network contains two feeders and one transformer feeder. The former have circuit breakers and cable connecting to other substations while the latter has circuit breaker and cable connecting to 11kV/LV transformer. A typical ringed network arrangement is shown in Figure 2.

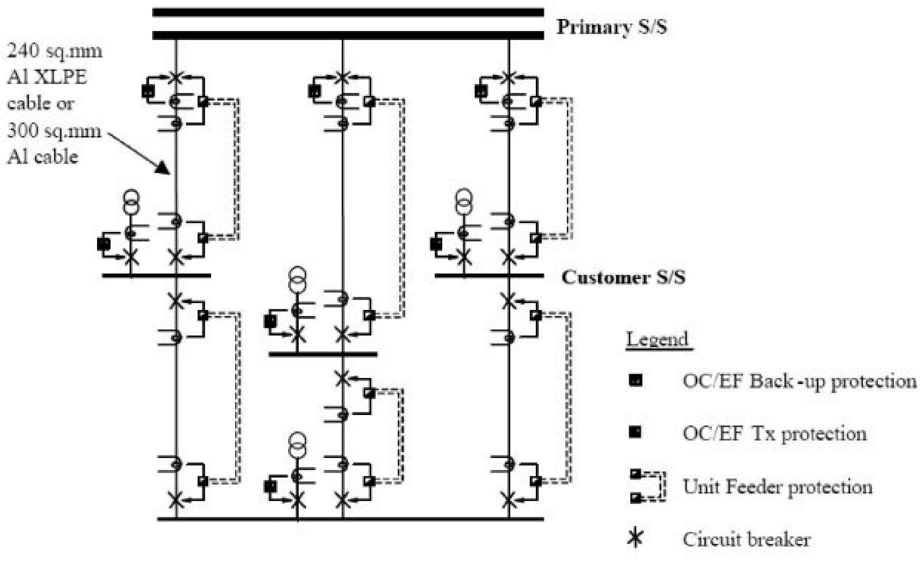

Figure 2. Typical 11kV close ring arrangement

2.2. Network Configuration

Distribution network refers to those 22kV or 11kV network supplying electricity to customers through cable or Overhead Line (OHL). The network configuration would directly affect the supply reliability. Of the three types of configuration, the closed ring configuration provides the highest possible supply reliability. Each customer substation has dual supply and so a single circuit fault would not cause any supply interruption. It is, in fact, aligned with “N-1” approach. In the ring configuration, each feeder is protected by either high-speed feeder protection or pilot wire protection with back up overcurrent and earth fault (OC/EF) protection equipped in the primary substation.

Generally, the number of outgoing feeders of a closed ring form primary substation is up to 4, since the more the number of outgoing feeder, the lower the fault current to be shared by each feeder. This would cause difficulty for the backup OC/EF protection to operate in case of malfunction of switchgear in customer substations. When the number of outgoing feeder is higher than 4, more loading will be supplied and the corresponding effect in the case of loss of supply will be much increased hence more legged closed ring is not preferred.

The Maximum Current Rating of 11kV cable is 7MVA and so the capacity of 4-legged closed ring should be 28MVA. However, with the “N-1” approach to the system reliability, the closed ring should be able to cater for the loss of one of the outgoing feeders from primary substation. That is to say, the remaining 3 feeders would take up the load due to the loss of the outgoing feeder. In order not to overload the outgoing feeders, the firm capacity of a 4-legged closed ring is limited to 21MVA.

To enhance the security of supply, operational flexibility and better asset utilization, it is essential to provide interconnections between primary substations. The 11kV interconnecting cables, normal open at one end, is commonly adopted to connect up two primary substations. With this arrangement, the spare capacity of the primary substations can be utilized more effectively and it can provide mutual backup between the two primary substations. Another way to enhance security of supply is connecting up two 11kV rings or connecting up two customer substations within the same 11kV ring. By this inter-ring or intra-ring arrangement as shown in Figure 3, the not restorable load under double circuit fault scenario can be reduced. This can somehow improve network security beyond N-1 security level.

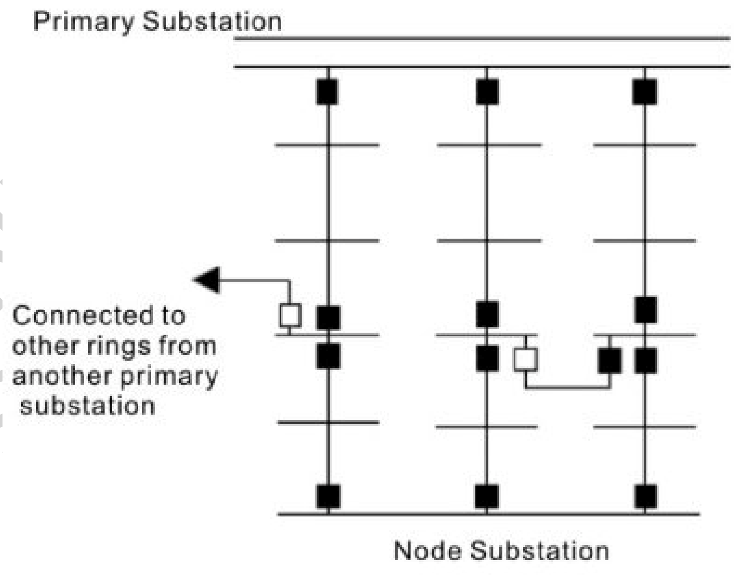

Figure 3. Typical interconnection arrangements in 11kV ring network

In rural area, Overhead line (OHL) is normally adopted to supply electricity. Due to the fact that there is no pilot cable in OHL network, pilot wire (differential) protection cannot be applied in OHL network. With no suitable discriminative protection, closed ring configuration is not possible to be adopted since the faulty section cannot be isolated. In this case, radial feed configuration is normally adopted for OHL.

OHL network is more likely to be disturbed by external factors, for example, lightning, animals or plants. Some of the disturbances are temporary so the circuit breakers at the source end substation are equipped with auto-reclose capability to cater for transient fault. In long OHL situation, auto-recloser can be adopted. Modern approach is the use of Pole Mounted Switch with remote control facilities. The installation of lightning arrester can improve the transient response capability of the OHL. Regular maintenance like a vegetation management program can reduce unnecessary tripping particularly during a possible line overload situation. Such measures could minimize the impacts resulting from these external disturbances.

In order to reduce the number of affected customers in case of fault, the loading of each radial fed OHL is usually limited to 1MVA or 500 customers which is regarded as basic load block. If more than one load block is connected in the same OHL circuit, alternative source is provided by means of connecting to another radial fed OHL with a normal open point (an isolator or pole mount switch). With this arrangement, the restoration time can be shortened by simply closing the normal open point after isolating the faulty section. With the function provided by Distribution Automation will be installed, the fault location and hence the supply restoration time can be greatly reduced.

Fault level refers to the magnitude of fault current in a particular voltage level; it is usually expressed in terms of kA or MVA. For a secure operation of power system, it is important to determine the fault level to ensure that the fault level is lower than the breaking capacity of equipments so that safety of personnel and satisfactory system performance is guaranteed. For example, two 50MVA 132kV/11kV transformers would not be operated in parallel since it may result in the 11kV fault level exceeding 350MVA, the fault breaking capacity of the 11kV switchgear.

Another reason for fault level determination is to ensure reliable operation of the protection systems. For example, maximum number of 11 kV feeders emanating from a primary substation to form a loop ring is limited to four so that the fault current shared by each feeder would be sufficient for protection grading purposes.

In order to maintain the efficiency of power transfer, the power factor of a customer's load should be maintained above or equal to 0.85 lagging. Usually customers are responsible for maintaining the power factor not less than this value by installing necessary equipments such as capacitor bank. However, one LV capacitor bank can be equipped for each transformer in a customer substation. This serves to further improve power quality.

2.3. Reliability Considerations

Network security refers to the ability of a power system to continuously supply electricity to customers. Network security can be measured in terms of number of interruptions in a given period or the average duration of interruptions. It should be pointed out that the network security is always proportional to its cost. Thus, it is important to strike a balance between network security and cost incurred so that cost effectiveness can be attained.

Generally, the supply to each customer is capable to meet the customer's peak load. When there is a fault occurred in the network, the supply may be interrupted depending on the location of fault and the network arrangement.

As the power is transmitted from high voltage (500kV, 400kV or 132kV) to low voltage (11kV or 380V), the impact of fault would become smaller in terms of load loss magnitude or number of affected customers. In order to prevent widespread load loss, different supply security arrangements are adopted to different load group according to their size.

The following is an example of a 3-Class approach on supply security classification.

Class 1 security

For such a loading group size below 1.5MVA, class 1 security is applied. With class 1 security, there is no alternative supply and in case of single fault in the supply circuit, the load group would loss supply. The supply restoration time is the repair time for the faulty equipment. Mobile generator may be provided as a temporary supply.

A single 11kV/LV transformer supplying a building of a group of customers also falls into class 1 security. If there is a fault on the transformer, the corresponding customers will loss supply until the transformer is repaired. It seems to be contradicting to the "N-1" criteria, but due to the fact that transformer faults are rare and there are abundant of 11kV/LV transformer in the distribution network, the provision of spare transformer is economically not justified. Besides, extra space is needed for the spare transformer which will increase the cost of customer premises. To strike a balance, one way to minimize impact of transformer faults, system planners would allows a single transformer supply load up to 1.5MVA (1MVA for OHL network) or less than 500 customers.

Class 2 security

For load group size of about 3.5MVA, class 2 security is applied and an alternative supply is provided via a normal open point. Since the cyclic rating of a typical 11kV cable is 7MVA, limiting the load group size of 3.5MVA can provide a mutual backup of the two supply network. If there is a single fault (excluding switchgear or busbar fault) in such network, supply can be restored by means of switching at the normal open point. Typical example of class 2 security network is the 11kV RMU open ring supply network.

Due to the fact that RMU network limits the operational and planning flexibility, it is not recommended in new development.

OHL network supplying load group higher than 1MVA or more than 500 customers should adopt class 2 security.

Class 3 security

For load group up to 21MVA, class 3 security is applied. It provides the highest security, each customer is provided with dual supply such that a single fault would not cause any interruption. The 11kV close ring network falls into this category. Each cable circuit is protected by high speed pilot wire (differential) protection; in case of single fault the corresponding faulty section will be automatically isolated without supply interruption.

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Biographical Sketch

Ir Dr. Chan Fuk Cheung received his education in both Hong Kong and United Kingdom obtaining B.Sc. and Ph.D. in 1972 and 1979 respectively. He has over 30 years experiences in the power systems industry specializing in power system protection, distribution automation, substation, lighting applications and energy services. He put a solid foundation for the protection systems, built the world largest distribution automation system in CLP Power Hong Kong. He has also involved in various management activities, including Business Process Re-engineering, Quality Systems, Contingency Planning and Procurement. He is currently the General Manager of CLP Engineering Limited, providing energy services, facilities management, E&M infrastructure projects, power engineering and lighting applications to its customers. Dr Chan is active in various learned society activities in HKIE, IEEE and the past IEE. He contributes in writing technical paper, giving lectures for our engineering profession as well as to promote our profession to secondary school students. He is a past Chairman of the Electrical Division of HKIE and a past Chairman of Power Engineering Joint Chapter of IEEE HK Section.