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Home » Power Systems » Key Factors to Consider In Substation Design

Key Factors to Consider In Substation Design

Substations are the points in the power network where transmission lines and distribution feeders are connected together through circuit breakers or switches via busbars and transformers. This permits the control of power flows in the network and the normal switching operations for maintenance purposes.

Figure 1(a) Substation Photo by ETA+ on Unsplash

We discuss the key factors to consider when designing substations as follows:

Table Of Contents

Security of Supply

In a perfect situation all circuits and substation equipment would be duplicated such that following a fault or during maintenance connection remains available. However, this would involve a very high cost, therefore techniques have been adopted to achieve a compromise between complete security of supply and capital investments i.e. a measure of circuit duplication is adopted while recognizing that duplication may itself reduce the security of supply e.g. by providing additional leakage paths to the ground.

Hence security of supply may be considered in terms of the effect of this loss of plant arising from the fault conditions or from the outage due to the maintenance. A good illustration of this is the British code of practice for the design of high voltage open terminal substations BS7354 that categorizes substations service continuity, recognizing that line or transformer faults destroy service continuity on the affected circuits.

Category 1

No outage necessary within the substation for either maintenance or fault e.g. the 1 ½ breaker scheme under maintenance conditions in the circuit breaker area.

Category 2

Short outage needed to transfer the load to an alternative circuit for maintenance or fault conditions e.g. the double busbar scheme with bypass isolator and bus-coupler switch under fault or maintenance conditions in the circuit breaker or busbar area.

Category 3

Loss of a circuit or section e.g. the single busbar with bus section breaker scheme for fault in the circuit or busbar area; the transformer-feeder scheme also comes under category 3 service continuity.

Category 4

Loss of substation; for example the single busbar scheme without bus sectionalisation for a fault in the busbar area.

Maintainability

The substation design must take into account the electricity supply company system planning and operations procedures together with knowledge of reliability and maintenance needs for the proposed substation equipment.

The need for circuit breaker disconnector bypass facilities may be obviated by an understanding of the relative short maintenance periods for modern switchgear.

Portable earthing points and earthing switch/interlock requirements will also need careful consideration. In the same way, the layout must allow easy access for winching gear, mobile cranes or other lifting devices if maintenance downtimes are to be kept to a minimum. Likewise, standard minimum clearances must be maintained for safe working access to equipment adjacent to operational live switchgear circuits or switchgear bays. Keep in mind that some safety authorities don't allow the user of ladder working and require access for mobile elevated working platforms or scaffolding.

Operational Flexibility

The physical layout of individual circuits and groups of circuits must allow the required power flow control. In a two transformer substation, operation of either or both transformers on one infeed together with the facility to take out of service and restore to service either transformer without loss of supply should be a normal design consideration. Generally a multiple busbar arrangement will provide flexibility than a ring busbar.

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Extendibility

The substation design should allow for future extendibility. The addition of bays of switchgear to a substation is usually possible and care must be taken to minimize the outages and outage durations for construction and commissioning.

When minor changes such as the addition of overhead line or cable feeder bays are anticipated, then busbar disconnectors may be installed at the outset [known as ‘’skeleton bays’’] thereby minimizing outage disruption. In cases, where future extension is likely to involve major changes, such as from a single to double busbar arrangement, then it is best to install final arrangement at the outset because of the disruption that might be involved.

Also note, the use of gas insulated switch gear (GIS) tends to lock the user into the use of specific manufacturer’s switchgear for any future extension work. In contrast to an open terminal switchyard arrangement that allows the user a choice of switchgear for future extension work.

Short Circuit Limitations

In order to keep fault levels down, parallel connections (transformers or power sources feeding the substation) should be avoided.

Multi-busbar arrangements with sectioning facilities permits the system to be split or connected through a fault limiting reactor; it is also possible to split a system using circuit breakers in a mesh or ring type substation layout though this requires careful planning and operational procedures.

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Protection Arrangements

The substation design must allow the protection of each system element by provision of suitable current transformers (CTs) locations to ensure overlapping of protection zones. The number of circuit breakers that require to be tripped following a fault, the auto-reclose arrangements, the type of protection and the extent & type of mechanical or electrical interlocking must be considered.

Land Area and Wayleaves

For you to construct, operate and maintain an overhead line or substation at all voltage levels, land acquisition and plant access are required. Generally, the rights to install such facilities and the rights to secure the associated rights of way or wayleaves are negotiated on a voluntary basis between the power line (utility) company and the land owner(s). Such negotiations will be required to take into account the due planning application laws and processes.

Nevertheless, because of the importance of a secure electricity supply to both public and industry, the governments recognize that the power line (utility) companies have a public role to play. Hence, where necessary, such wayleaves may be obtained under compulsory purchase schemes where due compensation is determined and paid to the landowners in accordance with the national regulatory processes.

The cost of purchasing a plot of land in a densely populated area is quite high. Therefore, there is a trend towards compact substation design made possible by the use of indoor gas insulated switchgear (GIS) substation designs or by using such configurations as the transformer-feeder substation layout. Furthermore, compact design reduces the civil work activities. Long multicore control cable runs and switchyard earth grid requirements are also reduced.

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Cost

It is very difficult to compare the costs of different substations layout designs because of the differences in performances and maintainability. The best way is to base your decisions for specific layout on technical grounds and then to determine the most economical means of achieving these technical requirements.

Busbar span lengths of about 50 m tend to give an economical design. However, the gantry structures involved have a high environmental impact & the current trend is for low profile substations.

Tubular busbars tend to offer cost advantages over tensioned conductor for busbar currents in excess of 3000 A.

The use of circuit breakers with current transformers (CTs) in the appropriate bushings, available up to 275 kV saves the use of separate post-CTs with their associated plant, structural, civil and space costs.

Considering some of the factors discussed so far, and the savings in cost of land mentioned above, manufacturers now consider that a 400 kV gas insulated switchgear (GIS) substation may produce overall savings when compared to a conventional open terminal arrangement, though this varies greatly depending upon site and territory, also the reduced bay centers can result in clearance difficulties where there are incoming overhead lines.

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