# SUBSTATION SWITCHING

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by



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# SUBSTATION SWITCHING

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## ABSTRACT

A power system network requires frequent changes in its configuration during normal operation. These changes are made by operating circuit breakers and isolators located in substations. In the past, switches were opened and closed by the operators using predefined guidelines. This task is performed in modern substations by digital computers either exclusively or in the form of assisting the operators in making proper decisions. The quality of power supplied to customers is enhanced if the computers automatically make appropriate switching decisions without significant delay.

This thesis describes the design of a digital computer based substation switching scheme which employs generalized rules for interlocking and sequence switching. In addition to interlocking constraints, generatoion and load balance, ratings of equipment, and continuity of power supply are taken into consideration.

When started for the first time, the program processes the data concerning the electrical layout of the substation and makes various lists and tables which are frequently used for making switching decisions. When changes in the configuration of a substation are requested, the program automatically determines alternative switching sequences and selects and implements the most economical sequence. It also assists the operator in the evaluation of abnormal circumstances. The program was tested by using five configurations of substations. It has been demonstrated that the program is suitable for implementing interlocking schemes and determining and implementing switching operations.

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# 1. INTRODUCTION

## 1.1 Electric Power System

Electric power systems consist of interconnections of electrical equipment, such as generators, transformers, transmission and distribution lines, switchgear and associated devices. Generated electric power is transmitted to load centers and then distributed to the users.

Generators produce electricity at relatively low levels of voltage. To avoid significant losses of power during transmission over long distances, much higher voltages are needed. This is achieved by using step-up transformers. Generating stations and load centers, scattered in large geographical areas, are connected by transmission lines to form networks. If the demand for electric power at a generating station exceeds its capacity, it is met from other sources. Electric power is transmitted on alternative routes if a line is out of service.

At load centers, transformers lower the voltage to levels which range from 5 to 34 kV. Power at these voltage levels is then distributed to various locations where the voltage is further reduced to make it suitable for use by the customers.

Transmission and/or distribution lines come together at substations which include switching devices for controlling the flow of electric current in the network. Proper operation of these devices is important for providing power to customers at acceptable levels of availability.

It is necessary to prevent undesirable switching operations and to automatically determine the appropriate route of power flow. Following a fault, or an abnormality, decisions must be made as quickly as possible so that the service is restored with minimal delay.

## 1.2. Computers in a Power System Operation

Extensive interconnections of transmission and distribution lines make it difficult to achieve both an economic operation and an adequate level of security. The operators cannot analyze the information produced in a large system and make appropriate decisions without significant delays. When making a switching decision, control engineers use their past experience, and an analysis of the present and expected operating states of the system. While decisions made by the operators are prone to errors, especially if they are made in an emergency situation such as, during a system disturbance, computers equipped with suitable programs can make correct decisions without much delay.

The cost of digital computers has been reduced considerably over the years. It has now become economically feasible to use several computers to perform tasks in a sharing and interactive environment. While connected to a communication network, computers exchange information to achieve integrated control of the system. This environment makes it easy to use new concepts because they come mostly in the form of computer software. Digital computers have, therefore, become an important tool which enhances the performance of a power system.

## 1.3. Past and Present Trends in Electric Power Substations

The development of devices for making and breaking electric circuits required much effort over a long period of time. In the early days, the quenching of an arc, that forms on the opening of a switch, was the major concern in substation performance. The quick-break knife-switch was perhaps the earliest form of a circuit-breaker. In those days, attendants had to chop the arc in two by using insulated hatchets [1].

During the first quarter of the 20th century, a more effective approach for the making and breaking of circuits was developed; this consisted of immersing the knife-switches in mineral oil. By the late 1920's, the mechanism of arc formation was better understood and arc controlling devices were introduced. The study of arc formation and arc quenching mechanisms eventually led to the development of modern circuit-breakers.

High voltage substations receive and transmit large amounts of power. Their continuous operation is, therefore, important in maintaining the integrity of the electric power systems. Flexibility or maneuverability in the switching schemes is necessary for maintaining the continuity of power supply. To achieve this, several switches are needed at each substation.

Most switching operations are performed by circuit breakers. These are expensive devices; the cost increases with the increase of the operating voltage and current interrupting capability. When circuit-breakers are to be serviced, they are disconnected from the rest of the system by switches, called isolators. These are not designed to make or break large currents, but are used to change the path of current flow when operated in combination with circuit breakers.

Circuit breakers have a limited life which depends on the number of opening and closing operations that they perform. To prolong their life, only necessary switching operations should be performed. It is important to eliminate "bad" switching decisions because they can result in loss of power supply, damage to equipment, fire, and exposure of operators to serious dangers. In abnormal situations, proper decisions must be made without substantial delay.

The suitability of using computers in making switching decisions has been proven over the years [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. Digital monitoring, control and protection of power systems is now a well-accepted trend [12, 13]. These computers can continuously monitor the state of a power system, perform on-line analysis of the system and initiate operations to change the system configuration for maintaining its integrity.

## 1.4 Objectives of the Research

The objective of the research reported in this thesis was to develop a substation switching scheme which should be

- applicable to substations of practical configurations. The rules of interlocking and sequence switching should be general and should be applicable to all configurations,
- based on digital technology,
- computationally efficient and suitable for real time application, and
- flexible to accommodate modifications and extensions of substations.

The perspective was to develop the system in such a way that it

- provides an economical switching strategy,

- minimizes operators' intervention,
- provides adequate security to the system,
- provides assistance to operators in evaluating the situation during abnormal circumstances, and
- integrates with the existing monitoring, control and protection systems.

## 1.5. Outline of the Thesis

The thesis consists of seven chapters. The subject of the thesis has been introduced in this chapter. A brief overview of the configurations used in substations are given in Chapter 2. In Chapter 3, the switches used in substations are described. Constraints on the operation of switches and the requirements for interlocking them are outlined. The sequence switching problem is then formulated. In Chapter 4, the basic data required to provide the structural information of the substation are described. The off line processing of the substation data, to generate information which helps in making switching decisions quickly, are described. In Chapter 5, the topology detection, interlocking and sequence switching techniques are described. In Chapter 6, some test results are presented. The final chapter summarizes the work done for this project and draws some conclusions.

Some of the concepts of integrated, hierarchical substation monitoring, control and protection are described in Appendix A. The evolution of digital control and protection is reviewed. Architectures for and communication requirements of an integrated hierarchical system are also described.

# 2. SUBSTATIONS AND SWITCHES

## 2.1. Introduction

The making and breaking of electric circuits, accomplished by the use of switches, are essential for the operation and maintenance of power systems. The most effective and versatile switch is the circuit breaker. Because of the exceptionally high cost of high voltage circuit breakers, electrical utilities also use other types of switches to reduce the overall cost of the substations. There are several ways in which inexpensive switches can be used along with the circuit breakers. This chapter introduces the various types of switches used in substations and the substation configurations generally adopted by the utilities.

## 2.2. Substations

A substation is a junction where circuits operating at various voltage levels come together. The circuits are connected together through transformers. Switches, transducers, and monitoring and control devices are used to monitor the system and perform the needed operations. A substation contains conducting elements, called busbars, to which several incoming and outgoing lines are connected. These connections are made through isolating switches and circuit breakers.

Most substations have a control room and a switchyard. The high voltage equipment and transducers are physically located in the switchyard. The equipment includes circuit breakers, isolators and earth switches, H.R.C. fuses, busbars, power transformers, shunt and series reactors, current transformers, potential transformers, power-line-carrier transceivers, line-traps and other devices. A control room houses the protection and control equipment. This includes low voltage switches, control boards, indicating and measuring instruments, relays, voltage and frequency control panels, synchronizing panels, breaker and isolator actuators and communication devices.

At the substations associated with major generating stations, voltage is stepped up for long distance transmission of power; these substations are called transmission substations. The substations near the load centers receive power at high voltage, step it down to lower levels and deliver it to the consumers. The substations that distribute power to the consumers are called distribution substations. Figure 2.1 shows a sample power system which includes transmission, sub-transmission and distribution substations.

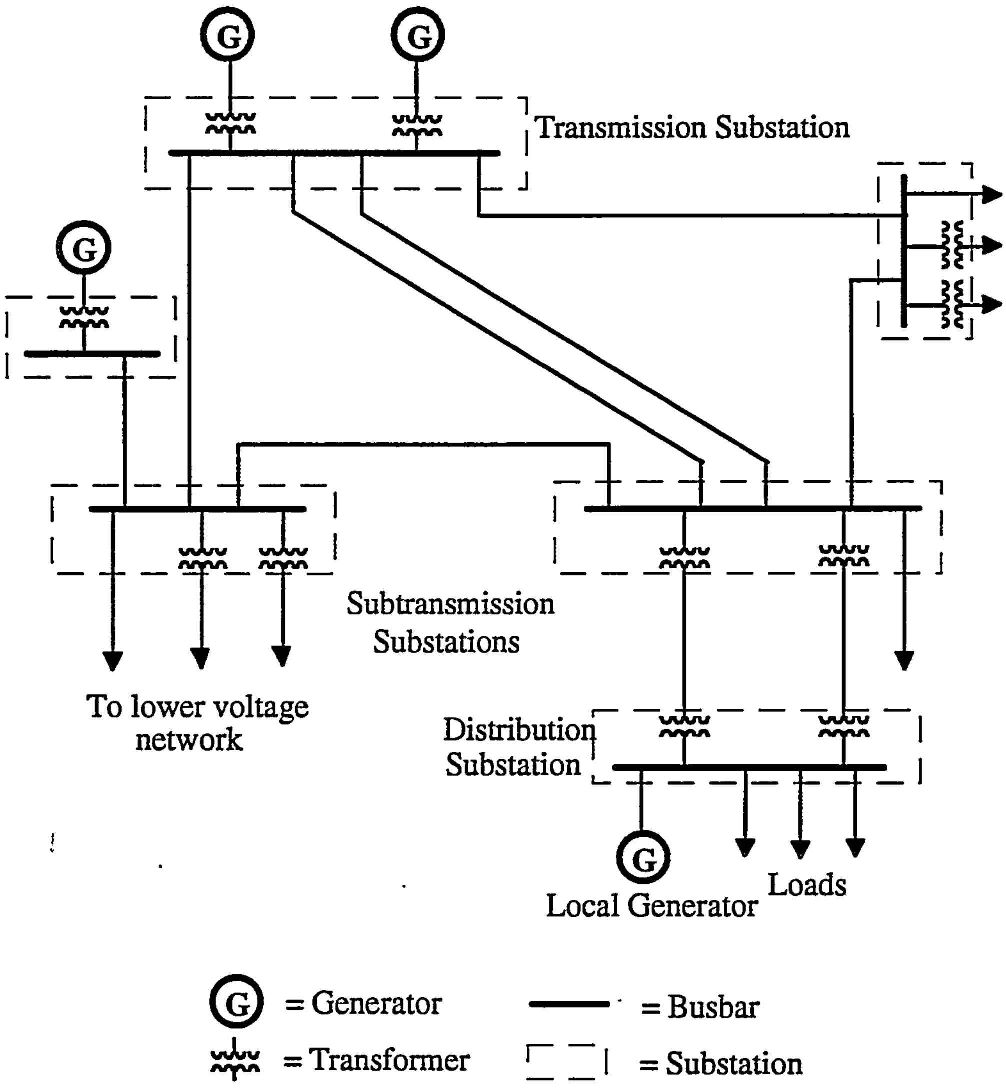


**Figure 2.1.** Substations in a sample power system.

The cost of the damage associated with a fault at a higher voltage level is greater compared to that at a lower voltage level. Also, faults in the high voltage substations can cause power failures to a large number of customers. These substations are, therefore, equipped with redundant switches and, consequently, more complex.

One of the functions of a substation is to periodically rearrange the circuits connected to it. This includes grouping of feeders, transformer changeovers and isolating parts of the network. The configuration of the network is changed by using switches. While doing this, it is important not to violate switching constraints and operational constraints of the system, and to keep the number of switching operations to a minimum. Interlocking and sequence switching are, therefore, important aspects of substation operations.

## 2.3. Switches Used in a Substation

Switches used in a substation include circuit breakers, isolators, earth switches, fuses and load-break switches. The capabilities and limitations of these switches and their application in substations are described in this section. The properties of these switches are used later, in Chapter 3, when the constraints for their operation are formulated.

### 2.3.1. Circuit breakers

Circuit breakers are used to make or break electric power circuits under different operating conditions, such as normal operating states, power swings and system faults. Ordinarily, circuit breakers operate infrequently, although some classes of circuit breakers are designed for more frequent operation [14].

The J&P Switchgear Book [1] lists the following functions that a circuit-breaker is expected to perform.

- It must be capable of closing on to full load.
- Under prescribed conditions, it must open automatically to disconnect the load.
- It must successfully and rapidly interrupt currents which flow when a short-circuit occurs on the system.
- With its contacts open, the gaps must withstand the circuit voltages.
- It must be capable of closing on to a circuit in which a fault exists, and of immediately re-opening to isolate the faulted section.

- It must be capable of carrying short-circuit currents until they are interrupted by another breaker (or fuse) closer to the fault.
- It must be capable of successfully interrupting low level currents, such as transformer magnetizing currents (inductive) and, line and cable charging currents (capacitive).
- It must be capable of withstanding the effect of arcing at its contacts.
- It must be capable of withstanding the electro-magnetic forces and thermal conditions caused by the flow of short-circuit currents.

### 2.3.2. Load-breaking fault-making switches

Load-break switches can open a circuit carrying full load currents but can not interrupt fault currents. They can sometimes substitute circuit breakers and provide switching facilities which cannot be provided by isolators. The cost of a load-break switch is approximately one third of the cost of a circuit breaker [1].

By using a combination of a load-break switch and a fuse, fault clearing and circuit isolation can be achieved. Because of its low cost, this combination is frequently used in distribution systems.

Load-break switches are used to increase the flexibility of switching when fewer than usual circuit-breakers are used. These switches are also used to substitute circuit-breakers, thereby reducing installation costs. Sometimes they are used for short-circuiting series capacitors [1]. Figure 2.2 shows some applications of load-break switches.

A load-break switch must be able to perform the following functions [1]:

- It must be capable of breaking the rated load currents at system voltage.
- It must be capable of interrupting small inductive and capacitive currents, such as disconnecting unloaded transformers, cables and overhead lines.

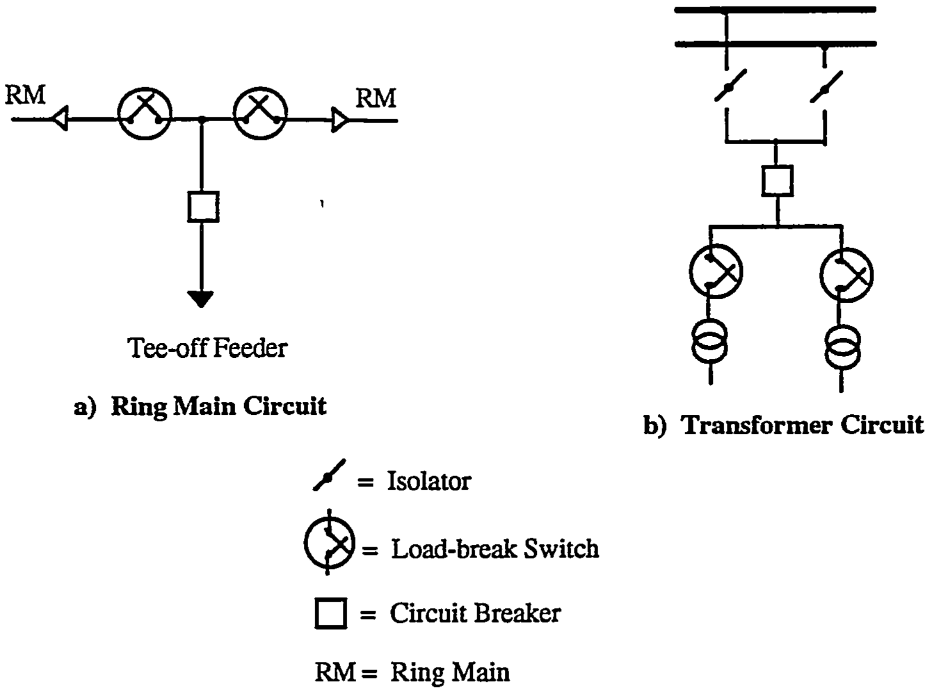


**Figure 2.2.** Examples of load-break switch applications.

- It must be able to close on to a short-circuit; this is called fault-making ability.
- It must be capable of carrying the fault currents while the fault is being cleared by an interrupting device. This time is usually considered to be three seconds.

Load-break switches differ from circuit-breakers in that they cannot interrupt short-circuit currents. Therefore, the system must allow a circuit-breaker to interrupt fault currents before opening a load-break switch.

### 2.3.3. Isolating switches

Isolating switches, also called isolators, are used to disconnect circuit-breakers, sections of busbars and parts of the system for maintenance and repair. They are also used to transfer circuits from one busbar to another and thus provide flexibility during system operation. They are able to carry abnormal and short circuit currents. They are slow moving switches which are inexpensive compared to load-break switches and circuit breakers.

Isolators are used to open circuits only after the flow of currents has been interrupted by other devices. Their operation is interlocked with the operation of other devices to ensure that, at the time of their operation, no currents are flowing in them.

These switches must be able to [15]:

- carry normal load currents continuously,
- carry fault currents until they are cleared by an interrupting device and,
- make and break small currents when the voltage difference across their terminals is not significant.

### 2.3.4. Grounding switches

A grounding switch is used for connecting equipment to a ground electrode (or grounding mesh) after it has been isolated from the system. Before performing maintenance, the equipment must be isolated and the charge trapped on it must be discharged to ground. Impedance devices are often used to connect conductors of an electric system to ground in order to limit the flow of currents in the event that the equipment is energized.

Some load-break switches, such as oil switches used in ring main distribution, isolators and circuit-breakers [1], have an integral facility for grounding the circuit. In some designs a common switch blade moves from the "on" position to the "off" position and then to the "earth" position. In other designs, separate blades are used for line switching and for grounding. They are interlocked to prevent the inadvertent grounding of the circuit while the circuit breaker is closed. The grounding is a deliberate action.

Grounding switches are interlocked with adjoining circuit breakers so that they cannot be closed with the appropriate circuit breaker in service; likewise, the circuit breaker cannot be brought into service without opening the grounding switch. In many substations the grounding switches are interlocked with the isolators adjacent to them.

### 2.3.5. Fuse switches

These are either load-break switches or isolators equipped with fuse elements. The fuses are used to protect equipment and lines from overcurrent. Fuse switches are used instead of circuit-breakers in distribution networks. When a fuse operates to open the line, it must be manually replaced by a new one.

## 2.4. Types of Switching Operations

Switching operations performed in power systems can be classified in three categories:

- Protection switching, where speed of operation is important.
- Operational switching, where speed is important but is not as critical as in protection switching.
- Maintenance switching, where the speed is not important.

## 2.5. Busbar Configurations

Substations differ in their configurations because of various reasons, such as their importance, voltage level, number of circuits and economic considerations. In this section, major substation configurations are introduced and their advantages and disadvantages are described.

### 2.5.1. Single busbar system

This is the simplest busbar arrangement in which a single set of busbars is used. All generators, feeders and transformer circuits are connected to it. This arrangement is used in most dc switchboards, in small ac substations and some generating stations. Figure 2.3 shows a typical single busbar substation.

This is the least expensive scheme. Some of its disadvantages include

- shutdown of the entire substation when the busbar or a circuit- breaker failure occurs,
- difficulty in performing maintenance, and
- and need for total shutdown when the substation is to be extended.

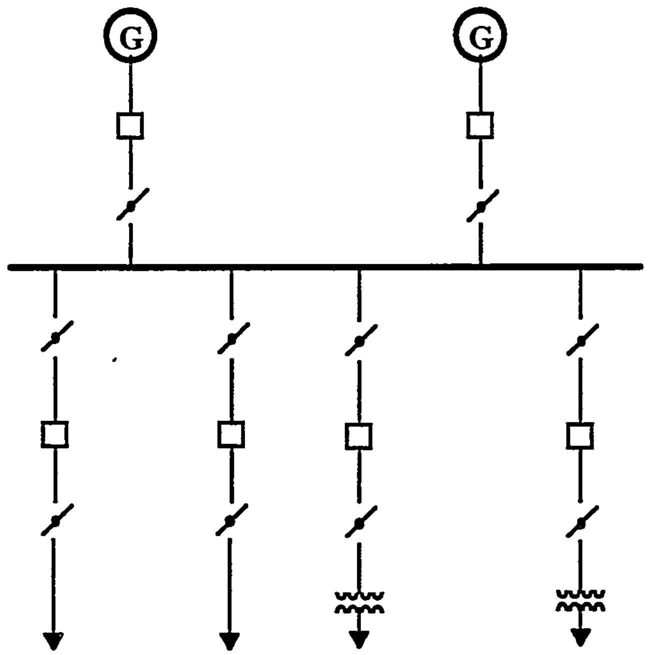


**Figure 2.3.** A typical single-busbar system.

## 2.5.2. Sectionalized single busbar system

A sectionalized busbar facilitates the shut down of a section for maintenance or repair without interrupting the supply to other sections. In this scheme, circuit-breakers of lower interrupting capacity are needed because the sections are electrically segregated from each other. Duplicate feeders can be connected to different sections so that supply is not interrupted unless both sections are out of service. In general, a circuit breaker, with an isolator on each side, is used. The circuit breaker can be completely isolated from the adjacent sections by opening the isolators when repair or maintenance is to be done. The sectionalizing isolators should be operated only after the circuit breaker has been opened.

A simple sectionalized single busbar scheme is shown in Figure 2.4. It indicates how fire risks are reduced by housing the sectionalizing circuit breaker between fireproof walls. Before any two sections are connected to each other, the two systems must be synchronized.

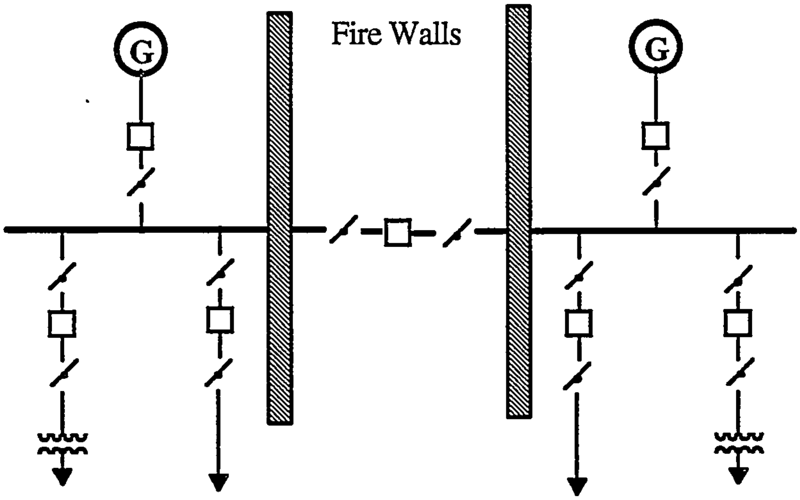


**Figure 2.4.** A typical sectionalized single-busbar system.

## 2.5.3. Ring busbar system

A ring busbar system is a multi-sectionalized single busbar scheme in which the ends of the busbars are connected to form a ring. This increases the flexibility in operating the system. The failure of one section does not interrupt the power supply to the adjacent sections as long as enough generating capacity remains available.

## 2.5.4. Duplicate busbar system

Major substations are usually equipped with duplicate busbars to increase flexibility during the operation of the substation and for doing maintenance on the equipment. Normally, one set of busbars is in use while the other remains available for use in the event of a bus fault in the substation. This scheme includes a bus-coupler circuit breaker and two isolators. Each incoming and outgoing feeder is connected to both busbars by a circuit breaker and two isolators as shown in Figure 2.5.

In this scheme, an appropriate sequence of operations must be used to transfer circuits from one set of busbars to the other. The bus-coupler circuit breaker is used to synchronize the systems connected to these busbars. The isolators are used to select the busbars and to disconnect the circuit breaker for maintenance.