

# SUBSTATION SWITCHING

A Thesis

Submitted to the College of Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

in the

Department of Electrical Engineering

University of Saskatchewan

by

6311  
Nov. 14 1994 OK

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Saskatoon, Saskatchewan, Canada

Spring 1995

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## ACKNOWLEDGMENTS

The author expresses his deep gratitude and appreciation to Prof. M.S. Sachdev for his supervision of this work. His thoughtful advice and constant encouragement during this work are highly appreciated.

The author wishes to thank Prof. R. Billinton for explaining his path finding algorithm. The author also acknowledges the helpful advice on programming, obtained from Prof. A.E. Krause and Mr. I.J. Macphedran.

The author expresses his deep appreciation to Wendy, Lillian and Ron Heichman for helping him in many ways.

Financial assistance provided by the Canadian International Development Agency, and the nomination for scholarship and study leave provided by the Institute of Engineering, Tribhuvan University, Nepal, are gratefully acknowledged.

UNIVERSITY OF SASKATCHEWAN

Electrical Engineering Abstract 94A378

**SUBSTATION SWITCHING**

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M.Sc. Thesis Submitted to the  
College of Graduate Studies and Research

September 1994

**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, generation 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.

## Table of Contents

COPYRIGHT	i
ACKNOWLEDGMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	viii
LIST OF TABLES	x
1. INTRODUCTION	1
1.1. Electric Power System	1
1.2. Computers in a Power System Operation	2
1.3. Past and Present Trends in Substations	2
1.4. Objectives of the Research	3
1.5. Outline of the Thesis	4
2. SUBSTATIONS AND SWITCHES	5
2.1. Introduction	5
2.2. Substations	5
2.3. Switches Used in a Substation	7
2.3.1. Circuit breakers	7
2.3.2. Load-breaking fault-making switches	8
2.3.3. Isolating switches	9
2.3.4. Grounding switches	10
2.3.5. Fuse switches	10
2.4. Types of Switching Operations	11
2.5. Busbar Configurations	11
2.5.1. Single Busbar System	11
2.5.2. Sectionalized Single Busbar System	12
2.5.3. Ring Busbar System	13
2.5.4. Duplicate Busbar System	13
2.5.5. Two-Circuit Breaker System	14
2.5.6. Sectionalized Duplicate Busbar System	15
2.5.7. Duplicate Busbars with By-pass Isolator System	16

2.5.8. Mesh System	17
2.5.9. Breaker-and-a-Half System	17
2.5.10 Multiple Bus System	18
2.6 Summary	19
3. THE PROBLEM	20
3.1. Introduction	20
3.2. Interlocking	20
3.3. Mechanical and Electrical Interlocking Schemes	21
3.4. Sequence Switching	21
3.5. Trends in Power System Monitoring, Control and Protection	22
3.6. Digital Switching Techniques	23
3.7. Problem Definition	26
3.8. Formulation of Constraints	27
3.8.1. General	28
3.8.2. Isolators	28
3.8.2.1. An example	28
3.8.3. Circuit Breakers	30
3.8.4. Grounding Switches	31
3.8.5. Load-break Switches	31
3.8.6. Transformers	31
3.8.7. Sequence Switching	31
3.9. Busbar Transfer	33
3.10. Summary	35
4. NETWORK REPRESENTATION AND DATA PREPARATION	36
4.1. Introduction	36
4.2. General Considerations	36
4.3. Input Data	40
4.3.1. Reading the static data	40
4.3.2. Generation and load data	44
4.4. Processing Input Data in Off-line Mode	46
4.4.1. List of lists and tables	46
4.4.2. Table of names of switches	47
4.4.3. Substation Matrix	49
4.4.4. List of different types of switches	51
4.4.5. Input-output links	52

4.4.6. Link interconnections	52
4.4.7. Busbar information	55
4.4.8. List of branches	55
4.4.9. Links and their corresponding branches	58
4.4.10 Unidirectional and bi-directional branches	60
4.4.11 List of new branches	62
4.4.12 List of toggled branches	66
4.4.13 List of predecessors of new branches	68
4.4.14 List of isolators and their adjacent circuit breakers	71
4.4.15 List of new switches	71
4.4.16 List of toggled switches	73
4.4.17 List of predecessors of new switches	74
4.5. Summary	76
<b>5. INTERLOCKING AND SEQUENCE SWITCHING PROGRAM</b>	<b>77</b>
5.1. Introduction	77
5.2. Overview of the Program	77
5.2.1. Features of the program	79
5.3. Topology Determination	79
5.3.1. Previous works	79
5.3.2. Methodology	80
5.4. Uses of Status Matrix	84
5.5. Operating a Switch	85
5.6. Sequence Switching	89
5.7. Determining Alternative Paths	93
5.8. Determining Alternative Switching Sequences	98
5.9. Selecting and Implementing an Appropriate Sequence	99
5.10. Summary	99
<b>6. TESTING</b>	<b>100</b>
6.1. Introduction	100
6.2. Test Substations	100
6.3. Configuration Data of the Test Substations	100
6.4. Testing the Program on Different Substations	119
6.4.1. Testing on test substation 1	119
6.4.2. Testing on test substation 2	124
6.4.3. Testing on test substation 3	127
6.4.4. Testing on test substation 4	131

6.4.5. Testing on test substation 5	133
6.5. Summary	135
7. SUMMARY AND CONCLUSION	136
7.1. Summary	136
7.2. Conclusion	137
REFERENCES	138
A. INTEGRATED CONTROL AND PROTECTION OF SUBSTATIONS	150
A.1. Introduction	150
A.2. Integrated Hierarchical Control and Protection System	150
A.3. Organization of a Hierarchical System	153
A.4. Evolution of the Integrated Hierarchical System	155
A.5. System Architecture	160
A.6. Communication Networks	166
A.6.1. Introduction to Local Area Networks	166
A.6.2. Terminology	167
A.6.3. Comparison of Different LANs	169
A.6.3.1. Comparison Between CSMA/CD and Token Passing LANs	169
A.6.3.2. Comparison Between Token Bus and Token Ring LANs	171
A.7. Summary	174



## List of Figures

<b>Figure 2.1.</b>	Substations in a sample power system.	6
<b>Figure 2.2.</b>	Examples of load-break switch applications.	9
<b>Figure 2.3.</b>	A typical single-busbar system.	12
<b>Figure 2.4.</b>	A typical sectionalized single-busbar system.	13
<b>Figure 2.5.</b>	A typical duplicate busbar system.	14
<b>Figure 2.6.</b>	A typical two-circuit-breaker system.	15
<b>Figure 2.7.</b>	A typical sectionalized two-circuit breaker system.	15
<b>Figure 2.8.</b>	Duplicate busbars with by-pass isolators.	16
<b>Figure 2.9.</b>	A typical mesh substation.	17
<b>Figure 2.10.</b>	A typical breaker-and-a-half system.	18
<b>Figure 2.11.</b>	A typical multiple busbar system.	19
<b>Figure 3.1.</b>	A substation with a bus coupling circuit.	29
<b>Figure 3.2.</b>	A part of a substation with sectionalizing and bus selecting switches.	33
<b>Figure 3.3.</b>	A section of a substation with bus selecting isolators.	34
<b>Figure 4.1.</b>	Switches, links, nodes and branches.	37
<b>Figure 4.2.</b>	A sample double-busbar substation.	41
<b>Figure 4.3.</b>	Procedure for preparing the table of link interconnections.	54
<b>Figure 4.4.</b>	Procedure for preparing the list of branches.	56
<b>Figure 4.5.</b>	The branches of the substation.	57
<b>Figure 4.6.</b>	Procedure of preparing list of branches corresponding to a link.	59
<b>Figure 4.7.</b>	The new branches of the substation.	63
<b>Figure 4.8.</b>	Procedure for preparing the list of new branches.	64
<b>Figure 4.9.</b>	(a) A diagram to illustrate predecessors. (b) Illustration of sending end and receiving end.	69
<b>Figure 5.1.</b>	A simplified flowchart of the program.	78
<b>Figure 5.2.</b>	Procedure for determining substation topology.	81
<b>Figure 5.3.</b>	A simple switching circuit.	83
<b>Figure 5.4.</b>	An illustration of a shunt path.	85

<b>Figure 5.5.</b>	Procedure for operating a switch.	86
<b>Figure 5.6.</b>	Procedure for connecting and disconnecting a link.	90
<b>Figure 5.7.</b>	A section of a substation represented by switches and branches.	94
<b>Figure 5.8.</b>	A network to demonstrate the procedure of deducing paths.	95
<b>Figure 5.9.</b>	The network of Figure 5.8 after splitting the bi-directional switches into two unidirectional switches.	96
<b>Figure 6.1.</b>	A double busbar substation with by-pass isolators.	101
<b>Figure 6.2.</b>	A mesh substation.	102
<b>Figure 6.3.</b>	A triple busbar substation.	103
<b>Figure 6.4.</b>	A double busbar substation.	104
<b>Figure 6.5.</b>	A breaker-and-a-half substation.	105
<b>Figure A.1.</b>	An integrated hierarchical control and protection system.	152
<b>Figure A.2.</b>	Hierarchy of digital computers in a power system.	154
<b>Figure A.3.</b>	Architecture 1.	162
<b>Figure A.4.</b>	Architecture 2.	163
<b>Figure A.5.</b>	Architecture 3.	164
<b>Figure A.6.</b>	Architecture of the Westinghouse system.	165
<b>Figure A.7.</b>	Architecture of the TEPCO system.	166
<b>Figure A.8.</b>	Bus, ring and star network configurations.	168

## List of Tables

<b>Table 4.1.</b>	Identification codes for switches.	38
<b>Table 4.2.</b>	Identification codes for links.	39
<b>Table 4.3.</b>	Data representing the layout of the substation.	43
<b>Table 4.4.</b>	Data stored in file GENLOD.DAT and their interpretations.	45
<b>Table 4.5.</b>	Table of names of switches.	47
<b>Table 4.6.</b>	Substation matrix.	50
<b>Table 4.7.</b>	List of different types of switches.	51
<b>Table 4.8.</b>	Input-output links.	52
<b>Table 4.9.</b>	Table of link interconnections.	53
<b>Table 4.10.</b>	List of busbar links.	55
<b>Table 4.11.</b>	List of branches.	58
<b>Table 4.12.</b>	Links and their corresponding branches.	60
<b>Table 4.13.</b>	List for identifying unidirectional and bi-directional branches.	61
<b>Table 4.14.</b>	List of new branches.	65
<b>Table 4.15.</b>	List of toggled branches.	67
<b>Table 4.16.</b>	List of predecessors of the new branches	70
<b>Table 4.17.</b>	List of new switches.	72
<b>Table 4.18.</b>	List of toggled switches.	74
<b>Table 4.19.</b>	List of predecessors of new switches.	75
<b>Table 5.1.</b>	Codes to represent the transition of status of input-output lines.	84
<b>Table 5.2.</b>	List of new switches with link 8 as the path-start-link.	96
<b>Table 5.3.</b>	List of predecessors of new switches.	97
<b>Table 5.4.</b>	Minimal paths expressed in switch and node numbers.	98
<b>Table 6.1.</b>	Data representing the layout of test substation 1.	106
<b>Table 6.2.</b>	Data representing the layout of test substation 2.	108
<b>Table 6.3.</b>	Data representing the layout of test substation 3.	111
<b>Table 6.4.</b>	Data representing the layout of test substation 4.	114
<b>Table 6.5.</b>	Data representing the layout of test substation 5.	116

# 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 20<sup>th</sup> 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.

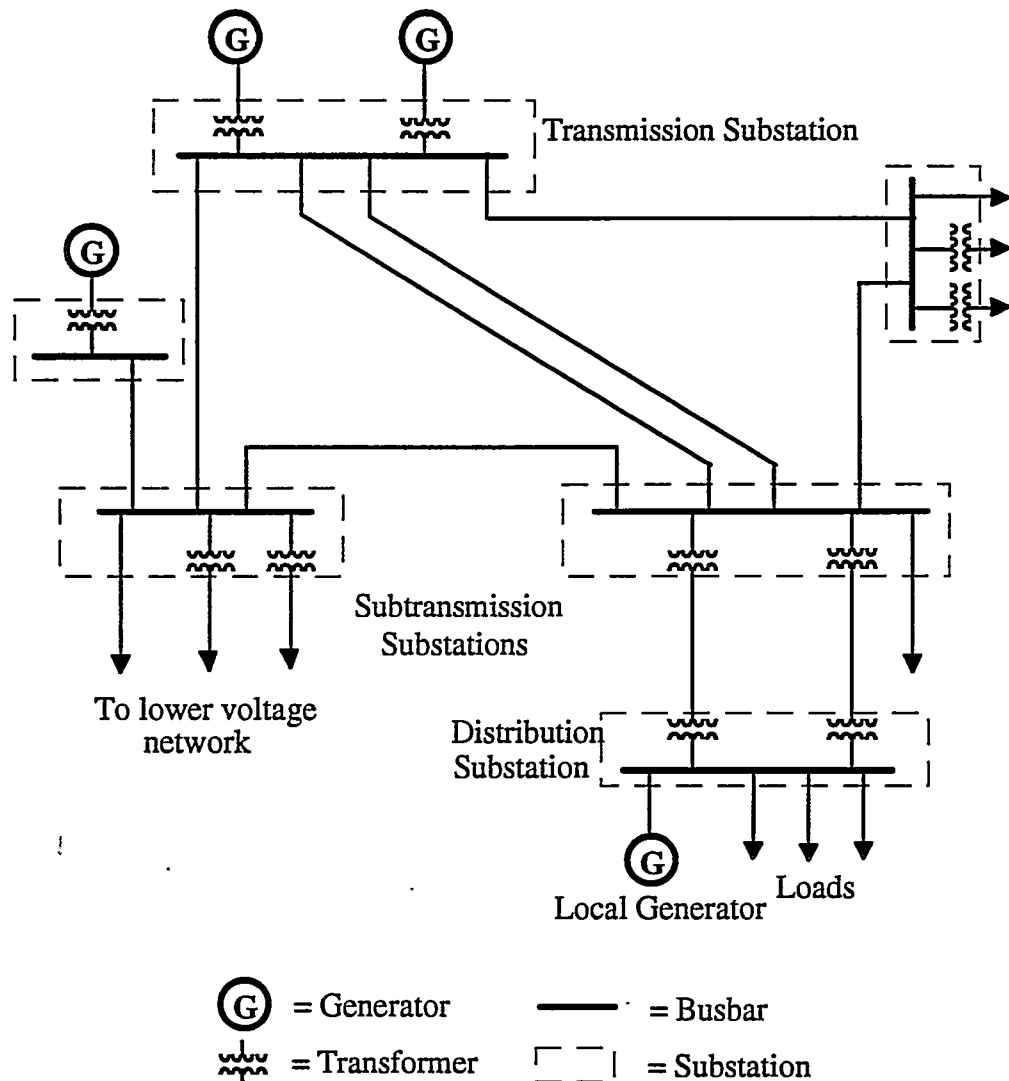
### **2.2. Substations**

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**

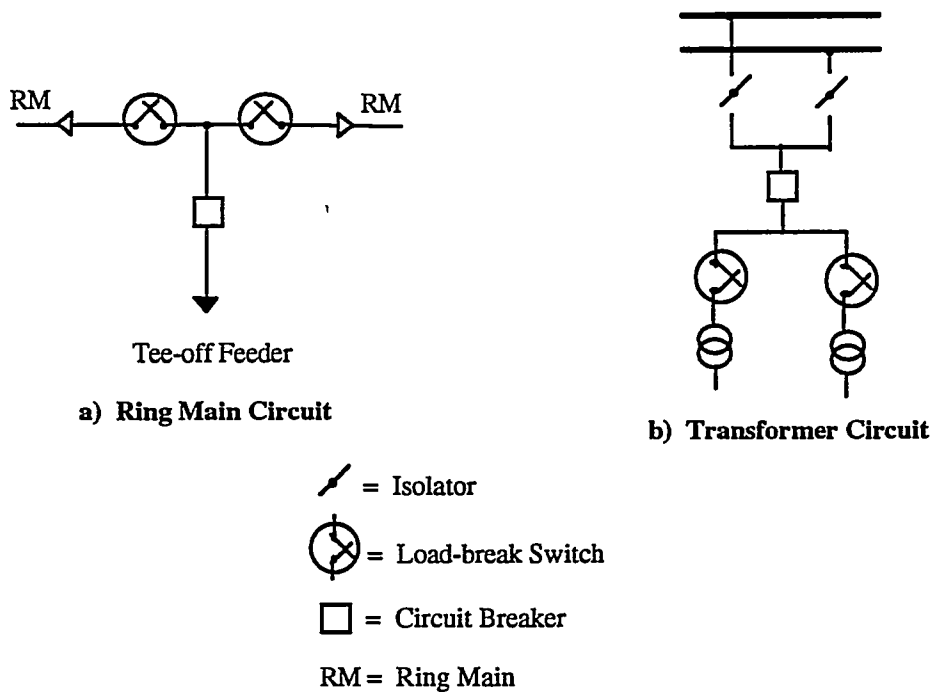
Load-break switches can open a circuit carrying full load currents but can not interrupt fault currents. They can sometimes substitute circuit breakers and provide switching facilities which cannot be provided by isolators. The cost of a load-break switch is approximately one third of the cost of a circuit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

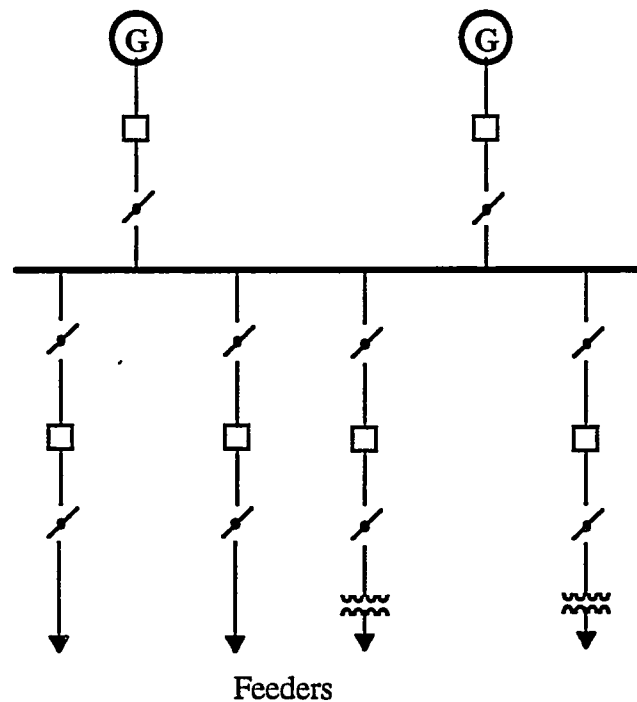
Substations differ in their configurations because of various reasons, such as their importance, voltage level, number of circuits and economic considerations. In this section, major substation configurations are introduced and their advantages and disadvantages are described.

### **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.

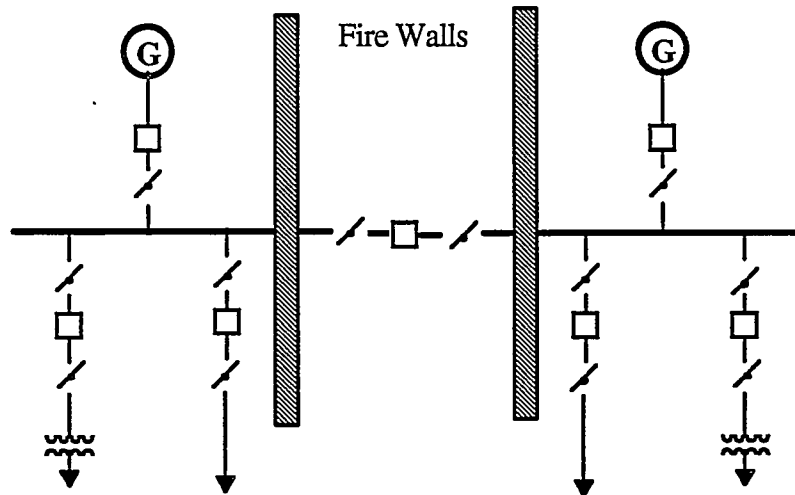


**Figure 2.3.** A typical single-busbar system.

### 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.