Relay Co-ordination of EHV, HV, MV and LV Systems of A Typical Thermal Power Station

Major Project Report

Submitted in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

RUCHI SHAH
13MEEE22

DEPARTMENT OF ELECTRICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481
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Undertaking for Originality of the Work

I, **Shah Ruchi Nipambhai (Roll.No.13MEEE22)**, give undertaking that the Major Project entitled **"Relay Co-ordination of EHV, HV, MV and LV Systems of a Typical thermal Power Station"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electrical Power Systems of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Certificate

This is to certify that the Major Project Report entitled **"Relay Co-ordination of EHV, HV, MV and LV Systems of a Typical Thermal Power Station"** submitted by **Ms. Ruchi Shah (Roll No:13MEEE22)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

In any thermal power station, auxiliary equipment plays vital role in smooth operation. Majority of the auxiliaries are HT/LT motors, distribution transformers etc. Auxiliary load of thermal unit is fed through unit transformers and station transformers. Transformers have unit protections such as differential, restricted earth fault and short circuit which operates instantaneously. Over-current and earth fault protections are provided in addition to unit protections. These protection relays are coordinated with down stream relays such that relay nearest to fault will operate first.

For proper protection, proper co-ordination of relays with appropriate relay settings is to be done. However the review of relay co-ordination is always essential since various additions/deletion of feeders and equipments will occur after the initial commissioning of plants. As power can be received from generators of power plant, the analysis becomes complex. Relay co-ordination can be done after selecting proper plug setting multiplier(PSM) and time multiplier setting(TMS) of the relay, considering maximum fault current at the relay location. Thus, for relay co-ordination it is necessary to analyze the system under steady state and having short circuit analysis. Time coordination is done in such a way that no upstream relay will operate first. With the help of IDMT over-current relay, one can calculate required time setting on having the short circuit currents, pickup currents and operating time required.

This thesis includes the simulation of a working system of a typical thermal power station, with the short circuit analysis performed for single phase to ground fault, development of relay logic for the same and later having relay co-ordination from the obtained results.

Nomenclature

bck .... Backup

O/C .... Opening and Closing

T_R .... Operating Time of Relay

$T_{R,5}$ .... Operating Time of Relay 5

$T_{R,5bck}$ .... Operating Time of Relay 5bck

$T_{R,3}$ .... Operating Time of Relay 3

$T_{R,3bck}$ .... Operating Time of Relay 3bck

$T_{R,6}$ .... Operating time of Relay 6

$T_{R,6bck}$ .... Operating Time of Relay 6bck

$T_{R,7}$ .... Operating Time of Relay 7

$T_{R,7bck}$ .... Operating Time of Relay 7bck

$T_{R,4}$ .... Operating Time of Relay 4

$T_{R,4bck}$ .... Operating Time of Relay 4bck

T_1 .... Transformer 1

T_2 .... Transformer 2

T_3 .... Transformer 3

T_4 .... Transformer 4

T_5 .... Transformer 5

Abbreviations

PSCAD . . . . . Power Simulation Computer Aided Design
SLD . . . . . Single Line Diagram
GT . . . . . Generator Transformer
EHV . . . . . Extra High Voltage
HV . . . . . High Voltage
MV . . . . . Medium Voltage
LV . . . . . Low Voltage
PSM . . . . . Plug Setting Multiplier
TMS . . . . . Time Multiplier Setting
PS . . . . . Plug Setting
HT . . . . . High Tension
LT . . . . . Low Tension
IDMT . . . . . Inverse Definite Minimum Time
L-L . . . . . Phase to Phase
L-L-L . . . . . All three phases short circuited
L-G . . . . . Single Phase to ground
L-L-G . . . . . Two phase to ground fault
L-L-L-G . . . . . All three phases to ground

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Chapter 1

Introduction

Adani Power Limited is the number one thermal power producer in India. It established first unit at Mundra in 2006. Today it is the leading Indian private power sector. They have been planning to achieve 20000 MW by 2020. Various domains in which Adani Power is linked to are engineering, procurement, construction, commissioning, operations and maintenance and transmission of large size supercritical units. Adani Power has also entered a 40 MW solar project. With a total capacity of 4620 MW, Mundra plant comprises of four 330 MW and five 660 MW units are installed with flue gas desulphurization facility. Apart from Mundra, it has its power plants at Tiroda and Kawai. In Bhadreshwar-Dahej, it is under planning etc. One of this units, unit of 330 MW is shown in the form of SLD model developed in PSCAD. From the major generation, only some portion is used to run the auxiliaries and rest of the power is send to grid and further to GETCO lines. The IDMT relays are employed to protect the power system against fault current. The short circuit analysis is done for the developed system, followed by development of relay logic to have the relay co-ordination from the short circuit results.

1.1 Objective

The main objective of project work is to analyze the system under steady state condition, to calculate short circuit currents at each bus in order to have proper relay co-ordination throughout the system.

- Power flow studies are necessary for scheduling future expansion of power systems as well as in determining the best operation of existing systems.
- A short circuit study will help to guarantee that personnel and equipment are protected by establishing proper interrupting ratings. When an electrical fault goes beyond the interrupting rating of the protective device, the consequences can be destructive, including injury, damaged electrical equipment etc.
- A co-ordination study maximizes power system selectivity by detaching faults to the nearest protective device, as well as helping to avoid malfunctioning that are due to transformer inrush or motor starting operations.

1.2 Methodology

- Literature survey.
- Simulation of single line diagram of a typical thermal power station(330 MW, 24 kV) in PSCAD 4.5
- Analyzing the short circuit current.
- Relay coordination(of EHV, HV, MV and LV systems) after knowing the fault currents at different buses.

1.3 Scope of Work

The present system that is developed in PSCAD software can be used to perform the transient stability in a similar fashion as done presently for short circuit analysis.

1.4 Outline Of Thesis

- **Chapter 1** This chapter gives an overview of the entire project which includes the introduction, objective, methodology to be followed, scope of the proposed work and the briefing of literature survey which is the base to build up the entire project.

- **Chapter 2** This chapter explains about the literature survey that is done for the project work.
- **Chapter 3** This chapter explains about about the main protection system which is used to protect the system from through fault currents and the other protection schemes available along with the types of faults that occur in the power system and the need for the protection system.
- **Chapter 4** This chapter explains the entire system that is being developed in the software based on the data available and the theoretical short circuit calculations that are done based on that data.
- **Chapter 5** This chapter explains about the simulated results for the short circuit current and the comparison between theoretical and simulated results which concludes that the simulated and calculated results fairly matches.
- **Chapter 6** This chapter explains that on having developed the relay logic, we get the operating time for the primary(main) relay and the back up relay. The co-ordination is done in such a way that no back up relay should operate first thus avoiding mal-operation. The graphs are obtained for fault currents at different buses and so from that we get the operating time for different relays.
- **Chapter 7** This chapter explains about the conclusion that can be made from the project and the future scope of the project.

Chapter 2

Literature Survey

For the better understanding of project, literature survey plays a very important role. Literature Survey consists of papers referred which gives fundamental knowledge of Power System Protection and Relay Coordination .

- **Y.G. Paithankar and S.R. Bhide** [1]A book entitled "Fundamentals Of Power System Protection" gives information about the Over-current protection of transmission lines which discusses about various protective device, relays used for protection(Over-current relays).

- **Badri Ram** [2] A book entitled "Power System Protection and Switchgear" which discusses about the different fault current calculation.

- **B.R. Gupta** [3] A book entitled "Power System Analysis and Design" which discusses about the short circuit calculation for symmetrical and unsymmetrical faults.

- **A. J. Mazon, K. J. Sagastabeitia and J. J. Zamora** [8] The paper "New Method for Detecting Low Current Faults in Electrical Distribution Systems" which discusses a new methodology, for the detection of low current single phase faults in radial distribution systems.

- **Saeed Lotfi-fard, Jawad Faiz and Reza Iravani** [4] The paper entitled "Improved Over-current Protection Using Symmetrical Components" which discusses the concept of symmetrical components to discriminate fault from non fault events using EMTDC/PSCAD software.

- **T.L. Baldwin, L. Mili M.B. Boisen, Jr. R. Adapa** [5] The paper entitled "Optimal Coordination of Directional Over-current Relays Considering Definite Time Backup Relaying" which discusses methodology that is presented for the consideration of definite time backup relays in the optimal coordination of directional over current. It is shown that the influence of considering second-zone distance relays and breaker failure relays impose important requirements for the determination of the time dial settings of directional overcurrent relays

- **Arturo Conde Enri queza, Ernesto Va zquez-Martineza and Hector J. Altuve-Ferrerb,** [6] The paper entitled "Time Over current Adaptive Relay" which recommends an inverse time over-current adaptive relay. This adaptive relay has a greater sensitivity and reduced operating times using only the information available at the relays site.

Chapter 3

Power System

3.1 Introduction

This chapter briefs about the basics of power system, what are the different different types of faults and what is the need of protection system.

3.2 Basics of Power System

- A power system comprises of different electrical components such as generating units, transformers(power and distribution), distribution feeders, transmission lines, isolators, relays, bus bars, circuit breakers, cables, instrument transformers, different types of loads etc [2].

- Faults can transpire in any part of power system such as earth fault and short circuit fault. Faults can be of the following types- phase to phase(L-L), two phase to ground(L-L-G), single phase to ground(L-G), three phase short circuited(L-L-L) etc which results in flow of heavy fault current through the system [2]. Fault level also relies on the fault impedance which in turn relies on the location of fault as seen from the source side. In order to calculate fault level at various parts in the power system, fault analysis is necessary [2].

- The protection system operates and detaches it from the the faulty part. The operation of the protection system should be rapid and also selective i.e. it should detach only the faulty section in the least or shortest possible time causing minimum harm to the system [3]. Also, there should be a backup protection if the main protection fails to function for which appropriate relay co-ordination is necessary. The system must be protected against flow of heavy short circuit currents which cause eternal damage to the equipments if not cleared within specific period [3]. For this purpose circuit breakers and protective relaying is offered to detach the faulty section of the system. Switchgear and protection devices are mounted at each voltage level for normal routine switching, control and monitoring and automatic switching during abnormal conditions like short circuits, over-current etc [3].

3.3 Requirement for Protection of Power System

Modern power systems are emerging with more transformers, generators and huge network in the systems. In order to protect the system, a high degree of reliability is required and for that need for trustworthy protective devices such as relays and circuit breakers comes in order to protect the system from harm, due to fault currents or abnormal voltages caused by faults [10]. The most common electrical danger against which protection needed, is the short circuit [10]. Protection is also necessary against overloads, under-voltage, open-phase, over-voltage, under and over-frequency, instability etc [10].

- Faults:- A fault in electrical equipment is defined as a undesirable condition in the electrical circuit due to which current is diverged from its intended path. As the fault impedance is low, so fault currents are relatively high [10]. In an electrical power system consisting of generator, transformer, transmission lines, load and switchgear, faults are usual [10].

- Its effects:- The nature of faults indicates any undesirable condition which causes a diminution in basic insulation strength between conductors [10]. Faults in certain imperative equipment can affect stability of power system [10]. During fault, voltages of three phases become unbalanced. For example, if a fault occurs in a motor, the motor winding is possible to get destroyed. Further if motor is not disconnected rapidly, excessive fault currents can cause injury to starting equipment, supply connections etc [10]. A fault in bus zone of power station can cause tripping of all generator units in power station.

- Following are the conditions for which protection is required :
- Overload
- Short Circuit
- Over temperature
- Reversal of power
- Under-voltage and Over-voltage

3.4 Types of Fault

3.4.1 Symmetrical Faults

The fault involving all three phases is called as a symmetrical(balanced) fault. Types of symmetrical faults:-

a. When all three phases are short circuited(L-L-L) [2]. This type of fault occurs infrequently. This type of fault offers the most severe duty on circuit breakers and therefore used in deciding circuit breaker ratings. It is an important type of fault with easy calculations [2].

b. All three phases to ground(L-L-L-G)

3.4.2 Unsymmetrical Faults

The fault which involves one or two phases is called as an unsymmetrical(unbalanced) fault. These types of faults occur normally in the power system [2]. Types of unsymmetrical faults:-

- Phase to phase(L-L)
- Single phase to ground(L-G)
- Two phases to ground(L-L-G)
- Phase to phase and third phase to ground

3.5 Summary

Thus, this chapter explains about about the main protection system which is used to protect the system from through fault currents and the other protection schemes available along with the types of faults that occur in the power system and the need for the protection system.

Chapter 4

System Description & Theoretical Calculations

4.1 Introduction

This chapter briefs about the system developed and the theoretical calculations for the short circuit current that are calculated from the data.

4.2 Description of the SLD model of a typical Thermal Power Station developed in PSCAD 4.5

A entire diagram of a power system representing all the three phases becomes very much convoluted and cumbersome for a system of practical size. Hence it is much more practical to symbolize a power system for each component. This representation is called a single line diagram. In this diagram, generator is represented by a circle, transmission line by single horizontal line and bus-bar by single vertical line. Generator and transformer connections such as star, delta and neutral earthing are shown by a symbol drawn by the side of their representation. Ratings of the generators, transformers and motor are mentioned below the diagram as shown in Fig.4.1 below:-

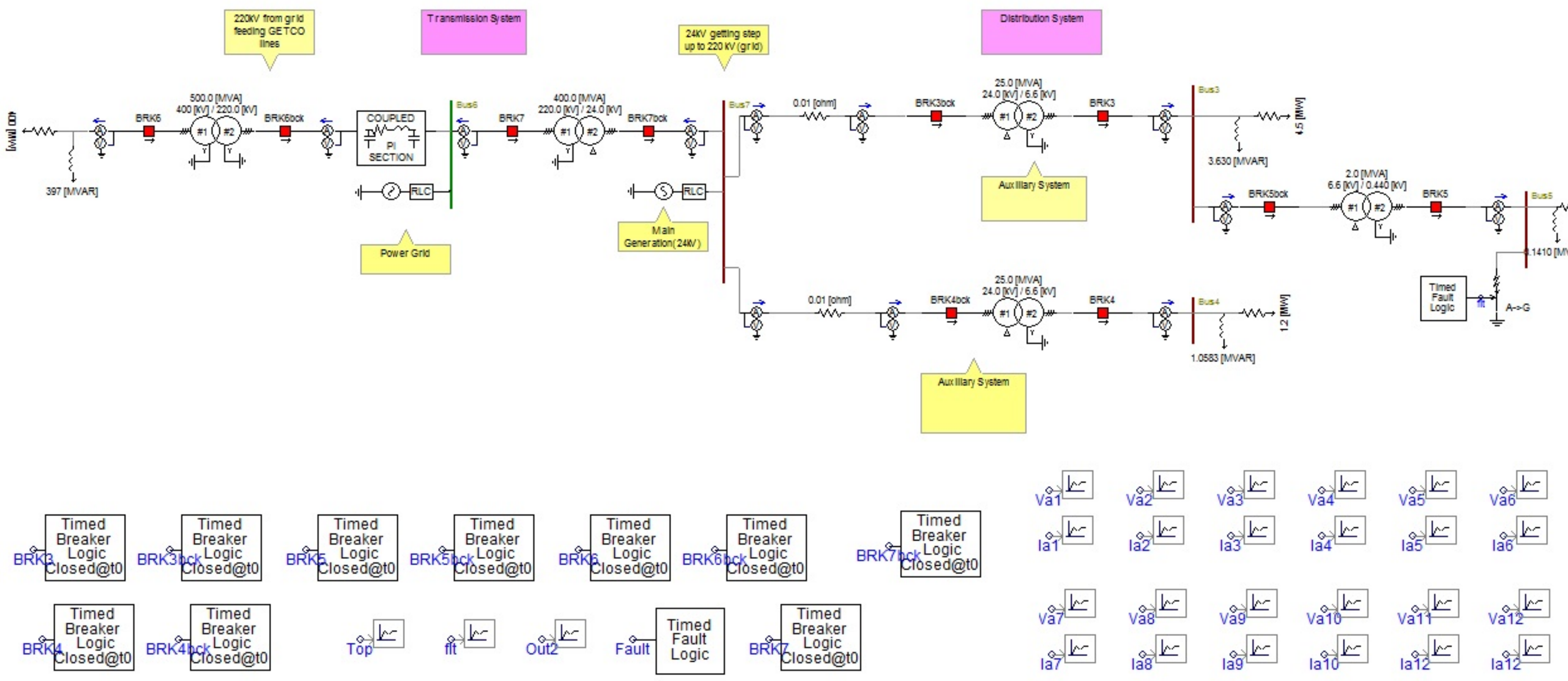

Figure 4.1: Single line diagram of a typical Thermal Power Station(for combined transmission and distribution system)

4.2.1 Normal Condition

In this thermal power station, power is generated by a generator acting as a source which produces 330 MW at 24kV. The power produced is transmitted to grid using step up transformer(220 kV). This step up transformer is called generator transformer(GT). This generator voltage(24 kV) is send to the power grid via step-up transformer T_1 upto 220 kV to reduce transmission losses which is further send to GETCO via step-up transformer T_5 to 400 kV though transmission lines which forms a transmission system. The generator auxiliary comprises of HT load (6.6 kV), LT load(440 V) which is fed through unit transformer(UT) which steps down the voltage to 6.6 kV(T_2 and T_3 respectively) and further by transformer T_4 to 440 V to run the auxiliary system. The model developed representing 330 MW thermal power station also consists of 3 Motors represented by an RL Load. The SLD developed above includes IDMT relays to protect the system against fault condition such as phase to earth fault or phase to phase fault. It includes overall 10 relays and 10 breakers including main relays and breakers and backup relays and breakers. At a time maximum two breakers are considered for time co-ordination at any fault point. For fault at Bus 5, on distribution side, the primary breaker is Brk5 and backup breaker is Brk5bck for maximum fault current at Bus 5. Similarly for fault at Bus 3, the primary breaker is Brk3 and backup breaker is Brk3bck for maximum fault current at Bus 3. Further for fault at Bus 6 on transmission side, the primary breaker is Brk7 and backup breaker is Brk7bck for maximum fault current at Bus 6 and lastly for fault at load side(400 kV) on transmission side, the primary breaker is Brk6 and backup breaker is Brk6bck for maximum fault current at load side(400 kV).

4.2.2 Abnormal Condition

Fault is nothing but an unexpected condition in electrical system because of which current is diverged from its deliberated path. As the fault impedance is low so the fault currents are relatively high [10]. At the time of faults, power flow is diverted towards the fault and the supply to the neighboring zone is affected. Circuit breakers are employed in power system so that it can segregate the faulty section from the healthy part and to maintain continuity of supply [10].

4.3 Short Circuit Analysis

- A short-circuit fault in a power system is an undesirable condition that includes one or more phases that are coming unintentionally in contact with ground or each other. Thus, short-circuit protection is necessary to protect apparatus and personnel from the devastating effects of the resulting extreme current flow, which is caused by the relatively low impedance of the short-circuit fault connection. In order to provide the required protection, we must determine the extent of short-circuit current at various points of our power distribution system.

a. Sources of fault current: The fault current can emerge from rotating electric machinery, which is normally in the form of condensers, synchronous generators, synchronous motors, electric utility systems and induction machines. The magnitude of fault current from these sources is limited by the impedance of the machine itself as well as the impedance between the machine and the fault itself [10].

b. The basics: A balanced 3-phase fault means that all three phases of the power system are simultaneously short-circuited to each other through a direct connection. Although the probability of this happening is less, relative to the probability of other types of unbalanced faults occurring(e.g. phase-to-ground and phase-to-phase faults).

4.3.1 Theoretical Calculation for Short Circuit Current at Bus 5(unsymmetrical fault)

Let Base MVA=100, Base MV=24

$$Base\ \ Current\ \ I = \frac{BaseMVA}{\sqrt{3} * BaseKV} \tag{4.1}$$

$$I = \frac{100}{\sqrt{3} * 24 * 10^{-3}} \tag{4.2}$$

$$I = 2.40 * 10^{3} \tag{4.3}$$

$$I = 2405.626\ \ A \tag{4.4}$$

$$Now, I_{a1} = I_{a2} = I_{a0} = \frac{1\angle 0}{0.14j + 0.14j + 0.04j} \tag{4.5}$$

$$Fault\ \ Current\ \ I_a = 3I_{a1} \tag{4.6}$$

$$= 3 * (-j3.125)\ \ pu \tag{4.7}$$

$$= -j9.375\ \ pu \tag{4.8}$$

$$= j9.375 * 2405.626\ \ pu \tag{4.9}$$

$$= 22552.74\angle -90 \tag{4.10}$$

$$= 22.55\ \ kA \tag{4.11}$$

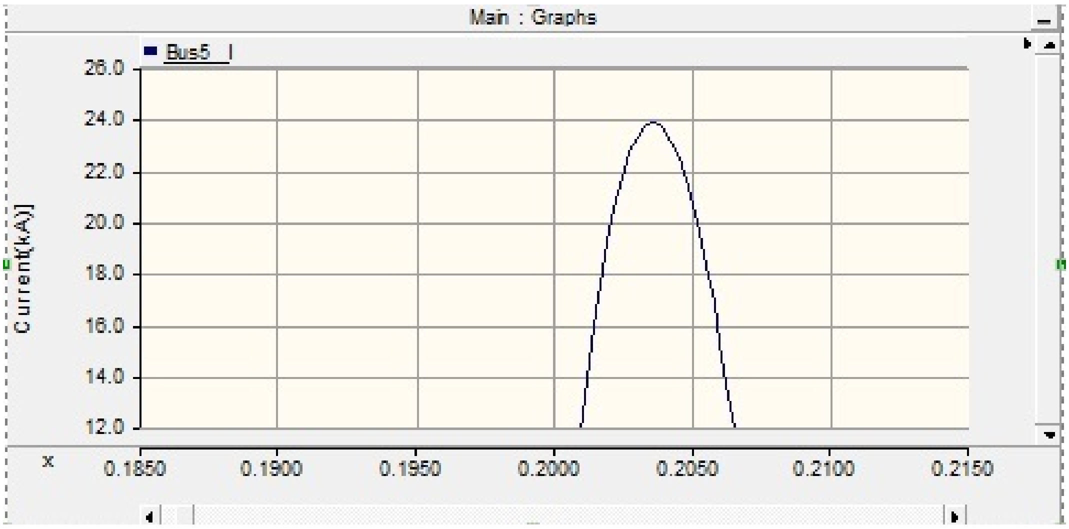

Figure 4.2: Current waveform after creating fault on Bus5 for L-G fault

- The above graph explains that the short circuit current obtained after simulation in the above figure is 24 kA and that obtained after calculation is 22.55 kA which indicates that both theoretical and practical calculations are almost similar.

Here calculations are shown for short circuit current at Bus 5. Similarly short circuit calculations are to be done for the rest of the buses similarly as done for Bus 5.

4.4 Summary

Thus, this chapter explains the entire system that is being developed in the software based on the data available and the short circuit calculations that are done based on that data.

Chapter 5

Simulations and Results

5.1 Introduction

This chapter explains about the simulated results of short circuit currents at each bus for the system developed.

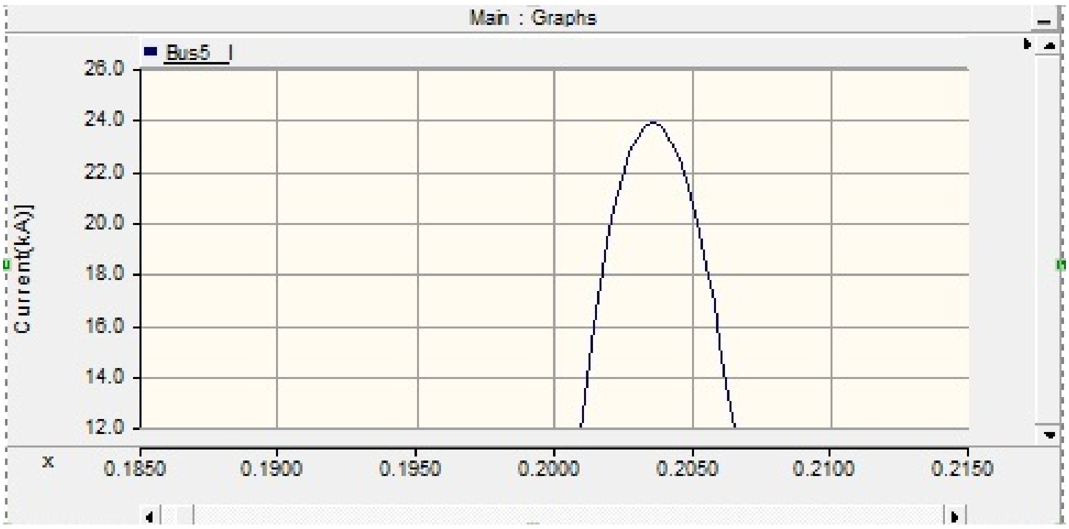

Figure 5.1: Short circuit current on Bus5 for L-G fault

- The above graph explains that the short circuit current obtained after simulation on Bus 5 is 24 kA and that obtained after theoretical calculation is 22.55 kA which indicates that both theoretical and practical calculations are almost similar.

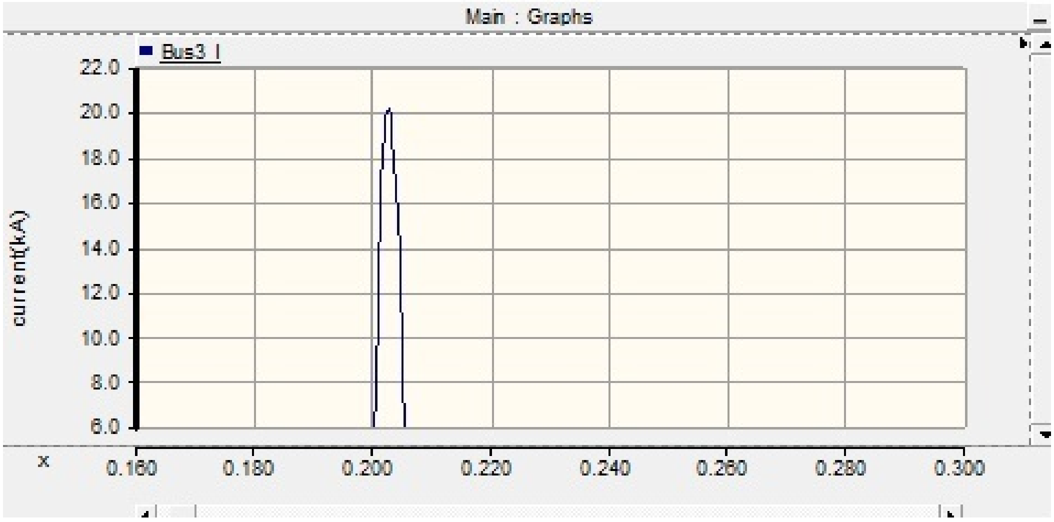

Figure 5.2: Short Circuit Current on Bus 3 for L-G fault

- The above graph explains that the short circuit current obtained after simulation on Bus 3 is 21.869 kA and that obtained after theoretical calculation is 20 kA which indicates that both theoretical and practical calculations are almost similar.

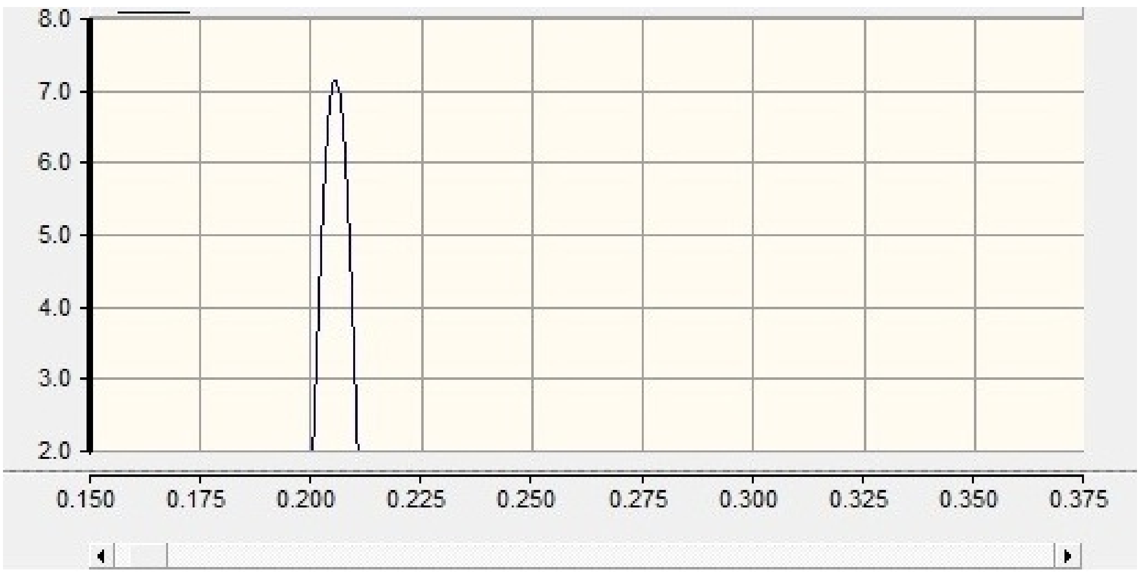

Figure 5.3: Short Circuit Current on Bus 6 for L-G fault

- The above graph explains that the short circuit current obtained after simulation on Bus 6 is 7 kA and that obtained after theoretical calculation is 10 kA which indicates that both theoretical and practical calculations are almost similar.

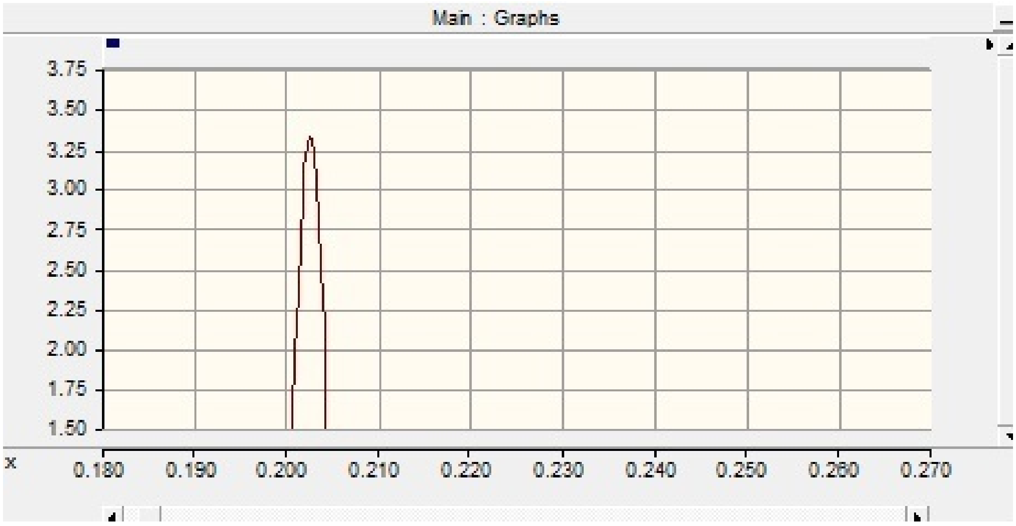

Figure 5.4: Short Circuit Current on load side(400kV) for L-G fault

- The above graph explains that the short circuit current obtained after simulation on load side(440kV) is 3.33 kA and that obtained after theoretical calculation is 4.373 kA which indicates that both theoretical and practical calculations are almost similar.

Table 5.1: Short Circuit Current at different buses

Sr.No	Actual Results	Simulated Results
At Bus 5(LV)	22.55 kA	24 kA
At Bus 3(MV)	21.86 kA	20 kA
At Bus 6(HV)	10 kA	7 kA
At load side(400 kV-EHV)	4.373 kA	3.33 kA

5.2 Summary

Thus, this chapter explains about the simulated results for the short circuit current and the comparison between theoretical and simulated results which concludes that the simulated and calculated results fairly matches.

Chapter 6

Relay co-ordination & Development of Relay Logic

6.1 Introduction

This chapter explains about the basics of relay co-ordination and the relay logic that is being developed for the IDMT relays for different fault currents. This logic is based on the inverse relation between operating time and fault current.

6.2 Relay co-ordination

- Relay co-ordination plays a vital role in the protection of power system. Proper co-ordination of relays with appropriate relay settings is to be done, for appropriate protection. Relay settings are made in such a way that proper co-ordination is attained along various series network.

- Relay co-ordination can be done by opting of proper TMS and PSM, considering maximum fault current at the relay location. After opting the plug setting and time multiplier setting, the co-ordination can be checked through graph.

- The operating time of IDMT relay is determined by its plug and time multiplier settings for a given fault current. Thus this type of relay is most suitable for proper coordination.

- The following things must be known In order to calculate the actual relay operating time.

a. Time Setting

b. Fault Current

c. Plug Setting

d. Current Transformer Ratio

e. Time/PSM Curve

6.3 Development of RELAY LOGIC

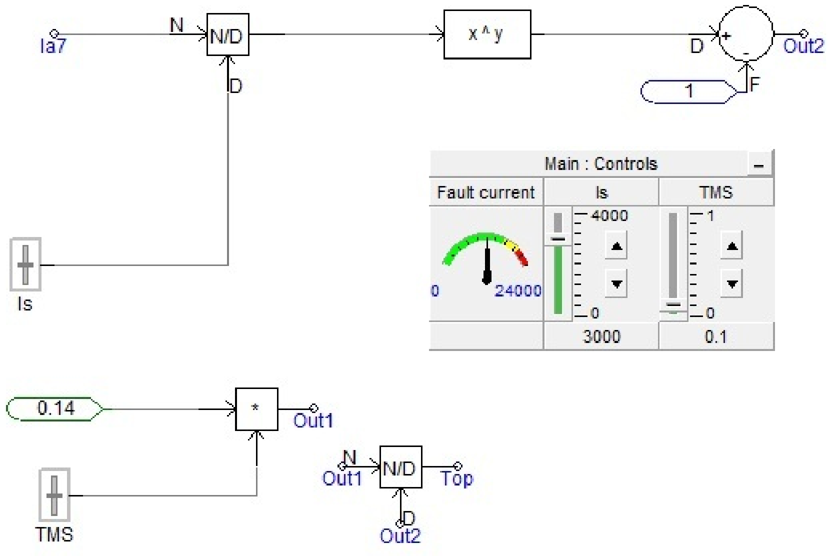

Figure 6.1: Relay Logic (for fault current at Bus 5)

The above logic as shown in Fig6.1 explains as to how the IDMT relay would work based on its characteristics of inverse relationship of current and time. The formula for having the IDMT characteristics is :-

$$Operating\ \ Time\ \ of\ \ Relay\ T_R = \frac{0.14(TMS)}{PSM)^{0.02} - 1} \tag{6.1}$$

Where TMS is the time multiplier setting which decides the operating time of the relay and PSM is the Plug Setting Multiplier which decides the current required by the relay to pickup.

$$PSM = \frac{I_{relay}}{PS(plugsetting)} \tag{6.2}$$

The relay logic developed above is just shown for fault current at Bus 5. This logic can be similarly shown for fault currents at different buses. On giving the signal of the corresponding fault current at that bus and applying to the logic developed, we get the required operating time of the main relay as well as the back up relay. The fault currents here are shown for the case of single phase to ground(L-G) fault. The same calculation can be done for the rest of the conditions(i.e L-L, L-L-L, L-L-G etc).

6.4 Calculation for operating time of Relays

6.4.1 Operating Time for Relay 5 for maximum fault current at Bus 5 $T_{R,5}$ for LV systems

$$T_{R,5} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.3}$$

Assuming TMS equals to 0.1 and PS(Plug Setting) equals to 100 %

The required operating time for Relay 5 $T_{R,5}$ for maximum fault current at Bus 5

$$T_{R,5} = \frac{0.14(0.1)}{(24000/3000)^{0.02} - 1} \tag{6.4}$$

$$T_{R,5} = 0.329s \tag{6.5}$$

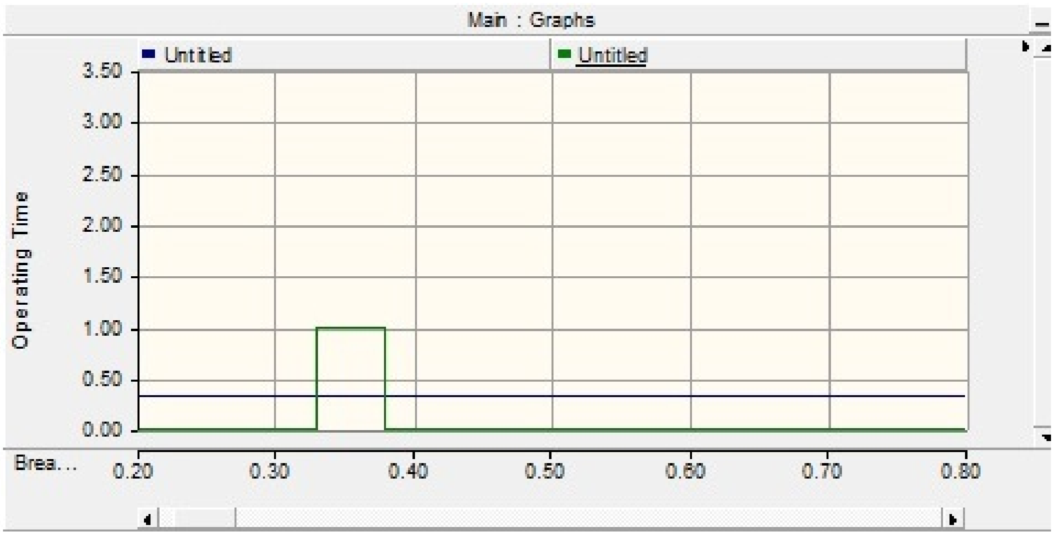

Figure 6.2: Graph for operation of Brk5

- The above graph explains that on having fault current at Bus 5, the breaker Brk5 will operate i.e. it will open at 0.329 s and will close after 0.05s i.e. at 0.379 s.

Assuming circuit breaker operating time + overshoot time + safety margin = 0.25 s

Thus, the required operating time for Relay 5bck $T_{R,5bck}$ for maximum fault at Bus 5 for LV systems

$$T_{R,5bck} = T_{R,5} + 0.25 \tag{6.6}$$

$$\Longrightarrow T_{R,5bck} = 0.329 + 0.25 \tag{6.7}$$

$$\Longrightarrow T_{R,5bck} = 0.571s \tag{6.8}$$

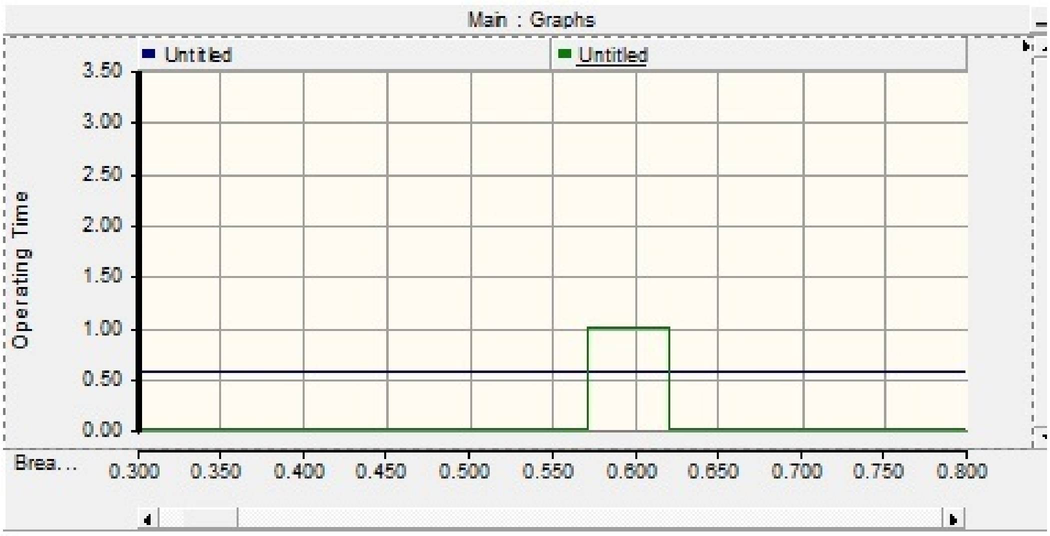

Figure 6.3: Graph for operation of Brk5bck

- The above graph explains that on having fault current at Bus 5, the breaker Brk5bck will operate in case the main breaker Brk5 fails to operate i.e. it will open at 0.571 s and will close after 0.05s i.e. at 0.621 s.

So, the TMS can be found out by following expression:
Operating Time for Relay 5bck $T_{R,5bck}$

$$T_{R,5bck} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.9}$$

$$WherePSM = \frac{24000}{3000} = 8 \tag{6.10}$$

$$0.571 = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.11}$$

$$\Longrightarrow TMS = 0.173 \tag{6.12}$$

6.4.2 Operating Time for Relay 3 $T_{R,3}$ for maximum fault current at Bus 3 for MV systems

$$T_{R,3} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.13}$$

Assuming TMS equals to 0.1 and PS(Plug Setting) equals to 100%

$$T_{R,3} = \frac{0.14(0.1)}{(10000/3000)^{0.02} - 1} \tag{6.14}$$

$$= 0.362s \tag{6.15}$$

The required operating time for Relay3 $T_(R,3)$ for maximum fault current at Bus 3 = 0.362 s

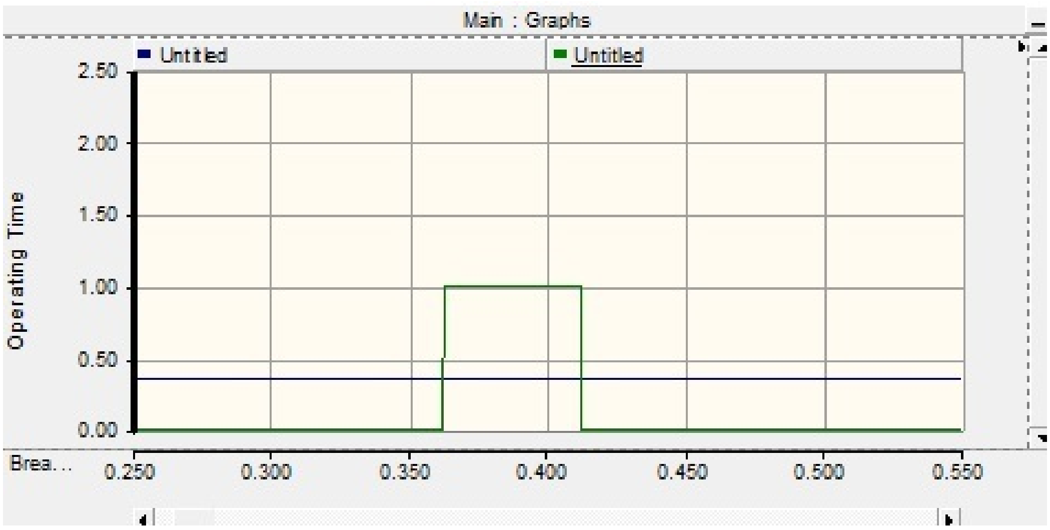

Figure 6.4: Graph for operation of Brk3

- The above graph explains that on having fault current at Bus 3, the breaker Brk3 will operate i.e. it will open at 0.362 s and will close after 0.05 s i.e. at 0.412 s.

Assuming circuit breaker operating time + overshoot time + safety margin = 0.25 s

Thus, the required operating time for Relay 3bck $T_{R,3bck}$ for maximum fault current at Bus 3 for MV systems

$$T_{R,3bck} = T_{R,3} + 0.25 \tag{6.16}$$

$$\implies T_{R,3bck} = 0.362 + 0.25 \tag{6.17}$$

$$\implies T_{R,3bck} = 0.612s \tag{6.18}$$

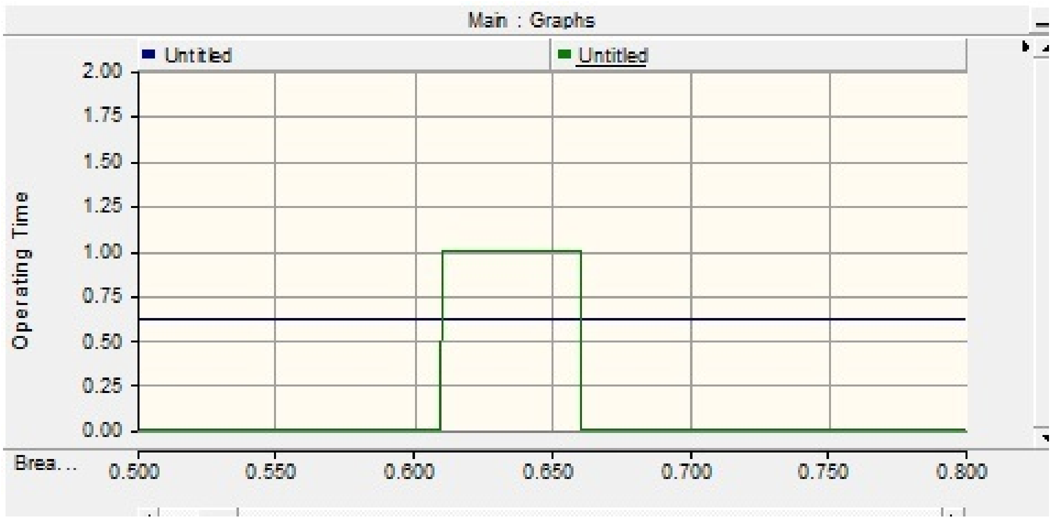

Figure 6.5: Graph for operation of Brk3bck

- The above graph explains that on having fault current at Bus 3, the breaker Brk3bck will operate in case the main breaker Brk3 fails to operate i.e. it will open at 0.612 s and will close after 0.05 s i.e. at 0.662 s.

So, the TMS can be found out by following expression:

Operating Time for Relay 3bck $T_{R,3bck}$

$$TR, 3bck = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.19}$$

$$Where PSM = \frac{20000}{1200} = 16.666 \tag{6.20}$$

$$0.61 = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.21}$$

$$\Longrightarrow TMS = 0.252 \tag{6.22}$$

6.4.3 Operating Time for Relay 7 $T_{R,7}$ for maximum fault current at Bus 6 for HV systems

$$T_{R,7} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.23}$$

Assuming TMS equals to 0.1 and PS(Plug Setting) equals to 100 %

The required operating time for Relay 7 for maximum fault current at Bus 6

$$T_{R,7} = \frac{0.14(0.1)}{(10000/1200)^{0.02} - 1} \tag{6.24}$$

$$T_{R,7} = 0.323s \tag{6.25}$$

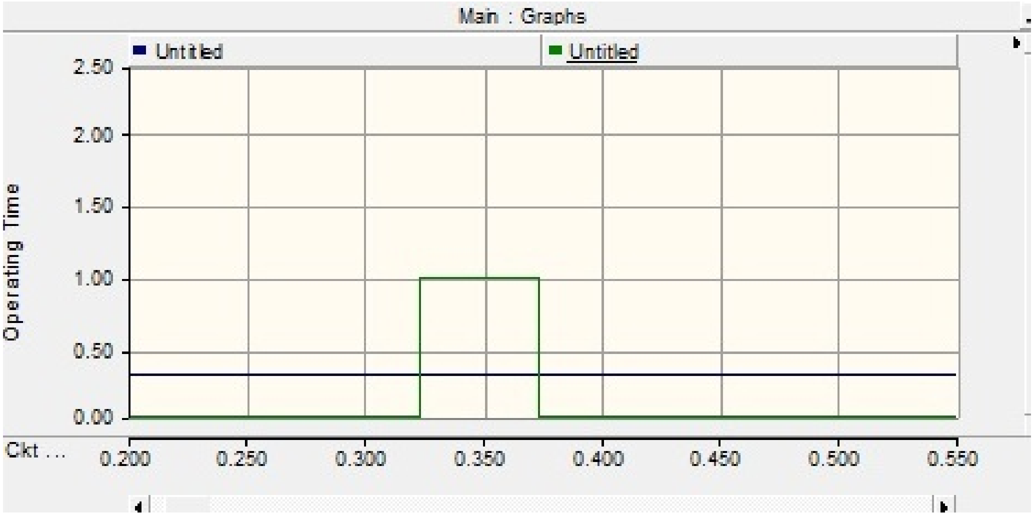

Figure 6.6: Graph for operation of Brk7

- The above graph explains that on having fault current at Bus 6, the breaker Brk7 will operate i.e. it will open at 0.323 s and will close after 0.05 s i.e. at 0.373 s.

Assuming circuit breaker operating time + overshoot time + safety margin = 0.25 s
Thus, the required operating time for Relay 7bck $T_{R,7bck}$ for maximum fault current at Bus 6 for HV systems

$$T_{R,7bck} = T_{R,7} + 0.25 \tag{6.26}$$

$$\implies T_{R,7bck} = 0.323 + 0.25 \tag{6.27}$$

$$\implies T_{R,7bck} = 0.573s \tag{6.28}$$

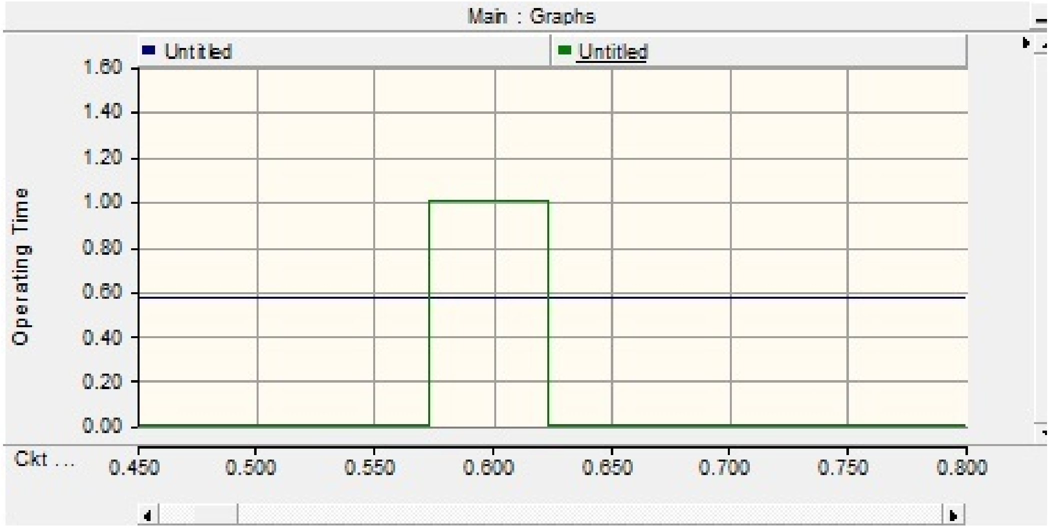

Figure 6.7: Graph for operation of Brk7bck

- The above graph explains that on having fault current at Bus 6, the breaker Brk7bck will operate in case the main breaker Brk7 fails to operate i.e. it will open at 0.573 s and will close after 0.05 s i.e. at 0.623 s.

6.4.4 Operating Time for Relay 6 $T_{R,6}$ for maximum fault current near load(440kV side) for EHV systems

$$T_{R,6} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.29}$$

Assuming TMS equals to 0.1 and PS(Plug Setting) equals to 100%

$$T_{R,6} = \frac{0.14(0.1)}{(3300/1000)^{0.02} - 1} \tag{6.30}$$

$$= 0.579s \tag{6.31}$$

The required operating time for Relay6 $T_{R,6}$ for maximum fault current near load side(400kV) = 0.579 s

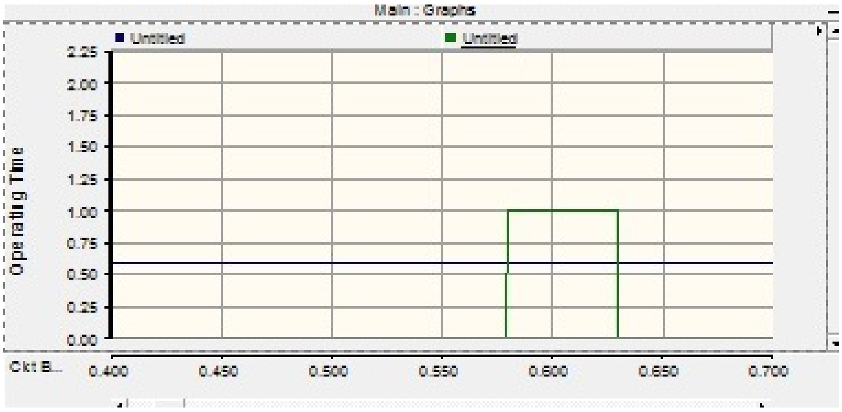

Figure 6.8: Graph for operation of Brk6

- The above graph explains that on having fault current at load side(440kV), the breaker Brk6 will operate i.e. it will open at 0.579 s and will close after 0.05 s i.e. at 0.629 s.

Assuming circuit breaker operating time + overshoot time + safety margin = 0.25 s

Thus, the required operating time for Relay 6bck $T_{R,6bck}$ for maximum fault current near load side(440kV) for EHV systems

$$\implies T_{R,6bck} = T_{R,6} + 0.25 \tag{6.32}$$

$$\implies T_{R,6bck} = 0.579 + 0.25 \tag{6.33}$$

$$\implies T_{R,6bck} = 0.829s \tag{6.34}$$

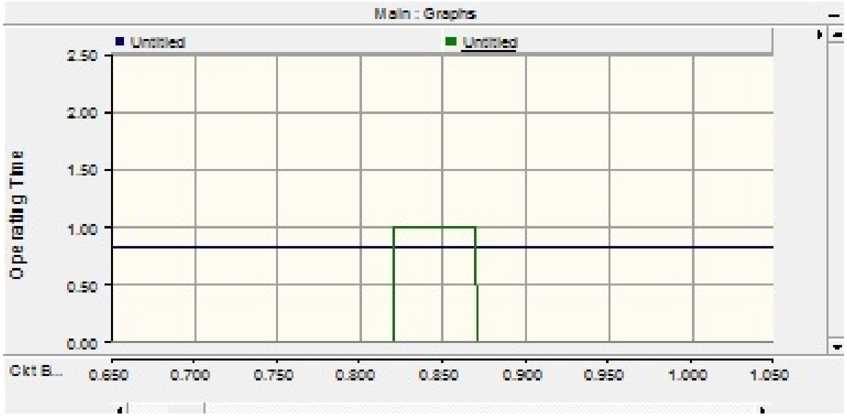

Figure 6.9: Graph for operation of Brk6bck

- The above graph explains that on having fault current at load side(440kV), the breaker Brk6bck will operate in case the main breaker Brk6 fails to operate i.e. it will open at 0.829 s and will close after 0.05 s i.e. at 0.879 s.

So, the TMS can be found out by following expression:

Operating Time for Relay 6bck $T_{R,6bck}$

$$T_{R,6bck} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.35}$$

$$wherePSM = \frac{3300}{1200} = 2.75 \tag{6.36}$$

$$0.829 = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.37}$$

$$\Longrightarrow TMS = 0.121 \tag{6.38}$$

6.4.5 Operating Time for Relay 4 $T_{R,4}$ for maximum fault current at Bus 4 for LV systems

$$T_{R,4} = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.39}$$

Assuming TMS equals to 0.1 and PS(Plug Setting) equals to 100%

The required operating time for Relay 4 $T_(R,4)$ for maximum fault current at Bus 4 = 0.362 s

$$T_{R,4} = \frac{0.14(0.1)}{(10000/3000)^{0.02} - 1} \tag{6.40}$$

$$= 0.362s \tag{6.41}$$

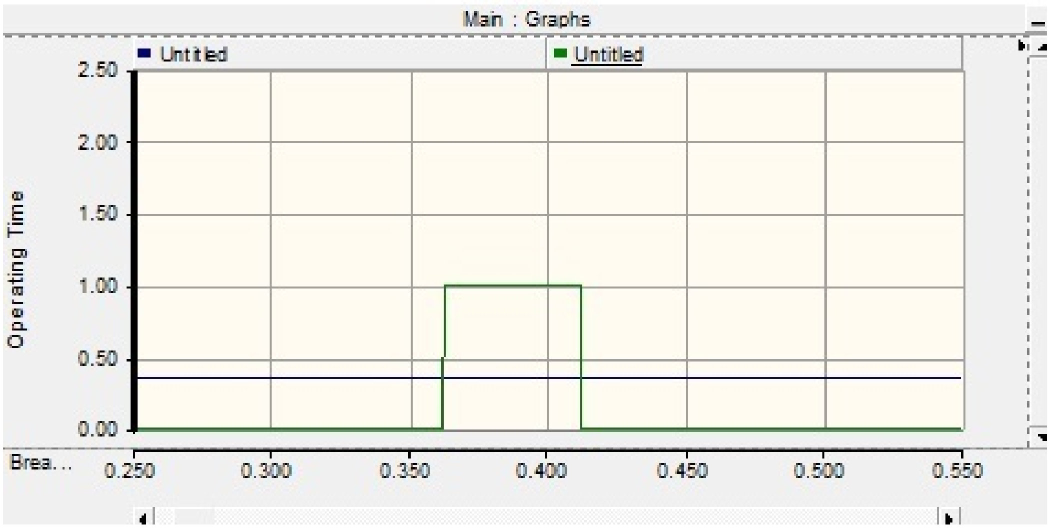

Figure 6.10: Graph for operation of Brk4

- The above graph explains that on having fault current at Bus 4, the breaker Brk4 will operate i.e. it will open at 0.362 s and will close after 0.05 s i.e. at 0.412 s.

Assuming circuit breaker operating time + overshoot time + safety margin = 0.25 s

Thus, the required operating time for Relay 4bck $T_{R,4bck}$ for maximum fault current at Bus 4 for LV systems

$$T_{R,4bck} = T_{R,4} + 0.25 \tag{6.42}$$

$$\implies T_{R,4bck} = 0.362 + 0.25 \tag{6.43}$$

$$\implies T_{R,4bck} = 0.612s \tag{6.44}$$

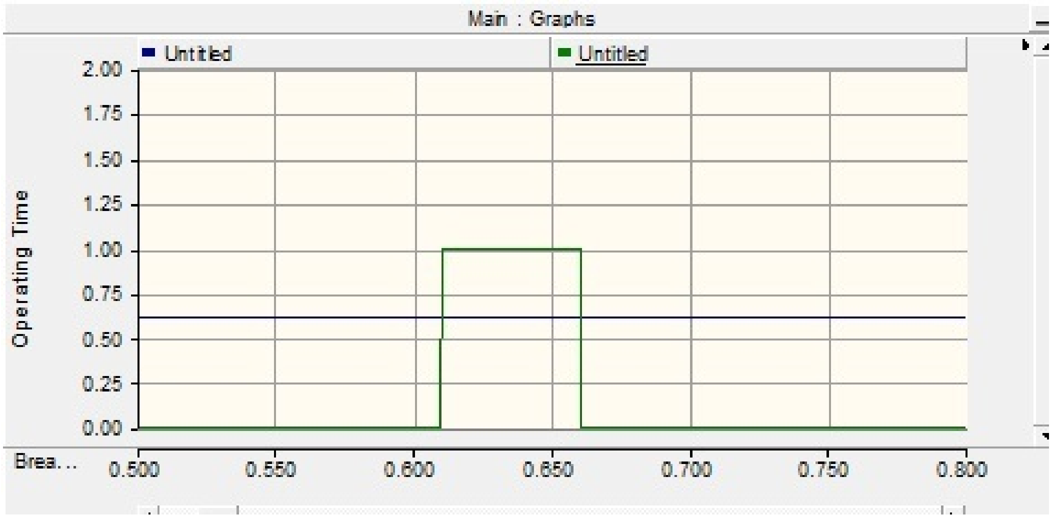

Figure 6.11: Graph for operation of Brk4bck

- The above graph explains that on having fault current at Bus 4, the breaker Brk5bck will operate in case the main breaker Brk4 fails to operate i.e. it will open at 0.612 s and will close after 0.05 s i.e. at 0.662 s.

So, the TMS can be found out by following expression:

Operating time for Relay 4bck $T_{R,4bck}$

$$TR, 4bck = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.45}$$

$$WherePSM = \frac{20000}{1200} = 16.666 \tag{6.46}$$

$$0.61 = \frac{0.14(TMS)}{(PSM)^{0.02} - 1} \tag{6.47}$$

$$\Longrightarrow TMS = 0.252 \tag{6.48}$$

Table 6.1: Operating time comparison of main relays and opening & closing time of main breakers

Sr.No	Main Relay	T_R	Main Breaker O/C Time
1	Relay 5	0.329	0.329 and 0.379
2	Relay 3	0.362	0.362 and 0.412
3	Relay 7	0.323	0.323 and 0.373
4	Relay 6	0.579	0.579 and 0.629
5	Relay 4	0.362	0.362 and 0.412

Table 6.2: Operating time comparison of backup relays and opening & closing time of backup breakers

Sr.No	Backup Relay	T_R	Backup Breaker O/C Time
1	Relay 5bck	0.571	0.571 and 0.621
2	Relay 3bck	0.612	0.612 and 0.662
3	Relay 7bck	0.573	0.573 and 0.623
4	Relay 6bck	0.829	0.829 and 0.879
5	Relay 4bck	0.612	0.612 and 0.662

6.5 Summary

Thus, this chapter explains that on having developed the relay logic and having the short circuit currents at each bus, we get the operating time for the primary(main) relay and the back up relay. The co-ordination is done in such a way that no back up relay should operate first thus avoiding mal-operation. The graphs are obtained for fault currents at different buses and so from that we get the operating time for different relays.

Chapter 7

Conclusion and Future scope

7.1 Conclusion

Any part of power system can be affected by faults such as short circuit and earth fault which results in the flow of heavy fault current through the system. Fault level also depends on the fault impedance which in turn depends on the location of fault referred from the source side. Fault analysis is essential in order to calculate fault level at various points in the power system.

- Actual working system of typical thermal power station is developed in the software PSCAD 4.5 and simulated for normal condition.

- Short circuit is carried out and the results almost matches with the calculated ones.

- Based on the results obtained, relay logic is being developed to have proper co-ordination between EHV, HV, MV and LV systems.

- According to relay logic developed, the relay operation time fairly matches with the actual system.

7.2 Future Scope

The present system that is implemented in PSCAD software can be used to perform the transient stability in a similar fashion as done presently for short circuit analysis.

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