Department of Electrical and Electronic Engineering

EEEN6007640076: Power System Protection

Overcurrent Protection Laboratory

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Contents

1 Executive Summary

Electrical Power System needs protection from abnormal occurrences called faults in the network. Different parts of the system are categorised into zones with primary and backup protection equipment assigned for each zone. The protection devices have built-in controls which is set by the user for it to identify faults. These settings are crucial, because it helps discriminate between normal condition and faulty condition. It should also prevent backup protection acting ahead of primary protection. Incorrect settings could cause catastrophic failures like system blackout, or permanent damage to large power system assets and customer equipment. It could also prematurely disconnect sect of customers at different zones. The study conducted in this project identifies the correct relay settings for the system, and discusses the merits and disadvantages of different combinations.

Over-current protection technique is used to isolate the faults in the given radial system by the client. Inverse Definite Minimum Time(IDMT) relays with Current Transformers are used to measure current, identify threshold crossing, and to send alarm signal during fault conditions. A Circuit Breaker(CB) receives the signal and acts upon it to isolate affected part of the system from the rest. At the leaf node of the system, fuses act as primary protection. The upstream relays acts as backup protection for the fuses as well as the downstream relays. The Plug Setting Multiplier(PSM) and Time Multiplier Setting(TMS) in relays decide the time of relay operation. For the relays R, S and T given in the client network, from upstream to downstream relays has PSM 325%, 550% and 725% chosen respectively. The TMS for the above relays, in a standard inverse setting is identified as 0.1, 0.15 and 0.2 respectively. The fuses and relays are graded with respect to time and current. The calculations are verified using PSCAD software simulations on model based power system network. Graphs and tables supporting the studies are also incorporated in the report.

Relay Coordination performed in this project has identified the necessary control settings for the relays to ensure primary and backup protection and is tested for different scenarios of fault magnitudes.

2 Introduction

2.1 Over-Current Protection

Over Current Relay(OCR) protection is one of the oldest techniques in Power System Protection. If magnitude of the current flowing in the system is above a certain threshold, then the faulty section of the system is isolated within a certain time frame. System current is measured using a Current Transformer(CT), which reduces the current range to the relay specifications. The secondary current of the CT is passed through a coil. The current carrying coil induces a magnetic field which produces a mechanical torque on a metallic disc prodding it into rotational motion. The mechanical torque on the disc is proportional to the magnetic field, which is proportional to the current the coil is carrying. Under normal operating conditions, the current magnitude is expected to be less than a certain threshold; and a restraining spring holds the disc from motion. During fault conditions, the current in the coil is expected to be high. Here, the moving disc is expected to make contact with the tripping lead by overcoming the restraining torque of the attached spring.

2.2 Time and Distance

The aforementioned type of OCR is an instantaneous one. Further delay to relay operations can be introduced by increasing the time taken to energise the relay disc, or by increasing the distance between disc contact and tripping lead. The former is achieved by adding resistance in front of the relay coil, thus forcing it to demand more current from the CT to operate. The latter is achieved by placing the tripping lead farther away from the disc contact. These settings are conventionally called as Plug Setting Multiplier(PSM) and Time Multiplier Setting (TMS) respectively.

3 Standard IDMT Analysis

3.1 Method and Assumptions

The relay coordination is performed by attempting to discriminate the operation time of fuses and relays with respect to time and current. This is done for a remote fault(farther away from relay) or a close-in/local fault(fault next to the relay). As the protection grading moves from downstream to upstream, the time of relay operation is expected to increase for a remote fault. For a close-in fault, the relay would see high current immediately and the operation time should be small. This is achieved by PSM and TMS calculation using Standard Inverse characteristics with the following assumptions:

- Higher values(above hundred) of current are rounded off to first significant figure
- Upstream relays are graded with respect to immediate downstream relays rather than the fuses

3.2 Fuse Characteristics

Operating time (s)	Current (A)
0.01	480
0.1	210
0.4	150
1	130
10	105

Table 1: Fuse Characteristics

3.3 Maximum Fault Current

For a 11kV system, the maximum fault current at each bus, where X_n is the magnitude of Thevinin impedance at the bus n, is calculated using the following equation:

$$I_f = \frac{11000 \times 0.5774}{X_n} \tag{1}$$

Bus number	Current (A)
4	1270
3	1587
2	2120
1	3180

Table 2: Maximum fault current at each bus

3.4 Fuse at leaf node

For a load of 0.5MW @ 11kV and assuming a resistive load the max load current is given by,

$$\begin{aligned} I_{fusemax} &= \frac{0.5 \times 10^6}{\sqrt{3} \times 11 \times 10^3} \\ &= 26.24A \end{aligned} \tag{2}$$

For a remote fault, that is beyond the fuse, the fault current at Bus 4, 1270A will flow through the fuse into the fault location. This would mean that the fuse will operate in time less than **0.01s** as per the characteristics mentioned in Table 1.

3.5 Relay T

3.5.1 PSM

The current setting of the relay is selected based on the following criteria:

$$(2 \times I_{maxLoad}) < I_{setting} < \frac{I_{fault}}{2} \tag{3}$$

For a 2MW load, using (2), maximum load current is 105A and maximum fault current is 1270A. By equation (3), the current setting $I_{setting}$ is chosen as 225A, such that: 210A < $I_{setting}$ < 635A. If I_N is the Rated primary current of the CT or the nominal current of the CT:

$$PlugSetting = \frac{I_{setting}}{I_N} \times 100 \tag{4}$$

For a CT primary value of 100A,

Plug setting chosen for relay T is 325%

3.5.2 TMS

For I_N defined in the equation (4), and if I is the fault current seen on the primary of the CT, the operating time or standard characteristic time of an IDMT relay is given by the following formula:

$$t = TMS \times \frac{0.14}{(\frac{I}{PSM \times I_N})^{0.02} - 1} \tag{5}$$

The minimum grading margin with respect to leaf node fuse is given by:

$$\begin{aligned} t_{min} &= 0.01 + 0.5s \\ &= 0.51s \end{aligned}$$

For t_{min}=0.51s, the minimum operating time for relay T for a remote fault beyond the fuse, TMS is calculated from (5) as 0.101 and rounded off to 0.1. The close in or local fault action time of the relay, for a maximum fault current of 1587A is calculated from the equation (5) as 0.434s.

Time multiplier setting chosen for relay T is 0.1 and operating time for local fault is 0.434s

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3.6 Relay S and Relay R

3.6.1 PSM

The current setting of the relays S and R are selected using the equation (3), and the plug setting are calculated using the equation (4) as:

Plug setting for relay S and R is 550% and 725% respectively.

3.6.2 TMS: Relay S

The minimum grading margin with respect to relay T's local fault action time is given by:

$$t_{min} = 0.434 + 0.5s$$
$$= 0.934s$$

For t_{min}=0.934s, the minimum operating time for relay S for a remote fault beyond the Relay T, the TMS is calculated from (5) as 0.143 and rounded off to 0.15. The close in or local fault action time of the relay S, for a maximum fault current of 2120A is calculated from the equation (5) as 0.768s

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Time multiplier setting chosen for relay S is 0.15 and operating time for local fault is 0.768s

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3.6.3 TMS Relay R

The minimum grading margin with respect to relay S's local fault action time is given by:

$$t_{min} = 0.768 + 0.5s$$
$$= 1.268s$$

For t_{min}=1.268s, the minimum operating time for relay R for a remote fault beyond the Relay S, the TMS is calculated from (5) as 0.196 and rounded off to 0.2. The close in or local fault action time of the relay R, for a maximum fault current of 3180A is calculated from the equation (5) as 0.933s

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Time multiplier setting chosen for relay R is 0.2 and operating time for local fault is 0.933s

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3.7 Standard IDMT Relay Settings

	T	**S**	**R**
Maximum fault current for relay (A)	1587	2120	3180
PSM setting (%)	325	550	725
Required trip time for relay (s)	0.51	0.934	1.268
Calculated TMS	0.101	0.143	0.196
Chosen TMS	0.1	0.15	0.2
Trip time for maximum fault current at the relay point (s)	0.434	0.768	0.933

Table 3: IDMT : Standard Inverse settings

3.8 Log-log graph

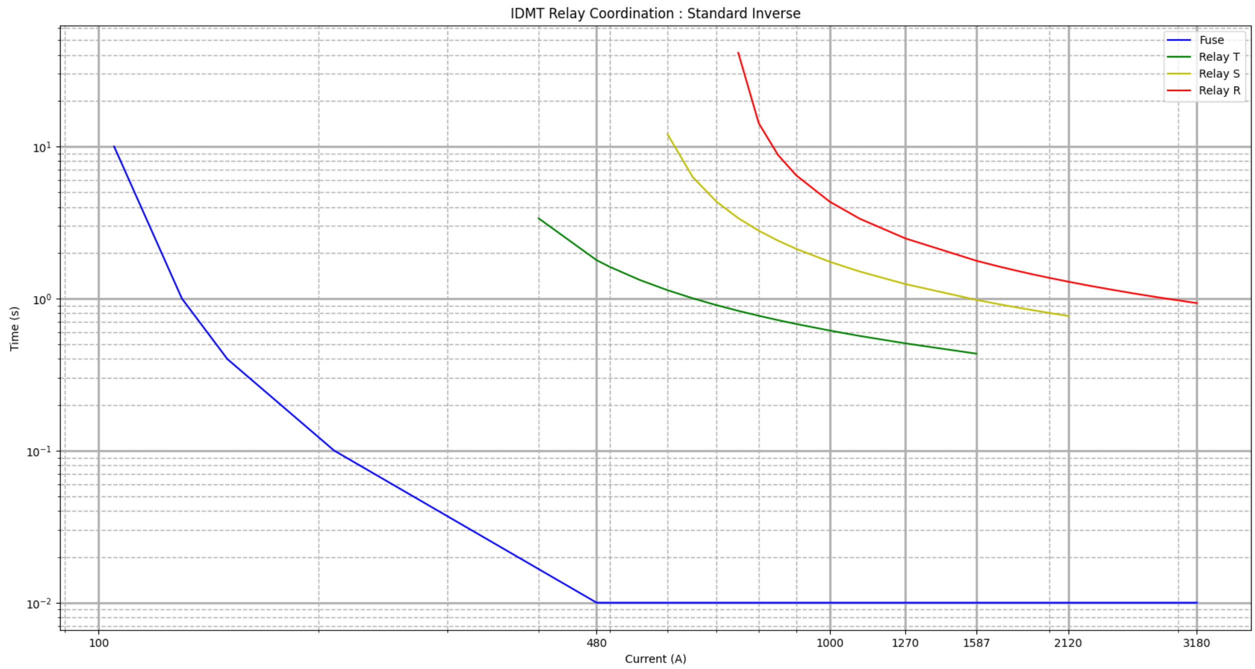


Figure 1: Standard IDMT characteristics

3.9 Observations

Following are the observations of relay coordination:

1. All relays operate under a second for its respective local fault
2. The fuse characteristics is only given up to 480A of current, even though the maximum fault current seen at the bus to which fuse is connected is in range of thousands of Amperes. The horizontal line extends to higher currents at 0.01 as fuse characteristic extrapolation
3. At 480A, the leaf node fuse is backed up by Relay T with 1.8s. As the current increases, the backup time reduces
4. At the local fault for relay T, at 1587A, the time of operation is 0.434s. It is backed up by relay S and R at 0.98s and 1.78s respectively
5. For relay S local fault at 2120A, the time of operation is 0.768s. It is backed up by relay R at 1.291s
6. Relay R local fault operation time is 0.933s
7. Downstream to upstream discrimination is at least 0.5s

3.10 Python code

Python code with all the above calculations is available at : `https://github.com/vinodhmj/projects/blob/master/python/protection.py`

4 PSCAD Simulation

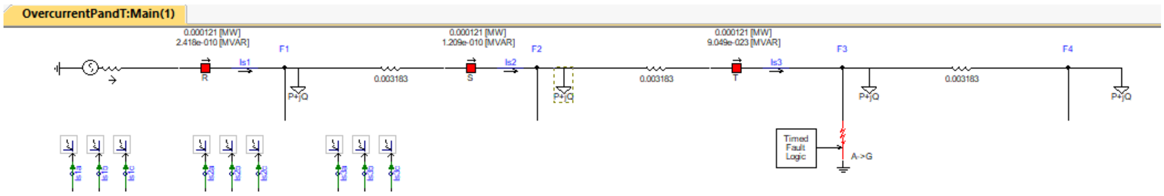


Figure 2: PSCAD model

Entity	Value
Line Inductance	0.003183H
Per phase Load	0.6667MW
Fault starting time	5s
Fault clearing time	7.5s

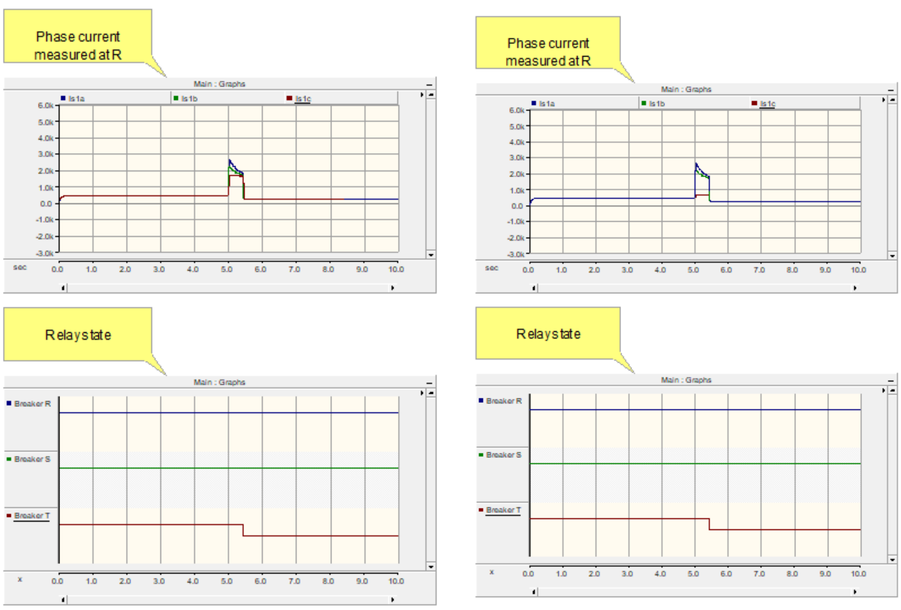
Table 4: System Parameters

The placement of Loads in the PSCAD model is different from the diagram given. This is due to the position of free programmable blocks Is1, Is2 and Is3 used to measure the current input to relays. Also, the relay operation is not affected with this placement of loads.

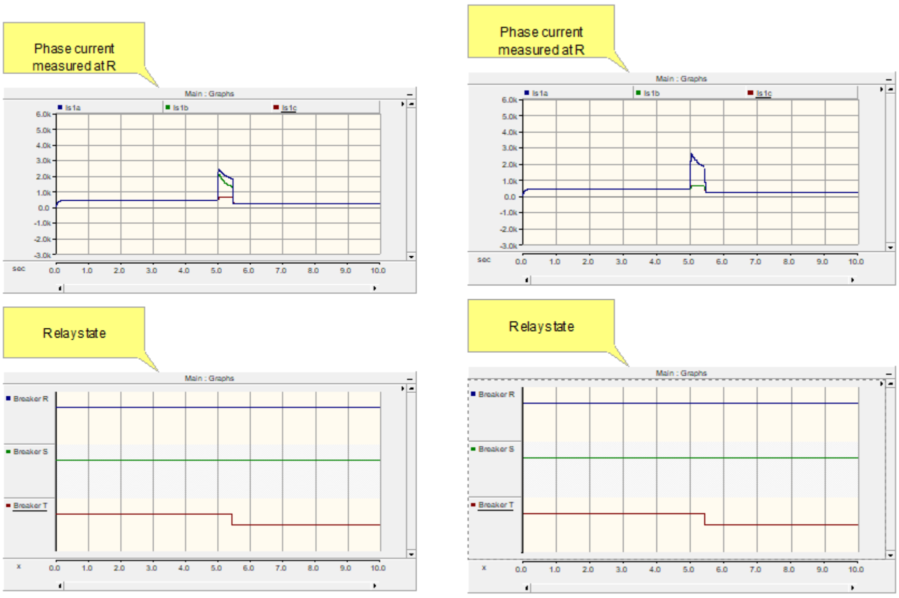
5 Standard Inverse Tests

5.1 Fault at F3

Procedure : Three phase to ground, Double phase to ground, Double phase and single phase fault applied at F3. For fault inception at 5s and fault duration of 2.5s, test if relay T is operating to break circuit breaker T.
Result : The Relay/CB T is operating as expected



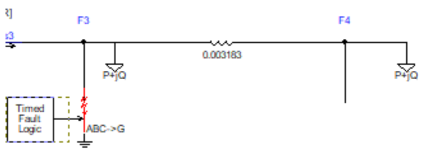
Left to Right : 3ϕ-g, 2ϕ-g at F3 with all breakers enabled.

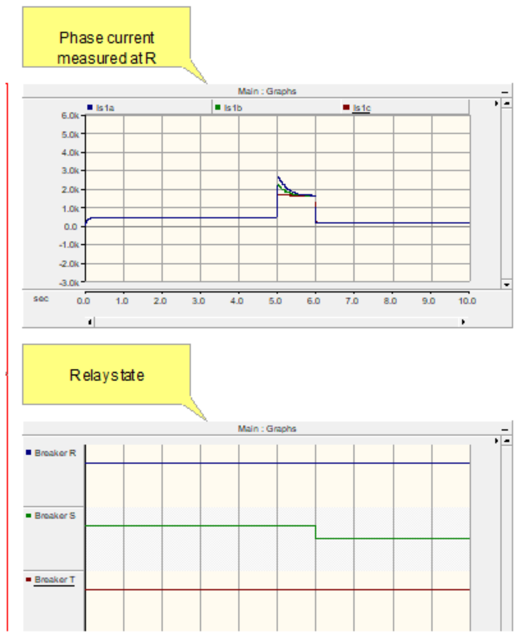


Left to Right : ϕ-ϕ and ϕ-g at F3 with all breakers enabled.

5.2 Backup protection for fault at F3

Procedure : Circuit Breaker “T” is disabled to see if a three phase fault at F3 is protected by relay S and circuit breaker S.
Result : The Relay/CB S is backing up Relay/CB T as expected

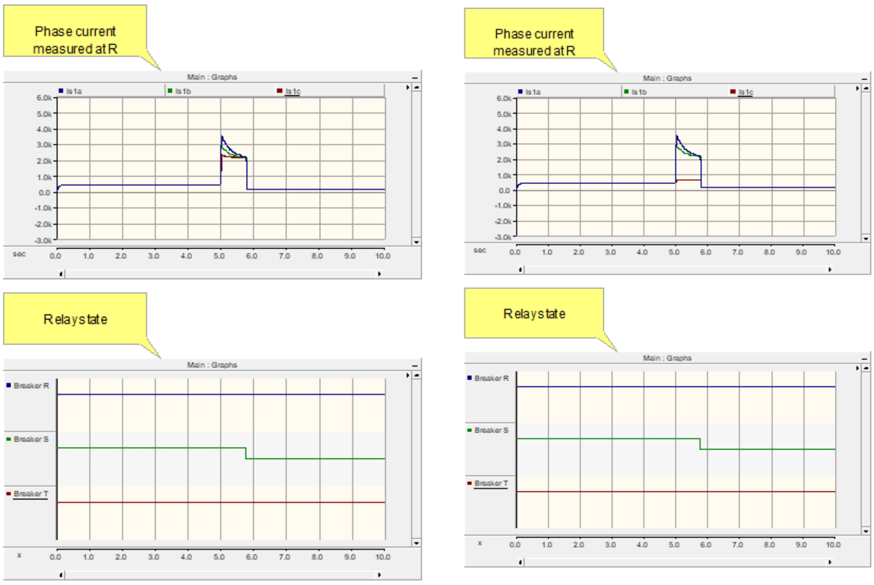




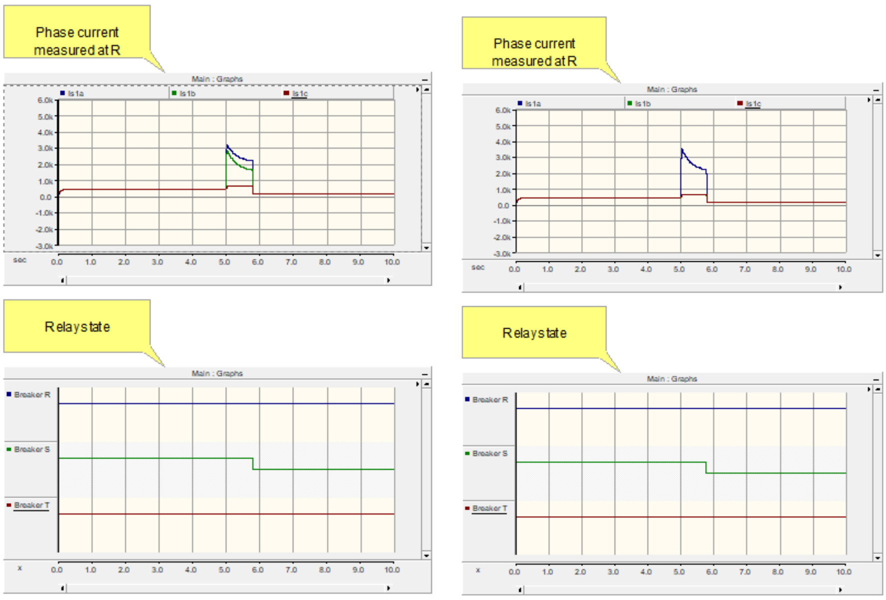
Left to Right : 3ϕ-g at F3 with circuit breaker T disabled.

5.3 Fault at F2

Procedure : Three phase to ground, Double phase to ground, Double phase and single phase fault applied at F2. For fault inception at 5s and fault duration of 2.5s, test if relay S is operating to break circuit breaker S.
Result : The Relay/CB S is operating as expected



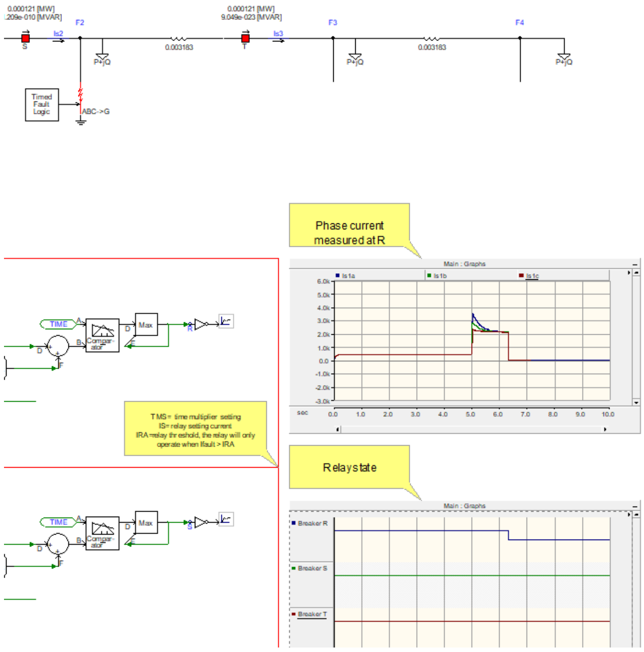
Left to Right : 3ϕ-g, 2ϕ-g at F2 with all breakers enabled.



Left to Right : ϕ-ϕ and ϕ-g at F2 with all breakers enabled.

5.4 Backup protection for fault at F2

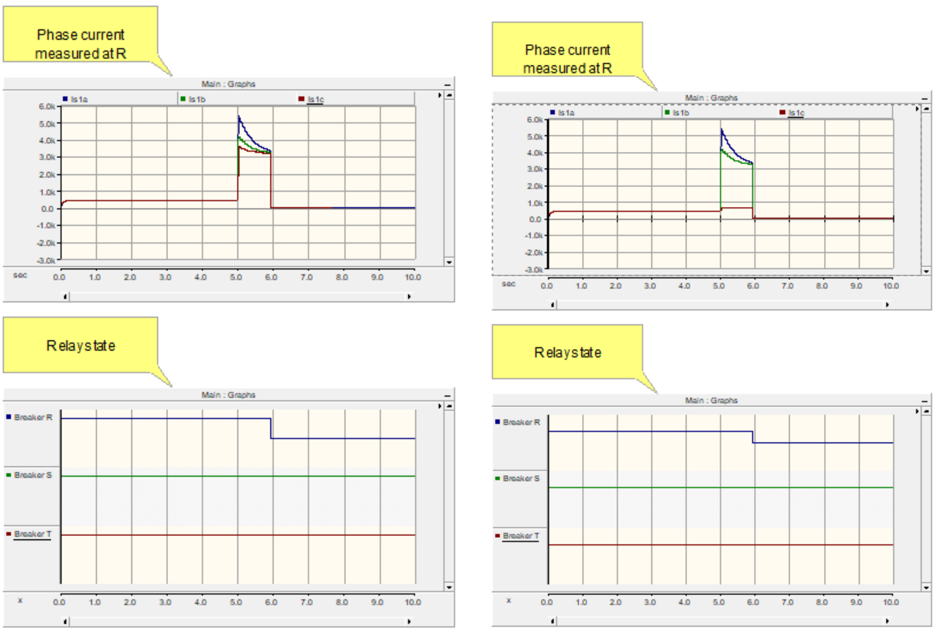
Procedure : Circuit Breaker “S” is disabled to see if a three phase fault at F2 is protected by relay R and circuit breaker R.
Result : The Relay/CB R is backing up Relay/CB S as expected



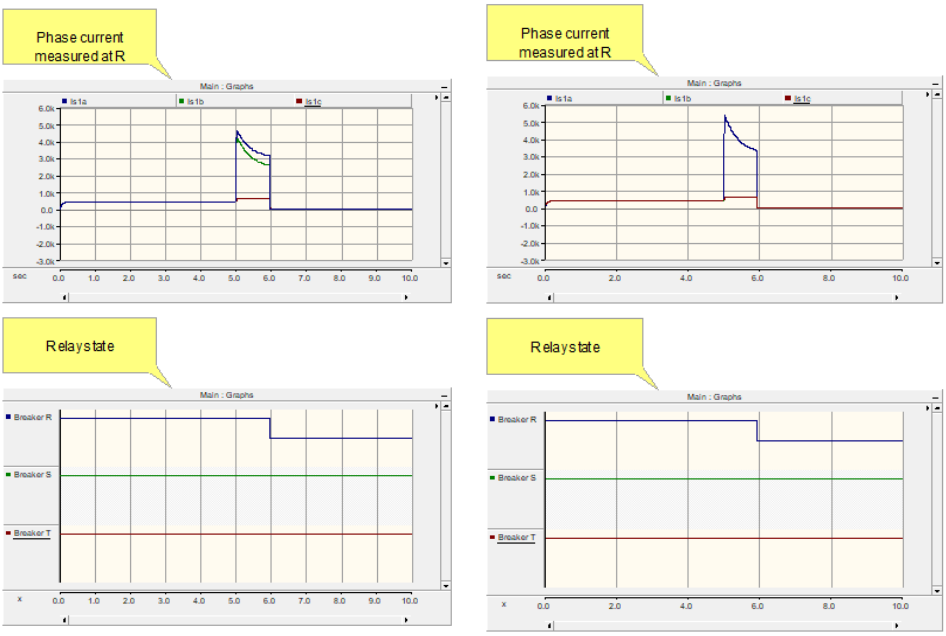
Left to Right : 3ϕ-g at F2 with circuit breaker S disabled.

5.5 Fault at F1

Procedure : Three phase to ground, Double phase to ground, Double phase and single phase fault applied at F1. For fault inception at 5s and fault duration of 2.5s, test if relay R is operating to break circuit breaker R.
Result : The Relay/CB R is operating as expected



Left to Right : 3ϕ-g, 2ϕ-g at F1 with all breakers enabled.



Left to Right : ϕ-ϕ and ϕ-g F1 with all breakers enabled.

6 Extremely Inverse Characteristic

6.1 Extreme IDMT Relay Settings

The extreme IDMT characteristics are calculated using the following equation:

$$t = TMS \times \frac{80}{(\frac{I}{PSM \times I_N})^2 - 1} \tag{6}$$

Following the similar procedure as per standard inverse and using the above equation, the table below shows the control setting for three relays:

	T	S	R
Maximum fault current for relay (A)	1587	2120	3180
PSM setting (%)	325	550	725
Required trip time for relay (s)	0.51	0.85	1.366
Calculated TMS	0.091	0.078	0.102
Chosen TMS	0.1	0.1	0.15
Trip time for maximum fault current at the relay point (s)	0.35	0.577	0.658

Table 5: IDMT : Extreme Inverse settings

6.2 Extreme inverse Log-Log curve

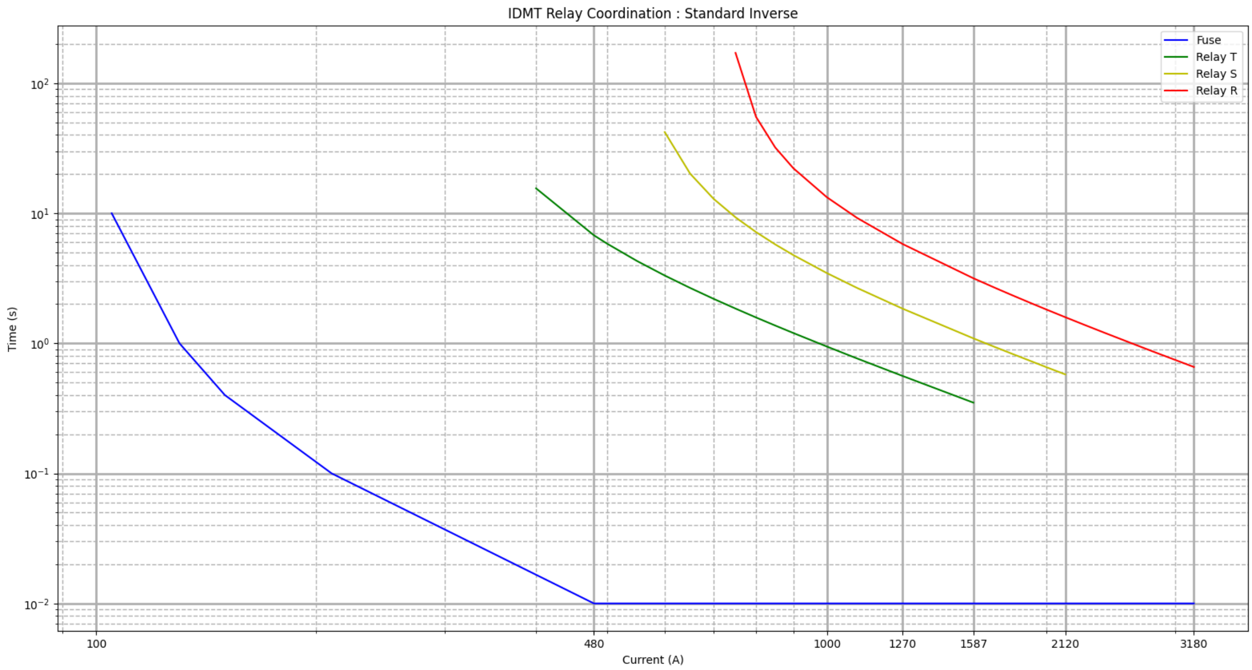


Figure 3: Extreme IDMT characteristics

6.3 Comparison with Standard IDMT curves

Relay	PSM	TMS	t@1270A (s)	t@1586A (s)	t@2120A (s)	t@3180A (s)
T (Standard)	325	0.1	0.507	0.434	-	-
T (Extreme)	325	0.1	0.561	**0.35**	-	-
S (Standard)	550	0.15	1.244	0.98	0.768	-
S (Extreme)	550	0.1	1.847	1.092	**0.577**	-
R (Standard)	725	0.2	2.483	1.773	1.291	0.933
R (Extreme)	725	0.15	5.801	3.165	1.589	**0.658**

6.3.1 Observations

1. For higher fault currents, fault location closer to the relays, the extreme inverse relay characteristics acts quicker with less operating time
2. For remote faults, extreme inverse characteristics takes more time to operate

7 Conclusions and Recommendations

Relay coordination for the system was performed and verified. The relay control settings, PSM and TMS calculated are applied to understand the time/current grading. Downstream fuse is backed-up by relays upstream. All relays operate under a second for their respective close-in faults. The client network was modelled in PSCAD software, and the calculated control settings were inputted into the elements to verify the calculations. The software experiment procedures and results are captured in section 5.

Furthermore, the IDMT relay settings were calculated for Extreme Inverse characteristic apart from Standard Inverse characteristic. Standard inverse characteristic is recommended due to its quick operation time over a wide fault current range. For the relays R, S and T given in the client network, from upstream to downstream relays has PSM 325%, 550% and 725% chosen respectively. The TMS for the above relays, in a standard inverse setting is identified as 0.1, 0.15 and 0.2 respectively. These settings are presented in table 3. The software simulation and calculation are found to be satisfactory for normal and faulty condition relay operations.