# ANALYSIS OF PROTECTION SCHEME OF 33 kV AUXILIARY RING NETWORK IN DELHI METRO RAIL CORPORATION TO ENHANCE SYSTEM PERFORMANCE

**A DISSERTATION SUBMITTED TOWARDS THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF**

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# DEPARTMENT OF ELECTRICAL ENGINEERING

## DELHI TECHNOLOGICAL UNIVERSITY

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## CERTIFICATE

This is to certify that the dissertation titled "***ANALYSIS OF PROTECTION SCHEME OF 33 kV AUXILIARY RING NETWORK IN DELHI METRO RAIL CORPORATION TO ENHANCE SYSTEM PERFORMANCE***" submitted towards the partial fulfillment of the requirements for the award of the degree of Master of Technology in Power Electronics System by **Mr. Tushar**, University Roll No. 2K13/PES/504, student of Master of Technology (Power Electronics System) in Electrical Engineering Department of Delhi Technological University (Formerly Delhi College of Engineering), is a dissertation on original research work carried out by him under my guidance during session 2015-2016. Any material borrowed or referred to is duly acknowledged.

I wish him all the best in his endeavors.

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# ABSTRACT

The objective of any proper protection scheme is to keep the power system stable and reliable by isolating only the components that are experiencing fault while leaving as much of the electrical network as possible still in operation. Major components of any protection systems are instrument transformers, relays, circuit breakers and sometimes communication channel. With the rapid progress in technology, this aspect of electrical engineering applications have become very specialized and now most of the electrical organizations have dedicated teams specializing in this aspect with dedicated softwares for iteration of complex electrical network.

Rail based mass transit system are gaining popularity in the country due to the punctuality, comfort and ease of travel provided to the consumers. In this backdrop, the importance of reliable power supply becomes very important. To ensure reliable supply for passengers safety and comfort, planned redundancies in the electrical network, selective and quick protection scheme are very essential for restoring power supply within the stipulated time frame in case of any incident.

This dissertation briefly presents the introduction to the system of auxiliary power distribution in Delhi Metro Rail Corporation, analyses the Protection scheme of 33 kV Auxiliary system ring feeders and suggests tripping logics to improve system performance during various fault scenarios. The tripping logics not only help in eliminating the previous drawbacks but also help in quick identification of faulty section resulting in timely resumption of supply from the various planned redundancies.

This tripping logic can also prove to be useful in any interconnected ring network or a micro grid which is currently the future of electrical distribution network in many countries.

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# CHAPTER-1

# 1. INTRODUCTION

## 1.1 General

Delhi Metro Railway Corporation Limited (DMRC) is providing metro services over a network of more than 193 route km. with 146 stations, which also include 54 route km under-ground sections in Delhi/NCR. DMRC runs almost 190 rakes consisting of 4/6/8 coaches for transporting about 2.6 million passengers everyday with peak headway of 138 sec. Punctuality on Delhi Metro is primary concern and on most days, it has been achieving 100% punctuality making it one of the most punctual metros in the world[7]. Popularity of DMRC can be gauged as even occasional disruption to train operation, due to any failure in equipments causes inconvenience to passengers and invites severe criticism from public and media[7].

For any Metro Transit System, availability of un-interrupted power supply is an essential requirement. Delhi Metro Rail Corporation Limited has adopted 33 kV AC ring distribution network for supplying the auxiliary load requirements at various stations where the voltage is stepped down to 415 V for feeding the auxiliary equipments. This system is typical than the utility distribution network as redundancies have to be catered for making the supply reliable especially considering the underground sections.

## 1.2 Layout of the Auxiliary Supply Scheme [4] [5]

DMRC receives EHV power supply at 220/132/66kV from different supplying authorities/DISCOMS (DTL/DISCOMS) at Receiving Substations (RSS) consisting of Traction Substations (TSS) and Auxiliary Main Substations (AMS). Every metro line is planned with two or more RSS [4] [5].

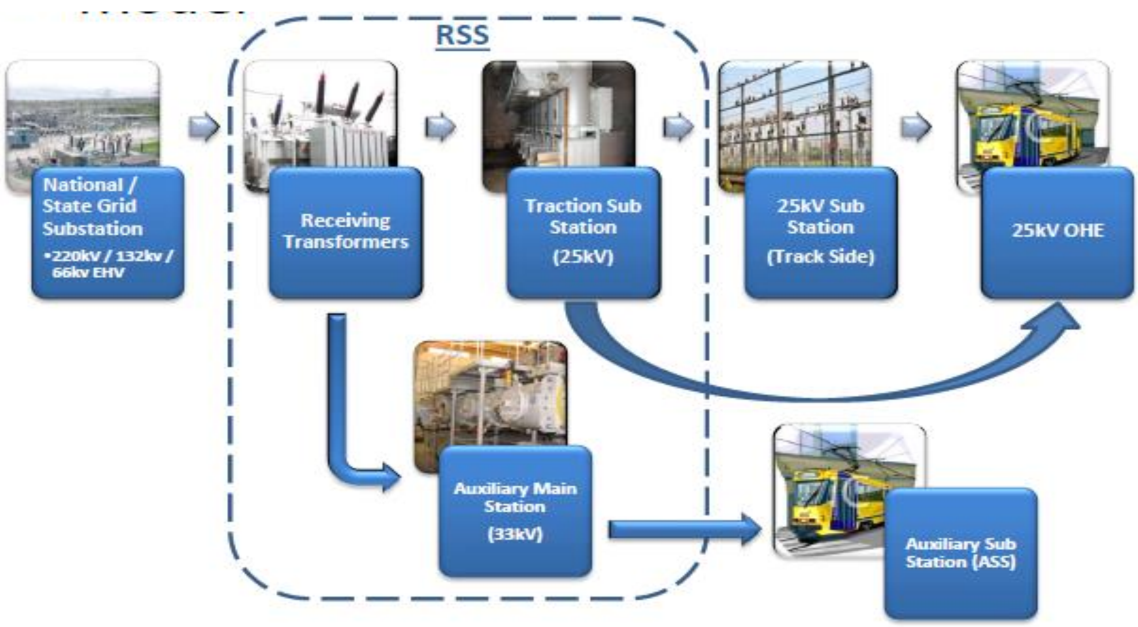


Fig. 1: Brief Description of Power Supply System of DMRC

Inside RSS, there are two substations namely the Traction Sub Station (TSS) and the Auxiliary Main Substation (AMS). While the output of TSS is 25 kV single phase AC, which is used to feed the traction overhead equipments i.e. OHE; the output of AMS is 33 kV three phase AC fed to the ASS.

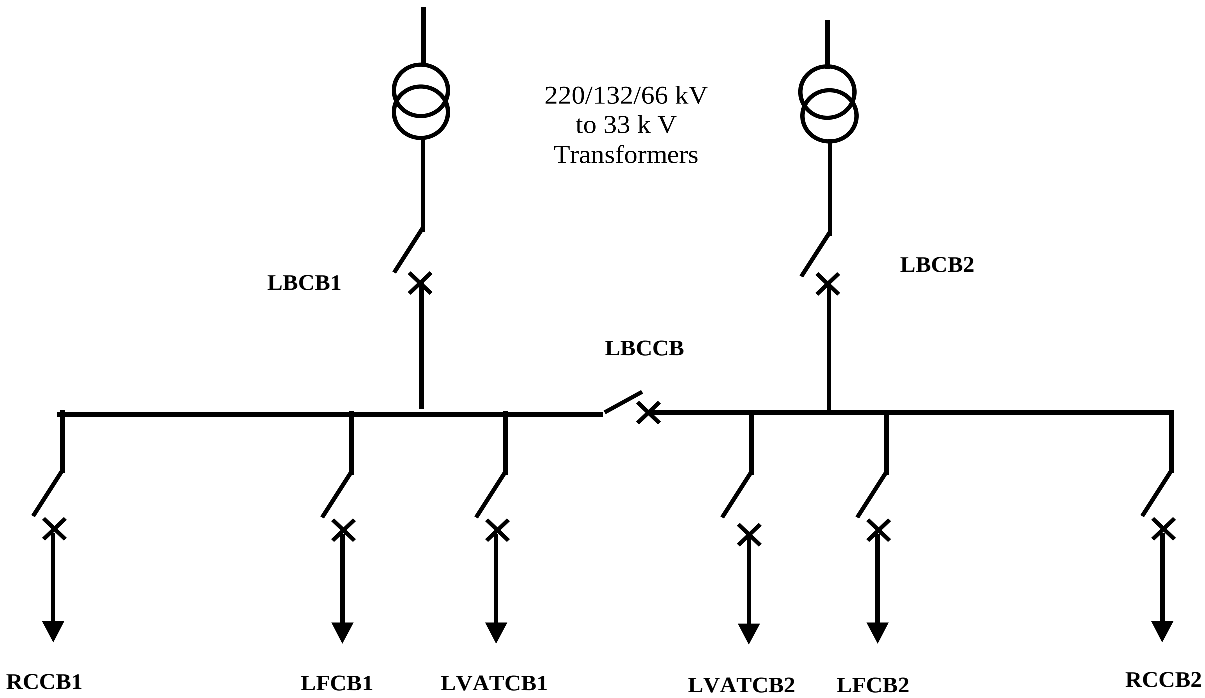


Fig. 2: Typical SLD of AMS inside RSS of DMRC[4] [5]

The RSS feeds auxiliary power at Auxiliary Substations (ASS) at each underground and elevated stations from an Auxiliary Main Substation (AMS) through duplicate redundant 33 kV switchgears (RCCB1 & RCCB2 in figure 2 above) via 33kV cable network (in ring formation) as shown in the figure 3 below.

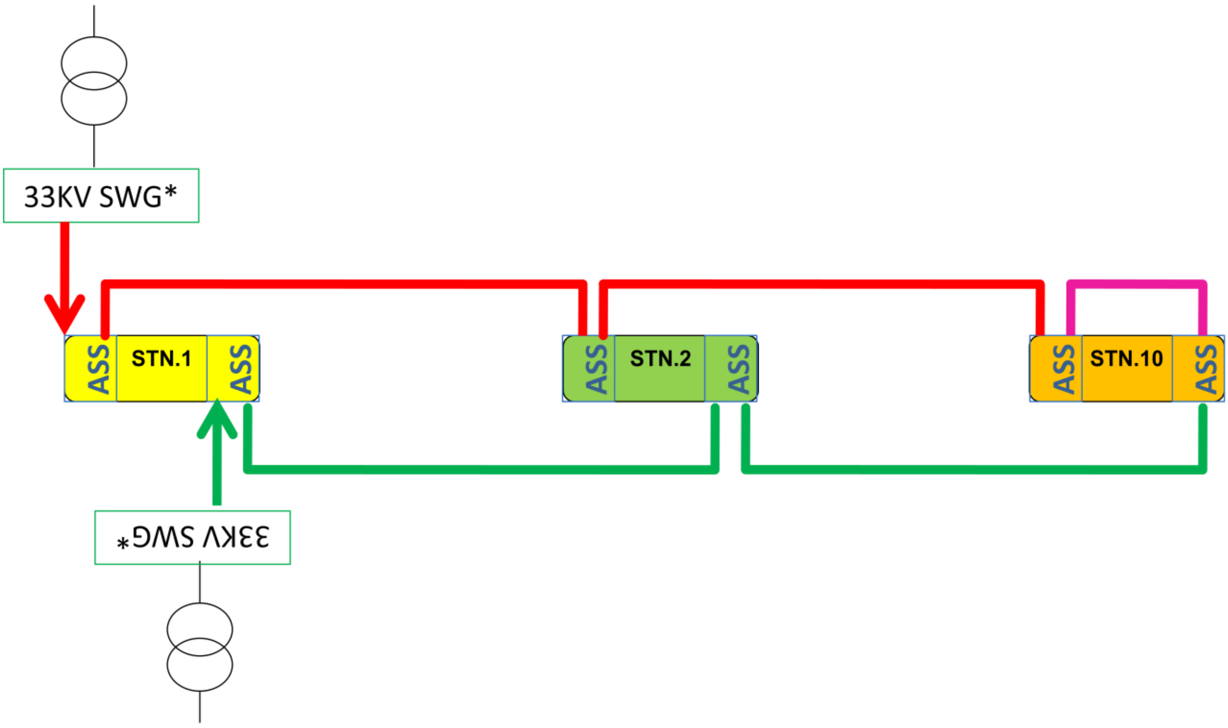


Fig. 3: Typical description of distribution of Auxiliary Power Supply in DMRC

In elevated corridor both the 33 kV cables emanating from the AMS transformers are terminated in a single ASS since typically a single ASS is provided in the elevated corridor. In the Underground stations there are typically two/three ASS each of which is fed from separate 33 kV cable emanating from AMS transformer.At each ASS, this 33 kV three phase is further stepped down to 415 V three phase for the local supply to the station. The power received at ASS is distributed to the auxiliary loads of the stations through LV distribution system.

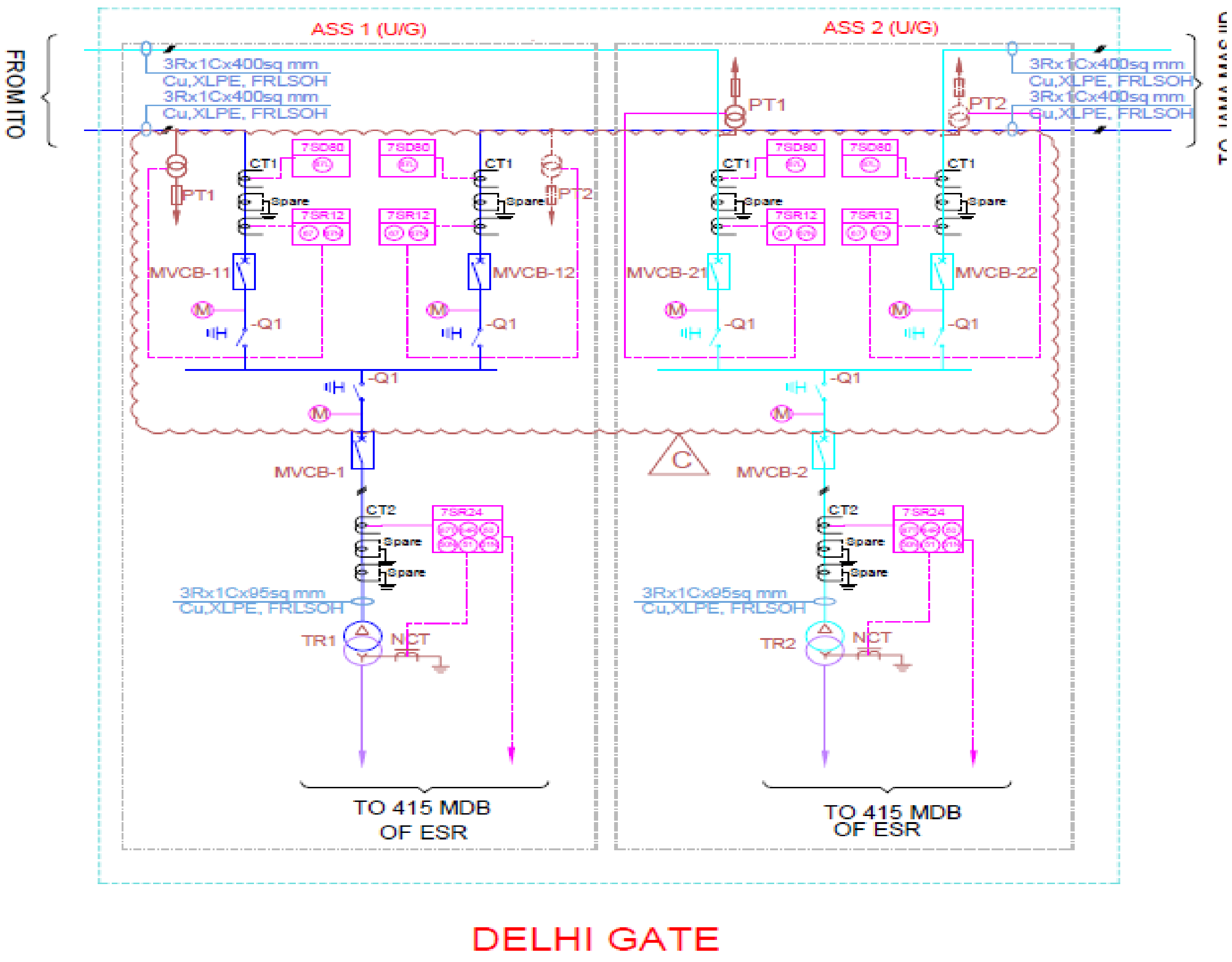


Fig. 4: Typical SLD of ASS at Underground Stations of DMRC [6]

The whole 33 kV installation is centrally controlled at Operation Control Centre (OCC) by using SCADA. Traction Power Controller is available round the clock at the OCC monitoring the power feed scenarios and respond at the earliest during fault conditions to resume supply immediately from the redundancies kept in the system. Later on, the Operation and Maintenance wing is intimated to perform corrective maintenance as soon as possible. Identification of faulty section, its isolation and resumption of supply from various planned redundancies in the system in shortest possible time is the backbone to ensure reliable supply system [7] [8] [9].

# CHAPTER-2

# 2. ANALYSIS OF THE PROTECTION SCHEME WITH THEIR DRAWBACK

## 2.1 Analysis of the Existing Protection Scheme

In the existing 33 kV system, following protection scheme was provided in DMRC:

i. No Protection was provided in the Elevated Section ring feeders and only Interrupters were provided (i.e. IT-11/21, IT-12/22 as shown in the below mentioned figure 5). Protection was available only at the AMS end.

ii. Main Protection of Pilot Wire which is a type of differential protection (87L) was provided in Underground sections only (Figure 6).

iii. Over Current/Earth Fault Protection(50/51/50N/51N)which works on the overcurrent principle was provided as a backup protection to Pilot Wire relay in the Under Ground section (Figure 6). Time grading between the over current relays is not available due to large ring network (typically 10 stations are fed from a single RSS) and limitation of available time settings at RSS due to the constraints of time settings of upstream breakers of the DISCOMs.

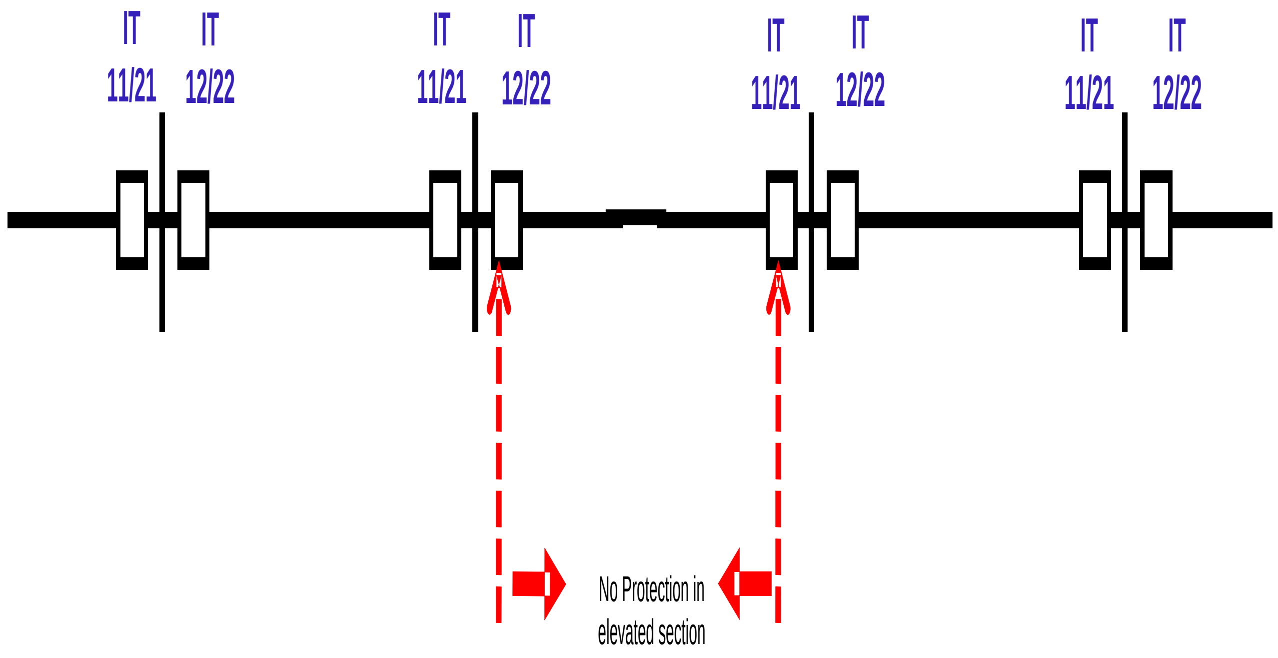


Fig. 5: Typical Protection SLD of Elevated ASS

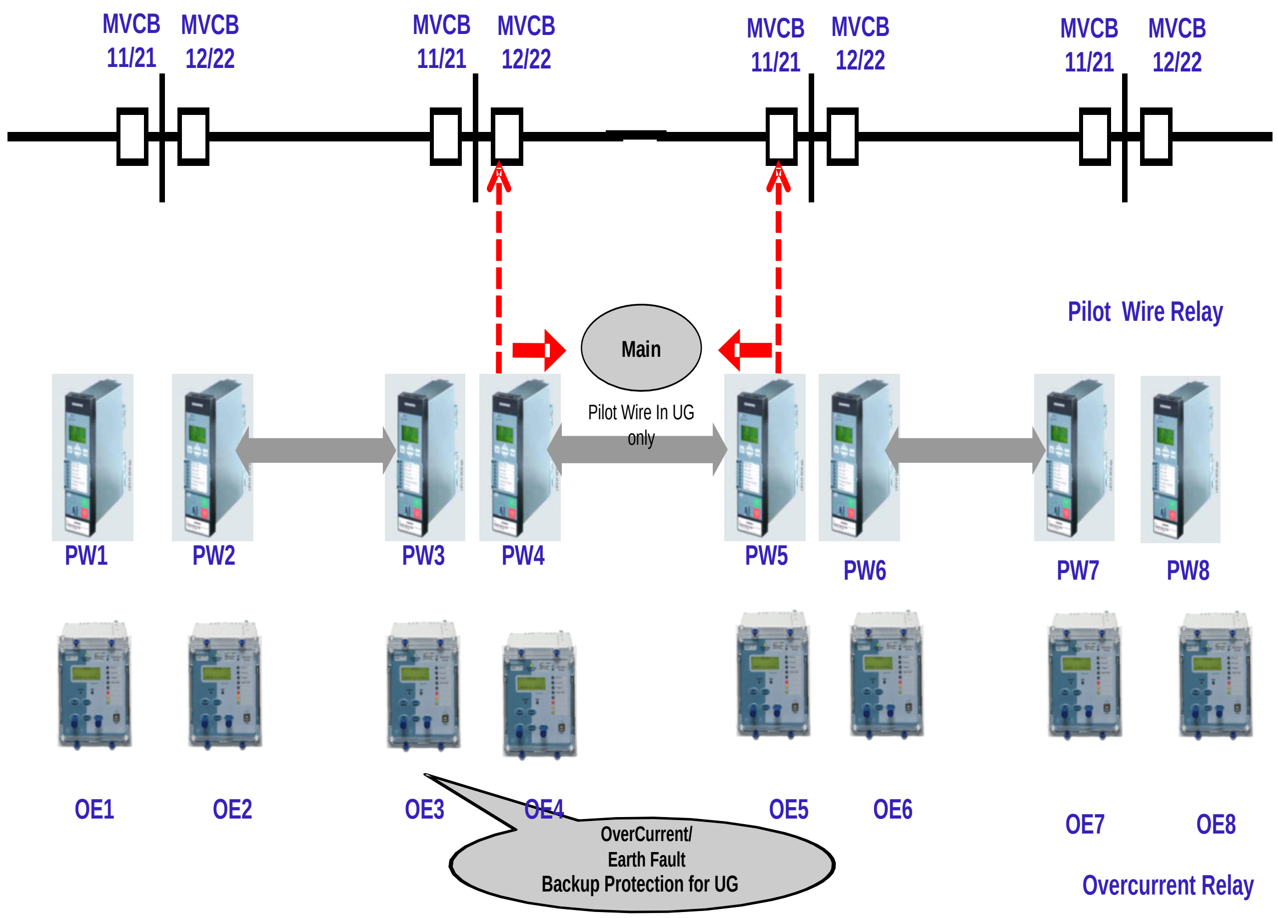


Fig. 6: Typical Protection SLD of Underground ASS

## 2.2 Drawbacks of the Existing Protection Scheme

DMRC has been in operation for many years and has had their share of failures. for any progressive organization it is very imperative that the failures are deeply studied and lessons are learnt for future. For this DMRC has developed strict procedures to analyze every failures by engaging senior officers in preparation of Unusual Occurrence Reports (UOR) and their analysis of the faults. Majority of the faults were related to cable faults in between the stations. One incident of fault in Bus Potential transformer was also reported. Break in communication of Pilot Wire Relays was also reported frequently.

The UOR related to various electrical faults were studied in discussion with Operation &Maintenance wing and drawbacks were noted. Following figures shall explain the drawbacks in details for proper understanding:

2.2.1 In case of cable fault in elevated section between two stations as shown in the figure 7 below, since no protection is available at the 33 kV ring feeders breakers, the over current relay at AMS breaker trips the associated breaker in the RSS. This posed a problem in isolating the faulty section by the Traction Power Controller (TPC) in early resumption of supply as the location of fault could not be identified.

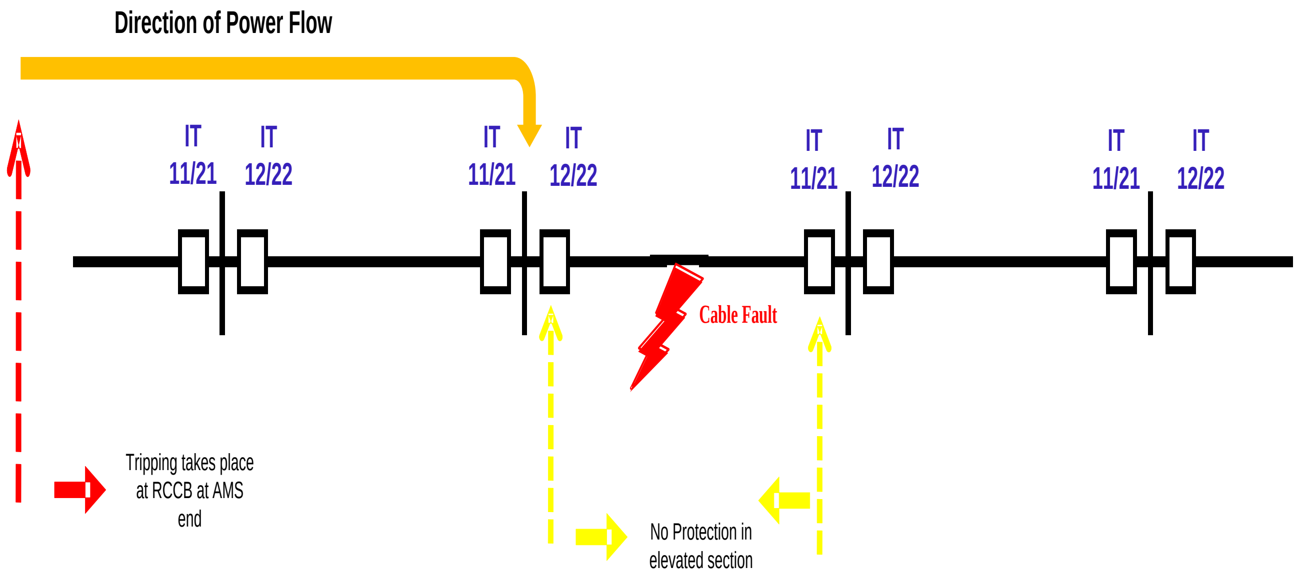


Fig. 7: Scenario during cable fault in Elevated section

2.2.2 In case of cable fault in the underground (UG) section between two stations, the pilot wire relay as per the location of fault(PW4 & PW5 shown in red color in the figure 8 below)shall be activated instantaneously and trip the respective breakers. The fault current persists till the time respective breakers (shown in red in the figure 8 below)clear the fault which may result in activation of Overcurrent relays (OE1, OE2, OE3 & OE4 shown in yellow in the figure 8 below) in the fault feed direction and caused spurious tripping of one or more breakers (shown in yellow in the figure 8 below). This posed a problem in isolating the faulty section by the Traction Power Controller (TPC) in early resumption of supply as the location of fault could not be identified.

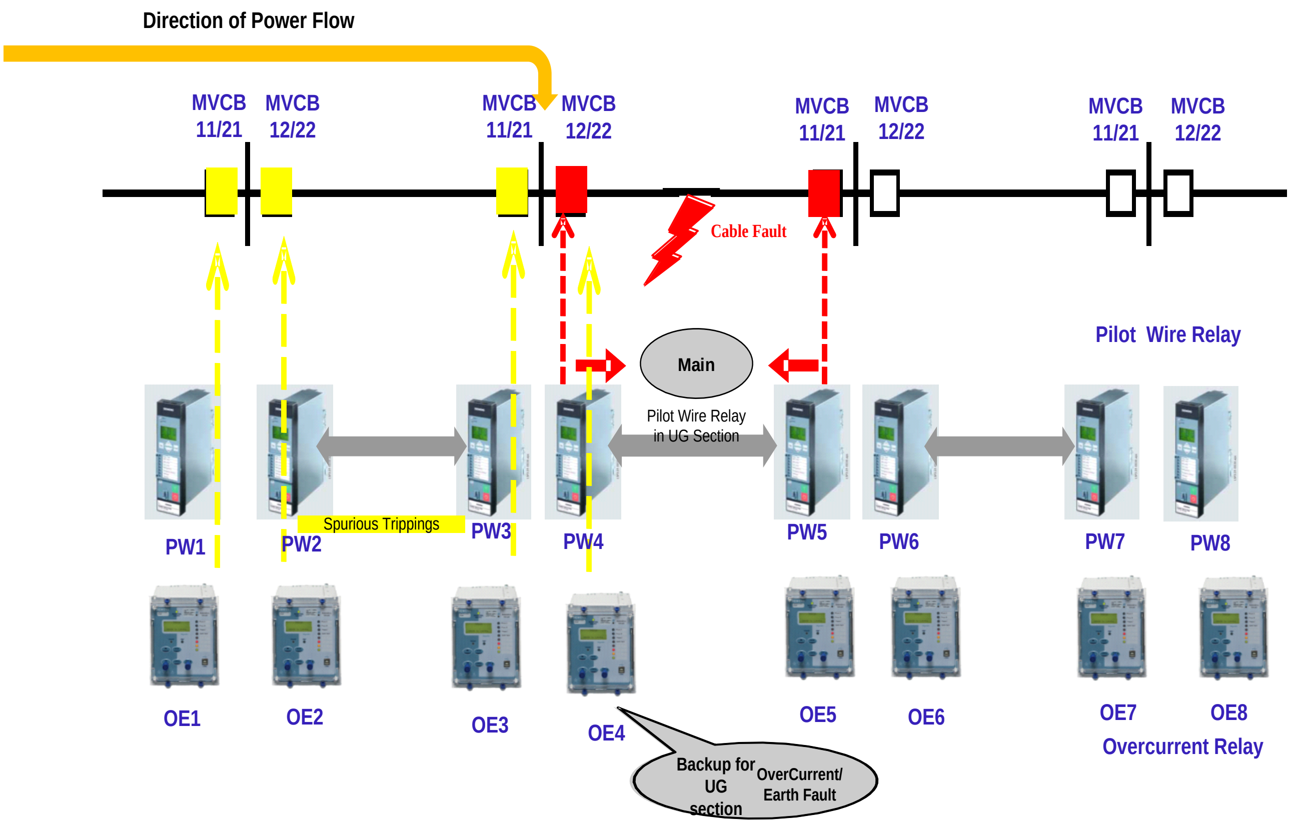


Fig. 8: Scenario during cable fault in Underground section

2.2.3 In the case of failure of pilot wire due to any reason on the cable fault section, the backup Overcurrent relay (OE 4 shown in red in the figure 9 below) gets activated and trips the associated breaker. The fault results in activation of other Overcurrent relays also(OE1, OE2 & OE3 shown in yellow in the figure 9 below) in the fault feed direction due to non availability of time discrimination and sometimes caused spurious tripping of breakers. This again posed a problem in isolating the faulty section by the TPC.

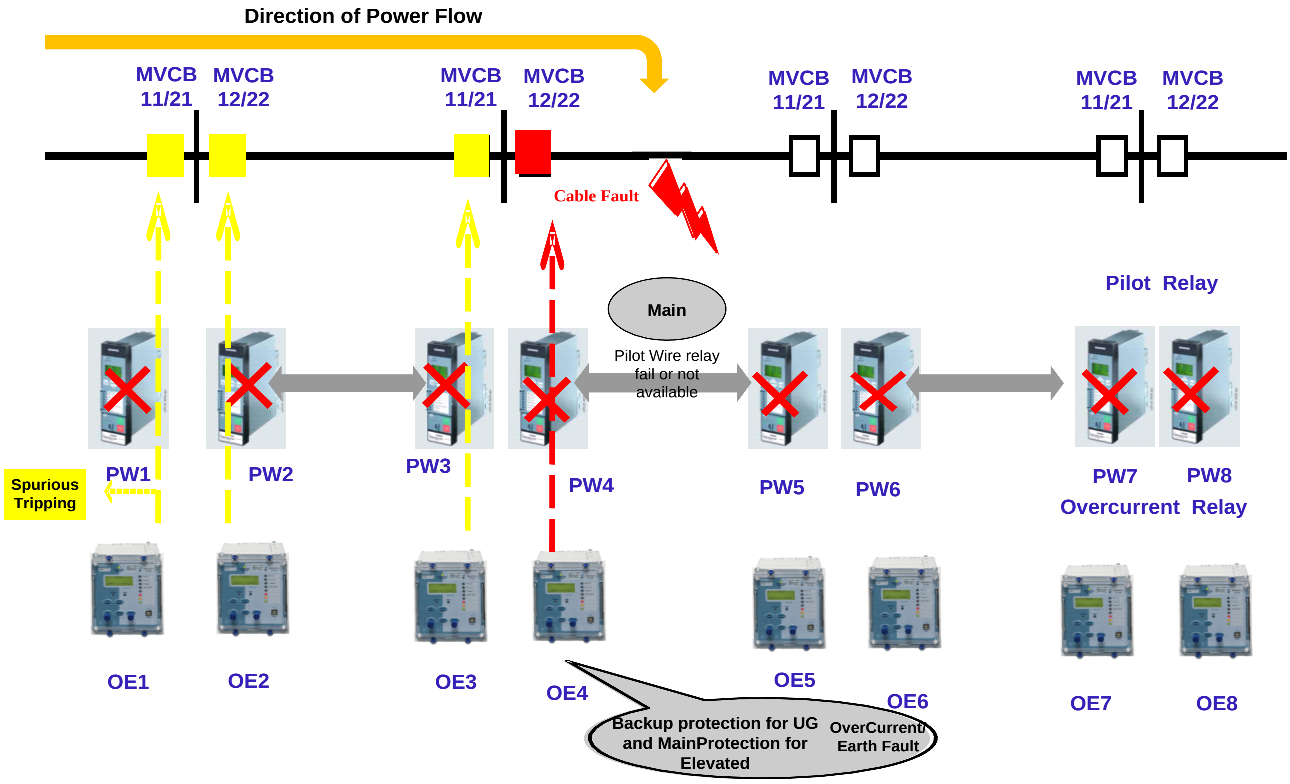


Fig. 9: Scenario during simultaneous Pilot Wire Relay failure and cable fault in Underground section

2.2.4 Even though rare in occurrence, nevertheless for any fault in the bus bar in the Elevated section, the Overcurrent relay at AMS breaker (shown in red in the figure 10 below) gets activated and trips the associated breaker in the RSS as there is no protection available at the 33 kV Ring Feeder breakers. This posed a problem in isolating the faulty section by the Traction Power Controller (TPC) and early resumption of supply as the location of fault could not be identified.

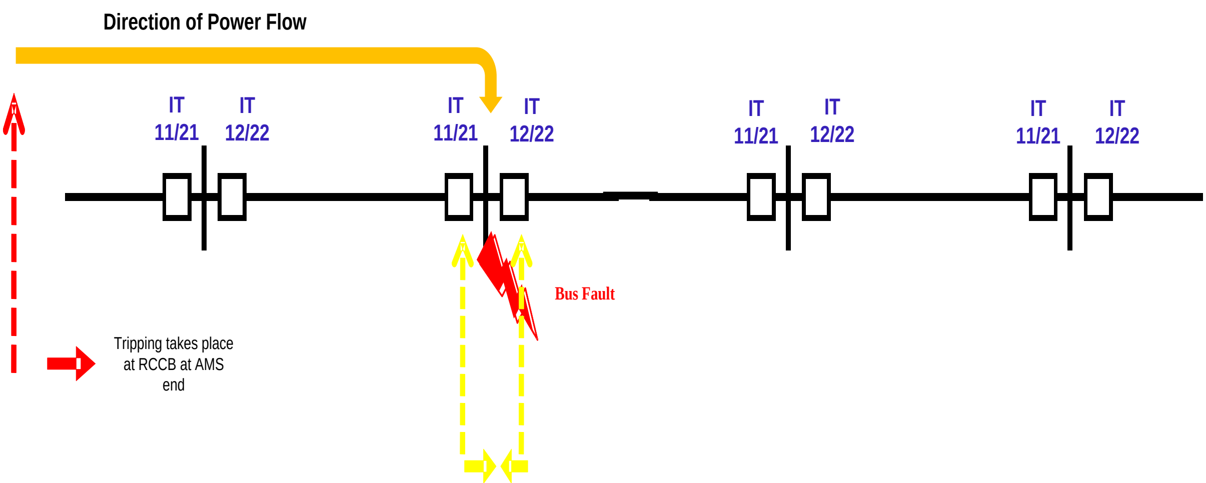


Fig. 10: Scenario during bus fault in Elevated section

2.2.5 Also similarly for any fault in the bus bar in the Underground section, the pilot wire relay does not sense the fault, the overcurrent relay (OE3 shown in red in figure 11 below) gets activated and trips the associated breaker. However, since time discrimination between the overcurrent relays is not available due to large ring network and constraint of available time setting at RSS,the fault will result in activation of other Overcurrent relays also (OE1 & OE2 shown in yellow in the figure 11 below) in the fault feed direction and may cause spurious tripping of breakers.This shall again pose a problem in isolating the faulty section by the TPC.

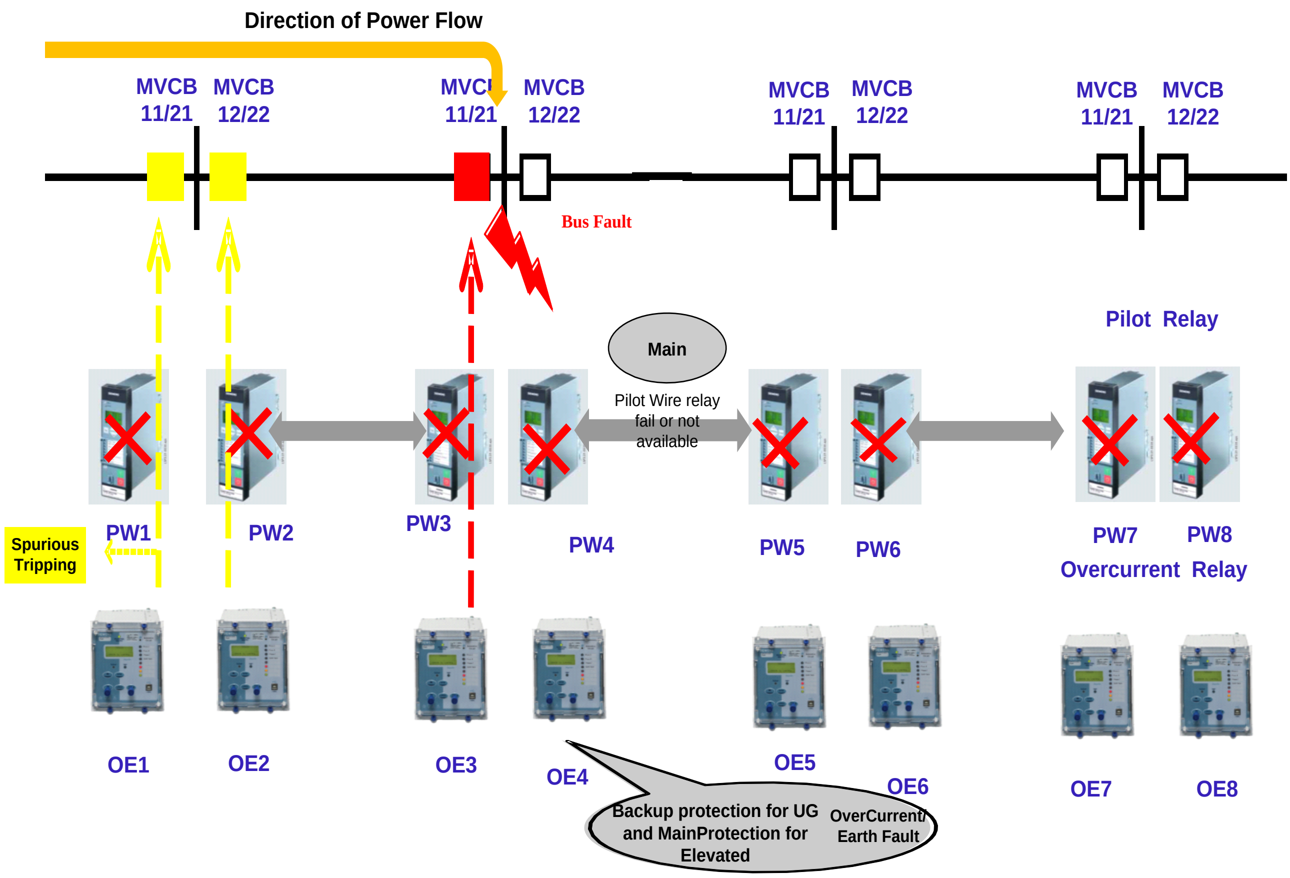


Fig. 11: Scenario during bus fault in Underground section

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# CHAPTER-3

# 3. LITERATURE REVIEW

## 3.1 General

The basic requirements of a protective system are Selectivity, Reliability, Sensitivity, Stability and Fast operation. Optimization of the protection system involves balancing the development of these qualities that could be competing among themselves. An optimized protection system shall quickly identify a fault, its location and isolate only the faulted part of the overall power system [16]

## 3.2 Overcurrent and Pilot Wire Differential Protection

Protection scheme based on the operation of the relay when the load current exceeds a preset value is termed as over current protection. There are two types of protection settings commonly employed in over current relays. First is Definite Time Overcurrent settings wherein the relay operates after a predetermined time when the current exceeds the pick up value. Second is the Inverse time over current settings in which the operating time depends upon the magnitude of the operating current above the pick up value. These relays can also additionally, by the help of directional unit, be made to operate depending upon the direction of the current or power flow. The direction of the same is found out by the characteristic angle between the operating current and operating voltage sensed by the instrument transformers [12].

In Pilot Wire scheme, wires (now optical fiber cables) are used to carry information signals from one end of the protected line to the other. This is a unit protection scheme and operates on the principle of differential protection. Out of two alternative operating principles of circulating current and balanced voltage, circulating current principle is employed in the auxiliary network of DMRC [12].

## 3.3 Previous research works

Most conventional distribution protection is based on short-circuit current sensing. Power electronic based micro sources can not normally provide the levels of short circuit required. Micro sources may only be capable of supplying twice load current or less to a fault. Some overcurrent sensing devices will not even respond to this level of overcurrent, and those that do respond will take many seconds to respond, rather than the fraction of a second that is required. Low cost approach such as differential current and/or voltage methods have shown promise [13].

In order to improve the reliability of electric supply, parallel double lines are often used in the important transmission system. Transverse differential current directional protection is widely used in the middle and low level voltage system. Transverse differential protection includes phase current differential and zero-sequence current differential [14].

Modem urban power distribution networks are gradually developing from a radial-type topology towards ring-type and even mesh-type topologies. There are many drivers behind this development, one significant being the need to increase the reliability and availability of networks. The basic overcurrent-based protection schemes do not necessarily guarantee selective operation [15].

The use of pilot wire protection schemes based on either the circulating current principle or the balanced voltage principle has been known for decades. Other possible solutions can include atleast the following principles such as Directional overcurrent protection, Distance relay protection, Line differential protection with a communication link between the relays. The common denominator for all the above mentioned solutions is the objective to realize unit protection that is a solution which provides absolutely selective protection for a defined part of the network, while remaining unaffected and stable for faults outside the protection zone [15].

The numeric technology in the multifunction relays gives us many tools to implement new solutions to problems that in past were only possible to solve using conventional techniques as implemented in Rasgas system by GE [17].

## 3.4 Conclusion

The previously mentioned drawbacks of the ring protection system of DMRC were, if not unique, were very distinct to the DMRC system. A survey of relevant publications brought out that most of the research literatures were pertinent to protection issues in traction system and very few relevant research material were available. It is also pertinent to mention here that DMRC has also started looking for assimilating Solar Power in their auxiliary network. In this scenario, it is expected that DMRC auxiliary network may in future behave as a microgrid with ring type distribution scheme. The above Literature backdrop also provided an insight for using the logical tool of the numeric relay to our advantage.

# CHAPTER-4

# 4. IMPROVEMENTS IN THE PROTECTION SCHEME

## 4.1 Improvements suggested in the Protection Scheme

Based on the comparison of the existing 33 kV Auxiliary protection scheme in DMRC and their drawbacks discussed previously, a common protection scheme for ring feeders in underground and elevated stations was developed and implemented as discussed below:

4.1.1 The ring feeder breakers shall be provided with Pilot wire differential protection and backup directional over current protection for both Underground and Elevated sections whose salient features are discussed below:

i. The Primary Protection for the cable faults between two stations shall be pilot wire differential protection (87L) which will trip the respective MVCB on either end of the faulty section of the cable keeping in view the advantage that no current or time discrimination is required as it works on the difference of current in the zone between the two pilot wire relays.

ii. Directional overcurrent/earth fault (67/67N) protection shall be provided as a backup to pilot wire relay in the ring feeder breakers. They should be set with the direction towards bus bar inside an ASS (i.e. alternately in Forward(OE1, OE3, OE5, OE7)/ Reverse direction(OE2, OE4, OE6, OE8) to the power flow direction shown in the figure 12 below). The tripping command to the breaker on account of Overcurrent protection will be issued only when the relay senses the overcurrent fault in the forward direction.

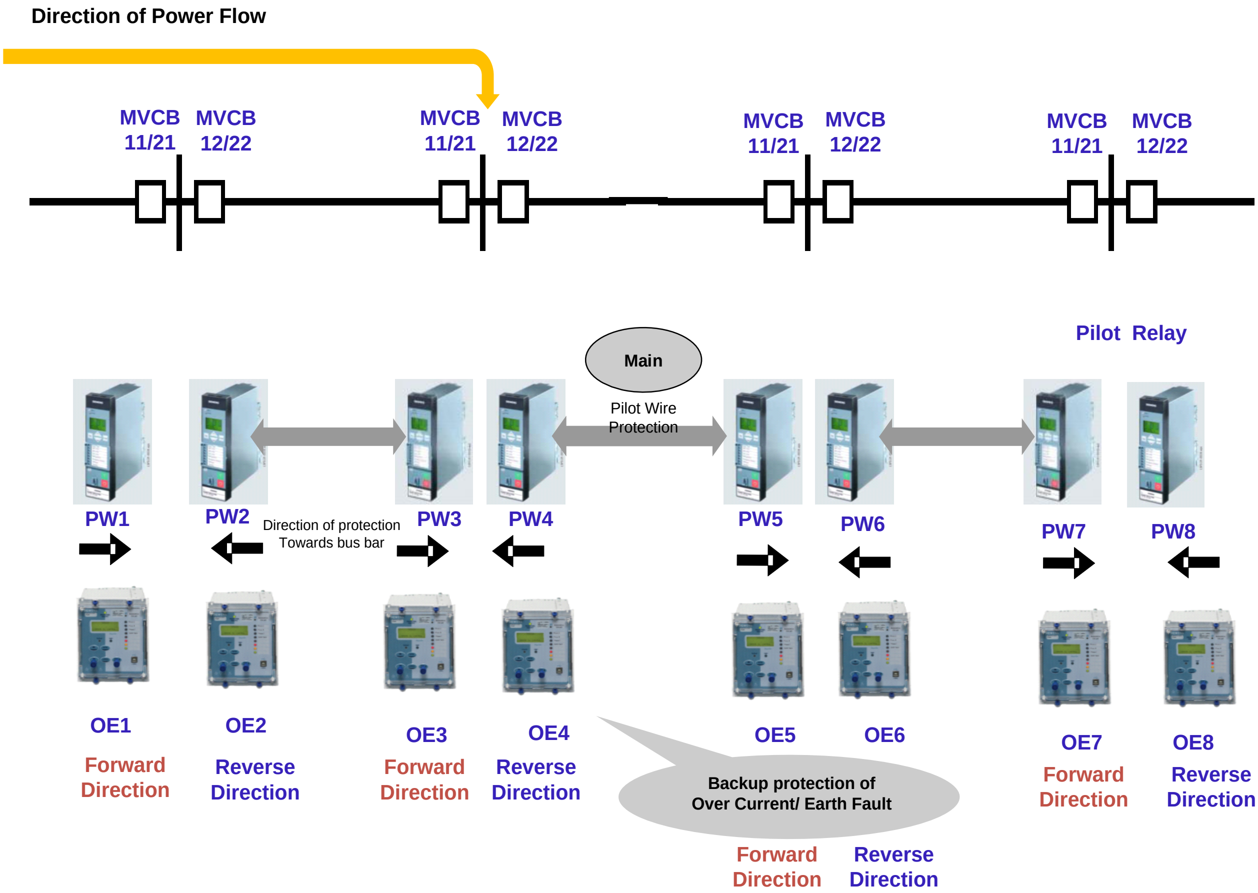


Fig. 12: Suggested improvements in the protection scheme [1]

4.1.2 Different tripping logic as discussed in the next chapter was developed in the relays to overcome the main drawbacks of identification of faulty section easily by the Traction Power Controller so as to guide him for resumption of supply from redundancies in case of any fault scenario. These logics were then programmed in the numerical relay available with different manufacturers who were supplying to DMRC.

# CHAPTER-5

# 5. BEHAVIOUR OF THE SYSTEM IN DIFFERENT SCENARIOS WITH THE IMPLEMENTED TRIPPING LOGICS

Different fault scenarios and the behavior of the Pilot wire protection and backup directional over current protection for ring feeder circuits are discussed with the configured tripping logic programmed and implemented.

## 5.1 Fault in the section between two stations with the tripping logic

i. In case of cable fault in the section between two stations, the pilot wire relay on MVCBs(PW4 & PW5 shown in red color in the figure 13 below) shall be activated instantaneously and trip the respective breakers. The over current relays experiencing the fault in reverse direction (OE2 & OE4) does not issue any tripping command due to directional settings. To eliminate any possibility of activation of overcurrent relays experiencing fault in the forward direction (OE1& OE3 shown in the figure 13 below), tripping logic shall be implemented in the over current relays such that any overcurrent relays (here OE2 & OE4 shown in the figure 13 below) experiencing fault in the reverse direction issues a blocking command (shown in yellow in the figure 13 below) to the forward direction overcurrent relay (here OE1 & OE3 shown in the figure 13 below) and block them from issuing tripping command to the breaker. This ensures that the respective breaker trips only on pilot wire protection and the spurious overcurrent tripping problems experienced in previous scenarios are not repeated. Thus faulty section can be identified and isolated by Traction Power Controller easily.

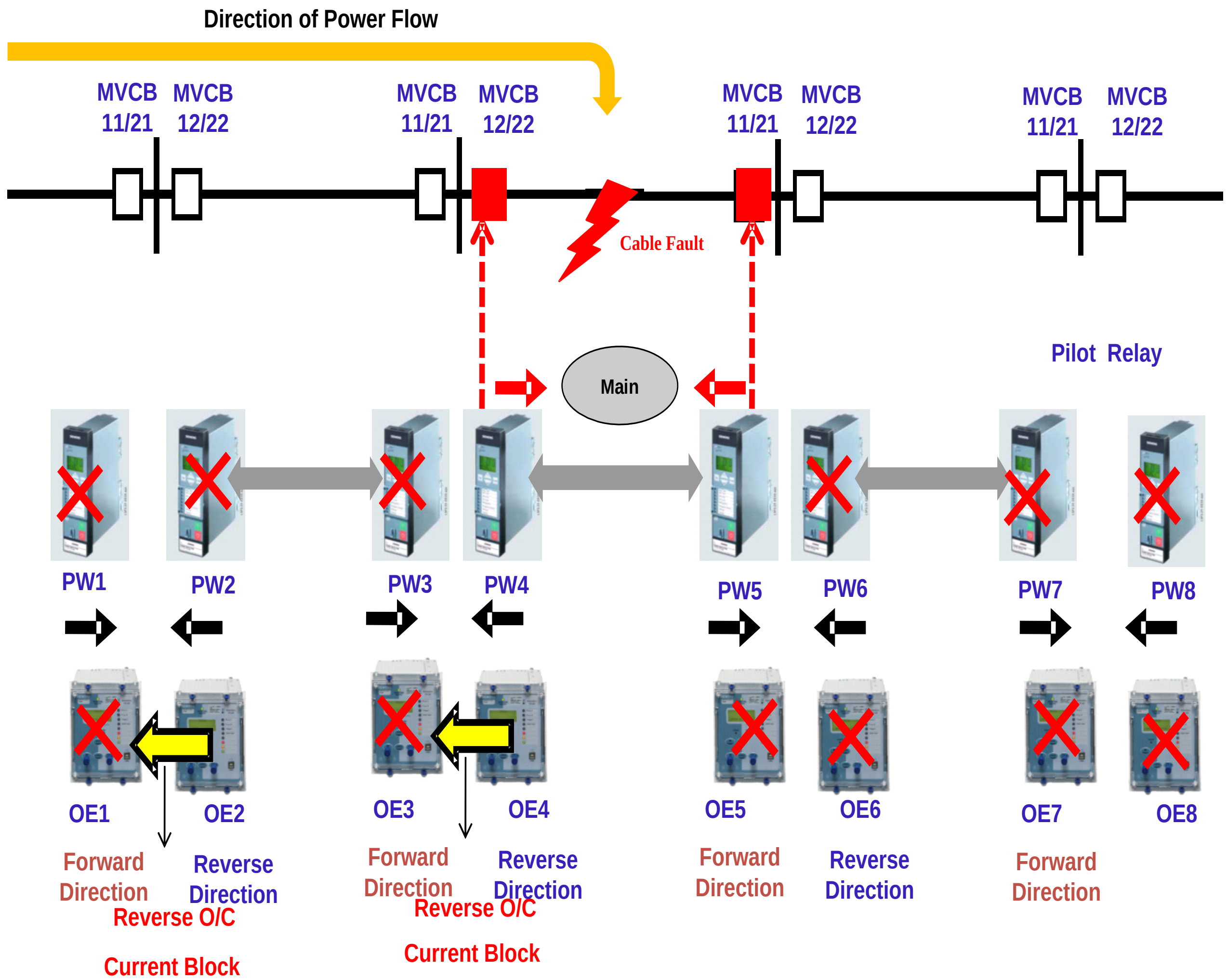


Fig. 13: Behaviour of the improved protection scheme with implemented tripping logic during cable fault between stations

ii. However the previous tripping logic shall remove the backup protection available in case of failure of pilot wire protection due to any of the commonly encountered problems of pilot wire, i.e. open circuit of pilot wire; improper connection after maintenance; relay failure etc. Therefore along with the blocking logic, another tripping logic should be implemented such that once an overcurrent relay set in reverse direction ( hereOE4 shown in figure 14 below) activates for reverse direction fault and also simultaneously gets the input of pilot wire protection (here PW4 shown in figure 14 below) failure, then the over current relay (here OE4) shall issue trip command to the corresponding ring feeder breaker to trip (as shown in pink in the figure 14 below).

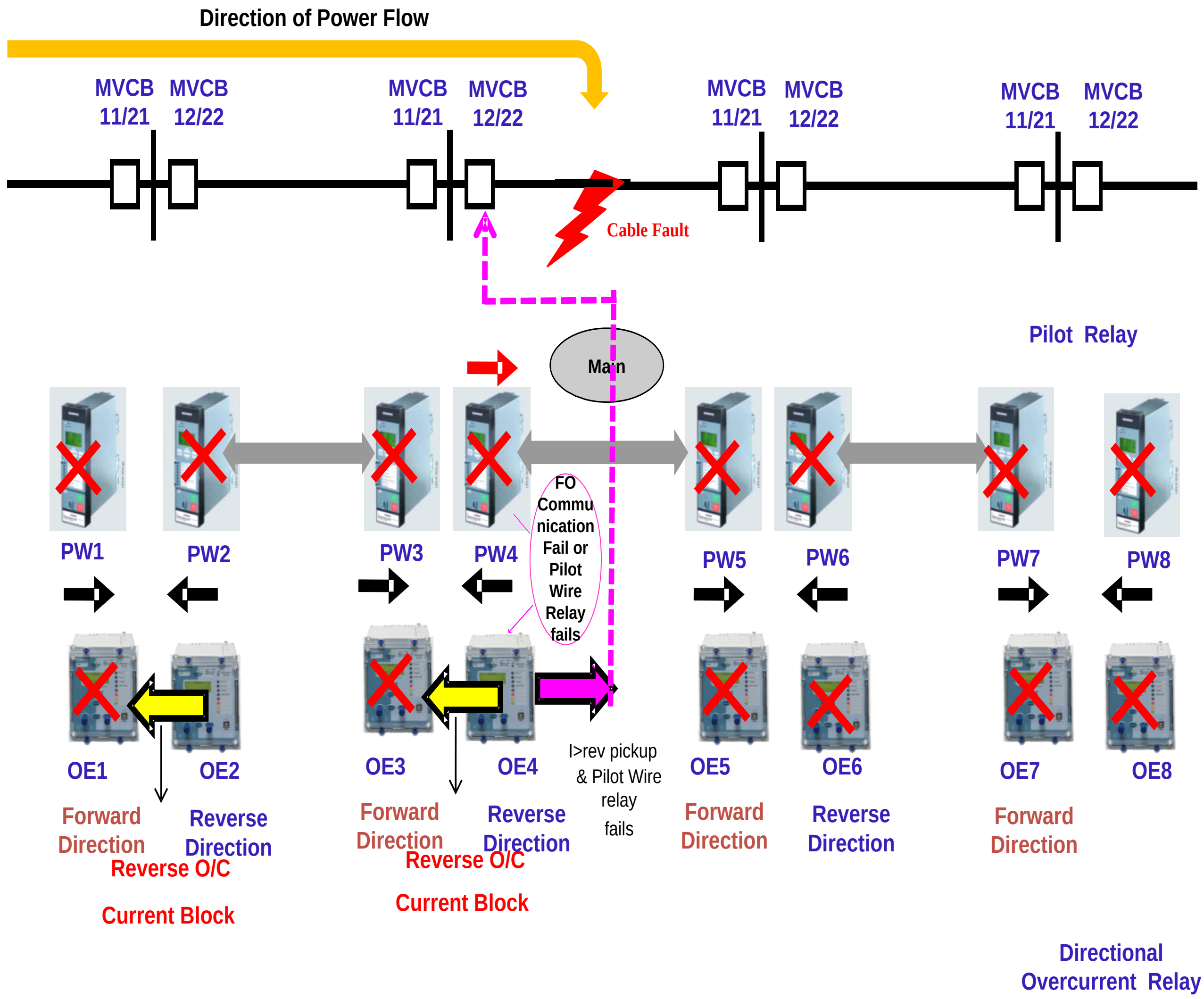


Fig. 14: Behaviour of the improved protection scheme with implemented tripping logic and Pilot Wire failure during cable fault between stations

The above logic shall ensure the availability of backup protection in the ASS if the primary protection fails. Thus faulty section can be identified and isolated by Traction Power Controller even during failure of Pilot Wire protection.

## 5.2 Bus Fault in any station and the tripping logic

In case of Bus bar faults, the corresponding reverse over current relay (here OE4 shown in the figure 15 below) does not activate in reverse direction and therefore does not issue any blocking command to adjacent over current relay (OE3 shown in the figure 15 below). The forward over current relay senses the fault in the forward direction and activates and issue a tripping command to the respective breaker (shown in red in the figure 15 below). A tripping logic should be implemented in such a way that the forward direction overcurrent relay (OE3 shown in the figure 15 below) while issuing the trip command (shown in red in the figure 15 below) in absence of the blocking command (since the blocking command is absent) shall also issue a trip command to the reverse direction overcurrent relay (OE4 as shown in yellow in the figure 15 below) or issue trip command to the adjacent breaker (MVCB 12/22 shown in yellow in the figure 15 below). This isolates the bus bars from both sides. Thus faulty section can be identified and isolated by Traction Power Controller easily.

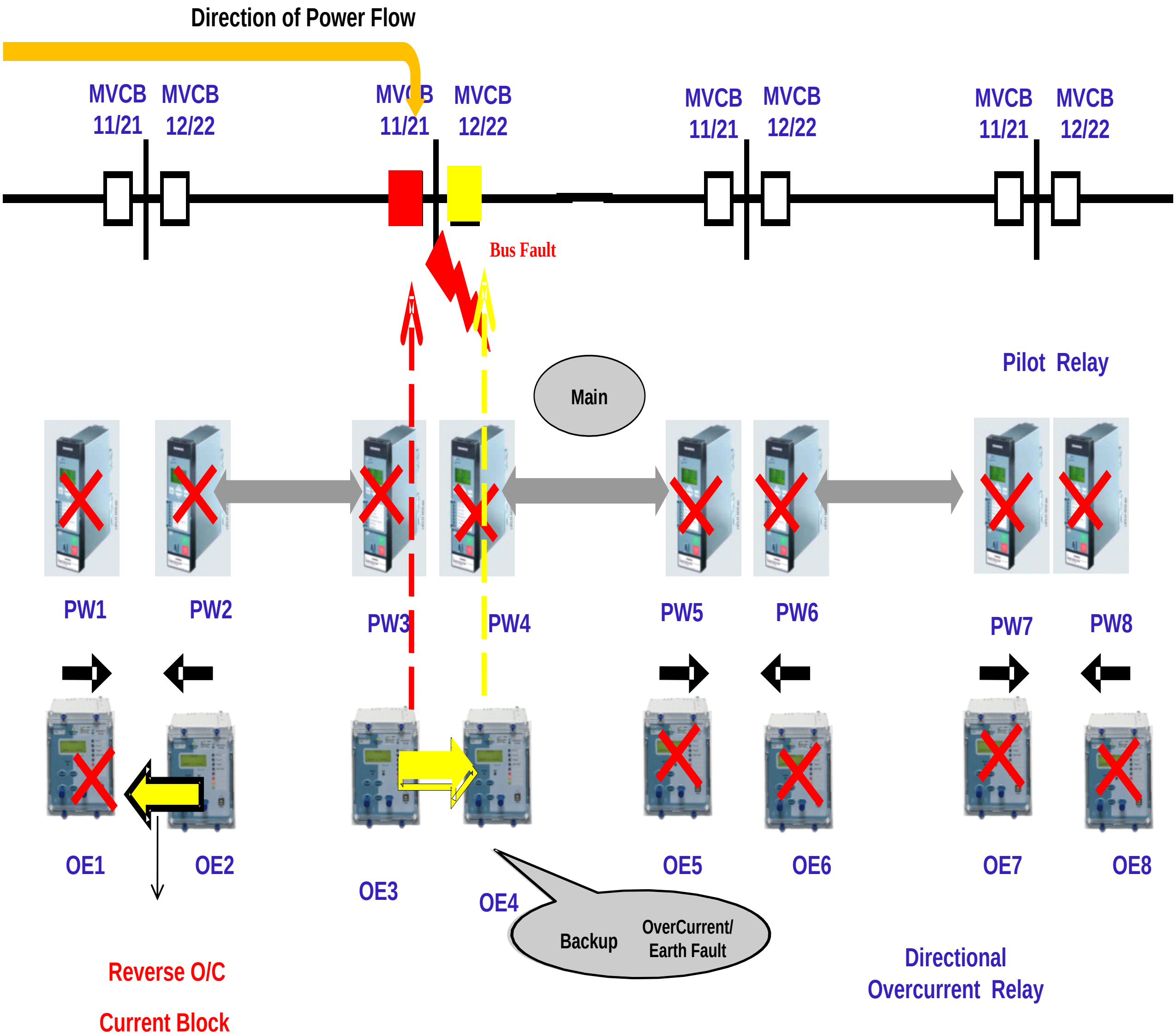

Fig. 15: Behaviour of the improved protection scheme with implemented tripping logic during bus fault

# CHAPTER-6

# 6. PROTECTION SETTINGS, DESCRIPTION OF EQUIPMENTS, VALIDATION OF THE SCHEME BY SECONDARY INJECTION TESTING METHOD AND DISCUSSION

## 6.1 Protection Settings

The advantage of the tripping logics discussed above is that all the ring feeders shall have the same settings and therefore only one level is required to be discriminated from the AMS breakers for correct functioning of the improvements suggested.

Accordingly, the DMRC 33 kV auxiliary network was simulated on a leading firm proprietary power system simulation tool (PSS® SINCAL) software (screenshots in figure 17 to 20 below) and protection settings as shown in the figure 16 below were decided for all the ring breaker feeders. A simplified SLD of the auxiliary network of DMRC was loaded on the software as detailed below in the screenshots using the relays used at ASS. The parameters of the different components were entered into the system and the output of projected settings was taken along with the coordination chart.

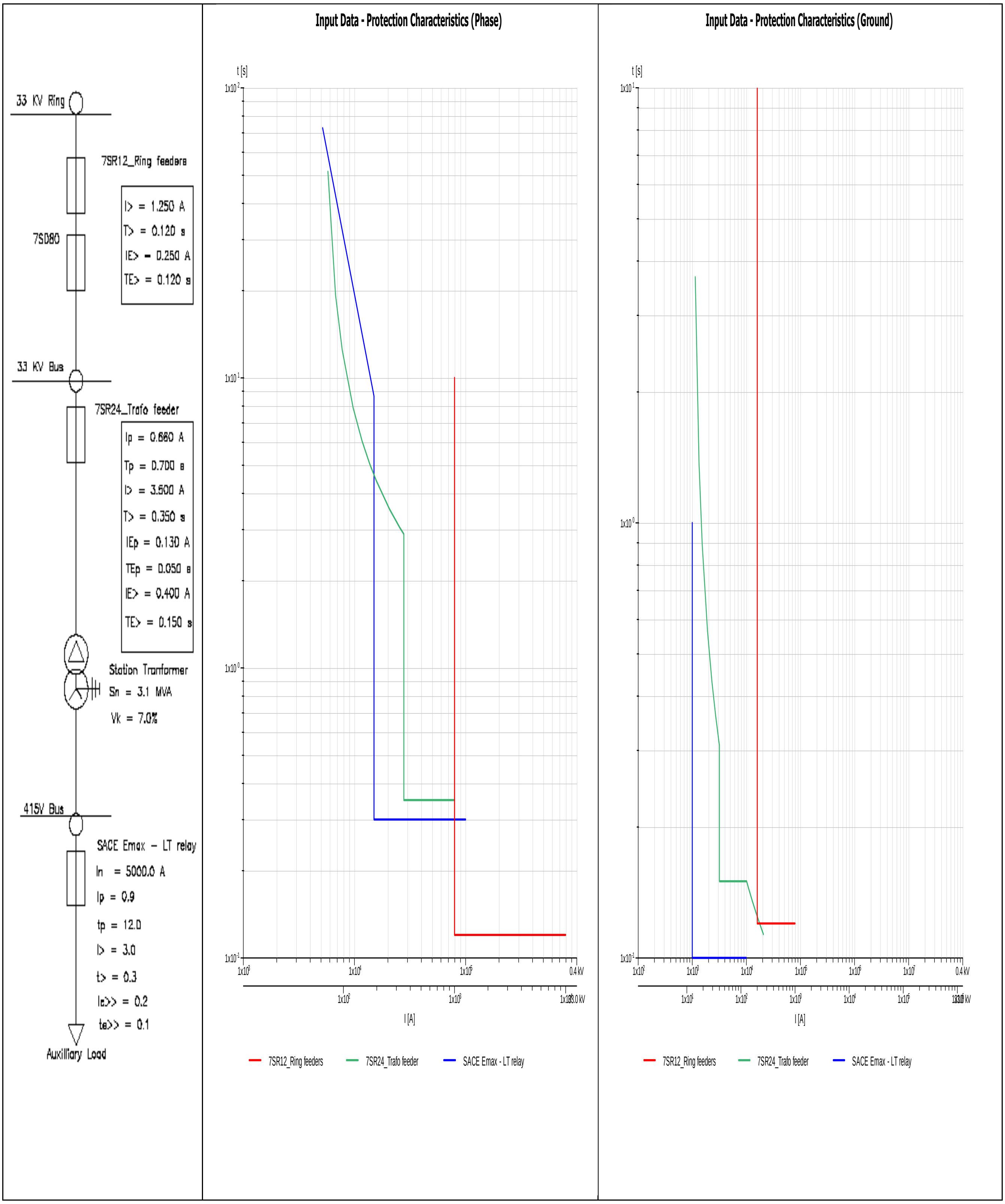

Fig. 16: Common current and time discrimination chart of protection settings of ring feeder breakers [1]

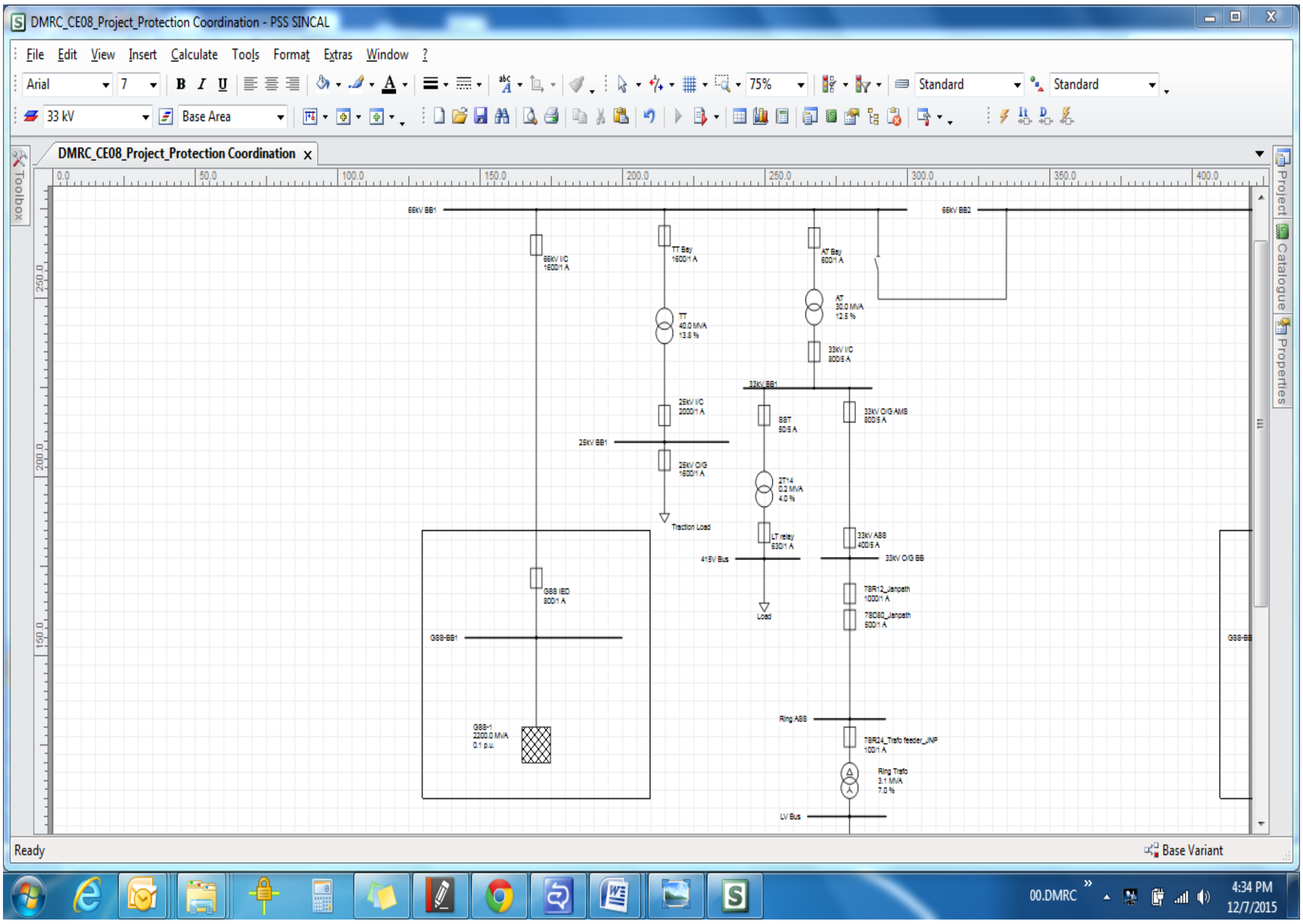


Fig. 17: Screenshot of simulation for deciding protection settings of the ring feeders [1]

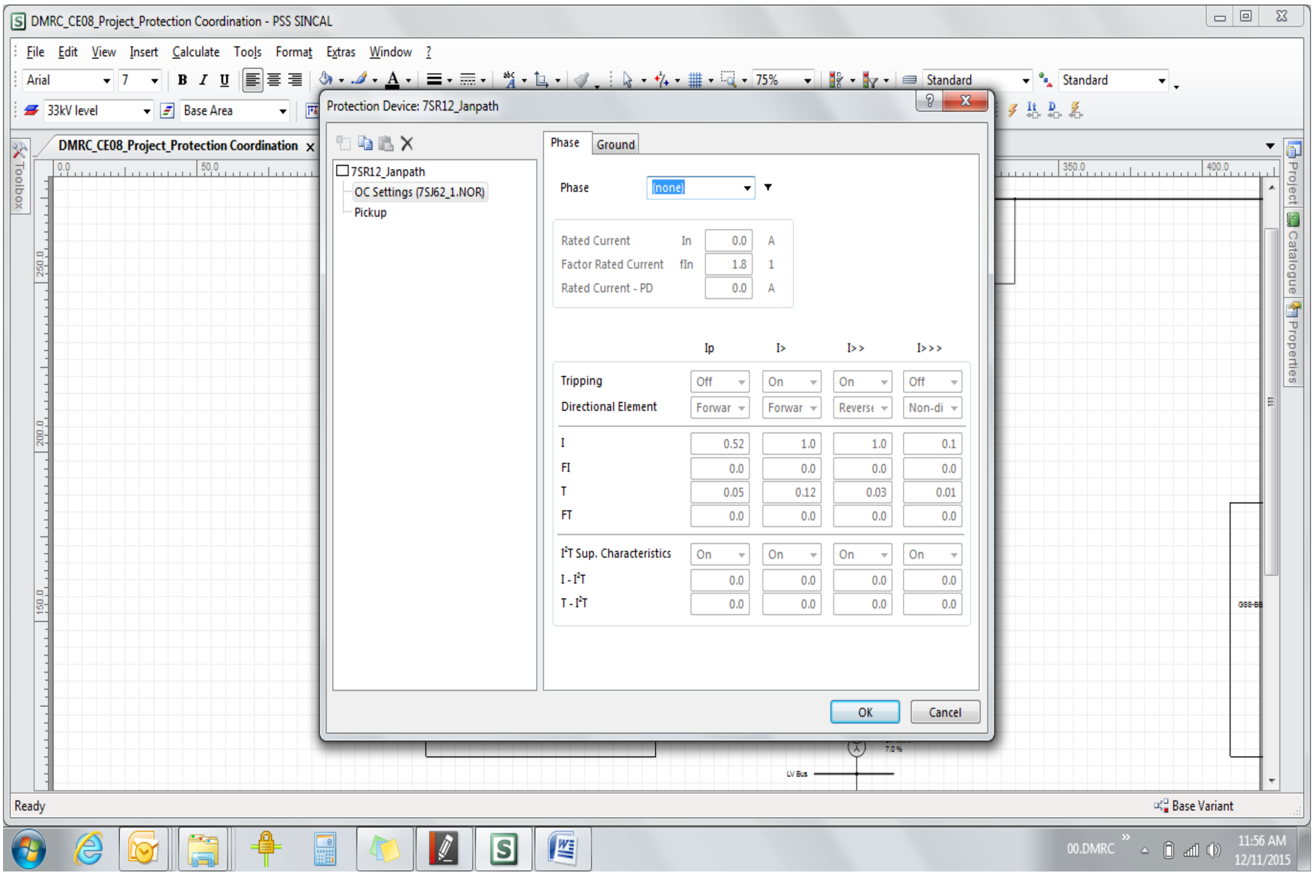


Fig. 18: Screenshot of simulation for deciding protection settings of the ring feeders [1]

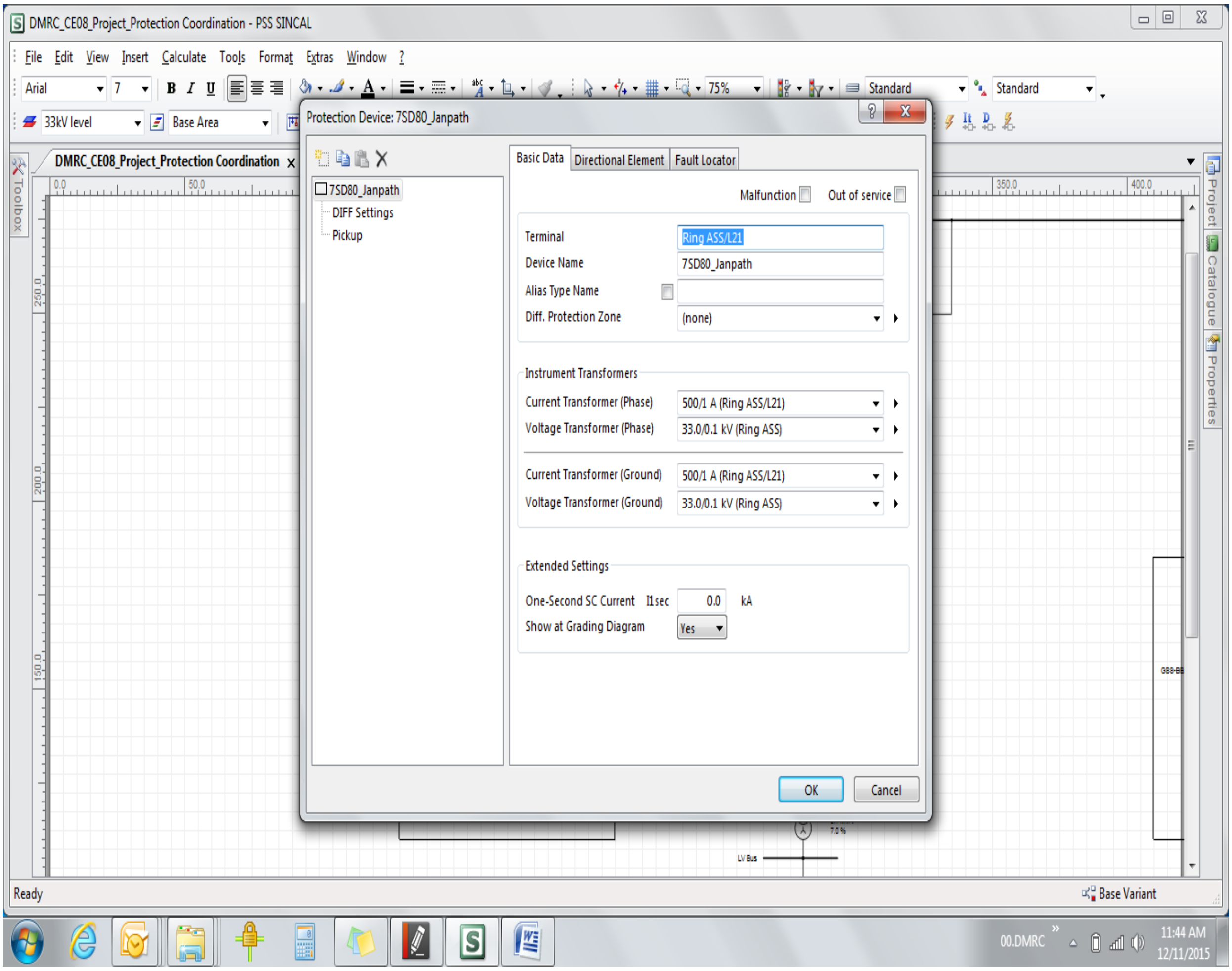

Fig. 19: Screenshot of simulation for deciding protection settings of the ring feeders [1]

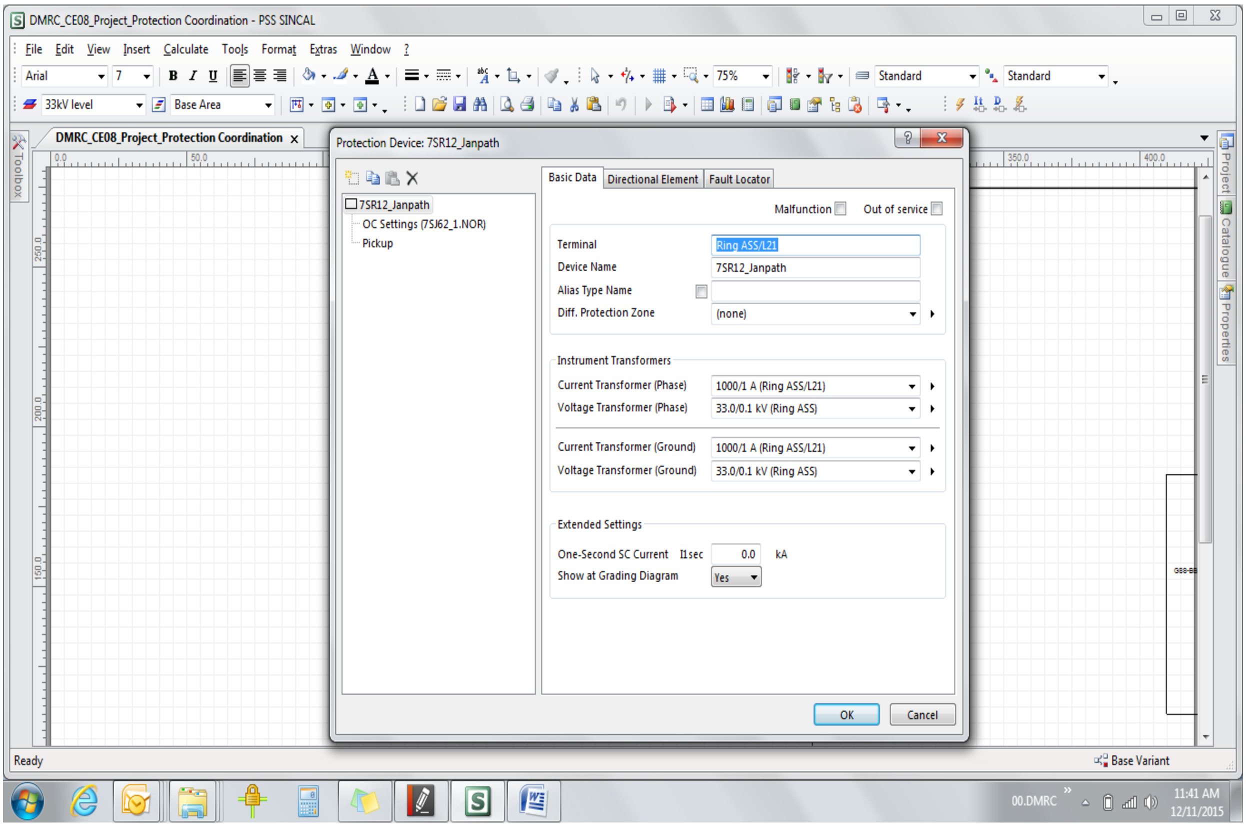

Fig. 20: Screenshot of simulation for deciding protection settings of the ring feeders [1]

## 6.2 Relays used in the Protection scheme

The protection scheme and implemented logic is being tested by secondary injection scheme during the commissioning of each Auxiliary Sub Stations (ASS) of DMRC and the results are in consonance to the behaviour in different scenario described previously. In the recently commissioned ASS, Siemens make protection relay 7SD80 line differential and 7SR12 Directional over current and earth fault relay have been used. A relay testing kit having two current sources and one voltage source is required for the testing of the relays.

General testing covering commissioning test such as General Measurement, Line differential Static, Line Differential Dynamic and 2nd Harmonics tests are performed on the 7SD80 relay as per the procedure defined in the testing documents. Similarly for 7SR12, General Measurement, Over Current (Forward & Reverse), Earth Fault (Forward & Reverse) and Operating Angle or Characteristic Angle of Relay are performed as per the routine procedures defined in the commissioning testing documents [11].

i. Over Current & Earth fault Relay 7SR12

7SR12 comes with the three binary inputs and five binary output as shown in the figure 21 below.

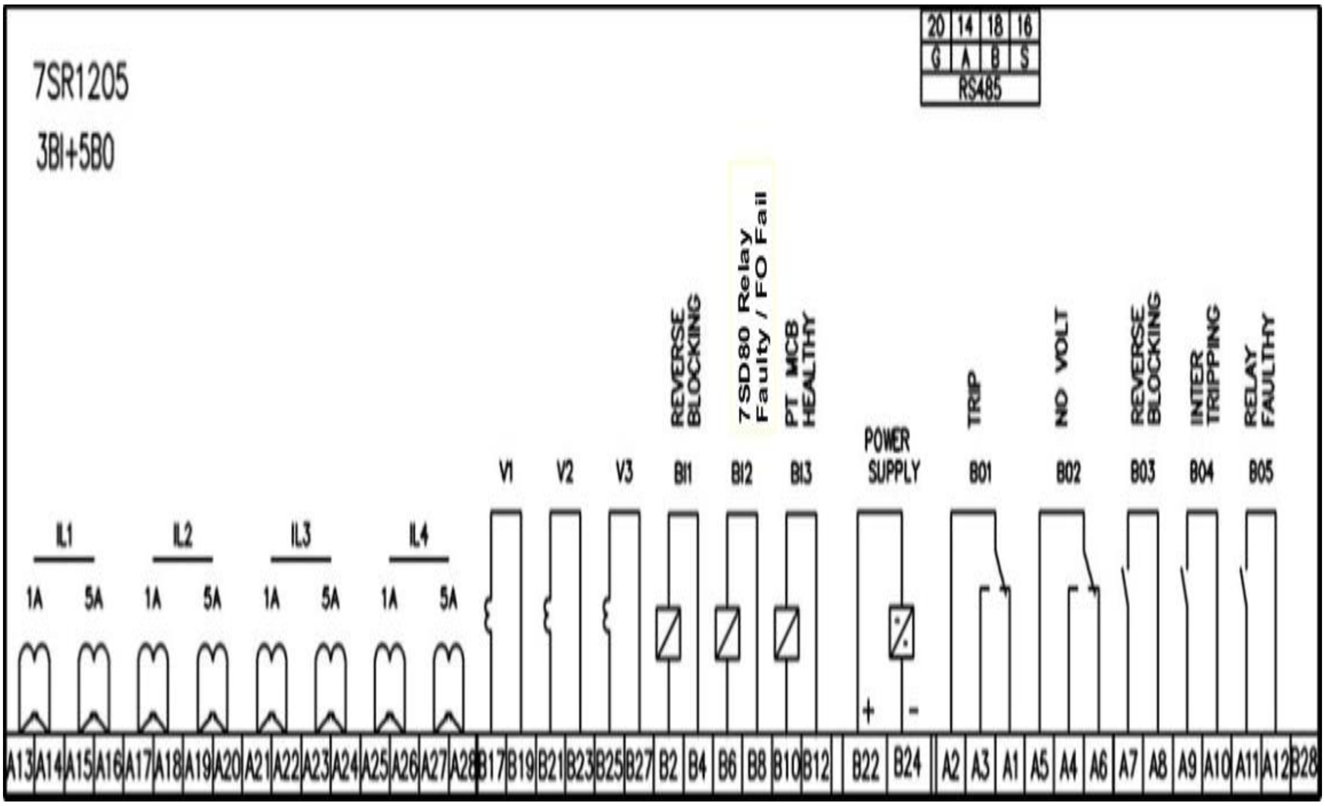


Fig. 21: Block Diagram of Overcurrent Relay 7SR12 on the ring feeders [10] [11]

Description of the Binary inputs and outputs as per the wiring in the terminals is described below.

| SI No | Description of Binary Inputs | Configuration |
|---|---|---|
| 1 | BI 1 | Reverse blocking signal from adjacent ring feeder. |
| 2 | BI 2 | Input from 7SD80 relay for relay fail and FO fail. |
| 3 | BI 3 | PT MCB healthy input. |

| SI No | Description of Binary Outputs | Configuration |
|---|---|---|
| 1 | BO 1 | Trip command to breaker. |
| 2 | BO 2 | No voltage signal. |
| 3 | BO 3 | Reverse blocking signal to adjacent breaker. |
| 4 | BO 4 | Inter tripping. |
| 5 | BO 5 | Relay faulty signal. |

ii. Pilot Wire Line Differential 7SD80

7SD80 comes with the three binary inputs and five binary output as shown in the figure 22 below.

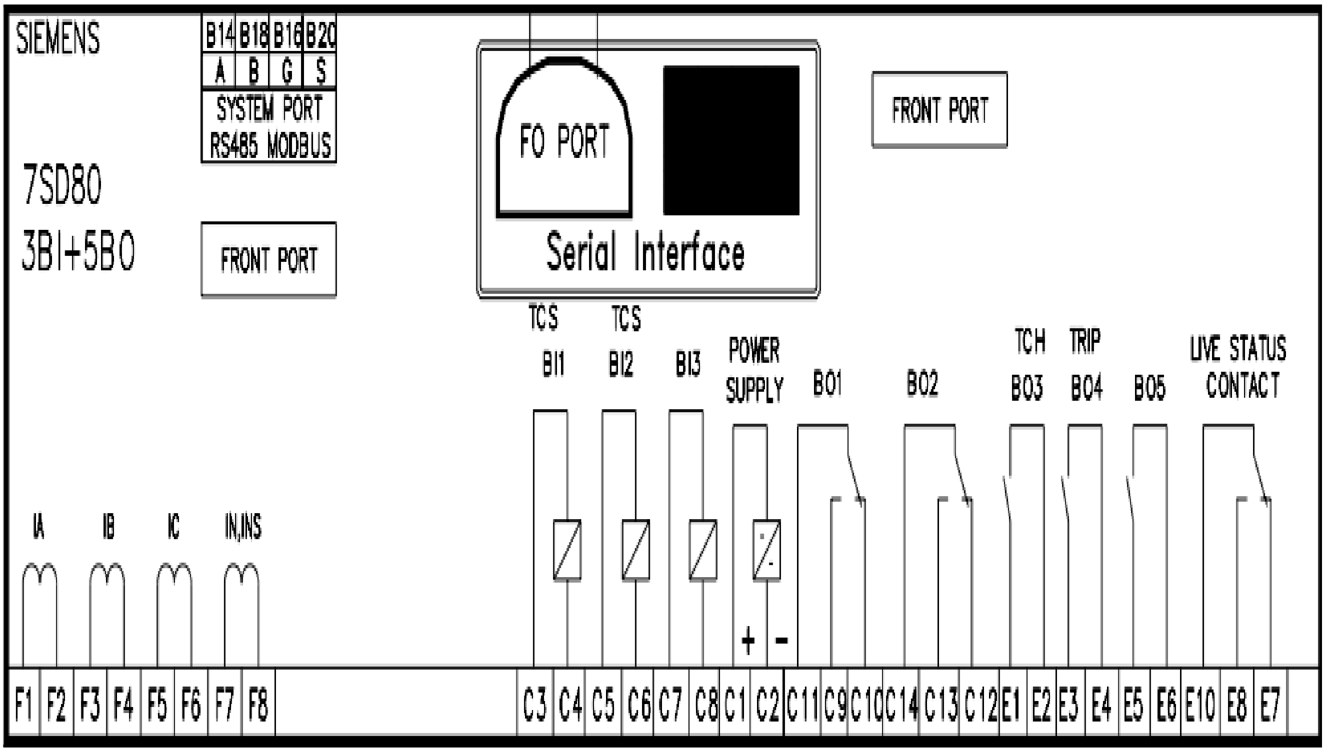


Fig. 22: Block Diagram of Pilot Wire Relay 7SD80 on the ring feeders [10] [11]

Description of the Binary inputs and outputs as per the wiring in the terminals is described below.

| SI No | Description of Binary Inputs | Configuration |
|---|---|---|
| 1 | BI 1 | Trip circuit supervision (pre closing) |
| 2 | BI 2 | Trip circuit supervision (post closing) |
| 3 | BI 3 | Spare |

| SI No | Description | Configuration |
|---|---|---|
| 1 | BO 1 | Spare |
| 2 | BO 2 | Spare |
| 3 | BO 3 | Trip circuit healthy |
| 4 | BO 4 | Trip |
| 5 | Live Contact Status | Relay fail / FO fail signal to 7SR12 relay |

## 6.3 Validation Of The Scheme By Secondary Injection Testing Method

The below mentioned figure 23shows the ring in and ring out circuit which contain similar relays at both end like on outgoing and incoming feeder. MVCB 12 is the outgoing feeder and the MVCB 11 is the incoming feeder as per the direction of power flow shown in the figure 23 below.7SD80 Pilot Wire line differential relay of same ASS has been connected with a Fiber optical cable and communication established through which they send information to each other and make the phase comparison to serve the differential function. The  Current Transformer (CT) has the ratio 400/1A for line differential and 800/1A for Directional Overcurrent relays on both the breakers of the Test Unit and adjacent ASS [6].

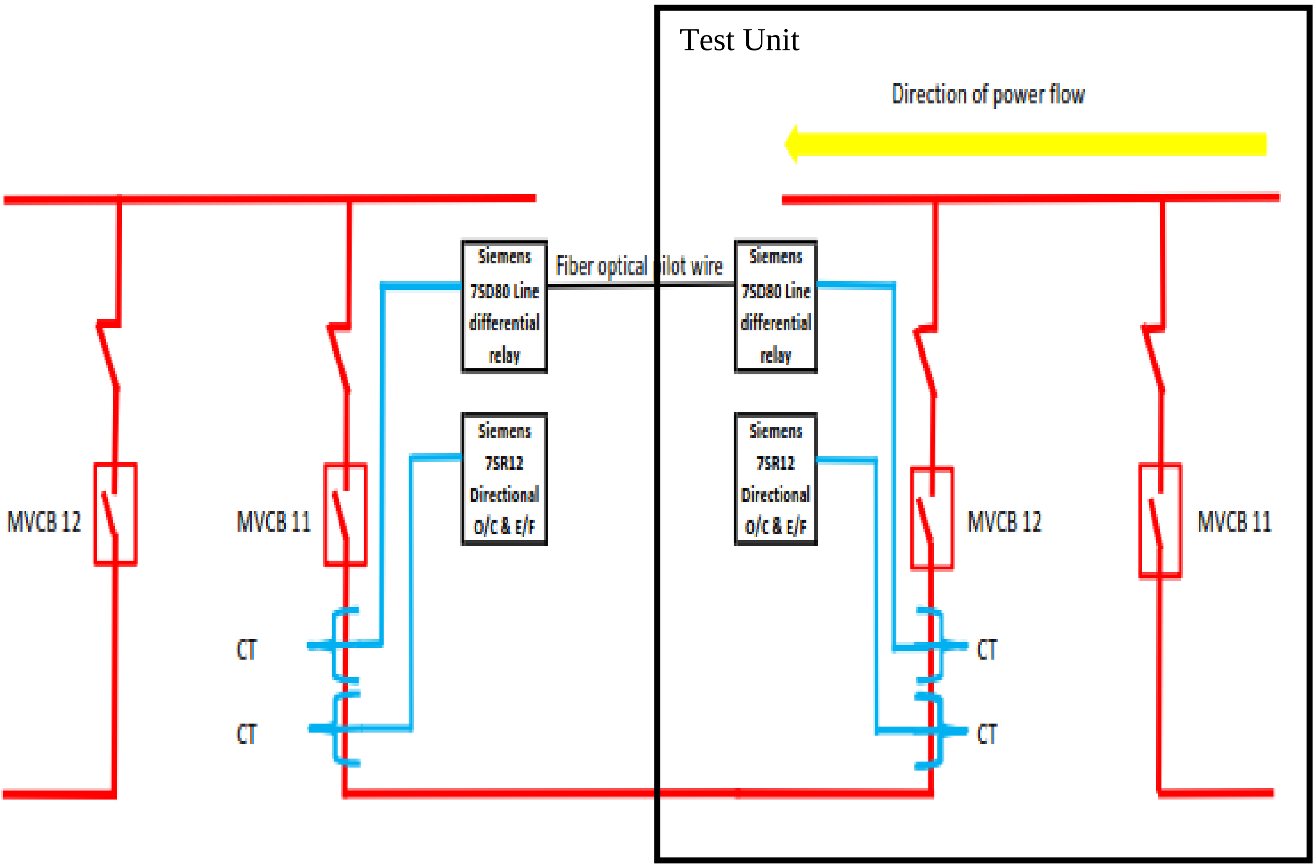


Fig. 23: Block Diagram of Test Setup

The Implemented Logic is tested by satisfying the following conditions:

1. When Pilot Wire differential relay 7SD80 and its Fiber Optic communication are healthy and if a fault occurs on the line, then the backup protection relay 7SR12 should be blocked from operating and clearing the line fault. Only the differential relay 7SD80 will operate and clear the fault.

2. When Pilot Wire differential relay 7SD80 or its Fiber Optic communication fail between the two differential relay, and if there is a fault on line, then in this case the relay which sense the fault in reverse direction will operate and block the tripping of the forward direction relay.

3. If there is a fault on bus bar then the directional relay will operate and trip the adjacent breaker via intertripping irrespective of the line differential relay is healthy and communication is healthy.

The secondary injection kit current source terminals are connected in the respective CT terminals in the LV panel of the breakers MVCB 11and MVCB 12 inside an ASS of the Test unit. As shown in figure 24 below the first current source (IL1, IL2, IL3 shown in the figure 24 below) is connected to the Overcurrent relay 7SR12 of MVCB 11 of the test unit (figure 23 above) and the second current source (I(L)-1, I(L)-2, I(L)-3 shown in the figure 24 below) is connected to the Overcurrent relay 7SR12 of MVCB 12of the test unit (figure 23 above). The Voltage source terminals (V L1-E, V L2-E, V L3-E) are connected to both the7SR12 relays of the test unit. To simulate the fault on the cable, 1.3 A current (above the current setting of 1.25 A) was injected in the CT secondary with nominal voltage 63.50 volt in secondary (i.e. phase voltage) as shown in the screenshot figure 24 below.

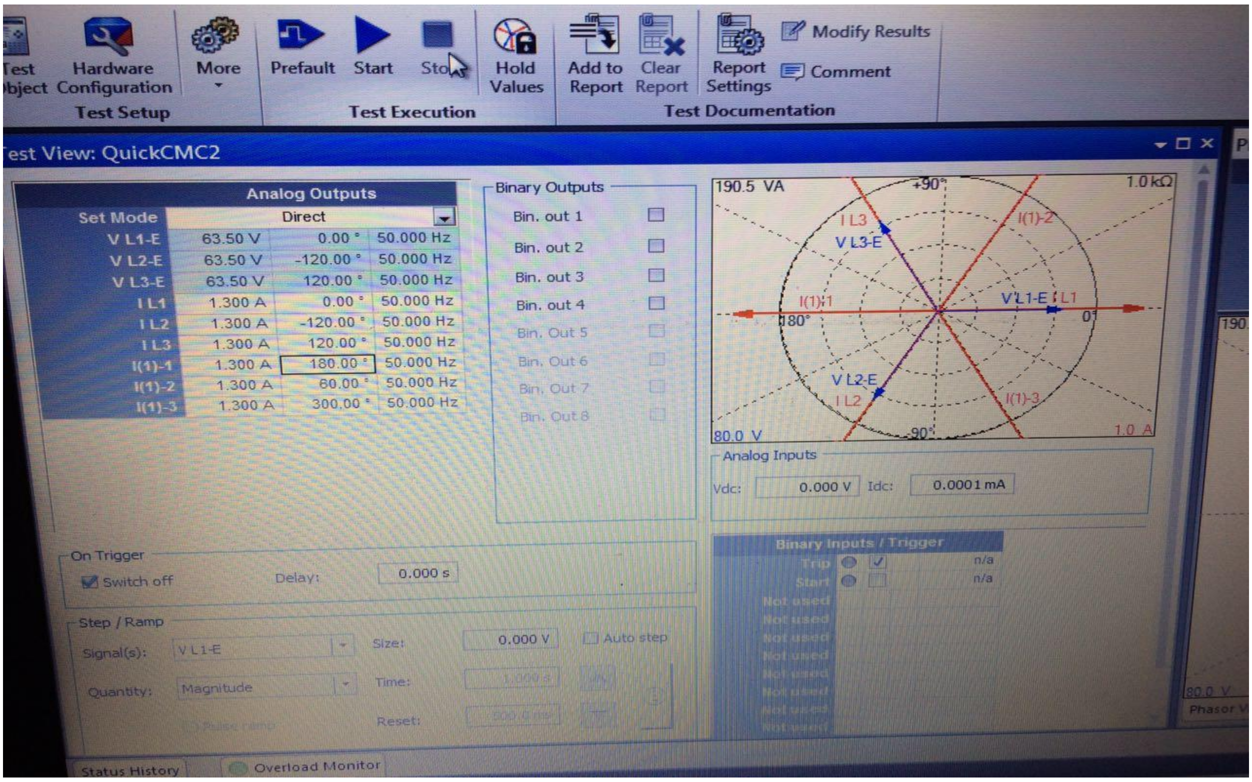


Fig. 24: Screen shot of secondary injection kit for establishing tripping logics

Depending up on the angle between voltage and current the corresponding relays will sense the fault in forward or in reverse direction. In above case as shown in figure 23 above, the relay of MVCB-11 sense the fault in forward direction and relay of MVCB-12 sense the fault the in reverse direction. The Overcurrent relay of MVCB 12 blocks the operation/tripping of the Overcurrent relay of MVCB - 11. 7SR-12 of MVCB-12 which is sensing the fault in reverse direction shall not issue any tripping command to the breaker. Also the Pilot Wire differential relay (which is healthy) does not sense any fault current in the testing arrangements and therefore none of the breaker trips which validates the first condition of testing.

In case of Pilot Wire differential relay or the fiber optic communication fails, then the Overcurrent relay sensing the fault in reverse direction, i.e. 7SR12 of MVCB-12 shall operate and simultaneously block the tripping of the forward direction relay. To validate the same, the above mentioned steps are repeated and Pilot Wire relay failure is simulated by taking out the fiber optic wire from 7SD80 of MVCB-12.The moment the fiber optical cable is plugged out from the 7SD 80 relay of MVCB-12, the continuous watching (watch dog) contact gives the input to over current relay 7SR 12 of MVCB -12 that the Pilot Wire differential relay is faulty or communication between the Pilot Wire relays has become unhealthy as per the philosophy shown in figure 25 below.

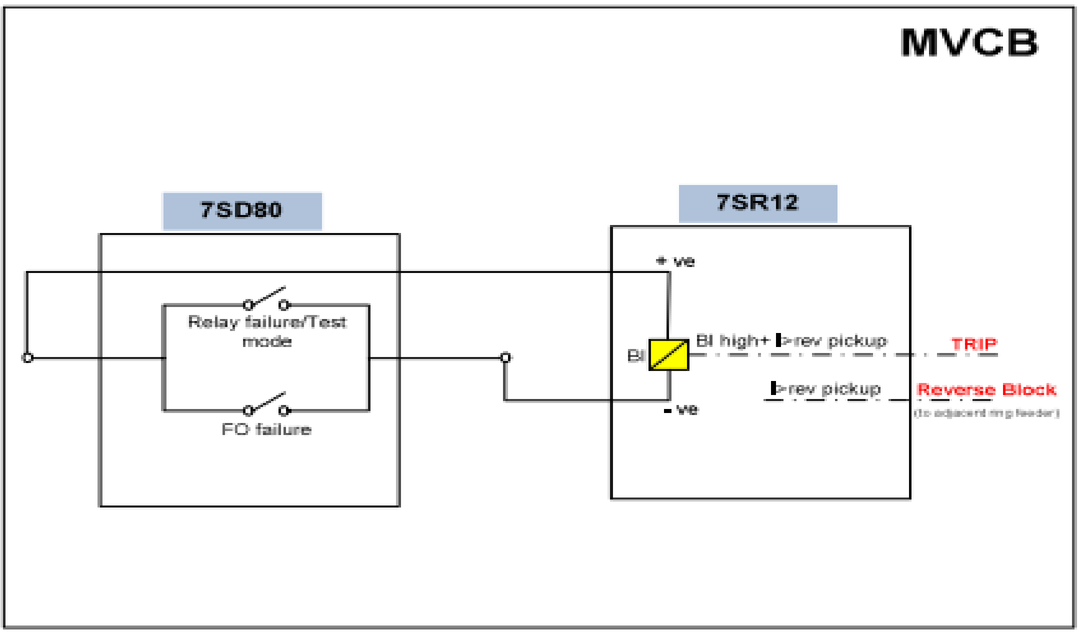


Fig. 25: Implementation of tripping logic during Pilot Wire Failure

Upon removing the fiber optic cable, the over current relay 7SR 12 of MVCB-12 operate and trips the associated breaker however no tripping takes place at MVCB-11. This validates the second condition.

To satisfy the third condition of case of Bus Fault, only the first current source element is connected to the corresponding relay i.e. 7SR12 of MVCB-11. The voltage and current setting is kept same as described above so as to simulate forward direction fault. In this case, both the breaker i.e.MVCB-11 and MVCB - 12 shown in figure 23 above trips thereby validating the intertripping logic in case of bus fault.

## 6.4 Discussion

The successful secondary injection testing has validated the desired operation of the intended improvements in the protection scheme. Therefore the solution based on use of Pilot Wire and Directional Over Current protective scheme combined with logical functions of the numerical relay is found to be workable.

The scheme can also be invariably used even when the direction of power supply is reversed (i.e. supply from different RSS in the metro line) without any dynamic changes required in the settings. This scheme is initially implemented on the upcoming installations of DMRC based on the technical advice of the feasibility of the scheme through various firms covered under the scope of contract agreements with DMRC. After the implementation, the suitability of the tripping scheme are being checked at all upcoming ASS installations as a part of commissioning tests.

# CHAPTER-7

# 7. CONCLUSION AND FURTHER SCOPE OF WORK

## 7.1 Conclusion

The scheme developed is dependent on the use of intelligent programmable numerical relays which due to decreasing cost has become the most preferred choices. The validation of the protection scheme by testing with secondary injection kit also lends credibility to the successful implementation of the discussed logics and scheme.

Other metros, like Lucknow (LMRC) and Kochi are also discussing the protection scheme and are likely to adopt similar scheme based on the above discussion. This scheme shall serve as a ready reference to other metros or railways.

The scheme can also be invariably used even when the direction of power supply is reversed (i.e. supply from different RSS on the metro line) without any dynamic changes required in the relay settings. This feature may also prove useful to the micro grids setup which is actively being researched now a days.

## 7.2 Further Scope of Work

i. The ASS relay timings should be synchronized with the RTUs of the concerned ASS which shall be further synchronized with the relay timings in the RSS and therefore provides same time reference for analyzing any fault when it occurs.

ii. As shown in the current and time coordination chart (Figure 16), the discrimination between LVCB and MVCB-1/2 can be achieved by incorporating an additional over current relay in the LVCB panel which shall be operational only for the overloading in the overlap zone.

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