Identification of The Optimum Protection Co-ordination in Medium Voltage Distribution System of Sri Lanka


Abstract: Majority of the faults in power network are transient and these faults can be cleared with proper installation of protective devices with appropriate protection settings. It is important to clear the faults as soon as possible by keeping the healthy network undisturbed while avoiding damages to lives and instruments.

Monthly tripping summary of Medium Voltage feeders of Grid Substations of Ceylon Electricity Board revealed that some feeders getting disturbed abnormally. Further, it is observed that Auto Reclosers are installed in downstream of these 33 kV feeders to respond to the transient faults but they are not yielding expected results. Hence, applying most appropriate protection setting to these protective devices are very much required for the higher reliability of the Medium Voltage network.

Two Medium Voltage feeders which were mostly disturbed were analyzed deeply and found that most of the feeder trippings are owing to Earth Fault. Further, with installation of temporary Digital Disturbance Recorder, it was observed that most of the faults have lasted less than 100 ms.

Four scenarios were analyzed to identify the optimum way of installing Auto Reclosers and protection setting for this Medium Voltage network. An algorithm was defined to find the optimum protection settings for any Grid Substations.

Key Words: Medium Voltage, Auto Recloser, Protection settings, Over Current, Earth Fault

1. Introduction

The main purpose of an electrical utility in a country is to supply an un-interrupted power to the end customers. Hence, transmission and distribution network ensure the transferring of the generated electrical power to end users. Overhead Medium Voltage (MV) distribution system is subjected to various electrical faults, mainly transient (temporary) faults and permanent faults. More than 80% of faults are transient [1] and usually these faults occur when phase conductors are electrically in contact with each other or ground momentary.

The protective device co-ordination is the process of determining most appropriate timing of power system interruption during abnormal conditions in the power system [2].

There are about 60 numbers of Grid Sub Stations (GSSs) in power system network in Sri Lanka [3] to step down the transmitted electrical power from High Voltage (220 kV or 132 kV) to MV (33 kV or 11 kV). The MV system has been experiencing nuisance trippings for ages owing to incorrect selection of protective devices, lack of discrimination between protective devices and bad maintenance and aging of electrical equipment in the system. Hence, proper selection of protective devices with proper protection co-ordination is required to maintain the power system reliability as well as to avoid damages to very costly equipment such as power transformers [4]. Therefore, co-ordination of protective relays at GSS and downstream Auto Reclosers (ARs) are very much essential to maintain the high reliability in MV distribution network.

2. MV System Protection

MV protection system consists of protective devices of power transformers, Bus couplers and MV distribution lines.
Over Current (OC) protection and Earth Fault (EF) protection are main protections for distribution line conductors and Bus Couplers. Most often, distribution protection has standardized settings, equipment and procedures. Standardization makes designing, operation and protection coordination easy and reduces engineering efforts [5].

Non directional / directional OC and EF protection and Standby Earth Fault (SBEF) protection are backup protections for power transformers in addition to main protections such as Differential protection and Restricted Earth Fault protection against external faults.

Protection relays are applied in the power network by considering the over current grading and fault discrimination.

When a fault occurs, the protection relay closest to the fault should operate by leaving the healthy network undisturbed. This is called grading and it can be achieved by using following methods [6, 7].

- Current grading
- Time grading
- Current and time grading

The grading margin is the time interval between operating times of two adjacent protective relays [7, 8]. Sufficient grading margin should be set between relays to avoid unnecessary operation of relays. The grading margin used for electromechanical and static relays are 0.4 s and 0.35 s respectively [7] while it is 0.3 s for digital and numerical relays [7, 8, 9]. When designing MV network, minimum number of grading levels should be used [9].

2.1 Protection Philosophies used in MV network

The relays having OC and EF protection functions perform on different philosophies as mentioned below.

- Instantaneous
- Definite Time (DT)
- Inverse Definite Minimum Time (IDMT)
- Directional

With the invention of new technologies, relays with one or more philosophies of above are available for the application of the network according to the requirement.

2.2 OC and EF Protection for MV System

If a fault is not cleared promptly, a fault external to the transformer (through faults) can damage the transformer causing severe overheating. OC and EF relays can be used to clear the transformer from the fault bus or line before the transformer is damaged. Power transformer protection for through faults should be limited to 2 s [8], according to ANSI Standard C37.91, Guide for Protective Relay Applications to Power Transformers.

OC and EF protection are primary protection to MV distribution lines. The pickup value for a relay is selected by considering maximum loading and transient current withstand capability of next downstream protective device location while Time Multiplier Setting (TMS) is selected considering the maximum fault current at the location of protective device installed. Primary protection should recover the line from the fault within 1 s duration [8].

3. Review of Existing Co-ordination In MV Network

System Control Center daily issues the incident report which shows the summary of trippings per day. Accordingly, more frequent trippings have happened with some 33 kV feeders. Two 33kV feeders which were subjected to frequent nuisance trippings were analyzed to check the adequacy of existing protection setting co-ordination in MV network.

![Figure 1 - History of Trippings in F1 of Seethawaka GSS](image-url)
3.1 Case Study 1 – Feeder 1 of Seethawaka GSS

Seethawaka GSS is a 132 / 33 kV substation which having three 31.5 MVA, 132 / 33 kV power transformers, five outgoing 33 kV feeders and one 33 kV generator feeder. It was found that Feeder 1 (F1) has large number of trippings per every month and hence, it was considered for this analysis. It was found that four downstream ARs have been installed in sub feeders of F1. A graph (Figure 1) is drawn for the tripping data of F1 for last two years. It is seen that, in most of the months, number of trippings per month in F1 are greater than 60.

Further analysis of trippings in F1 revealed that majority of trippings is owing to operation of EF relay (Figure 2).

![Figure 1 - Tripping Data of F1](image)

### July 2014
- EF Trip: 3%
- OC Trip: 2%
- OC+EF Trip: 95%

### August 2014
- EF Trip: 1%
- OC Trip: 3%
- OC+EF Trip: 98%

![Figure 2 - Comparison of Trippings in F1](image)

3.1.1 Digital Disturbance Records Analysis

Portable Digital Disturbance Recorder (DDR) was installed in to the F1 at Seethawaka GSS to study the behavior of F1 and DDR records for ten days (From 29th July 2014 to 07th August 2014) were obtained. Accordingly, F1 has tripped 27 times within these ten days, majority being due to EF. These faults were cleared with the operation of Instantaneous EF protection of the relay at GSS within less than 100 ms. EF current variation during each fault within these 10 days is shown in Figure 3.

In depth analysis of a DDR record of a tripping of F1 on 04th August 2014 at 19.48 hrs was done. The DDR record is given in Figure 4.

![Figure 4 - DDR Record at 19.48 hrs on 04th August 2014](image)

3.1.2 Existing Protection Settings of Seethawaka GSS

While analyzing the existing OC and EF protection settings of Seethawaka GSS, it is found that relays installed for 33 kV feeders are digital type MCGG relays and backup protection relay of transformers are numerical type MICOM relays. Further it is found that sufficient grading margin between protective devices are available but revision of EF settings is required since EF settings of AR are very sensitive and always tend to trip the F1 definitively without auto reclosing the line. Hence revision of AR settings is required with suitable settings to relays for better coordination. Further, it is required to check whether application of Very Inverse (VI) or Extremely Inverse (EI) curves are more suitable instead of Normal Inverse (NI) curves for downstream protective devices.
3.2 Case Study 2 – F5 of Badulla GSS

Badulla GSS is a 132 / 33 kV substation which is having three 31.5 MVA, 132 / 33 kV power transformers and eight outgoing 33 kV feeders. Since frequency of tripping of F5 is comparably high, it was selected for the analysis. The tripping data of F5 for last two years were analyzed and plotted in a graph (Figure 5). Data proves that, the frequency of tripping in F5 is more than 40 per month.

Comparison among operated protection functions (Figure 6) show that the tripplings owing to EF is comparably high in F5.

3.2.1 Auto Recloser Events Analysis

Trip data gathered from the GSS for six days from 11th November 2014 to 16th November 2014 were considered for this analysis. There were 22 number of line interruptions during the period considered.

There are nine downstream ARs installed in F5 at several locations, while three ARs are in series. These ARs are two types such as NEWLEC and NTEC. Events records of one AR in the F5 were deeply studied and EF current recorded during these line interruptions were plotted in Figure 7. According to these records, all are auto tripplings owing to operation of EF relay.

3.2.2 Existing Protection Settings of Badulla GSS

Existing OC and EF protection settings of power transformers, 33 kV bus section and 33 kV feeders at Badulla were referred. All relays at GSS are numerical type. Primary protection relay of 33 kV feeders and 33 kV bus section is ABB REF630. Backup protection relay of transformers is also REF630 and SBEF function is in primary protection relay; GE T60.

By using the fault levels at the location of protective device, OC and EF characteristics curves were plotted. It is found that there is no sufficient grading margin between ARs and relays at GSS.
Further it is revealed that, OC and EF settings of ARs are very sensitive which can cause to trip sub feeders even for small transient faults. Hence revision of settings of downstream ARs is required for better coordination with upstream relays. To obtain better grading margins between devices, it is required to check whether application of VI or EI curves instead of NI curves.

4. **Selection of Protection Settings For MV Network**

There have been several studies done worldwide to find the optimum allocation of ARs in distribution network [10, 11]. These researches have taken both radial and loop network examples into consideration and the solutions were relevant only to the discussed cases separately. New method of auto coordination is defined in some studies [12] to propose their solutions. As per these researches, it is revealed that optimum allocation of ARs depends on the network considered and the method of study.

Optimum protection co-ordination for CEB MV network will be determined by considering several scenarios that conform with standards and best practices. Typical 33 kV feeders each of which has none, one, two and three downstream ARs were considered for these scenarios.

Since, general guidelines are to be proposed in this study, a GSS having parallel connected 31.5 MVA, 132 / 33 kV three power transformers, three 33 kV bus sections and 33 kV feeders were considered in the analysis. In CEB network, power transformers have delta winding in Low Voltage side and hence system ground has been obtained by shunt connected earthing transformer having zero sequence impedance of 75Ω.

4.1 **Scenario 1 – No Downstream AR**

It is assumed that MV distribution feeders have both Lynx and Raccoon conductors of 20 km length under Scenario 1 (Figure 8). By using the calculated fault levels at the location of protective devices, TMS were calculated by maintaining 0.3 s grading margin between operating times of the devices. NI standard characteristic curve defined by IEC 60255 were applied for these IDMT relays. Downstream transformer fuses which operate on the thermal characteristics were not considered in this analysis.

As per the DDR record analyzed in case study 1, minimum of 100 ms of fault clearing time is required to clear transient faults for the downstream protective device. Hence, operating time of IDMT protection was selected as 100 ms to avoid the tripping of the feeder during transient faults. To operate relays during high fault current incidents, Instantaneous settings were used for feeder. The calculated operating times of protective devices are given in Table 1.

<table>
<thead>
<tr>
<th>Bay</th>
<th>Protection Function</th>
<th>Operating Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer 33 kV Feeder</td>
<td>SBEF</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>OC</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.72</td>
</tr>
<tr>
<td>33 kV Bus Section</td>
<td>OC</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.42</td>
</tr>
<tr>
<td>33 kV Feeder (Lynx)</td>
<td>OC</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.11</td>
</tr>
<tr>
<td>33 kV Feeder (Raccoon)</td>
<td>OC</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.11</td>
</tr>
</tbody>
</table>

As per the above protection settings, primary protection clears fault within 0.43 s and it is in the satisfactory range. Backup protection operates within 1.02 s and it is also less than 2 s of recommended range.

4.2 **Scenario 2 – One Downstream AR in Series**

33 kV feeder having one downstream AR installed was considered in the second scenario. Length of the 33 kV feeder was taken as 40 km while assuming the AR is installed at 20 km distance from the GSS. These lengths were selected by assuming the ARs are installing on feeders with the increase of the
The calculated OC and EF settings show that primary protection of the MV network cannot clear a fault within 1 s (it is 1.33 s) and backup protection system is in the defined range of 2 s (it is 1.90 s). It is seen that, this scenario is not conforming to the standards and practices.

4.5 Optimum Protection Co-ordination for MV Network

The third scenario which proposed two downstream ARs can be recommended as the optimum protection co-ordination system for the MV network of CEB. The fault levels and the maximum short time loadings of a 33 kV feeder of a GSS are different to each other. Therefore, pickup setting and TMS settings of protective devices can vary. Hence, an algorithm (Figure 10) to identify optimum protection co-ordination in MV Distribution System of Sri Lanka is defined with the settings derived in scenario 3. The plotted characteristic curves for OC and EF protection is shown in Figure 11 and Figure 12.
Obtain details of the MV system concerned
1. SLD of MV system
2. Details of downstream ARs
3. Distribution Conductor type, lengths and Impedance
4. Maximum fault level of GSS (33 kV level)
5. Maximum load current through protective devices

Calculate the maximum fault level at location of protective devices

Apply EF settings and calculate operating time

<table>
<thead>
<tr>
<th>Bay</th>
<th>Instantaneous / DT Setting</th>
<th>IDMT Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I (A)</td>
<td>Delay (s)</td>
</tr>
<tr>
<td>Transformer 33 kV Feeder (SBEF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformer 33 kV Feeder (EF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33 kV Bus Section</td>
<td>660</td>
<td>0</td>
</tr>
<tr>
<td>33 kV Distribution Feeder</td>
<td>640</td>
<td>0</td>
</tr>
<tr>
<td>Downstream AR 1</td>
<td>320</td>
<td>0</td>
</tr>
</tbody>
</table>

Check grading margins by plotting curves

Grading margin = 0.3 s

NO

Apply OC settings and calculate operating time

<table>
<thead>
<tr>
<th>Bay</th>
<th>Instantaneous / DT Setting</th>
<th>IDMT Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I (A)</td>
<td>Delay (s)</td>
</tr>
<tr>
<td>Transformer 33 kV Feeder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33 kV Bus Section</td>
<td>1650</td>
<td>0.4</td>
</tr>
<tr>
<td>33 kV Bus Section (Lynx)</td>
<td>1250</td>
<td>1.0</td>
</tr>
<tr>
<td>33 kV Distribution Feeder (Lynx)</td>
<td>1600</td>
<td>0.0</td>
</tr>
<tr>
<td>33 kV Distribution Feeder (Raccoon)</td>
<td>1600</td>
<td>0.0</td>
</tr>
<tr>
<td>Downstream AR 1 (Lynx)</td>
<td>1200</td>
<td>0.0</td>
</tr>
<tr>
<td>Downstream AR 1 (Raccoon)</td>
<td>1200</td>
<td>0.0</td>
</tr>
<tr>
<td>Downstream AR 2 (Lynx)</td>
<td>800</td>
<td>0.0</td>
</tr>
<tr>
<td>Downstream AR 2 (Raccoon)</td>
<td>800</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Check grading margins by plotting curves

Grading margin = 0.3 s

NO

Finalize OC and EF protection settings

Figure 10 - Algorithm to Identify Optimum Protection Co-ordination in MV System
4.6 Application of the Algorithm to F5 of Badulla GSS

The derived algorithm was applied to the F5 of Badulla GSS, which was having considerable number of trippings per month. Data collection and calculations were done according to the algorithm and derived settings were implemented to the relevant protective devices. Then, it is observed that numbers of trippings of F5 are reduced drastically (Figure 13).

5. Conclusion

Case studies 1 and 2 showed that the most of the 33 kV feeder trippings were due to EF which last for less than 100 ms.

To identify the optimum protection co-ordination between protective devices, four scenarios where 33 kV feeder has none, one, two and three downstream ARs were studied. The study revealed that 33 kV feeder with two downstream ARs is the optimum solution which can be satisfactorily applied to the MV network with adhering to the standards and practices in the world.

The defined algorithm can be used to find the optimum protection settings for any other GSS. The application of the algorithm to the feeder of the case study 2 proofed the frequency of tripping of the feeder can be reduced considerably.

References


Figure 13 - Comparison of no of Trippings of F5 of Badulla GSS with New