The effects of load growth on electrical protection for Eskom’s transmission system

This paper covers recent protection setting philosophy changes made by Eskom Transmission to cope with increased power demand in South Africa.

With demand increasing it has become important to ensure that protection settings are chosen correctly to avoid unnecessary tripping for load. It is also important to ensure that this is done without compromising the protection of equipment. It was therefore necessary to review the protection setting philosophy and make changes where required.

Auto-reclose setting changes

Auto-reclose (ARC) is used on the transmission system to reduce the impact of short duration line faults. A number of protection setting changes have been made to improve how auto-reclose is performed.

Three-cycle logic

Eskom used to employ a three-cycle sequence for sustained phase faults and a five-cycle logic for sustained earth faults.

For phase faults the system was: 3-phase trip, reclose, 3-phase trip and lockout.

For earth faults it was: 1-phase trip, reclose, 3-phase trip and lockout.

These sequences would be performed at both ends of the line. The single-phase dead time was selected to 1 second at both ends. The three-phase dead time was selected to three seconds at one end (dead line charging end), and four seconds at the other, which would perform a synchronisation check before closing. The dead times on lines between two power stations were typically selected to 25 and 30 seconds respectively, to allow for oscillations to decay.

According to the new philosophy the logic for a sustained earth fault is reduced to three-cycles, as follows:

1-phase trip, reclose, 3-phase trip and lockout.

This sequence is applied at both ends of the line.

The reason for this change is the low success rate of reclosing on the second attempt. Initiating lockout after the first reclose has failed reduces the number of voltage dips, breaker operations, and exposes equipment, for example transformers, to fewer faults. The logic for a phase fault has not been changed.

Selection of the synchronising and dead-line charging ends

According to the old philosophy, for any line joining two substations, the dead line charging (DLC) end was at the substation with the highest fault level. The other end would then be the synchronising (SYNCH) end. The reason for this was to ensure that if the fault was sustained the current flowing at the DLC end, as the one that would reclose first, would be high enough to ensure operation of protection relays. The only exception to this was lines close to power stations where the power station end was always the SYNCH end in order to protect the generators.

The new philosophy introduced the the logic shown in Table 1 for choosing the DLC end.

<table>
<thead>
<tr>
<th>Sub B</th>
<th>Sub A</th>
<th>Sub with higher FL</th>
<th>Sub A</th>
<th>Power station</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL&lt;10 kA</td>
<td>Sub B</td>
<td>Sub A</td>
<td>Sub B</td>
<td></td>
</tr>
<tr>
<td>FL&gt;10 kA</td>
<td>Sub B</td>
<td>Sub A</td>
<td>Power station</td>
<td></td>
</tr>
</tbody>
</table>

The logic in Table 1 ensures that the DLC end is now at the substation with the lower fault level, provided that the fault level of that end is greater than 10 kA. Using the lower fault level substation as the DLC end reduces the severity of the resulting voltage dip if the fault is still sustained. It also reduces the impact of the fault on equipment because the resulting fault current is lower. 10 kA is used as the guideline to ensure that there will be enough fault current for the protection to operate. It is important to note that the for this purpose the substation fault levels are determined with the line in question taken out of service because the fault level of substation A may be significantly affected by substation B.

If the fault level of both substations is lower than 10 kA then the substation with the higher fault level is chosen as the DLC end in order to increase the chance of protection operation. Power stations are still kept as the synchronising ends.

Dedicated synchronising end

Another change made was on automatic synchronising options at the SYNCH end. Previously, following a three phase trip, the DLC end would reclose first after three seconds. Should the reclose not be successful, the SYNCH end would close one second later. It was done this way to give ARC another chance if the DLC end had failed to perform this function. The roles would be reversed in that synchronising would now be done at the normal DLC end.

This has now been changed. The SYNCH end no longer performs the DLC function. The closing option of live-bus, dead-line is disabled at the SYNCH end under automatic reclose options. The reason this was done is that, what would happen is that, if a fault is sustained, the DLC end would close onto it and trip. One second later the SYNCH end would close onto the same fault and trip, causing an extra voltage dip to the system. The previous option did not help for sustained faults. If only helped in the unlikely event that the DLC end did not dead-line charge for technical reasons. The disadvantages exceeded the advantages.

Closing under dead-line, live-bus conditions is enabled at both the DLC and SYNCH ends for manual closing. This gives the operators flexibility to restore the network following a trip.

Synchronising settings

Angle setting: According to the old philosophy the synchronising angle was set to twenty degrees at the synchronising end, and forty degrees at the DLC end. This was done to give operators more flexibility when closing under manual conditions. This worked well in the past but now, because of increased load on the network and the long lines used on the Eskom network, the angles tend to be bigger, making it difficult to synchronize with these restrictive settings.

The solution to this problem was to increase the synchronising angles to sixty degrees at
both DLC and SYNCH ends. Studies have shown that increasing this angle setting will not have any significant impact on the generators provided it is not done close to them. There are some synchronising relays used on the Eskom network which can only be increased to forty-five degrees and this has been done.

The only exception to this rule has been at power station ends, which are still kept on twenty degrees in order to protect the machines.

Slip frequency setting: The slip frequency on synchronising relays was previously 0.05 Hz. Because the transmission system is static this setting does not play any role for normal line trips. However, recent major events which resulted in islands being formed have led to such a low setting being reviewed, as it made it difficult for operators to restore the network because it was too restrictive.

The new philosophy, based on analysis of those incidents, allows for 0.1 Hz at both ends of the line. This will not have any impact on rotating machines as it is the same setting used when synchronising generators to the system.

Voltage setting: Traditionally, the live-bus and live-line voltage ratio settings have been set at 80%. A number of recent incidents on the Eskom system have led to this setting being reviewed. Such a high ratio has made it difficult to restore the system on those networks where the voltage at one end is sustained from the underlying sub-transmission network, reducing those voltages significantly. Increased loads have also led to reduced voltages when certain key lines are out of service.

The solution has been to reduce the live-bus and live-line ratio settings to 60%.

ARC on backup earth fault and zone 2
Another change made on lines of 132 kV and lower was to enable backup earth fault to initiate ARC. This was done to improve reliability of supply. On sub-transmission lines where step distance is used, zone 2 is also set to initiate ARC in order to improve reliability.

Load encroachment
With increasing load it became necessary to establish the true limits of the lines, and also to ensure that protection would not operate when the line was operated very close to its limit.

Line ratings
A project was commissioned to determine the rating of each conductor type used on the transmission system. Line ratings used previously were based on the deterministic method, where certain quantities were assumed. The new probabilistic method is more accurate as it quantifies the probabilities of certain events taking place. Some of these events are the probability of certain ambient temperatures and current magnitudes being reached, electrical clearances being reduced and the probability of a voltage surge occurring.

The result of this project was that all conductor types used in the transmission system were quantified, and current ratings determined for different template temperatures. It was found that considerably higher currents could be allowed than was shown by the deterministic method.

Once this project was completed, the next step was to determine the template rating for each line on the transmission system. This was done span by span, and the information is now available on the transmission database. For a specific span a template rating was determined taking into account safety to the public and the integrity of the line.

Protection settings implications
It then followed that the protection setting philosophy should be reviewed in order to ensure that these ‘worst case’ currents would be allowed to flow without any risk of unnecessary protection operation. On transmission lines of 220 kV and above the zones of distance protection are set to allow at least a safety margin of fifty percent above the line rating, at a given template temperature.

On sub-transmission lines, 132 kV and below, plug settings for backup overcurrent are chosen higher than 120% of emergency rating of the line at the template temperature.

Backup coordination
Backup overcurrent and earth fault settings on sub-transmission lines were always done to achieve a trip time of 0.8 s for a fault in front of the relay. Transformers were set for a tripping time of 1.2 s.

This philosophy has been changed and the principle adopted is that these settings must be as fast as possible, without compromising downstream grading and local grading. Where customers are involved the settings at interfaces are optimised and agreed with customers.

Conclusions
Increased demands on the power system have necessitated the review of protection setting philosophies to ensure that power will always be delivered reliably, but without compromising on protection of equipment. These challenges will continue to face protection engineers as the network is operated closer and closer to voltage, temperature and stability limits.

References

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