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Clearing of transient faults in medium voltage networks by means of single-phase tripping

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SUMMARY

Within power utility networks, transient and permanent faults cause power interruptions to customers. Research has indicated that most faults that result in breakers tripping within MV networks are temporary in nature. Other sources have also indicated that approximately 30% of permanent faults started as a transient fault. All types of faults in an electrical network do put strain on electrical equipment to a certain degree.

This paper contains research performed on the effectiveness of single-phase tripping that aims to clear transient faults on MV networks (11 kV and 22 kV) without causing momentary supply loss to customers due to breaker ARC operations. For transient phase-to-earth faults only the affected phase’s breaker will open within 30 ms to clear the fault. For transient phase-to-phase faults only one of the two affected phase breakers will open within 30 ms. The fast operation greatly reduces the amount of ionised air and improves arc quenching that results in a better success rate of the single-phase tripping scheme.

The efficiency with which transient faults are cleared positively influences network reliability as transient faults will not result in permanent faults. The speed with which transient faults are cleared improves the power quality of the MV network with regards to voltage dips, sustained and momentary interruptions.

Lastly, the single-phase breaker scheme will result in up to 50 times fewer burn wounds to people or animals in the unfortunate case where inadvertent contact is made with the MV network due to the fast tripping capabilities of the scheme.

KEY WORDS:

Single-phase tripping, transient fault, capacitive coupling, medium voltage, power quality, arc quenching

1. INTRODUCTION

1.1 Background

Eskom, being the largest electricity supplier in South Africa, has quite an extensive medium voltage (MV) network. Currently, the majority of breaker operations within MV networks can be ascribed to transient faults caused by lightning, animals, vegetation and wind [1], [2]. Figure 1-1 shows an example where a conductor failure occurred due to a transient fault remaining on the electrical network for a prolonged period of time.

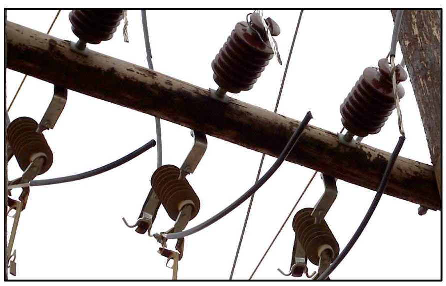

Figure 1-1 Conductor failures on MV overhead line due to initial temporary fault (lightning) [3]

1.2 Power Quality

Voltage dips represent a very important aspect within the power quality field due to the impact it can have on plant operations [4]. Severe voltage dips are generally caused by faults on the electrical network. The duration of such dips depends on the fault-clearing capabilities of protection equipment [5]. In the event that a voltage dip is short and small in magnitude, some plant equipment might be able to ride through the duration of the voltage dip successfully. However, for more severe voltage dips that are deeper and longer in nature, the chances for plant equipment to ride through such dips are quite slim [6].

If transient faults are cleared more effectively, it will influence power quality positively by reducing the length of voltage dips, limiting voltage dip propagation and the possibility of temporary faults developing into permanent faults significantly [5], [6].

2. SINGLE PHASE TRIPPING IN MV NETWORKS

2.1 Background

A number of sources have indicated that the majority of faults within MV networks are single-phase faults [1], [2], [7], [8]. Furthermore, it has also been documented that a large percentage of these faults are transient in nature [3], [9], [10].

The main hurdle to overcome in order to implement single-phase tripping on MV lines successfully is the secondary arc phenomenon. Secondary arc currents are normally encountered in single-phase auto-reclosing schemes on HV and EHV lines. This is due to the capacitive and inductive coupling, which the two healthy phases have on the faulty phase - thereby inducing the flow of a secondary arc current. It is important that, when implementing single-phase auto-reclosing philosophy, that the faulty phase must be de-energised long enough for the secondary arc to quench.

The majority of MV lines within the Eskom network are supplied form a Ynd substation transformer with a ∆ secondary winding configuration. The pole mounted transformers that supplies customers on radial MV lines have a ∆ load side and a Y supply side configuration (Dyn). In the event of a phase-A to earth fault on the delta configured MV line, the phase-A breaker will trip. This is graphically illustrated in Figure 2-1.

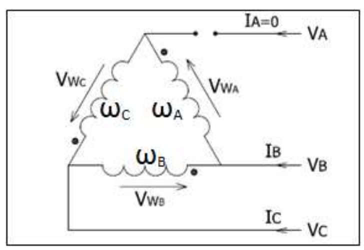

Figure 2-1 Transformer ∆ primary winding with phase-A breaker open [11]

With the phase-A breaker open, the voltage across the ω_B transformer winding remains unchanged at nominal system voltage ($V_{B\text{-}C}$). Transformer windings ω_A and ω_C will both maintain only half of their original voltages [11]. The single-phase tripping of breakers could yield the following advantages [12], [13]:

- Possibility of voltage dip ride through for plant equipment
- Reduces the impact of voltage dips that propagate onto adjacent MV lines if breakers are set to trip instantaneously for fault conditions
- Customers with single-phase loads, which are connected to the non-faulty phases will not experience a power interruption
- If there are only single-phase customers on the MV line, and provided that customers are equally split between phases, it will result in a significant decrease with regards to the average number of customers being interrupted during an earth fault.

2.2 Operating philosophy

Referring to Figure 2-2 below as an example, if there is a phase-A to phase-B fault between Breaker 2 and Breaker 3, only the phase-A single-phase breaker trips whilst the other two single-phase breakers remain in the closed position. The phase-A single-phase breaker remains in the open position for one-second, to allow the secondary arc to quench, and then recloses. In the event of a transient phase-A to phase-B fault, no other breaker on the line trips after the phase-A single-phase breaker quenches the arc successfully. In the event of a permanent phase-A to phase-B fault, the normal system protection isolates the fault after the phase-A single-phase breaker recloses.

The implementation of the single-phase breakers enables the quenching of transient phase-to-phase faults without causing a three-phase supply interruption to any of the customers on the line. The arc energy is also limited, which reduces the damage caused by the electrical arc.

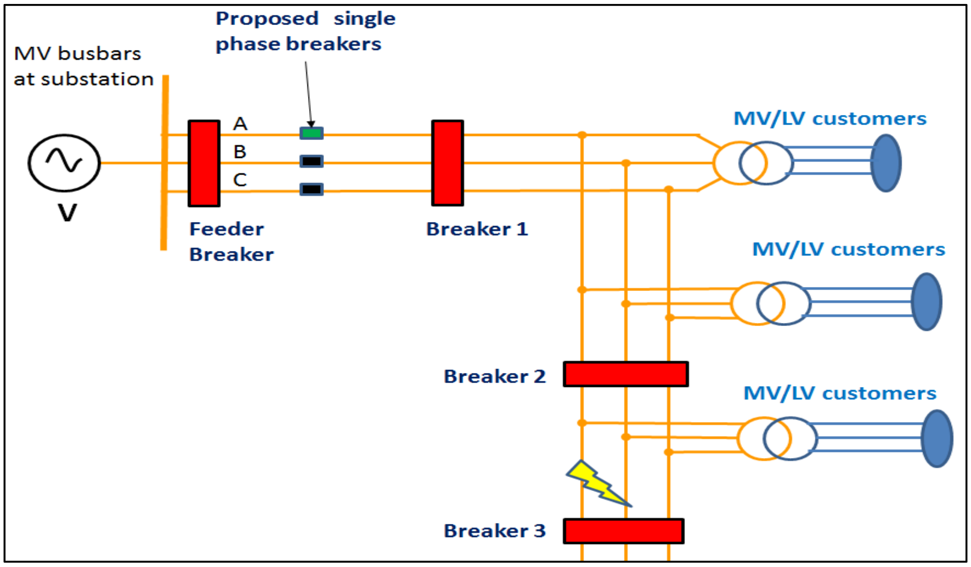

Figure 2-2 Illustration of a MV line with a phase-to-phase fault

2.3 Factors influencing the success rate of the single-phase tripping scheme

An important factor, which influences the success rate of the scheme, is the magnitude of the secondary arc current. The magnitude is dependent on the capacitive coupling of the electrical network and the inductive coupling due to the possible back feeding through Δ/Y transformers. If the sum of both these currents can be limited to a value below 35 A, it will greatly assist with the effectiveness of the proposed scheme [7]. The capacitive coupling component can be influenced by implementing this scheme on lines which operate at a lower voltage or have a shorter line length [14], [15].

The time it takes for the arc to quench can be decreased by reducing the amount of ionised air and plasma that is created during an electrical arc [16]. If there are excessive amounts of ionised air, plasma and carbon formed during fault conditions, it might lead to the unsuccessful quenching of the fault, resulting in a supply interruption.

3. IMPLEMENTING SINGLE PHASE BREAKER SCHEME

3.1 Measurement circuit

An ELSPEC logger was installed to measure the MV voltages and currents at the substation where the scheme was installed. Two feeders, the PTPE rural feeder and the PTDI urban feeder (electrification area) were used for testing the single-phase breaker schemes. Feeder CT's and VT's were used in order to measure the current and voltage as shown in Figure 3-1. All measurements were compared with breaker operation data on SCADA. An additional logger was also installed on the LV side of a Δ/Y pole mounted transformer on the MV line where the single phase tripping scheme was implemented.

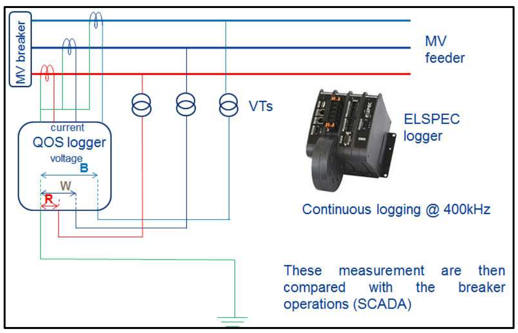

Figure 3-1 Measurement method

3.2 Onsite testing

In order to verify the correct operation of the single phase breaker scheme, two tests were performed which included phase-to-phase and phase-to-earth fault conditions. When creating a transient phase-to-earth fault condition the single phase breaker scheme cleared the fault within 10 ms as shown in Figure 3-2 and Figure 3-3.

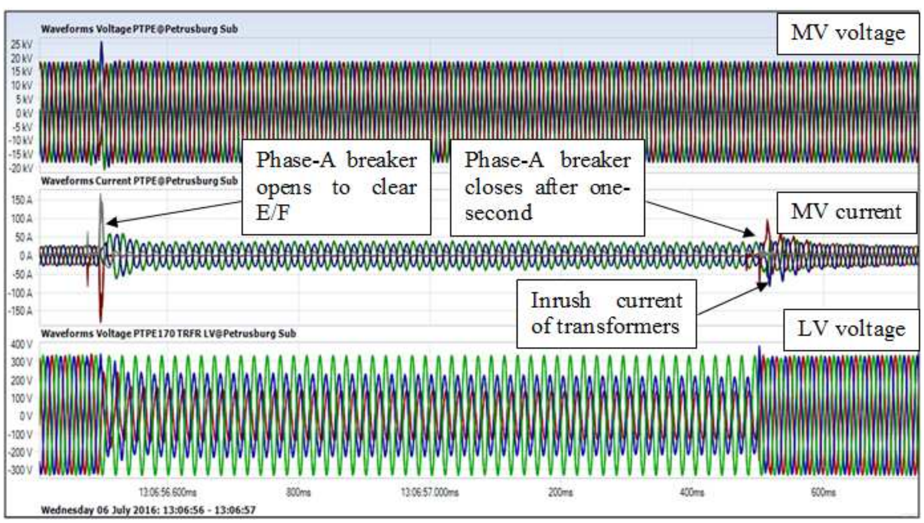

Figure 3-2 Transient earth-fault cleared by single-phase breaker on PTPE line

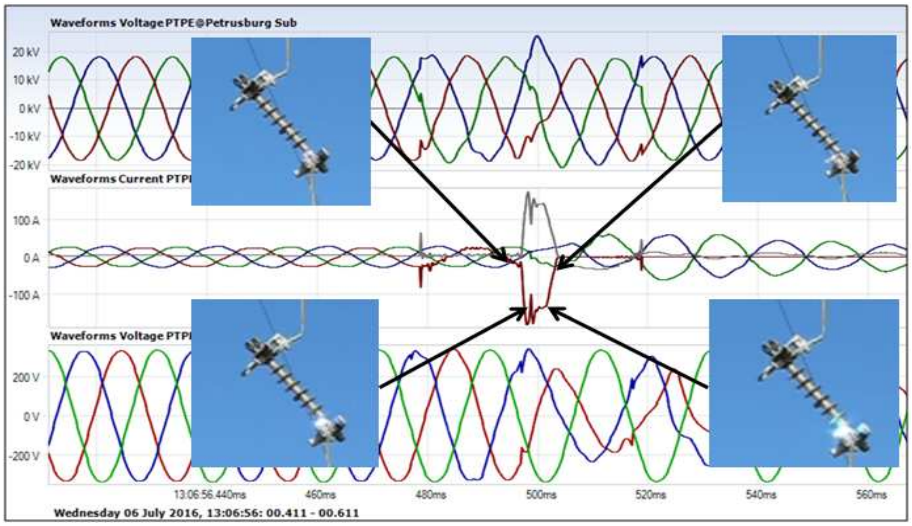

Figure 3-3 Waveforms of transient earth-fault with electric arc that is barely noticeable

The breaker where the E/F occurred was programmed with the following protection settings:

Table 3-1 E/F Protection settings of breaker at PTPE168-1

E/F protection parameter	Value
Time multiplier	0.15
Pickup current	40 A
Protection curve	Standard inverse - IMDT

For an earth fault current of 130 A, the calculated trip time of the breaker at PTPE168-1 would be approximately 910 ms. The 910 ms includes the sum of the IDMT protection trip time plus the 30 ms it takes for the breaker mechanism to physically open. The single-phase breaker fault-clearing time of 10 ms is a vast improvement when compared to the conventional 910 ms fault-clearing time. The fast clearing time reduces the arcing energy quite substantially. The voltage dip that would have propagated on the neighbouring 22 kV lines for 910 ms is now limited to only 10 ms.

When creating a transient phase-to-phase fault condition the single phase breaker scheme cleared the fault within 40 ms as shown in Figure 3-4 and Figure 3-5.

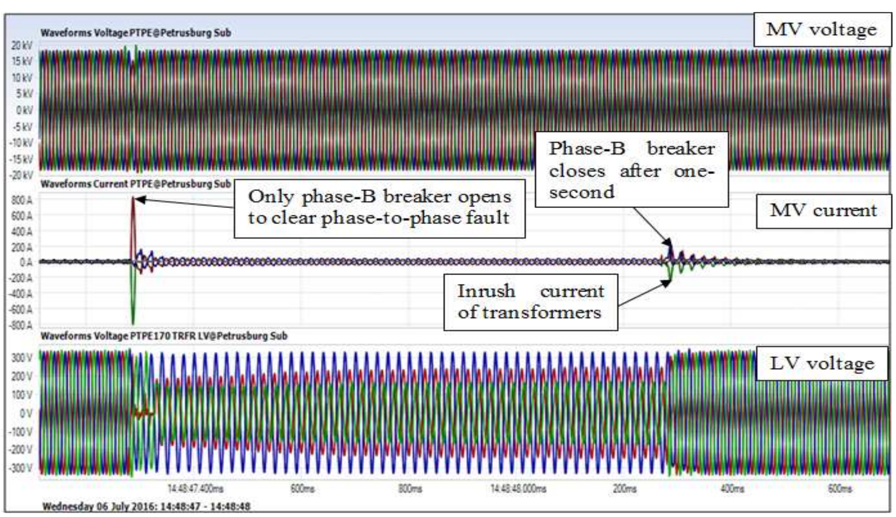

Figure 3-4 Transient phase-to-phase fault cleared by phase-B single-phase breaker

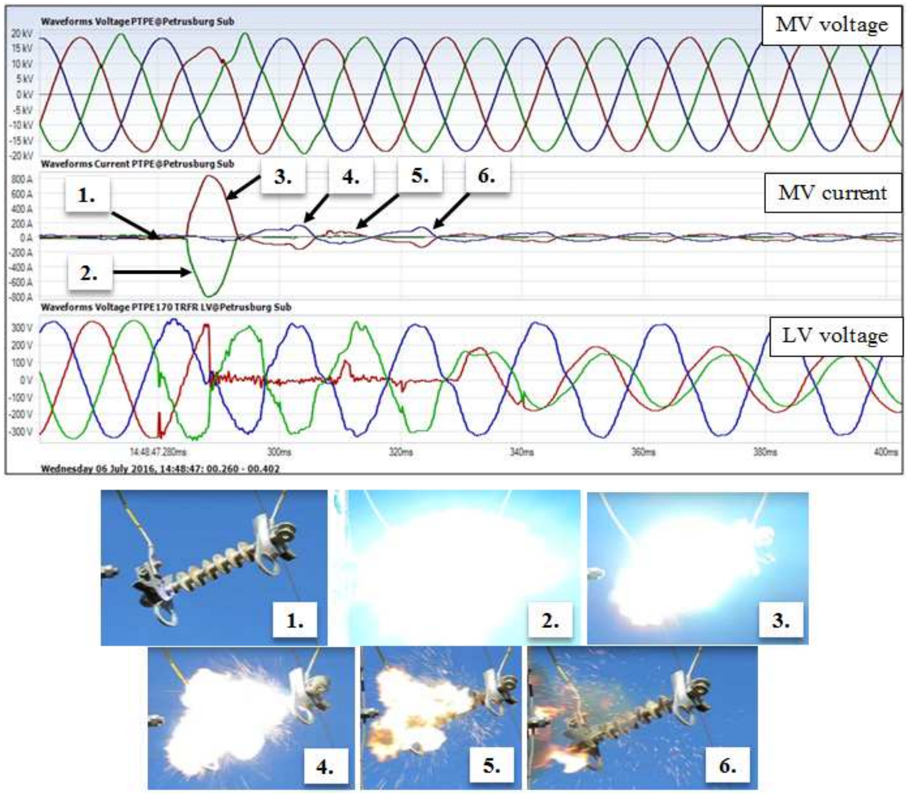

Figure 3-5 Waveforms of transient phase-to-phase fault as well as photos of the electric arc

The breaker where the fault occurred was programmed with the following protection settings:

Table 3-2 O/C protection settings of breaker at PTPE168-1

O/C protection parameter	Value
Time multiplier	0.2
Pickup current	80 A
Protection curve	Standard inverse - IMDT

For a fault current of 565 A, the calculated trip time of the breaker at PTPE168-1 would be approximately 732 ms. The 732 ms includes the sum of the IDMT protection trip time plus the 30 ms it takes for the breaker mechanism to physically open. The single-phase breaker fault-clearing time of 40 ms is a vast improvement when compared to the conventional 732 ms fault-clearing time. The fast-clearing time reduces the arcing energy quite substantially. The voltage dip that would have propagated on the neighbouring 22 kV lines for 732 ms is now limited to only 40 ms.

Figure 3-6 shows the difference in operations between the new single-phase tripping philosophy and normal three-phase tripping philosophy with regards to the LV voltages that would be experienced by an LV customer.

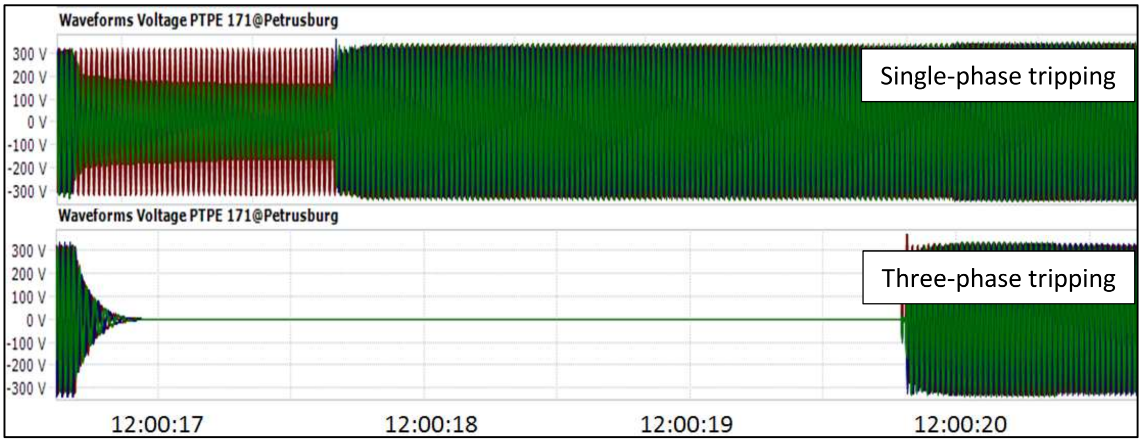

Figure 3-6 Difference between new single-phase tripping philosophy (top) and normal three-phase tripping philosophy (bottom)

4. RESULTS

Four months of voltage dip data was analysed at the Petrusburg substation; the focus being only on voltage dips caused by faults on the PTPE and PTDI lines. The information used to create a scatter plot was obtained from the continuous logging QOS recorder, which measured the MV busbar voltage at the substation. The measured voltage dip is combined with a hypothetical dip scatter plot to illustrate the improvement of voltage dip performance. The combined dip scatter plot can be seen in Figure 4-1. Note that the ***blue diamond shaped markers*** indicate the voltage dips measured at Petrusburg substation with the single-phase breaker scheme in operation. The ***red square shaped markers*** indicate the hypothetical voltage dip scatter plot, which would have been present if the single-phase breaker scheme was not installed.

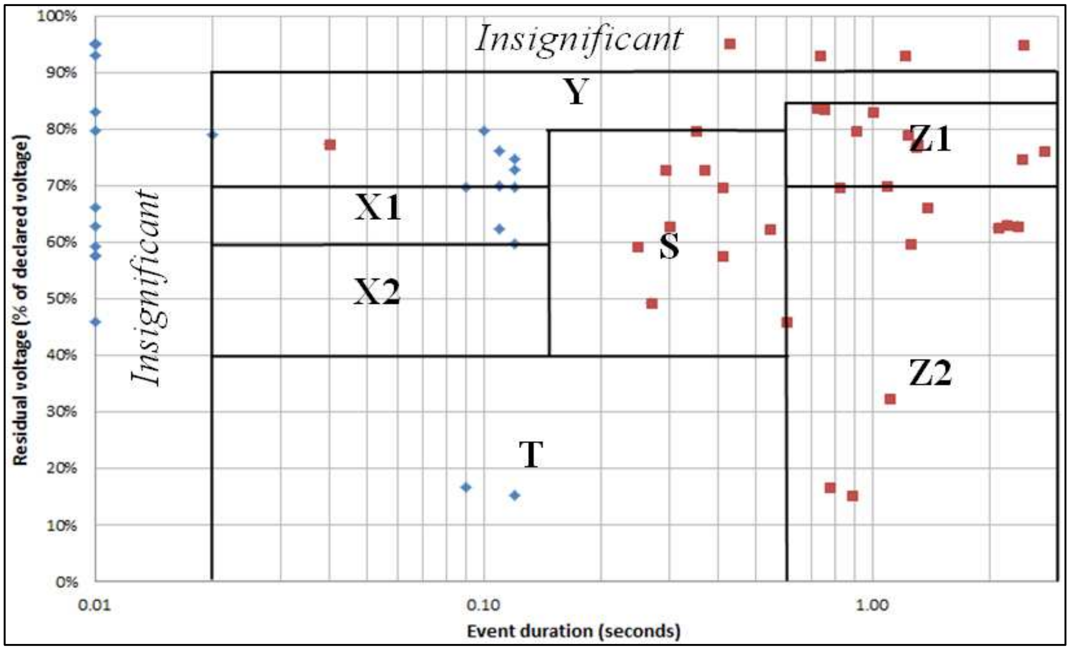

Figure 4-1 Comparison of voltage dip scatter plot results

Table 4-1 below shows a comparison between the measured voltage dip results and the hypothetical voltage dips from Figure 4-1.

Table 4-1 Comparison of voltage dip results

Voltage dip category	Number of voltage dips measured at substation ***after implementing*** single-phase breaker scheme	Number of hypothetical voltage dips at Petrusburg substation if single-phase breaker scheme **was not implemented**
Insignificant	14	4
Y	7	1
X1	3	0
X2	1	0
S	1	10
T	2	0
Z1	4	10
Z2	3	10

Table 4-1 illustrates that the single-phase breaker scheme reduces the effects of voltage dip propagation quite substantially. With the scheme being implemented, the voltage dips are much shorter - which affords plant equipment the opportunity to ride through the voltage dips caused by faults on the MV network.

Table 4-2 shows a comparison of momentary interruptions on the PTDI and PTPE lines. The comparison took three scenarios into consideration. Note that 19 of the 35 events were earth faults.

Table 4-2 Comparison of momentary interruptions on MV lines

Line name:	**PTPE**	**PTDI**
Single-phase breaker scheme implemented: Number of momentary interruptions	8	1
No scheme implemented: Number of hypothetical momentary interruptions	23	12

Implementing only the single-phase breaker scheme resulted in 74.3% less power interruptions experienced by customers.

5. CLOSURE

The research done in this paper was successful in showing the contribution towards power quality by developing a protection philosophy for the single-phase breaker scheme. Momentary interruptions, voltage dip propagations and voltage dip times will be reduced. One of the advantages of the single-phase breaker scheme is that three-phase LV motors will be able to ride through the single-phase event, which will reduce the overall plant downtime of customers.

The single-phase breaker scheme performed well in clearing transient faults from MV networks. This greatly contributes towards limiting the amount of equipment damage caused by transient faults on MV networks due to the fast fault-clearing capabilities of the schemes.

The scheme has a significant contribution to the safety of humans and animals in the case where inadvertent contact is made with the MV network, because of the fast fault-clearing capabilities of the schemes.

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