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Power Transformer Differential Protection For Three Eskom Feeders.

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***Abstract*—Differential protection's purpose is to offer phase fault protection that is both quicker and more discriminative than that provided by basic overcurrent relays. Transformer differential protection is the primary protection against earth faults and phase-to-phase faults. CTs on the HV side are counterbalanced by CTs on the LV side. There are a variety of distinct connections, but there are a few key considerations that apply to every design. This sort of protection continually monitors and compares the current flowing between CTs (in this example, HV and MV CTs) inside a protected zone. The following are the primary requirements of this protection, Highest sensitivity, Load stability over the whole tap range, Stability in through-fault circumstances, Stability for magnetizing inrush with associated DC offset decay, when a zone fault is identified, simultaneously opens both HV and MV breakers.**

Keywords—Power Transformer, Differential Protection, Current Transformers, Inrush Current.

I. INTRODUCTION

Eshowe substation is one of Eskom's substations, is roughly 40 years old, and is situated on the north shore of KwaZulu-Natal, approximately 60 kilometres from the coast. Since then, minor modifications have been made to handle load growth as the client base expands. Two 88kV lines from distinct substations supply the substation; one line is generally available. It consists of 1 x 10MVA transformer (88/22kV) feeding 1x 22kV reticulation line, 2 x 7.5MVA transformers (88/11kV) coupled in tandem feeding indoor switchgear with 5 x 11kV feeders, and 1 x 7.5MVA transformer (88/11kV) feeding 1x 11kV reticulation line. Three of the 11kV feeders serve the uThungulu District municipality, which includes Eshowe town, while the other two serve Eskom rural consumers. Their tap changers, however, utilise phase 3. The indoor switchgear with five 11kV feeders is secured by electromechanical phase 1 relays and features vintage oil-type indoor breakers. According to the map shown, the Eshowe substation may clearly be seen.

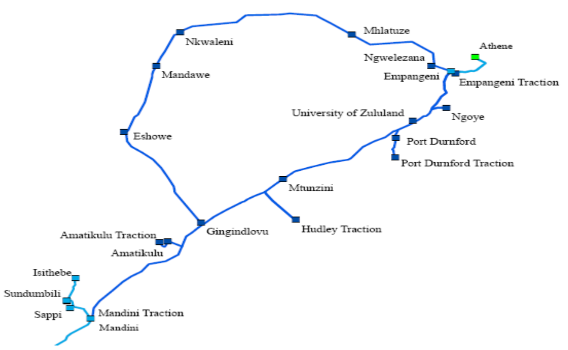

Fig. 1. Eshowe sbstation location.

Since 2007, the substation has undergone many failures. In 2016, it was projected that the substation's protection would be strengthened, and the project would begin in 2021. Differential protection of these three power transformers will be the topic of this research. The purpose of the project is to renovate the whole substation and expand capacity exclusively for 11kV voltage.

II. METHODOLOGY

As previously indicated, the focus of this paper is only on the differential protection relays of these transformers; here is a single-line schematic of all three power transformers to be protected by differential protection relays. This project's chosen brand is a Schweizer Engineering Laboratories (SEL). It is the most recent model.

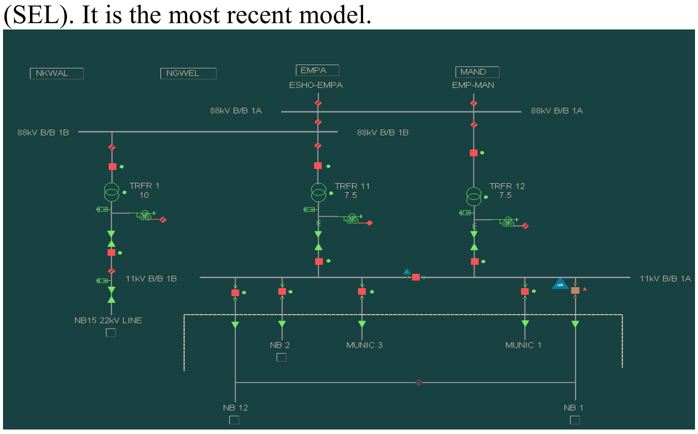

Fig. 2. Eshowe substation single line diagram.

A. *Differential Protection Element Settings.*

When compared to ordinary overcurrent relays, differential protection is designed to offer quicker and more precise phase fault detection[1], [2]. Earth faults and phase-to-phase faults are protected by the transformer differential protection. Current Transformers (CTs) on the High Voltage (HV) and Low Voltage (LV) sides are equal and opposite in their effect on the system. When an in-zone fault occurs, the Differential element will work instantly (20ms to 40ms) and open both the 88kV and 11kV transformer breakers, continually measuring and comparing the current going into and out of the protected zone (Transformer). These transformers feature a Protection Relay that has three differential elements as its primary relay (87R 1, 87R 2, and 87R 3)[3].

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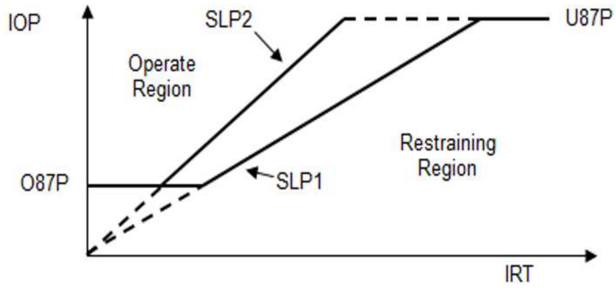

Fig. 3. Slope Operating characteristics[4].

IOP - Operating current or Differential current (A)
IRT - Restraint current or Bias current (A)
O87P - Minimum IOP level required for operation.
Operating Region - This region causes the relay to operate
Restraining region - The system is stable, and the relay does not see any fault current.
Slope 1 (SLP1) - Takes care of differential current resulting from CT errors and tap changing.
Slope 2 (SLP2) - Prevents undesired relay operation resulting from CT saturation for heavy external faults.
TAPn – CTR correction factor of Terminal 'n'.
MVA – Transformer MVA rating.
VTERM – Line – to – Line voltage of Terminal 'n'.
C – 1 if CTCON = Y(star) or sqrt3 if CTCON = D (Delta). C will always equal 1 for this relay standard.

These elements use input currents detected by HV and Medium Voltage (MV) CTs to determine operating (IOP) and restraint (IRT) values[5]. Figure 3 depicts the feature in use. Either a single-slope, percentage differential characteristic or a dual-slope, changeable percentage differential characteristic may be used to define the characteristic[6]. If the work quantity exceeds the curve value for the specific restraint amount, tripping happens. In addition, a minimum degree of operation must be met[7].

B. *Operating Current PU (087).*

Depending on how the Differential circuit is wired, the current taps TAP S to TAP T may be defined in one of two ways[8]:

- In most cases, the relay calculates the "TAPn" values automatically based on the MVA, winding voltage, CT ratio, and CT connection parameters that have previously been input.
- The TAP values may be input directly by setting MVA=OFF and entering the TAP1 through TAP4 values, as well as the other relevant parameters, directly.

The relay uses the following formula to compute the TAP values depending on the parameters given for the specific winding. They are utilized in this case to ensure that the entered settings fall within the relay's parameters. - The TAP settings fall between 0.1 X In and 31 X In. TAPmax/TAPmin ratio must be less than 7.5.

TAP S = (MVA ÷ √3 x VWDG1 x CTR1) (1)

= (20MVA) ÷ (√3 x 88KV x 200)
= **<u>0.66</u>**

TAP T = (MVA ÷ √3 x VWDG2 x CTR2) (2)

= (20MVA) ÷ (√3 x 11KV x 1200)
= **<u>0.87</u>**

Setting the operational current pickup as low as feasible for sensitivity, but high enough to prevent activation owing to steady-state CT error and transformer excitation current. In addition, the configuration must provide an operational current larger than or equal to 0.1x In when multiplied by the lowest of the previously computed TAPs. This location is inside Pu of Tap[9].

087P min = |TAP S – TAP T| (3)
= |0.66 – 0.87|
= **<u>0.21</u>**

Set 087P > 0.21 (4)
Set 087P at 0.3 (5)

C. *Differential Harmonic Restraints.*

The Differential Harmonic Restraint test is done to verify the right relay behavior of the differential protection's harmonic restraint, which is used in in-rush and over fluxing/over-excitation relay functions, for example[5]. This test requires three currents and is performed on the reference winding side. The fault was placed at the output side of the transformer.

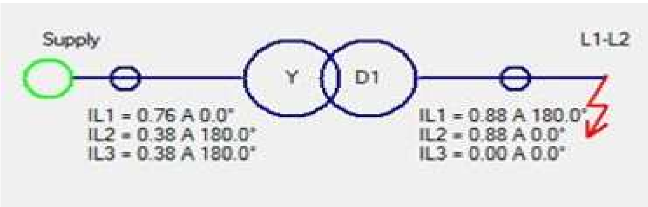

Fig. 4. Secondary fault injection, single line diagram.

The fault was placed at the primary side of the transformer, yes this test was successful.

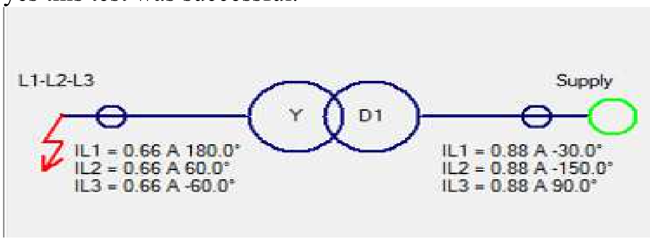

Fig. 5. Secondary fault injection, single line diagram.

D. *Restraint Slope percentages settings (SLP1 andSLP2).*

The percentage values for the Restraint Slope are used to distinguish between internal and external defects[10]. SLP1 and SLP2 must be adjusted to account current variances caused by tap-changing power transformers, magnetizing current, and relay mistake. Manufacturers estimate the Restraint Slope percentages using the ratio of the differential current owing to CT errors and the voltage fluctuation of the tap changer, represented as a percentage of winding current. SLP1 is set at 15%, whilst SLP2 is set to 50%[3].

E. Second Harmonic Blocking.

This value must be more than the amount of second harmonic present during transformer energization[11]. If the ratio of second harmonic current to fundamental current (IF2 IF1) is larger than the setting of PCT2, the relay may be configured to block the percentage-restrained differential element[12]. When additional equipment inside the differential circuit consumes large current on its own, decreasing the ratio (IF2 IF1), care must be given[13].

F. Fifth Harmoniuc Blocking.

According to industry standards (ANSI/IEEE C37.91, C37.102), over excitation occurs when the ratio of voltage to frequency (V / Hz) applied to the transformer terminals is greater than 1.05 per unit (pu) at full load or 1.1 pu at no load [14]. This ratio measures the flux density in the core. Over-excitation of a transformer generates odd-order harmonics, which may cause differential protection to malfunction. PCT5 is set at 35 percent[7]. See below for the differential element settings for TRFR 11 and 12 as computed by the EDNS settings department.

G. Differential Operating Characteristics.

By simulating faults within and outside the protected zone, the operational characteristic is evaluated. The entered device tolerances are considered during testing[15]. The following diagrams depict the results of tests done on the Omicron CMC 356 to determine the operating characteristics of the Omicron CMC 356's various operating modes[16].

Where:
Idiff - Is the differential or operating current of the relay
Ibias - Is the restraint or bias current.
Tact - The time the relay took to operate the trip contact.
Tnom - A predetermined value for the relay to operate the trip contact.
Green tick - Test passed.

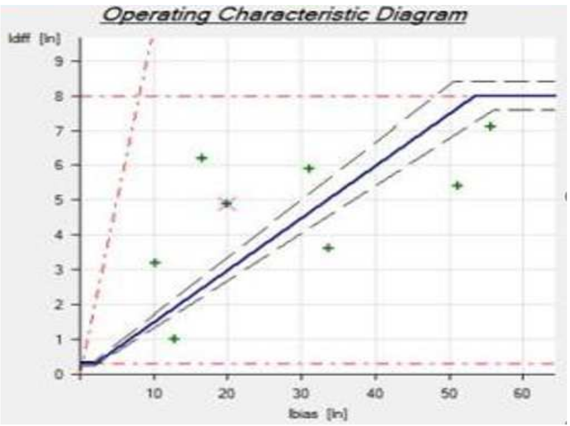

Fig. 6. Slope 1, Operating Characteristic.

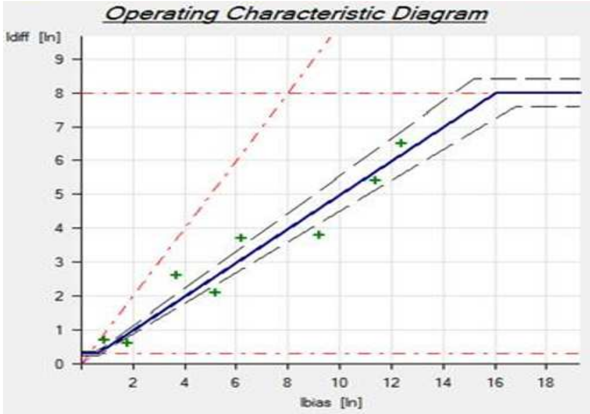

Fig. 7. Slope 2, Operating Characteristic.

III. Results

The Differential Configuration module verifies the wiring and configuration of the test item by simulating defects outside of the protected zone. If the relay still trips in such a test, this suggests a setup or wiring error inside the protection rack[17]. The figures show the results of differential configuration tests undertaken to ensure that the relay operates exclusively for internal failures and not external ones. The relay did not trip in any of the listed tests since the faults were beyond the protected zone. The first test was verify whether the relay can immediately trip when fault is injected and that was successful done.

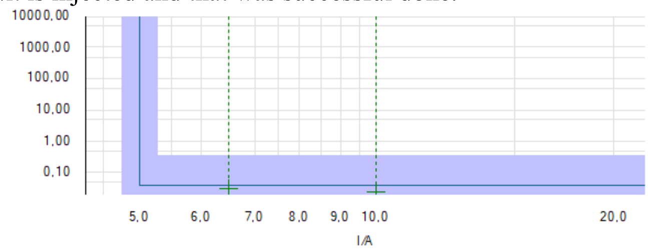

Fig. 8. Line A – B – C trip.

The verification at this stage was to ensure that the second harmonics did not cause the system to trip, that the system proved to be stable, and that it successfully passed all tests that were performed in the shortest amount of time possible. These results are for second harmonics.

Idiff	Ibias	Nominal Trip Time	Actual Trip Time	Dev (rel)	Dev (abs)	State	Result
0,00 In	0,00 In	N/T	N/T	n/a	n/a	Tested	Passed
1,00 In	1,00 In	0,0300 s	0,0337 s	12,33 %	0,0037 s	Tested	Passed
2,00 In	2,00 In	0,0300 s	0,0328 s	9,33 %	0,0028 s	Tested	Passed
3,00 In	3,00 In	0,0300 s	0,0339 s	13,00 %	0,0039 s	Tested	Passed
4,00 In	4,00 In	0,0300 s	0,0332 s	10,67 %	0,0032 s	Tested	Passed
5,00 In	5,00 In	0,0300 s	0,0332 s	10,67 %	0,0032 s	Tested	Passed
6,00 In	6,00 In	0,0300 s	0,0328 s	9,33 %	0,0028 s	Tested	Passed
7,00 In	7,00 In	0,0300 s	0,0328 s	9,33 %	0,0028 s	Tested	Passed
8,00 In	8,00 In	0,0300 s	0,0311 s	3,67 %	0,0011 s	Tested	Passed
9,00 In	9,00 In	0,0300 s	0,0273 s	9,00 %	-0,0027 s	Tested	Passed
10,00 In	10,00 In	0,0300 s	0,0263 s	12,33 %	-0,0037 s	Tested	Passed

Fig. 9. 2nd Harmonic results.

This is a graph that was plotted in the plane to prove consistence of second harmonics.

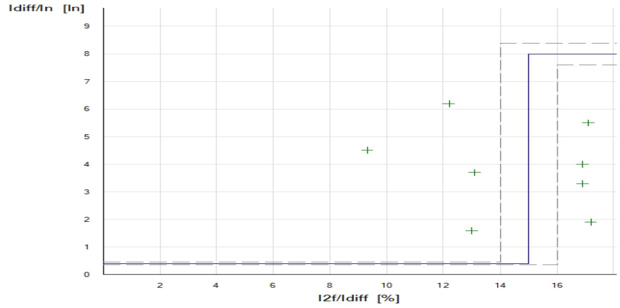

Fig. 10. 2nd Harmonic trip curve.

These results are of the fourth harmonics, this was tested and it proves to be stable. It was tested and phase angles were considered, to monitor the shift. All were successful passed.

Idiff	Ixf/Idiff	Angle (Ixf,Idiff)	Trip	State	Result
1,90 I/In	8,20 %	-120,0 °	Yes	Tested	Passed
4,20 I/In	8,00 %	-120,0 °	Yes	Tested	Passed
6,00 I/In	8,00 %	-120,0 °	Yes	Tested	Passed
7,20 I/In	7,90 %	-120,0 °	Yes	Tested	Passed
1,20 I/In	11,50 %	-120,0 °	No	Tested	Passed
3,50 I/In	11,30 %	-120,0 °	No	Tested	Passed
6,50 I/In	11,20 %	-120,0 °	No	Tested	Passed

Fig. 11. 4th Harmonic test results.

This is a graph that proves the relay did not operate and passed the test successfully.

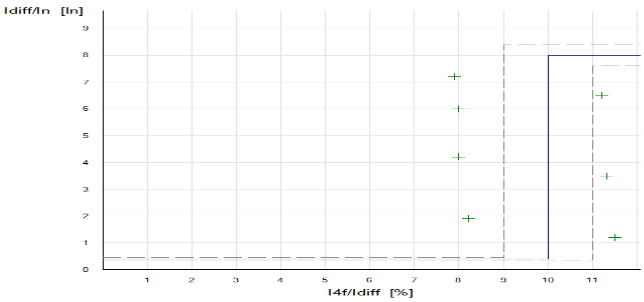

Fig. 12. 4th Harmonic trip curve.

IV. Conclusion

The protection systems of today are technologically and precisely advanced; yet, this substation was far behind the times since it still used electromechanical relays (CDG), and the upgrading was hastened because of the substation's obsolete protection schemes. The update was a great success, and the new protection has been demonstrated to perform properly in terms of selecting out-of-zone and in-zone faults, as faults were cleared by the new schemes correctly after energization. The value of the main equipment placed at this substation is in the millions of Rands, thus it was vital that the necessary commissioning processes were followed so that the protection correctly protected the electrical equipment.

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