Dual-Slope Percentage Bias Differential Relay (87) Protection Strategy for 11kV Underground Power Cable

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Abstract – *The study focuses on the protection strategy for an underground power cable (transmission) for a medium voltage distribution network using dual slope percentage bias differential relay (ANSI 87). The underground cable is the bridge that connects the power supply from generator to distribution substations, it must be well protected from internal fault that may cause insulation breakdown and leads to electrical failure; while remain unaffected for external fault conditions. The fault simulation is done with PSCAD software, and the suitable protection settings for the applied differential relay is proposed. The study found that the relay is stable for external faults while allowing sensitive settings to pick up internal fault if the setting was carefully chosen*

Keywords: *dual slope percentage bias differential relay protection, internal fault*

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I. Introduction

Power system is made up from combination of generation, transmission and distribution. The main equipment such as generator, transformer, transmission cable (overhead or underground), circuit breakers and loads, work together to complete the operation of the power system. The protection system is introduced to protect the equipment from being damaged by fault. There is no any system which will not experience fault, even at the finest engineering design, as fault is unpredictable except for careless actions made by human. Thus, protection system plays a significant role to detect, recognize and isolate the fault from the system to prevent electrical disruption, to protect working personal and the equipment from being damaged by fault [1]. Although fault event does not occur frequently in practical cases, but the scheme shall fulfil the possible worst-case scenario that could happen to the system.

In the literature review, a single slope percentage bias relay was most often used for cable protection. However, is was prone to malfunction due to current transformer (CT) saturation [2]-[4]. For this reason, a dual slope relay was introduced by Sharp and Glassburn [5]. In this study, a dual-slope percentage bias differential relay is studied and used to provide protection to an underground cable. The cable must be well-protected from internal fault, else it will cause disruption of supply to the connected loads.

II. Network Modelling

The study network is modelled in PSCAD as shown in Fig. 1. The study system comprises a 3400 kW generation supplying the P+jQ load via cable through a 4.5MVA transformer The three phase line to line voltage is considered to be 11V. The generation is capable of supplying an active power of 3.56 MW and reactive power of 2.21 Mvar to le load. The impedance of the cable is discussed in details in the next section.

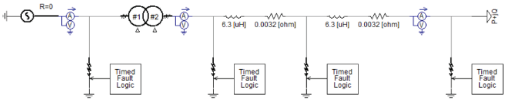


Fig. 1. Single line diagram of the modelled network in PSCAD

Table 1 shows the technical data of the underground cable. The calculation for voltage drop is obtained by referring to standard voltage drop table in [6], where the cable is carrying rated current from the generator. The acceptable range of voltage regulation for 6.6kV up to 11kV system is ± 5% according to TNB requirement. Thus, it is important to ensure that the voltage drop across the transmission cable is small enough to compensate with losses in other parts of the system. The dual slope percentage bias differential relay is designed to protect this underground cable from experiencing internal faults.

TABLE I
TECHNICAL DATA OF THE UNDERGROUND CABLE (UGC)

Item	Parameter
Length	25 meter
Type	Ix3C 240mm^2 Aluminum XLPE/SWA/PVC
Rating	6350/11000 V
$I_{(max)}$	386 A
$V_{drop\ (max)}$	1.67 (with 223A)
Resistance	0.0068 Ω/phase
Inductance	12.6 uH

III. Methodology

Referring to Fig. 2, the studies is started with modelling of power system network in PSCAD. Then, symmetrical and unsymmetrical faults are applied and analyzed on the fault characteristics. From the observed magnitude of fault currents, a suitable setting for dual-slope percentage bias differential relay is proposed to ensure that the protection relay responds to internal fault while remain unaffected for external fault. If the proposed setting has resulted in error response of the relay, the setting has to be recalculated. The response is then collected for further analysis purposes.

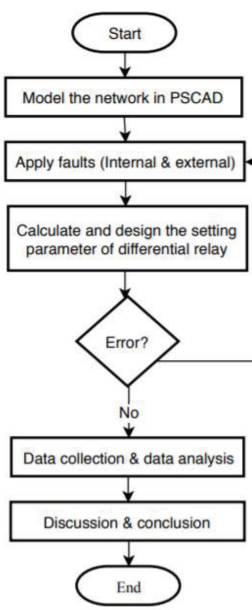


Fig. 2. The flowchart of the project

IV. Fault Analysis

Faults are applied in 4 different locations as shown in **Error! Reference source not found.**, where the fault type covers single line to ground (L-G), double line (L-L), double line to ground (L-L-G) and three phase fault (L-L-L-G).

TABLE II
FAULT CURRENT MEASURED BY CURRENT DIFFERENTIAL RELAY

Fault type	I_{DIFF} (A)	I_{BIAS} (A)
	Internal Fault	
L-G	526	413
L-L	6274	3292
L-L-G	6273	3287
L-L-L-G	7635	3964
	External Fault	
Transformer primary side	≈ 0	≈ 170 (All fault type)
Transformer secondary side	≈ 0	≈ 150 (All fault type)
Input of outgoing feeder	≈ 0	≈ 670 (L-G), 6350 (L-L & L-L-G), 7670 (L-L-L-G)

Table II tabulates the summarization of fault current measured by the differential relay. The differential relay reads the current flowing in and out from the protected unit which then form the difference of current (I_{diff}) and average current (I_{bias}). Kirchhoff current law (KCL) is applied in the measurement. The I_{diff} (y-axis) is obtained by subtracting current flowing out from the current that flows in the protected unit; while I_{bias} (x-axis) is the average current that flows through the protected unit, obtained by dividing two from the summation of current that flows in and out from the equipment. The concept of tripping is shown in Fig. 3. The analyzed fault current is used to determine the settings in term of the bias slope percentage and pick up difference currents for the differential relay

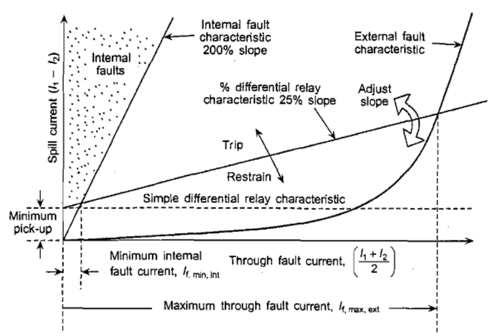


Fig. 3. Tripping curve for percentage bias differential relay [1]

V. Relay Setting

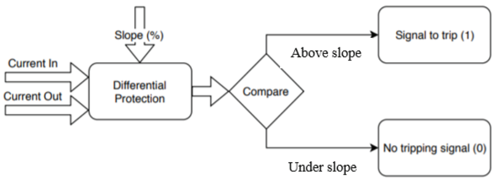


Fig. 4. Operating concept of percentage bias differential relay

The operation of differential relay can be simplified to the ratio of I_{diff} over I_{bias} which falls above or below the region from slope [6,7]. If the measured fault falls above the slope, which is the tripping or operating zone, then the relay will issue tripping signal; while if it falls under the slope, which known as restraining zone, then no tripping signal will be issued. The process is visualized in Fig. 4.[8,9]

The slope percentage is determined by the calculation as follows:

For first slope (K1) region,

$$214/800 \times 100\% = 26.75\%$$

For second slope (K2) region,

$$6274/3292 \times 100\% = 190.58\% \text{ for (L-L)}$$

$$6273/3287 \times 100\% = 190.84\% \text{ for (L-L-G)}$$

$$7635/3964 \times 100\% = 192.61\% \text{ for (L-L-L-G)}$$

The selected setting of slope percentage for K1 is 25 % and K2 is 180%; while the pickup I_{diff} (IS1) is 400A and pick up I_{bias} (IS2) is 800A.

VI. Modelling of the Differential Relay

Fig. 5 shows the modelled percentage biased differential relay in PSCAD while Fig. 6 is the algorithm of the relay. Case 1 and 2 are the relay algorotihm provided in PSCAD. Using these algorithms, the tripping operation can be represented in mathematical formula as written in equation (1.1) and (1.2). If the measured I_{diff} fulfilled the tripping condition, then tripping signal will be issued by the relay to open the circuit breaker to isolate fault.

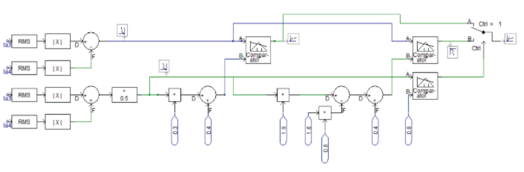


Fig. 5. Modelling of dual slope percentage bias differential relay in PSCAD

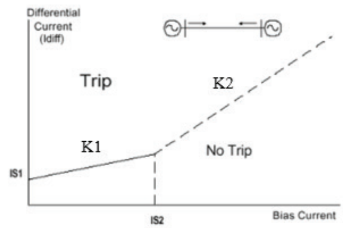


Fig. 6. Allocation of setting parameter on relay's operating graph [4]

Case 1: Ibias < IS2,

$$|Idiff| > (K1*Ibias) + IS1 \quad (1.1)$$

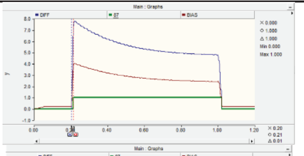
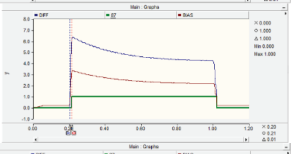
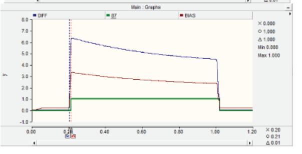
Case 2: Ibias => IS2,

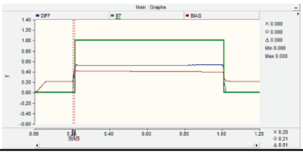
$$|Idiff| > (K2*Ibias) - [(K2-K1)*IS2] + IS1 \quad (1.2)$$

VII. Result and discussion

The tripping response of the differential relay is observed after setting is inserted by reinjecting 4 types of fault scenarios. Table III shows the output response of differential relay with tripping signal in bolded green line, I_{diff} in blue line and I_{bias} in red line. In Fig. 7, it represents the fault plotting at the tripping region of the differential's relay operating graph. The relay reacts correctly towards internal fault where the fault falls in the operating region; while for external fault, the relay remains unaffected since the measured fault current falls in the restraining region. During slope K1, it is designed to cater for smaller fault value while for the higher slope K2, it is designed to increase the selectivity during higher fault current.

TABLE III
RESPONSE OF RELAY TOWARDS INTERNAL FAULT

Fault Type	Signal From Scope
L-L-L-G	
L-L-G	
L-L	

L-G	

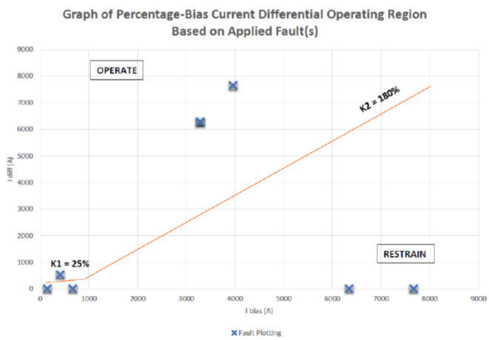


Fig. 7. Faults plotting in operating region of relay

The tripping operation during fault condition can be proved by substituting the measured value into equation (1.1) and (1.2) for respective cases of Ibias smaller or equal and higher than IS2.

From case 1:

During I_{bias} < IS2 = 413A < 800A

I_{diff} = 526A > (0.3*413) + 400 = 523.9A

From case 2:

During I_{bias} => IS2 = 3292A, 3287A, 3964A > 800A

I_{diff} = 6274 > (2*3292) – [(2-0.3)*800] + 400 = 5624A

I_{diff} = 6273 > (2*3287) – [(2-0.3)*800] + 400 = 5614A

I_{diff} = 7635 > (2*3964) – [(2-0.3)*800] + 400 = 6968A

From the calculation, it is proven that the modelled differential relay operates conditionally.

VIII. Conclusion

The percentage bias current differential relay is suitable to be used in protecting the underground cable as the tripping response is instantaneous (speedy), high selectivity (operates for internal faults only) and simple operation. The response of this unit protection relay is desired in instantaneous mode because, during three phase fault, the cable may experience insulation breakdown if the fault continue for more than 0.2 seconds, as referred to critical time calculation in [6]. As a result, the dual slope characteristic provides the benefit of design flexibility as the slope increases for a higher value of measured fault current. This enables the protection relay to detect, recognize the correct fault, and isolate it from the network as rapid as possible.

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