Performance Evaluation of Overcurrent Protection Relay Based on Relay Operation Time (ROT)

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Abstract – *Protection system plays an important role in detecting the presence of disorders and may prevent damage that can caused interference. Thus, the reliability of the system to maintain continuity of supply to the load will be improved. Overcurrent protection is among the most important and earliest protection scheme in power system. However, the interruptions in power system can happen by fault current. Besides, the improper setting or wrong selection and positioning of power protection devices are among the reason. Therefore, to maintain and improve the performance of the protection system, this project presents a model of overcurrent protection scheme in power system network to investigate the effect of overcurrent relay performance on relay operation time (ROT) centered on several cases. The model of overcurrent protection system is developed and analyzed by using PSCAD simulation software based on several requirement or conditions such as various type and location of faults and relays. Besides that, analysis under the implementation of different curve characteristic and various standards are also performed. Furthermore, the impacts of distributed generator installation on the power system protection when faults are occurring are also studied. The results have shown that the ROT of relays was varies and changed with all variables in the performed test.*

Keywords*: Overcurrent protection relay, relay operation time, pscad simulation software, power system protection.*

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I. Introduction

A power system must not only capable of meeting the present load but also requires the flexibility to meet. The system must be kept in operation continuously without major breakdown [1]. A good protection scheme must achieve the basic features of protection system such as selectivity, stability, speed and sensitivity [2]. However, the relay that should be operated due to the fault sometimes does not work properly such as delay occurring in operation or it does not function at all when required. This might be due to the problems from the setting of the relay or several conditions.

The protection system is needed to provide quick isolation of fault and faulty area from the service. This is to allow the largest possible part of the power system to continue its service. There are several types of protection system that have been applied in the power system distribution such as distance protection, overcurrent protection and differential protection. This project however will only focus on overcurrent protection, which is used with the overcurrent relay as the measuring instrument to detect the current magnitude which exceeds the specified adjustable current magnitude [1].

In this paper, a model for overcurrent relays is provided. To assess the performance of this model an overcurrent relays model is designed and simulated by using PSCAD. Once it is validated, further analysis on the performance of the relay operation time based on several conditions and cases are carried out. The cases that were performed are different type of faults, different type of characteristic curve, different type of curve standard and DG installation in power system. This is to investigate and study the relationship between relay operation times with the condition or event happened.

The remainder of the paper is arranged as follows. Section II offers a literature review on overcurrent relays. Section III presents the details of the circuit modelled in PSCAD. Section IV focuses on simulation results. Finally in Section V, conclusions are drawn and future work is outlined.

II. Overcurrent Protection

Overcurrent protection is a scheme that protect~~ive~~ the devices or components in the power system from damage due to excessive current flow. The protection system detects the fault based on the fact that the fault current is obviously larger than the usual load current after the fault occurs. The overcurrent is divided into two subtypes which are instantaneous overcurrent and inverse-time overcurrent. The instantaneous overcurrent will operates instantaneously if the input current is larger than the setting value. For inverse-time overcurrent it is operate in the way which the operating time is inversely with the input current [2].

A. Principle of Relay Operation

There are a lot of different types of relays used in protective scheme. However, they are followed by the same logic pattern. Figure 1 shows the protective scheme logic chart. There are inputs, measurement, determination and output. The input will represent current, voltage, frequency or perhaps other value that exist in protective circuit at any instant in time. The relay measures these values and then determines the circuit operating condition whether it is within normal parameters or not. Under normal operating condition output is zero which it is set to open or close contact at rest. However, in any intolerable fault level, the relay will imposes operating signal value under control circuit usually in terms of DC volt. These tripping signals are then fed into one or more circuit breaker to cause them to open, so as to isolate the faulty part from the rest of unfaulty power system.

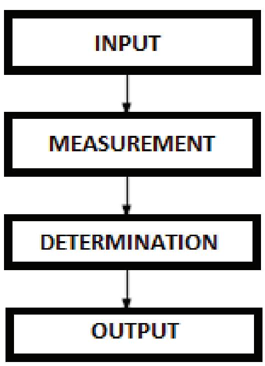

Fig. 1. Protective Scheme Logic Operation

B. IDMT Overcurrent Relay

Inverse definite minimum time (IDMT) relay has inverse time characteristic, where the relay operating time is inversely proportional to the fault current [3]. If the fault current is higher, the operating time of relay will be lesser [4]. It can be graded for a very large range of operating times and fault currents [5]. The characteristic of IDMT overcurrent relay is depends on the type of standards selected. It can be ANSI, IEEE and IEC or user defined. The overcurrent relay will then calculate the operation time corresponding to that particular characteristic curve [6]. Besides, there are two important principle of IDMT to understand which are inverse time and minimum time. Inverse time means when the current is increase the time will decrease where the operating time for relay is faster by increase in current. Definite minimum time means when the current is high the operation of relay is faster where for every protection relay has their own fixed time depend on time delay setting [7-9].

Inverse Definite Minimum Time (IDMT) is affected by the inverse proportional relationship between the operating time of the relay and the function of current. For overcurrent relay there are two adjustments which are plug setting and time dial setting. Plug setting determines the current at which the relay will start operate while time dial setting controls the relay's disc movement.

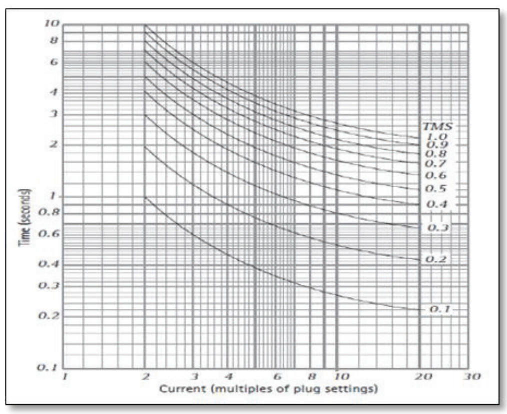

Fig. 2. Inverse Time Characteristic Curve.

The curve in Figure 2 display the relationship between operating current in terms of current setting multiplier along the x-axis and operating time in seconds along the y-axis. A current setting multiplier indicates the number of times the relay current is in excess of the current setting. The current setting multiplier is also referred to as plug setting multiplier (PSM) [10-11]. Thus,

$$PSM = \frac{Primary\ Current}{Primary\ Setting\ Current} = \frac{Primary\ Current}{Relay\ Current\ Setting\ x\ CT.Ratio} \quad (1)$$

This inverse time characteristic also can be shifted up or down by adjustment of the time-dial setting where by using the appropriate TDS settings, the grading of protection network system can be achieved where the range of TDS is normally form 0.1 to 1.0 [12]

The current or time tripping characteristics of IDMT relays can be varied according to the tripping time required and the characteristics of other protection devices used in the network [3]. For these purposes, IEC 60255 and IEEE C37.112 defines a number of standard characteristics as follows [13]:

- Standard Inverse (SI)
- Moderately Inverse (MI)
- Very Inverse (VI)
- Extremely Inverse (EI)
- Long Time Inverse (LTI)

III. Mathematical Expression

The characteristics of an IDMT overcurrent relay depend on the type of standard selected for the relay operation. These standards can be ANSI, IEEE, IEC or user defined. The relay will calculate the relay operating time based on the chosen standard characteristic curves and the parameters defined [10]. In accordance of IEC and IEEE/ANSI standard, the characteristics of IDMT relays are represent mathematically by the following equation:

$$t = \frac{k\beta}{\left(\frac{I}{I_S}\right)^{\alpha} - 1} + L \qquad (2)$$

- t = relay operating time in seconds
- k = time multiplier setting
- I = fault current level in secondary amps
- Is= pick-up current selected
- L = constant
- α, β and L for various standard overcurrent relay types manufactured under ANSI/IEEE and IEC standard.

The constants α and β determine the slope of the relay characteristics. The values of α and β and L for various standard overcurrent relay types manufactures under ANSI/IEEE and IEC standards are given as in Table 1.

TABLE I
ANSI/IEEE AND IEC CONSTANT FOR STANDARD OVERCURRENT RELAYS

Curve Description	Standard	α	β	L
Moderately Inverse	IEEE	0.02	0.0515	0.114
Very Inverse	IEEE	2.0	19.61	0.491
Extremely Inverse	IEEE	2.0	28.2	0.1217
Inverse	CO8	2.0	5.95	0.18
Short-time Inverse	CO2	0.02	0.0239	0
Standard Inverse	IEC	0.02	0.14	0
Very Inverse	IEC	1.0	13.5	0
Extremelv Inverse	IEC	2.0	80.0	0
Long-time Inverse	UK	1.0	1.20	0

IV. Model in PSCAD

For circuit analysis, only certain part from overall system will be study in details. Figure 3 shows the circuit model for analysis designed in PSCAD software while Figure 4 shows the circuit model in single-line diagram view. The circuit was used to investigate the performance of overcurrent relay when subjected to faults, characteristic curve, curve standard and DG installation. The major components and parameters of the model are:

- Three phase voltage source, 50Hz, 132kV phase voltage.
- Three phase fault block to introduce single-phase-to- ground, double-phase-to-ground and three-phase-to-ground faults.
- Three phase load.
- Duration of simulation time = 10s
- Time to apply fault = 1s

The load in circuit model is supplied with 132kV from the grid through the transformers of 132/33kV and 33/1kV at both feeders. In normal condition, the distributed generator (DG) is not in service. The DG was only operated for the study on effect of DG installation to the performance of relay operation time. In the circuit model, the faults were applied at t=1 sec. The analysis was made based on relay operation time study. There are four cases were studied which are various type of faults, different type of relay curve characteristic, different of curve standard and impact of DG installation. All data were recorded and discussed.

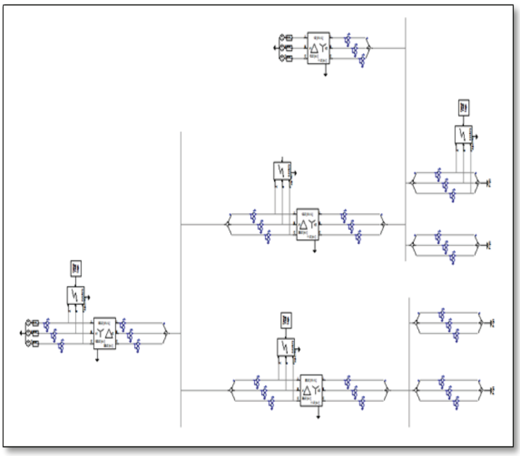

Fig. 3. Software Model Developed In PSCAD.

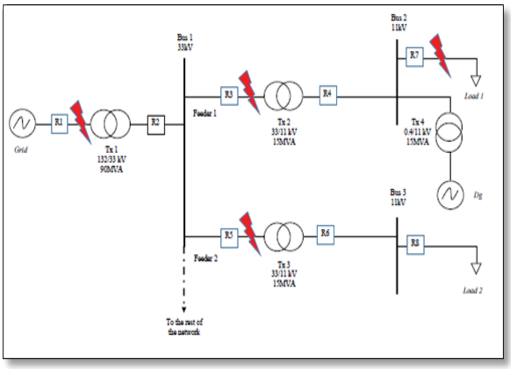

Fig. 4. Single Line Diagram Model.

To guarantee a reliable, fast and safe operation of overcurrent relay. The overcurrent relays setting such as time dial setting, pickup value, and curve characteristic should be choose carefully. Otherwise, the relay will not properly functioning (not tripping) or gives the wrong tripping command. The pickup current of the relays are varies which depends on their rated current. The pickup current setting of overcurrent relay is generally ranged from 50% to 200%. For this project the pickup current for overcurrent relay setting is 70% was chosen, therefore the current pickup is at 0.7 x rated current, as shown in Table 2.

TABLE 2
(a) PICKUP CURRENT FOR NORMAL CIRCUIT,
(b) PICKUP CURRENT FOR CIRCUIT WITH DG.

Relay	Rated Current (kA)	Pickup Current (kA)	Relay	Rated Current (kA)	Pickup Current (kA)
R1	0.278	0.49	R1	0.141	0.25
R2	1.118	1.96	R2	0.558	0.98
R3	0.263	0.46	R3	0.681	1.2
R4	0.751	1.31	R4	2.063	3.61
R5	0.525	0.92	R5	0.53	0.93
R6	1.549	2.71	R6	1.549	2.76
R7	0.387	0.68	R7	0.418	0.73
R8	0.774	1.35	R8	0.79	1.39
(a)			(b)		

Table 2 shows the tables of pickup current for two different conditions. Table (a) shows the pickup current setting for normal circuit whereas Table (b) shows the pickup current for circuit with installed DG. The pickup current settings for both conditions are different due to different in rated current. In normal circuit the rated current was contribute by grid supply only, while the rated current with DG installation were contributed by both supply sources of DG and grid.

V. Protection System Evaluations

In this part will be discussed on the result of the project. As stated before, the objective of this project is to investigate the performance of protection system based on relay time operation (ROT). Several situations and conditions were performed in order to study the IDMT overcurrent relay performance. The relay and protection scheme performances were studied based on several cases which are various type of faults, various IDMT relay curve characteristic, different of IEC 60255 and IEEE C37.112 curve's standard and impact of distributed generation (DG) installation in power system.

A. Various type of fault

Various types of faults are one of the ways to study the performance of protection scheme. In this project various types and locations of fault were applied to the circuit to study the performance of protection scheme based on relay operation time (ROT). The results were recorded for standard inverse characteristic curve of IEC 60255. IEC 60255 is a common standard used by most of utility company in Malaysia. The fault is given in several location such as grid, transformer 2, transformer 3 and load 1 as shown in Figure 4 where each fault given are single-phase-to-ground, double-phase-to-ground and three-phase-to-ground.

TABLE 3
COMPARISON OF THE RESULTS FROM PROPOSED RELAY MODEL VARIOUS TYPE AND LOCATION OF FAULTS.

Fault Location	Time (sec)	Single Phase	Double Phase	Three Phase
Grid	Operating	0.156	0.156	0.156
	Trip	1.156	1.156	1.156
Transformer 2	Operating	NO	0.328	0.328
	Trip	NO	1.328	1.328
Transformer 3	Operating	NO	0.328	0.327
	Trip	NO	1.328	1.327
Load	Operating	NO	0.268	0.161
	Trip	NO	3.268	3.161

Based on Table 3, the relays will be functioning faster when the fault is applied for TPG followed by DLG and SLG. The recorded relay operating time shows that when fault is given at load side, the three phase to ground fault gives fastest relay operating time (t=0.161s) compare to when double phase to ground fault were applied (t=0.268s). Besides, the relays also operated based on location of fault applied, if fault occurred before relay, the relay will not operate since the recorded current will be smaller (I ~ 0A) compare to pick up current. Besides, the relay will operate faster when the fault point is near to the relay which the higher the fault current magnitude the faster the relay operates.

However, some relays are shown only small significant of different in ROT. Moreover, the result also shows that the same pattern of not-operate (NO) when SLG fault were given at transformer 2 and transformer 3. This event were happened due to the type of transformer winding in the circuit where both start (secondary of Transformer 1) and end (primary of transformer 2 and 3) of the transformer winding is delta type winding. One of the disadvantages of delta-delta winding transformer where the transformer does not have neutral or common connection where core will be equal to the full line voltage in case of earth fault at one phase. Besides, the smaller difference of fault current to relay pick-up current was detected at load side. Therefore, the one phase fault given will not operate the relay.

B. Comparison between IDMT Curve Characteristic

There are a hundred type of protection standard practice in the world. Among of them are IEEE C37.112 and IEC 60255. IEEE C37.112 is a standard for relay characteristic curve which mainly used in North America. IEC 60255 is a standard that are famously used in most of Europe countries. IEC 60255 shares the similarities in many ways with British Standard. In Malaysia most of the standard follows the British Standard or IEC Standard. For utility company such as Tenaga Nasional Berhad (TNB), the IEC 60255 Standard is used in practice for the protection system [3].

TABLE 4
COMPARISON OF THE RESULTS FROM PROPOSED RELAY MODEL VARIOUS TYPE OF RELAY CHARACTERISTIC CURVE

Time (sec) \ Curve	Standard Inverse	Very Inverse	Extremely Inverse
Operating Time (s)	0.328	0.183	0.104
Ideal Operating Time (s)	0.268	0.115	0.050
Trip Signal Time (s)	1.328	1.183	1.104
Ideal Trip Signal Time (s)	1.268	1.115	1.050
Percentage Error (%)	6	6.8	5.4

Trip signal time = time at which fault is applied + Operating time

Table 4 shows the comparison of relay model between all of the three types of curve characteristic. The result is based on the Relay 1 (R1) when three-phase-to-ground fault at transformer 2. The result shows that the fastest ROT of R1 is for the curve characteristic of extremely inverse which is 0.104s followed with 0.183s and 0.328s for very inverse and standard inverse respectively. The table also shows the comparison between ROT from simulation and ideal ROT based on calculation by using formula [2.2]. The result from simulation is a bit different from the ideal calculation where the percentage different for the standard inverse is 6%, while the very inverse having 6.8% different and extremely inverse has the smallest percentage different of 5.4%.

C. Comparison of IEC 60255 & IEEE C37.112 Curve Standard.

The comparison were made between two different types of relay curve standard which are IEC 60255 and IEEE C37.112 curve standard of extremely inverse curve as shown in Table 5. Based on the table, the practice of IEEE C37.112 Standard for the relay protection will result in the fastest (ROT) compare to when the IEC 60255 Standard is used. The difference is obviously shown for recorded relay operation when fault is given at transformer 3 is 0.05s for IEEE Standard compared to IEC Standard which is 0.103s.

The different between these two standards is due to the different curve characteristics. Even though, the characteristic curve is the same for both standard which is extremely inverse curve with sharing the same equation (2.2), but the characteristic of the curve is differ from one another. In real application of power system, North America region have small voltage compare to European region where to supply the same power, the voltage for North America region is 120V while the European region is 240V. Therefore, the lower the value of voltage, the higher the amount of current. When fault is occurred at power line of North America region, it will results such high value of current compare to European region. That is why the relay constant for IEEE C37.112 Standard needs to be more sensitive in time operating if compared to relay with IEC 6022 Standard. Besides, the flexibility of the setting for phase over current (51) protections should be appreciated.

TABLE 5
COMPARISON OF THE RESULTS FROM PROPOSED RELAY MODEL IEC 60255 VS IEEE C37.112

Fault Location	Time (sec)	IEEE C37.112	IEC 60255
Grid	Operating	0.015	0.006
	Trip	1.015	1.006
Transformer 2	Operating	0.049	0.104
	Trip	1.049	1.104
Transformer 3	Operating	0.05	0.103
	Trip	1.05	1.103
Load	Operating	0.09	NO
	Trip	4.09	NO

D.Relay Operation with DG and without DG Installation

This part is to examine on how the installation of distributed generation (DG) effect to the relay operation time. The installation of DG commonly offers several compelling advantages but in certain circumstances the presence of DG in power system will lead to the protection problem. One of the obvious conditions is when there is no longer single direction power flow commonly from upstream generator or grid supply. With multiple sources, reverse power flow from DG unit also happened, this event will affect the coordination and operation of the standard overcurrent protection scheme [13-16].

TABLE 6
COMPARISON OF THE RESULT FROM PROPOSED RELAY MODEL WITH DG VS WITHOUT DG

Fault Location	Time (sec)	With DG	Without DG	Percentage Different (%)
Grid	Operating	0.134	0.156	15
	Trip	1.134	1.156	
Transformer 2	Operating	0.249	0.328	27
	Trip	1.249	1.328	
Transformer 3	Operating	0.247	0.327	28
	Trip	1.247	1.327	
Load	Operating	0.710	2.161	101
	Trip	1.710	3.161	

Trip signal time = time at which fault is applied + Operating time

Table 6, it can be seen that when the DG was in-service and fault was given at load 1, the ROT of Relay 1 (R1) is 1.71s if compared to R1 when DG is out-of-service which the ROT recorded is 3.161s. This relay behavior is shown by other relays too where the relay operation is faster after DG installation. Moreover, the false tripping or sympathetic tripping is happened when fault were applied at transformer 2, transformer 3, and grid side. Besides, the result shows the comparison of percentage different of ROT before and after distributed generator (DG) installation. The result calculated is based on Relay 1 (R1). As discuss before, the ROT for the relay in a system with DG is much faster compare to relay in a normal system. Furthermore, based on the table, the percentage different is increase from generator to the load, from 15% to 101%. The differences shows that the farthest the fault location from grid the higher the percentage different of ROT. This situation happened due to the combination of current to the fault point. When fault occurred at the grid, the grid is near to the fault point, therefore the contribution from the grid to the fault is higher compare to when the fault happened at load side where the contribution of the grid to the fault point is low due to the distance of the fault point, compare to the contribution from DG result in slow operating time. Besides, the current recorded is higher when fault at grid which is 40.97kA compare to 1.039kA in normal circuit where the network is absent of DG. This phenomena also result in faster operation of relay when DG units were installed.

VI. Conclusion

By using PSCAD software, the testing of the software model is done. There are four test have been done which are various type of fault, different type of IDMT curve characteristic, implementation on different standard of curve and lastly installation of single-DG to the power system. Each of the cases were studied and discussed as in previous chapter. The curve characteristic study is based on IEC 60255 which are standard inverse, very inverse and extremely inverse. Whereas, for the curve standards, IEC 60255 and IEEE C37.112 were compared. It can be concluded that, the ROT of relays were varies and changed with all variables in the performed test. The relay operation time is faster when three phases to ground fault, EI curve characteristic curve, IEEE C37.112 Standard and DG installation were implemented for each of the cases respectively. The failure of relay operation will interfere with the continuity of supply to the load and decrease the reliability of protection system. In order to make the protection system safer, reliable and faster operation of overcurrent relay, the coordination of the proposed overcurrent relay model in the power system protection scheme should take into account; this will be reported in a future publication.

Appendix

Nomenclature

Symbol	Defination
NO	Not Operate
TNB	Tenaga Nasional Berhad
ROT	Relay Operation Time
IDMT	Inverse Definite Minimum Time
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineer
SGL	Single Line to Ground
DGL	Double Line to Ground
TPG	Three Phase to Ground

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