Indonesian Journal of Electrical Engineering and Computer Science
Vol. 8, No. 2, November 2017, pp. 407 ~ 413
DOI: 10.11591/ijeecs.v8.i2.pp407-413

Evaluation of Protective Relaying Reliability in Renewable Energy Environment

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Abstract

The decrement in supply of fossil fuel led to the exploration of new energy sources, which varies from wind energy to solar energy, which are known as Renewable Energy. The main problem with these power sources are the inconsistency of their energy that depends very much on the environmental factors. The embedment of these power sources onto conventional power transmission network would affect the sensitivity and reliability of protective relaying. Two different types of solar power plant connection to power system network are presented in this paper, namely Bus Connection and T-Off Connection. Computer Aided Protection Engineering (CAPE) software is used to model the networks being protected by distance protection, and simulate short circuit scenario. This paper specifically focuses on evaluating the impact of the in-feed current being contributed by both network configurations to the reliability of distance protection.

Keywords: *Distance protection, Solar PV, In-feed current, T-Off Connection, Bus Connection*

1. Introduction

Renewable energy (RE) has been chosen as an alternative power source because it is eco-friendly, eco-green and mainly due to its sustainable in nature. If it is adapted onto power transmission network, the inconsistent and unpredictable input power from RE would lead to changes in the behavior of power system. Thus, this will affect the reliability and sensitivity of the protective relay [1]. Relay malfunction indicates the unreliability of power protection equipment; it may cause major power blackout, which is a catastrophic consequence [2-3]. The objectives of this paper is to demonstrate the in-feed current effects from solar power plant by analyzing the impact of in-feed current and determining the suitable way in connecting solar power plant to conventional power transmission network. Therefore, it is important to analyze the behavior of protection relay, specifically distance protection relay with solar power plant connected to power system network [4].

The analysis of both proposed power system will involve only Zone 1 and Zone 2 of distance protection relay. Zone 1 is normally set at 80% of the protected line with instantaneous tripping mechanism while Zone 2 reach is set at least 120% of the protected line with 20-30 cycles delayed tripping mechanism [5]. In this study, distance relay with Mho characteristic is chosen due to its ability to implement both directional and distance measuring functions in one unit with one contact [6]; thus, the choice is reliable. The contribution of in-feed from new RE is different from the in-feed due to a conventional power generator. The in-feed by renewable is not constant; furthermore, input sources are highly unpredictable and intermittent in nature which lead to the variable in-feed fault currents seen by the distance relays. Base on this concept, reference [7] proposed an adaptive relay algorithm scheme. Reference [8] has found that the effect of in-feed current usually occurs at a point, where two generator sources are connected in parallel to each other.

Distance relay settings can also be determined based upon the network topologies and in-feed constants [9]. When fault lies within the power network, the existing topology is identified with the help of circuit breaker status. Based on the topology, the in-feed constants are selected and desired relay settings for the different zones are transferred to the respective distance relays [10]. This paper exhibits two types of solar power plant connection to power system

Received July 27, 2017; Revised September 22, 2017; Accepted October 13, 2017

network, which are Bus Connection and T-Off Connection. The recommended solar PV connection with respect to distance protection sensitivity is provided.

2. Research Method

The chosen test system is based on Malaysian Standard: Guidelines for Power System Steady State, Transient Stability and Reliability Studies [11] and also MS 2572 document. CAPE Database Editor module software is used to model the test system. The base case network without RE is shown in Figure 1; RE power plant, specifically solar photovoltaic (PV) is later included in the test system for different types of solar PV connections in a power system: Bus Connection and T-Off Connection. The subtransient and transient parameters are added to the equipment model since this research work analysis requires subtransient, transient and synchronous reactances, which are essential for short circuit analysis.

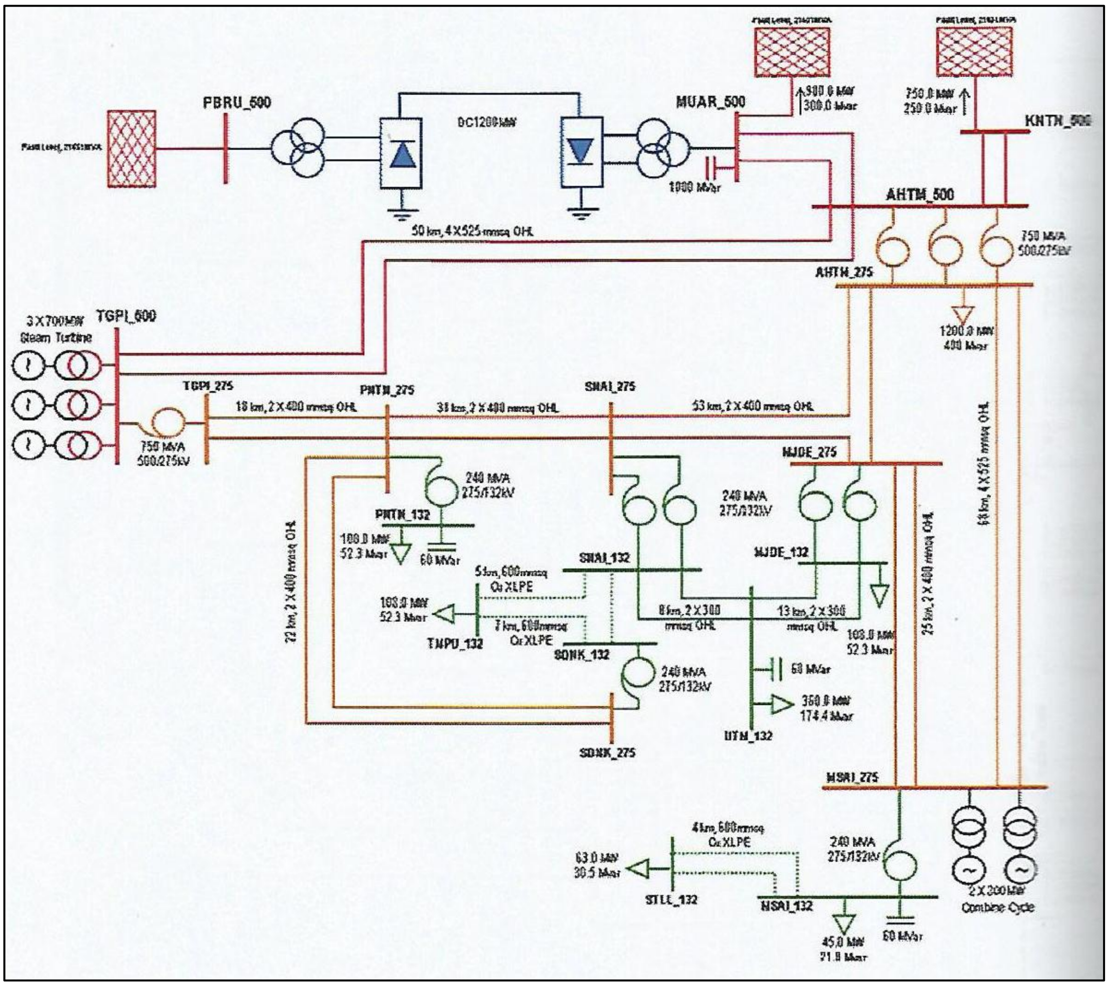


Figure 1. Test system based on MS 2572 document

A solar PV power plant with the capacity of 50 MW is to be installed at 132 kV transmission line; the proposed connection point is between 13205 SNAI_132 and 13204 UTM_132 as shown in Figure 2.

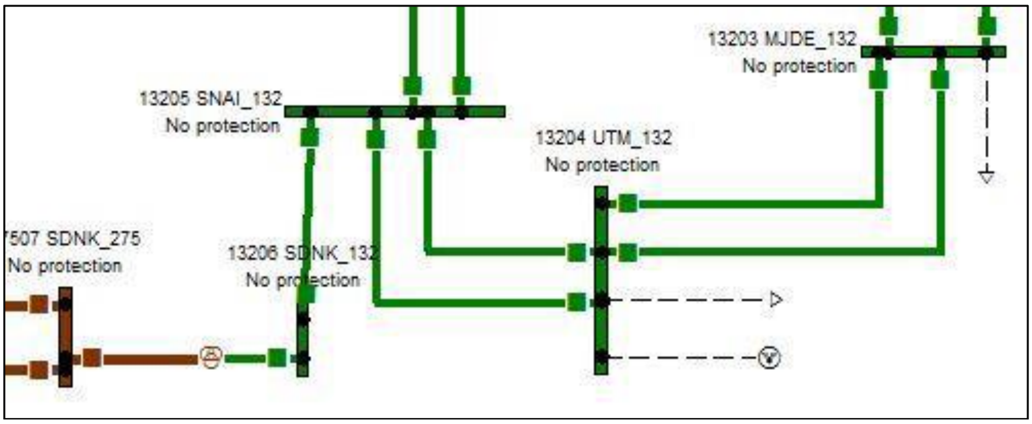


Figure 2. The location of proposed solar PV power plant

2.1. Case Study: Proposed Solar System Connection Configurations

There are two types of connection that can be suggested to embed solar PV power plant onto the existing transmission lines, either T-Off Connected or Bus-Connected. The difference between these two connections will be explained in Case Study 1 and 2 respectively. Figure 3 shows the flow of this research work in order to achieve the objectives.

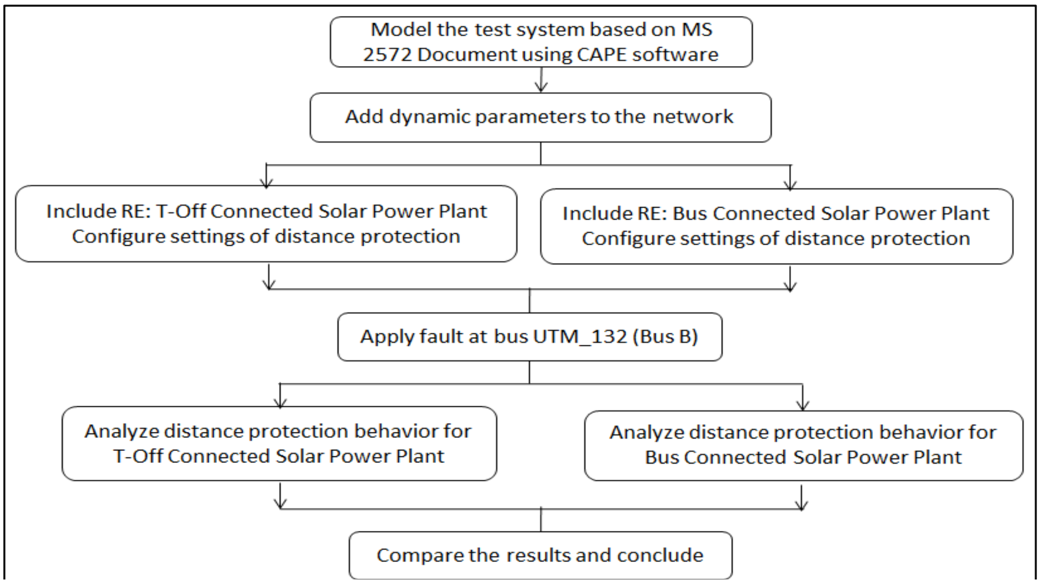


Figure 3. The Flow of Research Work

a. Case study 1: T-Off connected solar PV power plant

Figure 4 shows the configuration for T-Off Connected Solar PV Power Plant, which is at the middle of the line SNAI_UTM132 line, which is indicated as LSS_132. The structure of the T-Off Connection is preferable because it is cheaper than Bus Connection since the existance of bus is not required at the point of solar PV connection. Thus, SNAI_UTM132 line is not modified, instead the solar PV power plant is tapped onto the line through a jumper wire. This line is protected by a distance relay that measures bus voltage (V) and line current (I) to configure the line impedance (Z). The value of V and I are monitored through voltage transformer and current transformer. Voltage transformer is usually installed at the bus; nevertheless, since no bus exists at LSS_132, this distance relay depends on the voltage measured at bus SNAI_132. As a result, the arrangement and placement of distance relay protection could expose the system to the in-feed current effect; thus, it contributes to under reaching of distance relay.

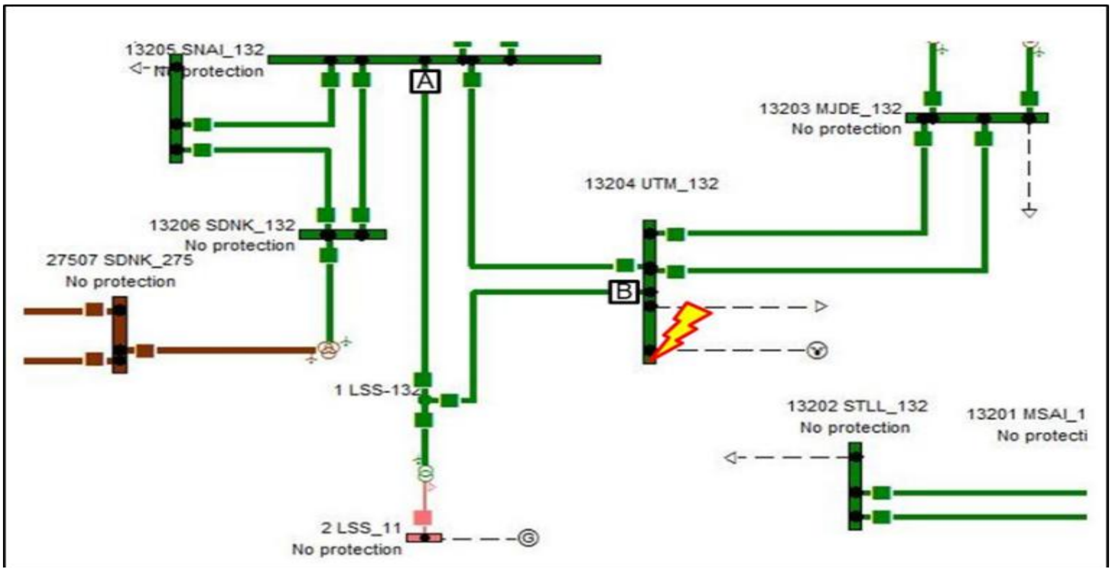


Figure 4. T-Off Connected Solar Power Plant

Figure 5 shows that the total line impedance for T-Off connection is 2.202 ohms as it covers the entire SNAI_UTM132 line. Zone 1 reach of distance relay A is set at 80% of protected line, which is 1.76 ohms with an instantaneous operation time while Zone 2 reach is set at 120 % of the protected line with the operation time being delayed to 300 milliseconds. In impedance values, Zone 1 reach is set at 1.76 ohms while Zone 2 reach is set at 2.64 ohms respectively

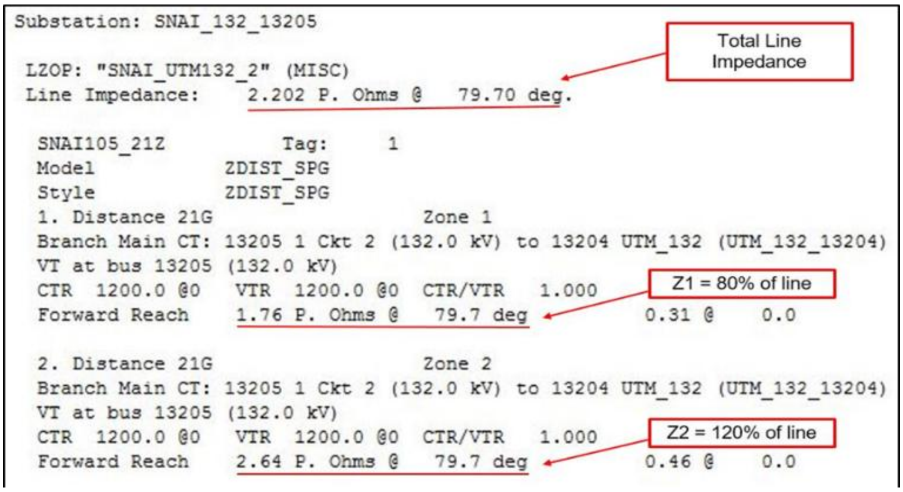


Figure 5. T-off distance relay parameter

To analyze the effects of in-feed current, a single line to ground fault is applied at bus UTM_132 (Bus B). The apparent impedance and operating time of distance relay are monitored. Figure 6 shows the T-off connection mho characteristics of distance relay.

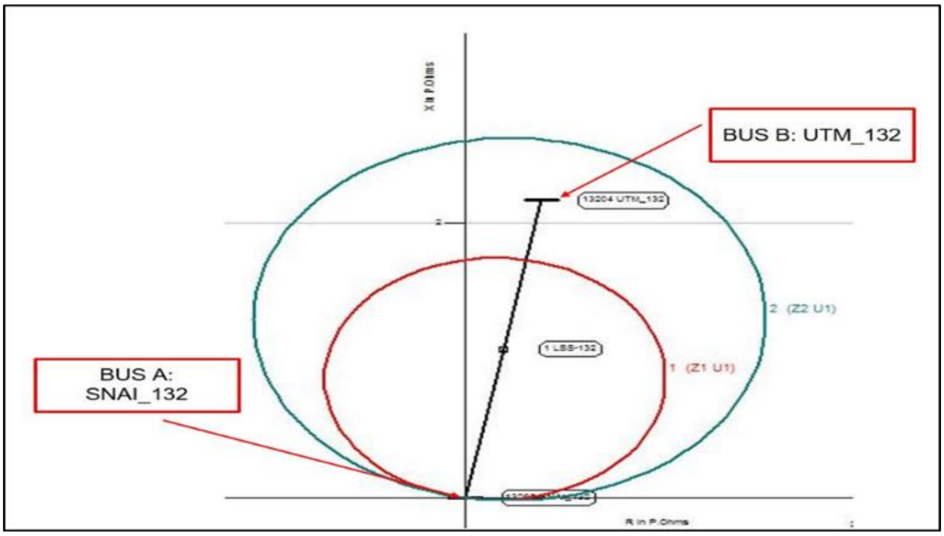
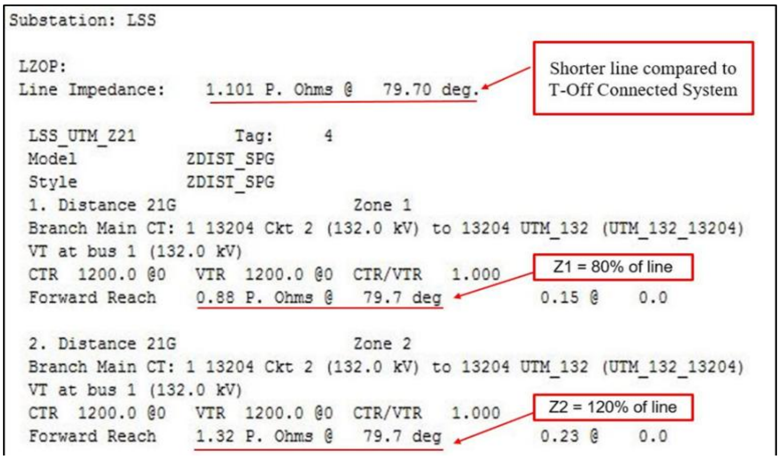


Figure 7. bus connected solar power plant model

The line impedance is reduced to 1.101 ohms, the reach for both Zone 1 and Zone 2 would also be lower than the reach for T-Off distance relay. Thus, Zone 1 reach is set at 0.88 ohms while Zone 2 reach is set at 1.32 ohms; the reach of distance protection for each zone is shown in Figure 8.



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Substation: LSS

LZOP:
Line Impedance:    1.101 P. Ohms @   79.70 deg.

LSS_UTM_Z21          Tag:      4
Model            ZDIST_SPG
Style            ZDIST_SPG
1. Distance 21G                  Zone 1
Branch Main CT: 1 13204 Ckt 2 (132.0 kV) to 13204 UTM_132 (UTM_132_13204)
VT at bus 1 (132.0 kV)
CTR  1200.0 @0   VTR  1200.0 @0  CTR/VTR   1.000
Forward Reach    0.88 P. Ohms @   79.7 deg          0.15 @    0.0

2. Distance 21G                  Zone 2
Branch Main CT: 1 13204 Ckt 2 (132.0 kV) to 13204 UTM_132 (UTM_132_13204)
VT at bus 1 (132.0 kV)
CTR  1200.0 @0   VTR  1200.0 @0  CTR/VTR   1.000
Forward Reach    1.32 P. Ohms @   79.7 deg          0.23 @    0.0
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Figure 8. Bus Connected Distance Relay Parameter

3. Results and Analysis

The behavior of distance protection are analyzed for two different solar PV power plant connection systems, which are T-Off Connected Solar Power Plant and Bus-Connected Solar Power Plant. When fault occurs in the system, the magnitude of the fault current contributed by solar power plant depends on solar power penetration at bus LSS_11. The variation of fault current contributed by solar PV power plant could create different apparent impedance as seen by distance relay. A single line to ground fault is applied at bus UTM_132; this unsymmetrical fault contributes 281.6A, 1163.8A, 3322.1A and more than 3322.1A respectively. An observation is made to analyze the effect of the in-feed current for both network configurations. The dependability and reliability of both systems are determined through monitoring the impact of in-feed current onto both configurations, which could lead to the over-reaching/under-reaching of distance relay.

3.1. Case Study 1: T-off Connected Solar Power Plant

The results obtained for T-Off Connected Solar PV Power Plant with various magnitude of current contribution are tabulated in Table I. For Case Study 1, the fault is applied at 2.202 Ω, which is within Zone 2 reach. It is found that the relay operates correctly for all fault current contributions by solar PV power plant from 281.6 A to 3322.1 A, with only Zone 2 detecting the fault but not Zone 1. However, when fault current contribution of higher than 3322.1 A is introduced to the system, distance relay operates within Zone 1 time although the fault is applied at Zone 2. The actual applied fault location is at 2.202 Ω but the apparent impedance measured by the relay is 1.35 Ω, which is within the Zone 1 reach. Thus, causing the relay to operate within Zone 1 operating time regardless of the fact that fault has been applied at Zone 2 region.

Table 1. Relay Response for T-off Connected Solar Power Plant

Fault Current Contribution by Solar Power Plant (A)	Location of Fault	Apparent Impedance Measured by Relay (Ω)	Zone 1 (Zone 1 Reach = 1.76 Ω) Relay Status	Zone 2 (Zone 2 Reach = 2.64 Ω) Relay Status
281.6	2.202 Ω within Zone 2 reach	2.22	Not Operating	Operating
1163.8		2.12	Not Operating	Operating
3322.1		1.89	Not Operating	Operating
> **3322.1**		1.35	Operating	Operating

The in-feed current from solar PV power plant causes the relay to detect fault that occurs at Zone 2 region. Its effect could be explained using Ohm's Law, assuming the voltage is kept constant. As the current contribution increases, the magnitude of the apparent impedance decreases. At the same time, both Zone 1 and 2 reach are maintained at 1.76 Ω and 2.64 Ω respectively. Once the apparent impedance becomes lower than Zone 1 reach, it will cause the relay to operate within Zone 1 operating time.

3.2. Case Study 2: Bus Connected Solar PV Power Plant

Table 2 shows data collected for Bus Connected Solar PV Power Plant with the in-feed current from solar PV power plant. With the introduction of bus in the Bus Connected Solar Power Plant configuration, the protected line impedance is reduced to 1.101 Ω compared to 2.202 Ω in T-Off connection. Hence, the reach of distance relay for both Zone 1 and Zone 2 are 0.88 Ω and 1.32 Ω respectively, which is significantly smaller than distance relay reach for T-Off connection. Table 2 further shows distance relay response to unsymmetrical faults at different fault current contribution by solar power plant.

Table 2. Relay Response for Bus Connected Solar Power Plant

Fault Current Contribution by Solar Power Plan(A)	Location of Fault	Apparent Impedance Measured by Relay (Ω)	Zone 1 (Zone 1 Reach = 0.88 Ω) Relay Status	Zone 2 (Zone 2 Reach = 1.32 Ω) Relay Status
281.6	1.101 Ω within Zone 2 Reach	1.10	Not Operating	Operating
1163.8		1.10	Not Operating	Operating
3322.1		1.10	Not Operating	Operating
3294.8	0.55 Ω 50% of the protected line	0.55	Operating	Operating

The outcomes of this study proves that Bus Connection is more reliable than T-off Connection due to its immunity towards in-feed current effects. The apparent impedance measured by the relay for all three current contributions show the value of 1.10 Ω, which is the same as the applied fault impedance at 1.101 Ω. When fault occurs at Zone 2 region, the relay operates within Zone 2 operating time only. To further proves the reliability of the relay for this network configuration, a fault at 50 % of protected line is simulated using CAPE software, which is represented by 0.55 Ω impedance value. The apparent impedance measured by the relay and the location of the fault shows the same value of 0.55 Ω. Thus, proving the reliability of this relay since the location of the fault should be similar to the apparent impedance detected by the relay.

4. Conclusion

Comparing the performance of distance relay between both Bus Connection and T-Off Connection has deduced that the under-reach/over-reach effects to distance relay due to the in-feed current is more severe in T-Off Connection configuration. The effects depend on the location at which the protection relays are being installed. The reach OF distance relay for Zone 1 and Zone 2 in T-Off Connected system is more than the reach for Bus Connected system. From the results obtained, it can be concluded that the T-Off Connection can only be applied for a limited magnitude of in-feed fault current contribution thus, solar power capacity.

An ideal distance relay protection should always be able to detect the exact zone of fault occurrence on the transmission line. When the relay is affected by the in-feed current from the solar power plant, it will eventually lead to over-reach/under-reach of distance relay. Thus, it compromises the reliability and dependability of distance protection relay. Although Bus Connection is more reliable, the cost to establish this configuration is significantly more expensive compared to the cost to create T-Off Connection. Thus, it is recommended for future studies that the distance relay is embedded with current differential relay to provide a better protection system.

Acknowledgement

The research team would like to acknowledge the Ministry of Energy, Green Energy and Water Malaysia (KeTTHA) and Department of Higher Education for funding this research (20140135FRGS). The team would also like to extend acknowledgements to Universiti Tenaga Nasional, Malaysia for providing the facilities and making this research possible.

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