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Assessment on The Impact of Distributed Generation (Renewable Energy) Penetration to The National Grid Protection System Performances using ERACS Software

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Abstract: This paper is an assessment on the impact of distributed generation penetration to the national grid protection system performance based on a model simulated using software named ERACS. In recent years, the need and demand of using renewable energy as power source has increased greatly. This demand then led to the integration of distributed generation on the grid. Distributed generation has a lot of advantages. It can act as emergency supply, offering high quality power as well as reducing the carbon emission. However, it also has advantages that cause major concern, with protection being a major concern. Two models are used to simulate different scenario, focusing on protection blinding impact to the overcurrent relay used that is Inverse Definite Time Relay using ERACS. The results of the simulation are then studied in order to determine the relay performance during normal condition and when injected with renewable energy.

Keywords: Distributed Generation, Renewable Energy, Power flow, Overcurrent relay, ERACS

1. Introduction

The increasing demand for energy and the concern of global warming makes the world to use renewable energy (RE). Popular RE that are widely used are solar, wind and mini hydro. In order to channel the harvested energy, distributed generation or DG introduced to power system. DG is a type of generation of electricity which extracts power from various renewable energy sources, which is usually connected to medium and low voltage distribution level. The term DG itself means it's a generation that is not centralized and usually a small scaled generator which can be connected directly into the distribution network [1].

To put it simple, DG usually is not connected directly to the main generation or bulk power transmission. It is usually connected near the consumer. Traditionally, the distribution network is a radial network, which means the power distribution travel from the higher power level to lower power level. The addition of DG to the present distribution network changed the way of power flow for the whole distribution network system. Hence, distribution network now consists of centralized generation and distributed generation.

The new distribution network which consists of centralized generation and distributed generation makes the energy distribution more convenient as the consumer can get the power supply from the centralized distribution system as well as from distribution generation. However, the merge of this two network have increased the complexity of the overall power system protection of the distribution network [2].

Installation of DG can bring a lot of benefits such as act as emergency backup during utility outage, offer higher power quality, saving cost on network expansion, energy saving and carbon emission reduction Although undeniably distributed generation have benefits in energy distribution, it has its own drawbacks. The drawbacks considered in this

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paper are more towards the protection system as the addition of distributed generation changed the distribution network from radial to mesh network. The changes in return also changes the protection requirement on the system [3].

2. Power Scenario in Malaysia

2.1 Demand

The energy demand has shown increasing curve for the past years and as country that rely on fossil fuel burning to supply the electrical energy demand, this has become a grave issue for the environment. The burning of fossil fuel to generate electricity emits carbon dioxide to the atmosphere. In the last four decades, Malaysia carbon emissions increase from 1990 to 2005 with accelerating value of 235.6%. This high value largely contributed by the increasing national energy demand (210.7%). The high emission of carbon into the atmosphere leads to environment pollution and in 2009, Malaysia voluntarily committed to reduce 45% of its carbon emission. This commitment was from 2015 United Nations Climate Change Conference (COP 21) [4].

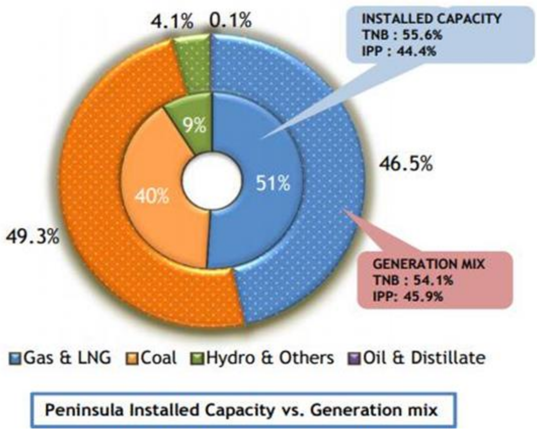

Fig.1 - Peninsula Malaysia installed capacity vs. generation mix

In order to reduce its greenhouse gasses, Malaysia opted to renewable energy as the optional source of energy supply to meet the demand. Although Malaysia still rely on fossil fuel for its main source of electricity energy, numerous potential renewable energy has been explored and implemented to meet the demand. The usage of renewable energy in generating electrical energy shows that there is a reduction of carbon dioxide emissions through the Feed-in Tariff scheme that were handled by SEDA [5].

2.2 Implementations

Malaysia's RE usage and development is handled by SEDA or Sustainable Energy Development Authority Malaysia. There are a total of 187.3 MW of RE installed capacities. This represented a year-over-year growth of 52% and in correspondence with previous years, solar PV for individual is the largest contributor of the number of applications with 2,502 applications.

In terms of number of the approved RE installed capacities, solar PV (Photo Voltaic) for non-individual is the largest contributor with 56.79 MW, followed by biomass with 46.39 MW, biogas 38.37 MW, solar PV individual with 20.60 MW, small hydro with 20.54 MW and lastly solar PV community with 4.66 MW. By the end of 2015, the cumulative number of approved FiA applications have increased to 7,437 representing 1,154.26 MW of approved RE capacity [6].

SUMBER TBB • *RE Resources*	**Permohonan** • *Application*		**Kapasiti** • *Capacity*	
	Bilangan *Number*	%	**MW**	%
Biogas • *Biogas*	106	1.23%	198.42	13.07%
Biojisim • *Biomass*	56	0.65%	545.25	35.92%
Hidrokuasa Kecil • *Small Hydro*	42	0.48%	339.35	22.35%
Solar Fotovolta • *Solar Photovoltaic*	8,438	97.63%	398.07	26.22%
Individu • *Individual*	7,445	86.14%	67.64	4.46%
Bukan Individu • *Non-individual*	580	6.71%	320.04	21.08%
Komuniti • *Community*	413	4.78%	10.38	0.68%
Geoterma • *Geothermal*	1	0.01%	37.00	2.44%
Jumlah • Total	8,643	100%	1518.09	100%

*Kuota diperuntukkan bagi solar PV hanya sehingga 2015

*Quata allocated for solar PV was offered up to 2015 only

Fig.2 - Total number of applications received as of 2015 for quota offered up to H1 2018* (except for solar PV) [6]

3. Power System Protection

3.1 Protection Zone

In power system protection system, zones are assigned to the devices to avoid complete failure of the system. In order to limit the area of the power system that is disconnected due to fault, protection is arranged in zones and each zones are equipped with their own protection components. Protection ones usually divided according to the devices existed in the power system [7]. The zones are protected by their respective protection devices and in some zones, there will be on overlapped in protection zones. Overlapped protection zones is responsible to make sure that there are no zones unprotected and also acts as backup protection or the main protection devices.

There are times when primary protection devices may fail to do it task. The failure may be caused by the current transformer or relay failure. In cases where the CT or relay failed to operate, a second line of defence is needed. Thus, it is a common practice to provide another zone to back up the protection system if the primary protection fail. The backup protection system is completely different form the primary protection system and usually placed in a different area from the backup protection system. In addition, in order for the backup protection to do it function, the primary protection must operate in clearing the fault. In other words, the backup protection operating time must be delayed by an appropriate amount of time over the primary protection [8].

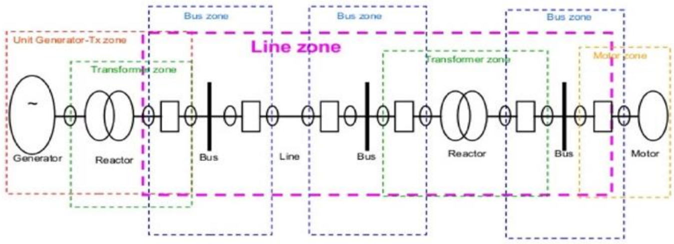

Fig. 3 - Protection zones

3.2 Overcurrent Relay

Inverse Definite Minimum Time (IDMT) relays is a common protection relays. They are used on transmission lines to see to that the line current doesn't exceed safe values and if it does, triggers the circuit breaker. As the name suggest, when the current keeps increasing, the relay takes minimum time to trip the circuit. Inverse means "higher the current value, lesser the time taken for the relay to trip the circuit". Current in the line and the time taken for the relay to trip the circuit breaker (CB) follow an inverse proportionality [9].

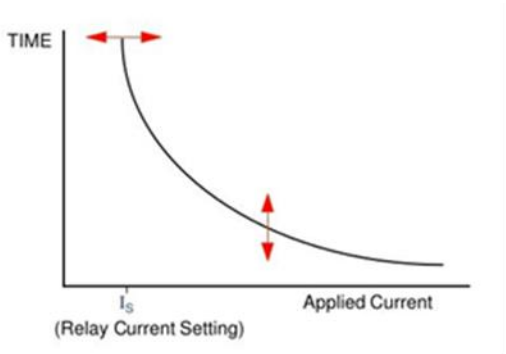

Fig. 4 - Standard IDMT characteristic

4. Impacts

Nowadays, Distribution Network Operator or DNOs are facing problem especially with their DG installations or in networks with high DG penetration levels. The protection consequences often relate to worst-case faults only, hence the small scale problem that can lead to dangerous problem usually remain hidden in the network as long as such situation does not occur Therefore, the need for protection analysis during the DG interconnection process must be underlined. The power flows and the short circuit currents may even have upstream directions or at least their amplitudes will change due to presence of DG. Protection system problems involving DG penetration are dependent to the type of protection system and the type of distribution network. The main concern of protection failure that the author focused is protection blinding [10].

Protection blinding is a dangerous and vital issue in protection system. The same goes to DG connected distribution networks protection system. Protection blinding may prevent the correct operation of the relay. This happen when the DG unit and the substation are feeding the fault in parallel. Due to the short circuit impedances, the current flowing through the feeder relay decreases. Overall fault levels always rise due to the DG penetration, however the current measured by the relay is the value that dictates the operation of the feeder protection.

Protection blinding may become non-operational in certain parts of the network, typically in the tail parts of the feeder including DG units. The most problematic fault types are two phase faults and faults with high impedances. Especially with definite-time relays, blinding is an issues as the operation may become totally blocked when the lower tripping level is no more exceeded. Thus, the inverse-time relays with blinding condition may cause delay in the operation of protection. These problem may lead to problems with thermal limits of components and lines [11].

5. Modelling

5.1 Parameter

The parameter determined are all based on Malaysia Distribution System and the data for each parameter were obtained from public information as per journals, official websites and annual report of TNB as well as manufacturing company. The data are processed and set to be as accurate as possible in the setting of the equipment albeit it is not completely according to teal world settings.

Table 1. IDMT relay setting

Relay	CT Ratio	PS	TM
A	550.1	1A	0.2
B	330.1	1A	0.15
C	100.1	1A	0.1

5.2 Model

Model that are used is a radial distribution network with 3 bus bar, which each are equipped with their own IDMT over current relay. Each bus bar has their own load and have different fault current level. The setting of the IDMT OC relay is calculated based on their fault data. Each bus is protected with overcurrent relay. Bus C equipped with Relay A (RA), Bus B with Relay B (RB) and Bus C with Relay C (RC).

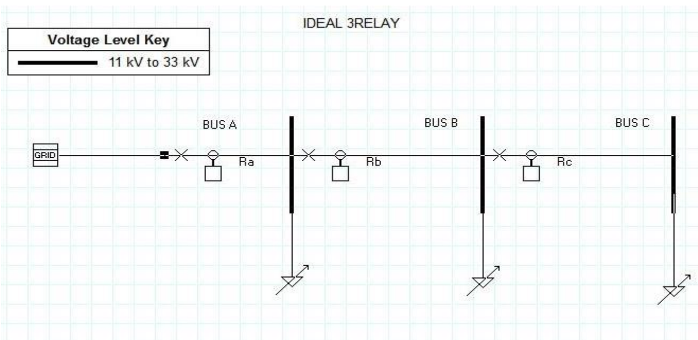

Fig. 5 - Model without DG

The second model is the same as the radial model without DG. However, in this model, DG were injected in Bus Bar B in order to see the effect of the DG to the distribution system. The value of DG injected to the system varies from 1 MVA to 30 MVA.

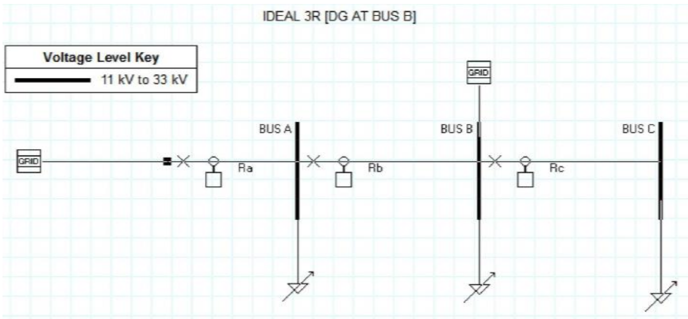

Fig. 6 - Model with DG attached on Bus B

Table 2. DG value in MVA and MW

DG Value (MVA)	DG Value (MW)
1	0.63
2	0.753
3	0.874
4	0.994
5	1.1112
10	1.685
20	2.742
30	3.696

6. Result and Discussion

6.1 Simulation Result for Model without DG

The model is simulated and the value of each equipment obtained through load flow. Protection analysis, as well fault analysis is done to both of the models to assess the concerns. Each bus has their own maximum and minimum fault and when put into simulation, ERACS does not allow the fault study to be more than the maximum fault of the system. This means that the fault applied cannot exceed the maximum fault current during fault study. Theoretically, R_C will act as the primary protection for line BC/Bus C while R_B is the back-up protection for line BC/Bus C and primary protection for Line AB/Bus B. R_A on the other hand is the back-up protection for line AB/Bus B and BC/Bus A if R_B and R_C failed to operate or the fault current is too high, R_A simultaneously act as primary protection for line that connect supply to Bus A.

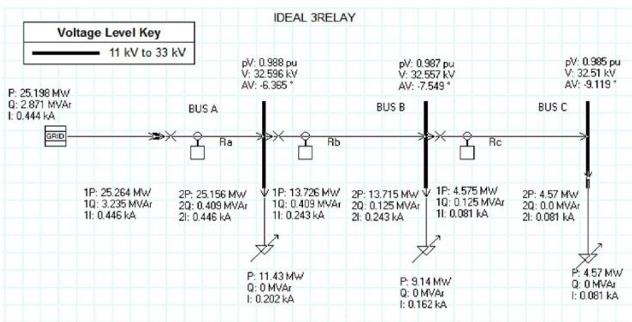

Fig. 7 - Load flow for No DG

Table 1. IDMT relay setting

Fault Location	Fault Current (I_F)	ROT(s)
BUS A	4.013	0.721
BUS B	3	0.841
BUS C	1.495	1.397

Based on the graph, the IDMT relay is functioning healthily. The graph shows that RC will trip at 0.292s when fault happen at Bus C and since RC only protect its zone hence it will not act as back-up protection for other zone. When the fault happens at Bus C higher than RC abilities, the time taken for RC to trip is longer (0.682s) and exceed its standard operating time (0.2s) hence RB will trip first at 0.486s. This clearly shows the relationship of RC and RB as primary and back-up protection for the network. RA also exhibits the same motion as RB in acting as the back-up protection and primary protection for the whole network.

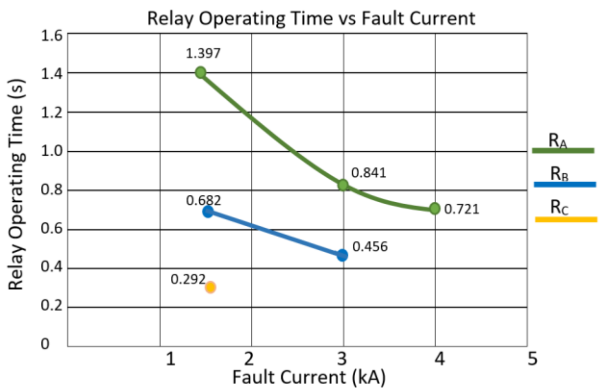

Fig.8 - Operational time curve

6.2 Simulation Result for Model with DG

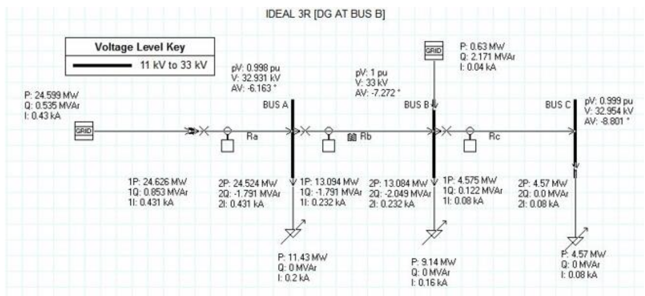

Fig.9 - Load flow for DG=1MVA

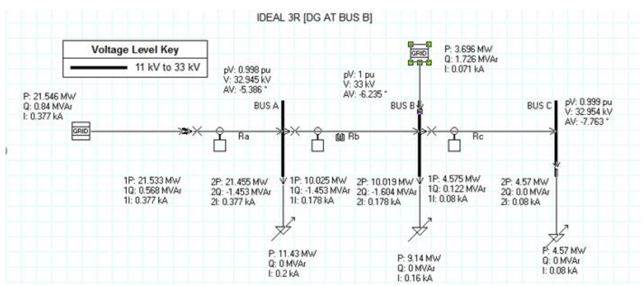

Fig. 10 - Load flow DG = 30MVA

Theoretically, when certain amount DG is injected to the network, the fault current of the system increased due to the fault contributed by the injected DG. However, with the increasing fault current in the system, relay will lose its reliability to protect its protection zone. This is because, when DG injected, the relay may be blinded to the fault current contributed by the DG. The supposedly high fault current will not be detected by the relay and the back-up relay will trip if the main protection relay did not see the fault. As per Table 4, during injection between 1MVA to 3MVA, the relay still functioning as usual. Although the relay operating time of Ra exceeds the maximum operating time, the system is still considered safe as the relay trips below 1second. However, as the DG penetration value increase, the relay operating time for the relays also increase.

The increasing values of DG caused the relay operating time to increase beyond their maximum operating time. However, the most notable value of ROT happens at 30 MVA. ROT of Ra increased to 6second which demonstrate the effect of blinding that happen in the system. This shows that, blinding is possible when we injected DG into the distribution system. When the model is injected with DG, the healthy relay starts to operate longer than their maximum operating time. As the value of DG injected increase, so does the relay operating time.

Table 3. Fault currents and ROTs

DG Value (MVA)	BUS A		BUS B		BUS C	
	Ifault (kA)	ROT (s)	Ifault (kA)	ROT (s)	Ifault (kA)	ROT (s)
1	4.031	0.727	3.017	0.49	1.509	0.293
2	4.048	0.879	3.035	0.55	1.513	0.315
3	4.065	0.902	3.052	0.64	1.518	0.419
4	4.083	1.076	3.07	0.79	1.522	0.545
5	4.1	1.25	3.087	0.94	1.526	0.671
10	4.185	1.425	3.175	1.09	1.547	0.793
20	4.353	1.599	3.35	1.4	1.587	0.911
30	4.516	6.831	3.525	1.54	1.624	1.026

From the data obtained, blinding does occur in the protection system when DG injected into the distribution network. The first model that were simulate without DG shows that the relay is functioning healthily. The relay was able to act as primary protection for their protection zone and act as back up protection in their respective overlapped zones. When the model is injected with DG values, it is shown that the relays are not functioning as healthy compared when it was in normal condition without DG attached. As per graph below, it is clearly visible that as when DG with 30MVA injected to the model, blinding occur instantly on Bus B.

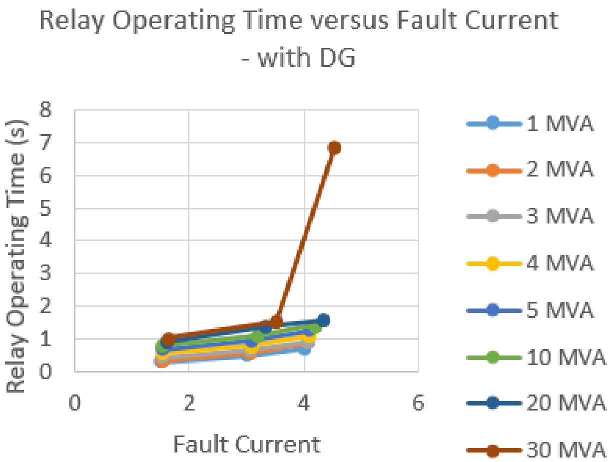

Fig. 11 Relay operating time vs fault current

For the system that were designed for this project, the maximum DG that can be injected to the system is 20 MVA before blinding occurs at 30 MVA. This value is equal to 2.74 MW, which means the system designed by the authors can accommodate solar injection as solar produced as much as 2 MW per day. However, for any DG that exceed 20 MVA, the system can't accommodate as blinding may occur.

7. CONCLUSION

In general, the penetration of DG in the power system undeniably have its own benefit. However, this benefits also have their own drawbacks. High penetration of DG cause the unidirectional power flow changed into bidirectional and in turn cause the power system complexity increase. This complexity affecting the protection system performance as the changes occur within traditional protection scheme. Although protection blinding is a rare case, it may happen when DG is injected to the system. This will result in jeopardizing the whole protection system which result in interruption of supply. For future works the author suggest that the system is built with more safety devices installed for better simulation of the system. The next system that the author proposed is that the system will need consider the protection devices from the source and from the DG to understand more clearly on the relationship of the protection devices.

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