Impact of DG on Voltage Profile and Power Losses for 33/11kV Pencawang Pengagihan Utama (PPU) Bakar Batu and PPU Century (Johor Bharu) using PSCAD Software

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Abstract – *Distributed Generation (DG) has become the world's primary focus for solving the energy crisis and pollution. Therefore, it is crucial to investigate the impacts of DG on the existing radial distribution network to ensure the reliability and efficiency of the network. This paper presents the impact of DG in terms of voltage profile and power losses in the Malaysia distribution network. A 33/11kV Medium Voltage (MV) distribution network based in PPU Bakar Batu and PPU Century, Johor Bharu was modelled and simulated using PSCAD/EMTDC simulation software. Several cases with different location of DG placement and size of DG were carried out in this study. The simulation results showed an improvement of voltage profile within the allowable limit of 0.95p.u and 1.05p.u and a minimization of power losses after DG was installed in the network. The suggestions for the optimal location for DG installation was analyzed based on the results of the pre and post interconnection of DG*

Keywords: *distribution generation (DG), Malaysia distribution network, power losses, voltage profile*

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I. Introduction

Since climate change and the reduction of fossil fuels resources are critical challenges for the 21st century, the world is urgently trying to solve these problems by taking a variety of methods. Malaysian Government aimed to reduce greenhouse gas emissions by 45 percent in 2030 with the use of renewable resources to reduce the dependency on fossil fuels to generate electricity [1]. Hence, distributed generations (DG) mostly come from renewable resources such as solar PV and wind farms is one of the methods to generate electricity while reducing global warming issues. Many studies have been reported showing the benefits of DG on the power system network such as reducing the power losses on transmission and distribution lines, improving the reliability of the network, acting as backup power during peak demand and improving voltage profiles [2],[3].

However, the conventional power system normally operates to feed the downstream sources by only allowing the power to flow unidirectional, which is from the substations to the customer sides. This network system was designed radially and passively with low-cost and simple operation. Therefore, if DG is injected into the network, it will alter the operation of the conventional network when the power flows from the DG to the head terminal of the network which caused reverse power flow.

Thus, it is crucial to investigate the impacts of DG to minimize the negative impact on the existing radial distribution network. Numerous in-depth researches have been conducted to evaluate the technical impact of DG, especially on voltage profile [4]-[6], power losses [7]-[9], reliability [10]-[11], short circuit current [12] and protection [13].

Previous studies investigated the impact of DG on the radial network system based on the IEEE bus system or US network. These networks might be different from the Malaysia distribution network. Therefore, this paper presents several case studies to evaluate positions of DG placement impact to voltage profile and system losses based on the Malaysia 33/11kV Medium Voltage at PPU Bakar Batu and PPU Century, Johor Bharu. No specific DG is used in this simulation.

II. Research Methodology

A. Modelling of Distribution System

There are two distribution networks modelled in PSCAD/EMTDC software, which are based on PPU Bakar Batu and PPU Century, Johor Bharu, Malaysia. The test system for PPU Bakar Batu consists of one generator, two transformers and a total of 13 busbar which consists of different load values as shown in Fig.1. Meanwhile, the test system for PPU Century also has one generator, two transformers and 10 busbars as represented in Fig.2. In the PPU Bakar Batu test system, buses 11 to 13 represent the connection of the PPU to SSU Southkey through a long cable by considering the line impedance. However, in PPU Century, bus 10 is the SSU Sky 88 connected by a long cable. The transformer that used to step down the voltage from 33kV to 11kV is 30MVA each but due to some specification of the simulation software, the value of the transformer was changed to 100MVA in the simulation.

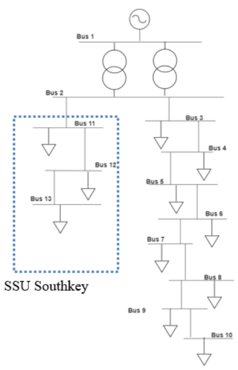

Fig. 1. 33/11kV PPU Bakar Batu Schematic Diagram

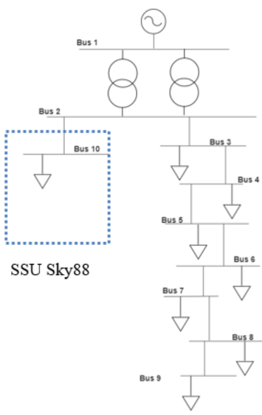

Fig. 2. 33/11kV PPU Century Schematic Diagram

From the network diagram, the system used 240$mm2$, 3C XLPE Copper (Cu) type cable to connect between the transformer and the load. Besides, all the loads connected are modelled at a power factor of 0.90 as TNB required consumers who are taking supply at 33kV or below need to maintain the power factor between 0.85 to 0.95 to avoid the power surcharge penalty. The line impedances are only considered for the cable connected from PPU to SSU as the distance between is longer than the load that is directly connected to PPU. The summary of the distribution network parameters for PPU Bakar Batu and PPU Century is shown in Table I and Table II respectively.

TABLE I
OVERALL NETWORK CHARACTERISTIC FOR PPU BAKAR BATU

Characteristics	Quantity
Total Connected Load (MVA)	78.15
Total cable length from PPU to SSU (km)	1.8
Total Transformer Rating (MVA)	100
Reactance (Ω/km)	0.297
Impedance (mH/km)	0.0007
Power factor	0.9

TABLE II
OVERALL NETWORK CHARACTERISTIC FOR PPU CENTURY

Characteristics	Quantity
Total Connected Load (MVA)	49.75
Total cable length from PPU to SSU (km)	2.3
Total Transformer Rating (MVA)	100
Reactance (Ω/km)	0.3795
Impedance (mH/km)	0.0095
Power factor	0.9

Since the PSCAD/EMTDC simulation software requires to insert the load data at real power (P) and reactive power (Q), equations (1)-(2) are used to convert the apparent power, S of the load to P and Q. The power factor used is 0.9.

$$P = S\cos\theta \qquad (1)$$

$$Q = S\sin\theta \qquad (2)$$

B. Measurement of Voltage Profile

In a radial distribution network, the voltage will decrease along the line when the current passed through the impedance. The voltage can be calculated per unit as in formula (3).

$$V(pu) = \frac{Vactual}{Vbase}$$

The voltage constraints are $V_{min} < Vi < V_{max}$, where $V_{min} = 0.95$p.u and $V_{max} = 1.05$p.u.

C. Measurement of Power Losses

When the system is without DG, the power loss is the total power delivered from the generator subtract by the total power received by the load as in equation (4). When DG is installed into the system, the power losses become the total power delivered from the generator and distributed generation deduct the total power received by the loads same as in equation (5).

$$PL = PG - PTL \qquad (4)$$
$$PL = PG + PDG - PTL \qquad (5)$$

Where PL is the power loss, PG is the power delivered from the generator, PDG is the power delivered from the distributed generator, PTL is the total power received at the loads.

III. Case Studies

Case 1- Distribution network without DG at PPU Bakar Batu
Case 2- Different DG sizes at bus 2 at PPU Bakar Batu
Case 3- Different DG sizes at bus 13 at PPU Bakar Batu
Case 4- Distribution network without DG at PPU Century
Case 5- Different DG sizes at bus 2 at PPU Century
Case 6- Different DG sizes at bus 10 at PPU Century

IV. Simulation results and discussions

A. Impact of DG on Voltage Profile at PPU Bakar Batu

Four different sizes of DG which are 15MW, 25MW, 40MW and 50MW will be installed into the network and analysed for each location to determine the impact on the voltage profile. The results are measured by using the multimeter in PSCAD. Case 1 is the base case without DG installation while Case 2 is the different DG sizes installed at the same location, bus 2 of the PPU Bakar Batu. The results of the voltage profile at Case 1 compared with Case 2 is tabulated in Table III.

TABLE III
VOLTAGE PROFILE AT DIFFERENT DG SIZES AT BUS 2, PPU BAKAR BATU

Case	DG injection power (MW)	Voltage (p.u)			
		Bus 2	Bus 3	Bus 10	Bus 13
1	0	1.0000	1.0000	1.0000	0.9290
2a	15	1.0000	1.0000	1.0000	0.9289
2b	25	1.0000	1.0000	1.0000	0.9290
2c	40	1.0000	1.0000	1.0000	0.9291
2d	50	1.0000	1.0000	1.0000	0.9292

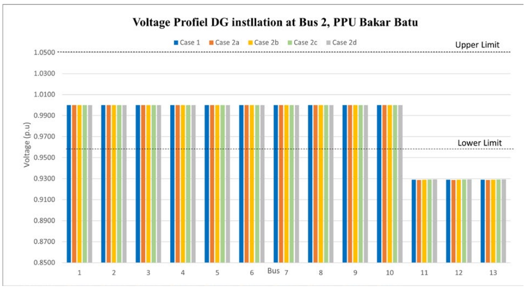

Fig. 3. Load voltage profile before and after DG inject at Bus 2, PPU Bakar Batu.

Based on Fig 3, the load voltage at bus 1 to bus 10 are maintained at 1.00 p.u. However, the voltage profile at buses 11 to 13 is much lower compared with other buses due to the cable impedance. The voltages at buses 11 to 13 are drops below the allowable limit of 0.95p.u to 1.05p.u. When DG is injected into bus 2, the feeder front of the network, the bus voltage is increasing with the increase of DG size. But, the improvement of the voltage still does not satisfy the minimum limit of 0.95p.u.

Case 3 is different DG sizes installed at the same location, bus 13 of the PPU Bakar Batu. The results of the voltage profile at Case 1 compared with Case 3 is tabulated in Table IV.

TABLE IV
VOLTAGE PROFILE AT DIFFERENT DG SIZES AT BUS 13, PPU BAKAR BATU

Case	DG injection power (MW)	Voltage (p.u)			
		Bus 2	Bus 3	Bus 10	Bus 13
1	0	1.0000	1.0000	1.0000	0.9290
3a	15	1.0000	1.0000	1.0000	0.9956
3b	25	1.0000	1.0000	1.0000	0.9983
3c	40	1.0000	1.0000	1.0000	0.9998
3d	50	1.0000	1.0000	1.0000	1.0002

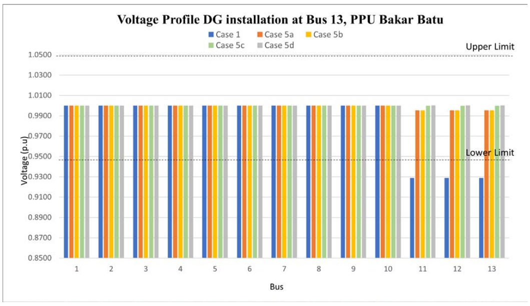

Fig. 4. Load voltage profile before and after DG inject at Bus 13, PPU Bakar Batu.

When a DG is connected at bus 13, which is also known as the feeder end of the PPU Bakar Batu, the voltages drop at the load have overcome and a great improvement of voltage profile at load voltage under buses 11 to 13. It is obvious that when the size of DG increases from 15MW to 50MW, the voltage improvement is increasing. The increase of voltage profile is within the allowable voltage constraints.

This indicates that DG with a range of 15MW to 50MW DG is suitable to install at the feeder end of the PPU Bakar Batu substation to improve the load voltage profile to a minimum limit of 0.95p.u and reduce the voltage drops of the circuit due to line impedance.

B. *Impact of DG on Voltage Profile at PPU Century*

The same size of DG which are 15MW, 25MW, 40MW and 50MW will be installed into the PPU Century to determine the impact on the voltage profile. Case 4 is the base case without DG installation while Case 5 is the different DG sizes installed at the same location, bus 2 of the PPU Century. The results of the voltage profile at Case 4 compared with Case 5 is tabulated in Table V.

TABLE V

VOLTAGE PROFILE AT DIFFERENT DG SIZES AT BUS 2, PPU CENTURY

Case	DG injection power (MW)	Voltage (p.u)			
		Bus 2	Bus 3	Bus 9	Bus 10
4	0	1.0000	1.0000	1.0000	0.9783
5a	15	1.0000	1.0000	1.0000	0.9781
5b	25	1.0000	1.0000	1.0000	0.9781
5c	40	1.0000	1.0000	1.0000	0.9781
5d	50	1.0000	1.0000	1.0000	0.9783

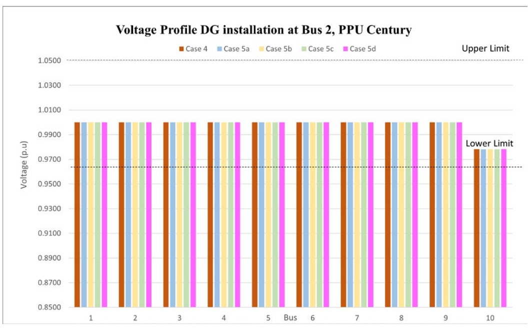

Fig. 5. Load voltage profile before and after DG inject at Bus 2, PPU Century

Based on Fig 5, the load voltage at buses 1 to bus 9 are maintained at 1.00 p.u. When 15MW, 25MW and 40MW DG are connected to bus 2 of the network respectively, the voltage at bus 10 is reduced 0.0002p.u. Therefore, if DG is injected into the feeder front, there will be voltage drops at bus 10 compared with the case without DG installation. Since DG installation at bus 2 does not show an improvement in voltage profile at bus 10, therefore another analysis of Case 6 is carried out. Case 6 is different DG sizes installed at the same location, bus 10 of the PPU Century. The results of the voltage profile at Case 4 compared with Case 6 is tabulated in Table VI.

TABLE VI

VOLTAGE PROFILE AT DIFFERENT DG SIZES AT BUS 10, PPU CENTURY

Case	DG injection power (MW)	Voltage (p.u)			
		Bus 2	Bus 3	Bus 9	Bus 10
4	0	1.0000	1.0000	1.0000	0.9783
6a	15	1.0000	1.0000	1.0000	1.0003
6b	25	1.0000	1.0000	1.0000	1.0010
6c	40	1.0000	1.0000	1.0000	1.0014
6d	50	1.0000	1.0000	1.0000	1.0014

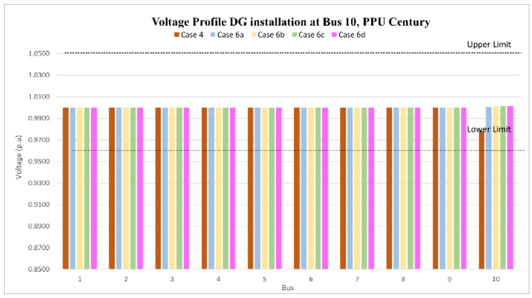

Fig. 6. Load voltage profile before and after DG inject at Bus 10, PPU Century

The load voltage at bus 10 is above the minimum limit of 0.95 p.u before DG installation even though there is some voltage drop at the line due to cable impedance. Therefore, it is not necessary to install DG on this network. However, DG can be installed in the network to overcome the voltage drop. Fig 6 shows an obvious improvement of voltage profile at bus 10 when the size of DG increase from 15MW to 50MW. Hence, the voltage drops at the network are overcome after DG is connected.

C. *Impact of DG on Power Losses at PPU Bakar Batu*

The power flow at the generation and load sides are obtained from the multimeter in the simulation. In this simulation, only active power loss is considered in the analysis. The power losses before installation of DG and after installation of DG at bus 2, PPU Bakar Batu is shown in Table VII.

TABLE VII

POWER LOSSES AT DIFFERENT DG SIZES AT BUS 2, PPU BAKAR BATU

Case	DG injection power (MW)	Power Losses (MW)
1	0	2.2908
2a	15	2.0246
2b	25	1.8835
2c	40	1.7154
2d	50	1.6244

The power at the network is lost due to line impedances and transformer losses. The high amount of power losses in the case without DG installation is also caused by the high current flow through the cable when $Ploss = I^2R$, where I is directly proportional to power loss. When current flow through the cable decrease, the power loss in the network also decrease.

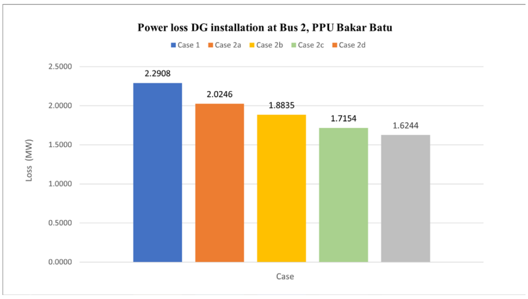

Fig. 7. Power Losses before and after DG inject at Bus 2, PPU Bakar Batu

When there is no DG installed into the network (Case 1), the power loss recorded is the highest, which is 2.2908 MW. The power loss at Case 2a is 2.0246 MW, Case 2b is 1.8835 MW, Case 2c is 1.7154 MW and Case 2d is 1.6244 MW. It can prove that when the size of DG injected into bus 2 increases from 15 MW to 50 MW, the power loss at the system decreases gradually as shown in Fig 7. The result has also shown that a significant decrease from 2.2908 MW to 1.6244 MW in the power loss when the largest DG, 50 MW was installed at bus

The power losses before installation of DG and after installation of DG at bus 13, PPU Bakar Batu is represented in Table VIII.

TABLE VIII
POWER LOSSES AT DIFFERENT DG SIZES AT BUS 13, PPU BAKAR BATU

Case	DG injection power (MW)	Power Losses (MW)
1	0	2.2908
3a	15	1.2924
3b	25	1.2554
3c	40	1.2404
3d	50	1.2374

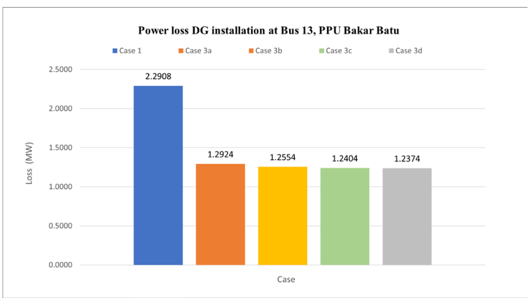

Fig. 8. Power Losses before and after DG inject at Bus 13, PPU Bakar Batu

When DG is installed at the end of the feeder, bus 13 of PPU Bakar Batu network, the power loss at the system decrease but the reduction is not significant. The largest DG size, 50MW placed at bus 13 recorded the highest reduction in power loss which is from 2.2908 MW to 1.2374 MW.

By comparing the location of the front feeder (bus 2) and feeder end (bus 13) for DG installation, it shows that the larger the DG connected to the feeder end of the network, the higher the power losses reduction can be achieved. The highest power loss reduction of 45.98% can be seen when the largest DG, 50 MW injected into the end feeder of the network and 29.09% when injected into the front feeder of the network.

D. *Impact of DG on Power Losses at PPU Century*

The power losses before installation of DG and after installation of DG at bus 2, PPU Century is shown in Table IX.

TABLE IX
POWER LOSSES AT DIFFERENT DG SIZES AT BUS 2, PPU CENTURY

Case	DG injection power (MW)	Power Losses (MW)
4	0	1.2195
5a	15	1.0452
5b	25	0.9610
5c	40	0.8498
5d	50	0.7917

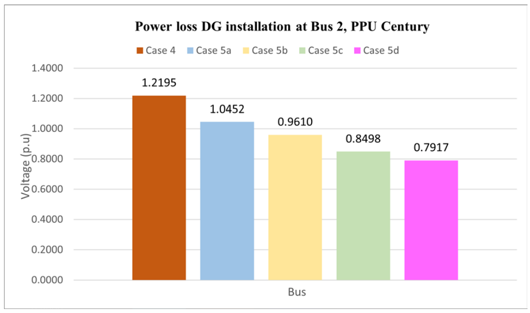

Fig. 9. Power Losses before and after DG inject at Bus 2, PPU Century

Fig. 9 shows that when the size of DG injected into bus 2 increases from 15 MW to 50 MW, the power loss at the system decreases gradually. The result also showed that a significant decrease from 1.2195 MW to 0.7917 MW in the power loss occurred when the largest DG, 50 MW was installed at bus 2. It can be concluded that the installation of DG into bus 2 and the feeder front of the network can cause the power loss at the network to reduce.

The power losses before installation of DG and after installation of DG at bus 10, PPU Century is shown in Table X.

Fig 10 shows the power loss at the system decreases but the difference is not significant when the size of DG injected into bus 10 increases from 15 MW to 50 MW. Case 6d, when the largest DG placed at bus 10 recorded the highest reduction in power loss which is from 1.2195 MW to 1.0323MW.

TABLE X
POWER LOSSES AT DIFFERENT DG SIZES AT BUS 10, PPU CENTURY

Case	DG injection power (MW)	Power Losses (MW)
4	0	1.2195
6a	15	1.0403
6b	25	1.0413
6c	40	1.0353
6d	50	1.0323

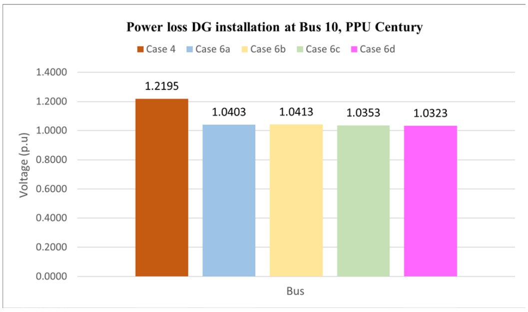

Fig. 10. Power Losses before and after DG inject at Bus 10, PPU Century

By comparing the location of the front feeder (bus 2) and end feeder (bus 10) for DG installation, it shows that DG connected at the feeder front of the network can minimize the power losses of the network more than the feeder end. The largest DG size, 50 MW placed into bus 10 only helps the system to reduce the power loss at 15.35% while placed into bus 2 successfully contribute 35.08% power reduction.

Regarding the analysis, it shows that the size of DG and location of DG installation affects the power losses of the PPU Bakar Batu and PPU Century substation. If DG is injected into the substation, the current flow from the generator at the substation to the loads is reduced therefore the power loss of the system will be reduced. The bigger the size of DG installed into the system, the lower the power need to generate by the generator of the substation hence the network can reduce the dependency on the main generator.

V. Conclusion

Based on the simulation result of the voltage profile, it showed that after DG was installed at the existing distribution network, improvement of voltage profile at the load was noticeable when compared to the system without DG installation. The placement of DG was able to share the responsibility with the main generator, which enables the load to meet the demand with the substation. Hence, the voltage at the load was going to increase as DG will be able to support the load demand. Although some cases showed that the DG will cause the load voltage profile to reduce when compared with the case without DG installation, for example in Cases 2a, 5a, 5b and 5c. In these cases, the DG was successful in improving the overall voltage profile within the allowable range of 0.95p.u to 1.00p.u. according to the TNB standard for Medium Voltage transmission lines. The best location for DG installation is at the feeder end of the network to reduce the voltage drops.

Based on the simulation result on power losses, it proved that the location of DG installation is important and need to be analysed before installing a DG. When DG was installed at the feeder front of PPU Bakar Batu, the power loss was lower than the DG installed at the feeder end of the network. However, in the simulation of PPU Century, the power loss reduction at the feeder end, bus 10 was lower than the feeder front, bus 2 of the network. Therefore, the location of DG must be analysed before placing the DG as an inappropriate connection of DG may cause a drawback to the existing network.

In a conclusion, it can be suggested that the bigger the size of DG, the higher the voltage can be improved at the load sides. Furthermore, the higher the power losses can be reduced. Based on this study under the Malaysia Medium Voltage network, it can be concluded that the impact of DG is highly dependent on location and sizing. Optimal placement of DG will improve the voltage profile of the system within the acceptable limits, in between 0.95p.u. to 1.05p.u. according to Malaysia's voltage level regulation limits. Besides, it can also reduce the system power losses. The optimal location for connection of DG at PPU Bakar Batu is at bus 13 while the optimal location for DG connection is at bus 10.

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