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Dynamic Simulation Model of Microgrid Based on Photovoltaic for Power Quality Improvement

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Abstract: A microgrid consists of cluster of loads and distributed generators that operate as a single controllable system. Power quality can be improved by proper load sharing between grid and integrated photovoltaic. Microgrid system used for renewable distributed generators and PV power generated can be stabilized according the load demand is presented in this paper. MATLAB/Simulink software is used to design the photovoltaic generation which is validated on IEEE 14-Bus network system. Power quality for furthest lines from main generation area will be improved by integrated PV to weakest buses in the network. As a result, power flow is improved and the power loses is reduce significantly. The performance of the PV injection is also compared with different power rating under different operating conditions. The test results revealed that the power quality at weak buses is significant improved and the load sharing between network grid is achieved with additional power injection.

Keywords: Microgrid; IEEE 14-Bus system; solar farm; power quality

1.0 INTRODUCTION

A microgrid consists of cluster of loads and distributed generators that operate as a single controllable system. Power quality can be improved by proper load sharing between network grid. Based on study conduct by Koran et al. (2014), they did propose new type of PV source simulator [1]. This is involved a three-phase ac-dc dual boost rectifier which cascaded with three-phase dc-dc interleaved buck converter. The performance then simulated in steady- state and transient condition using commercial solar power inverter [2].

Modified transport delay based phase-lock loop (TDPLL) which using two delays instead of one has been implemented to regulate the bus voltage. This method has been introduced by Elrayyah et al. (2013) [3]. Microgrid system can operate in parallel and isolated from the main power grid as stand alone. It also can be integrated with the grid in the gird-connected application [4-6]. Microgrid system commonly used for renewable distributed generators which currently the efficiency of power generated still low compared to common distributed generator that using coal and fuel as main heat sources.

By analyze the pattern of several renewable energies used, the control system to support demand can be improved and power distribution will be more stable. Reactive current

in resonant circuit can be minimized by operate the system near resonant frequency. This method also able to provide resonant soft switching, galvanic solation, high gain and low switching losses [7].

Power transfer capability (PTC) through transmission line should be improved in order to reduce power losses at the transmission lines. Unified Power Flow Controller (UPFC) based on Fuzzy Logic controller has been implemented to enhance the power flow, reduce power losses and improve bus voltage of the power system network [8-10].

In this paper, the model of microgrid will be designed and integrated with power system network to improve the power quality of the grid. MATLAB/Simulink software is used to design the microgrid system and test bus system. Power quality of the microgrid will be improved by connecting the PV model to the weakest bus. This will cause the power of line and buses around it significantly improved and reduce the dependency on the main generator. Thus, the stability of the power system network will be improved.

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2.0 MODELLING

2.1 IEEE-14 Bus System

The IEEE-14 Bus model consists of 2 power generators, 3 Synchronous Condensers, 11 Distribution Loads and 5 Power Transformers. The output power from the DG system can be affected by the increase amount of DER components into distribution networks. Based on study by Villalva et al. (2009), ambient condition gives the major impact of the output power [11].

This model is running on Discrete Simulation Type. Therefore, the component that used for this simulation need to be in discrete type. Each buses and lines are included 3-phase VI measurement and the value will be used to determine real power and reactive power. The arrangement of model follows IEEE-14 Bus System as shown in figure 1. Based on the layout of Fig. 1, it used to construct in MATLAB/Simulink as shown in Fig. 2. The parameter used is precisely check to ensure it can operate in discrete type model. Every buses, lines, components and each phase are label as reference in further update.

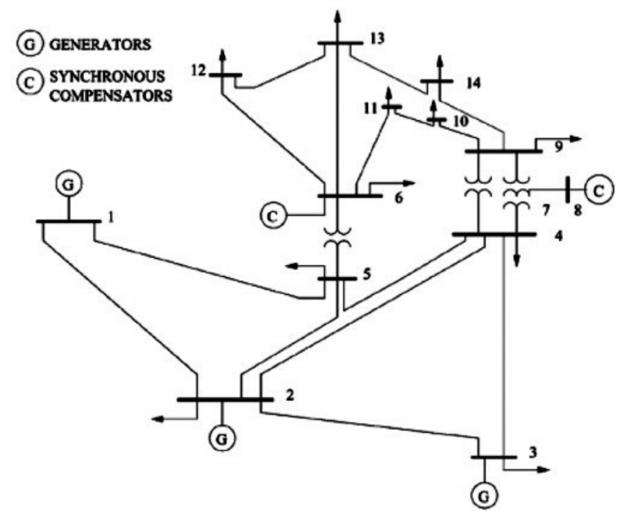

Fig. 1. IEEE-14 Bus System

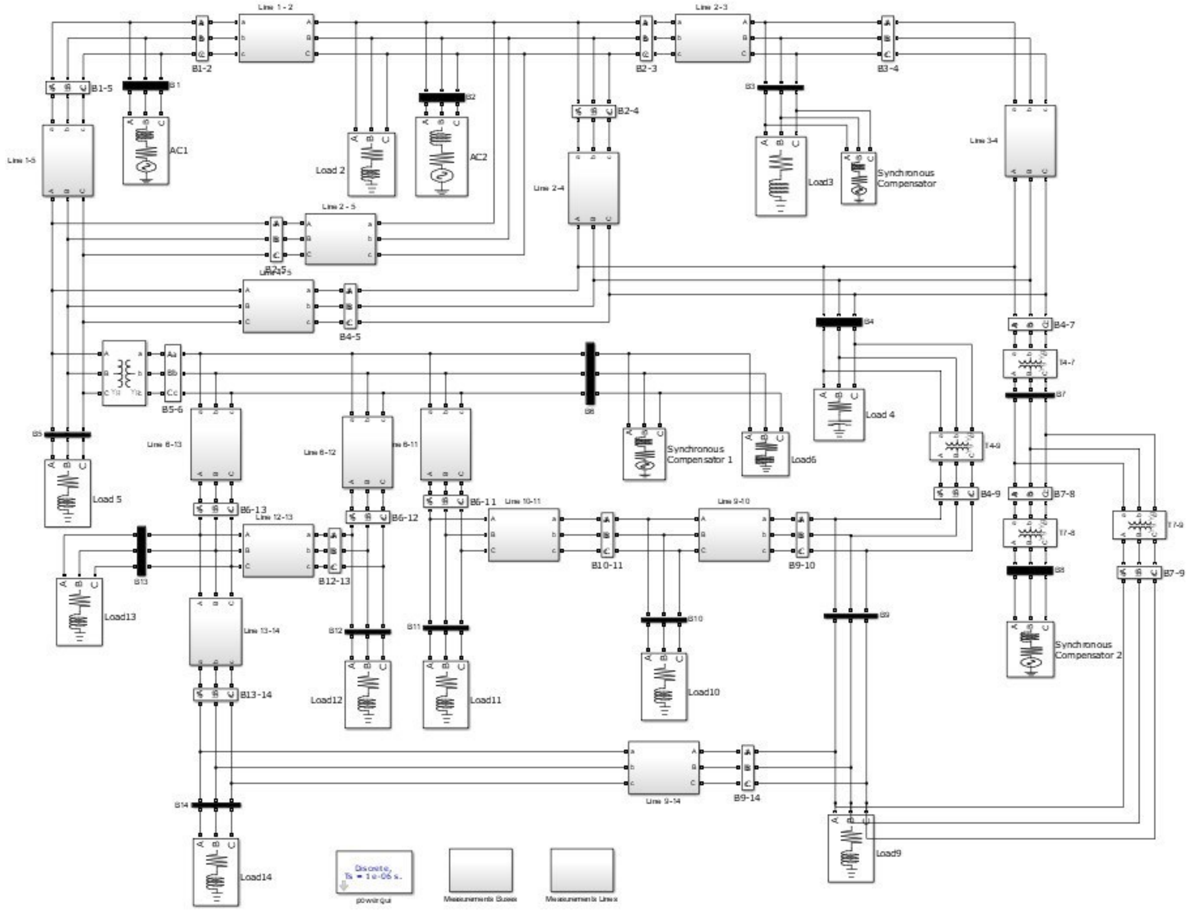

Fig. 2. IEEE-14 Bus System MATLAB/Simulink Model

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2.2 Solar Farm System

Large network will have difficulty on distributed the power equally. This become obvious when the system only has few generator and distance between generators with the buses is greater. One of the solution to support those lines is by inject it with additional power. For this research, solar energy is used to injection power. The impart of the injection process is depending on amount of power that injected. However, the lines surround the surround the injection area should have improved proportionally to the power from the solar farm.

Solar Farm System model need to consider component for the irradiance, temperature, photovoltaic panel, converter, inverter, controller and transformer as shown in Fig. 3. Since this photovoltaic system need to be injected to IEEE 14 Bus System, the component blocks will use in discrete simulation type.

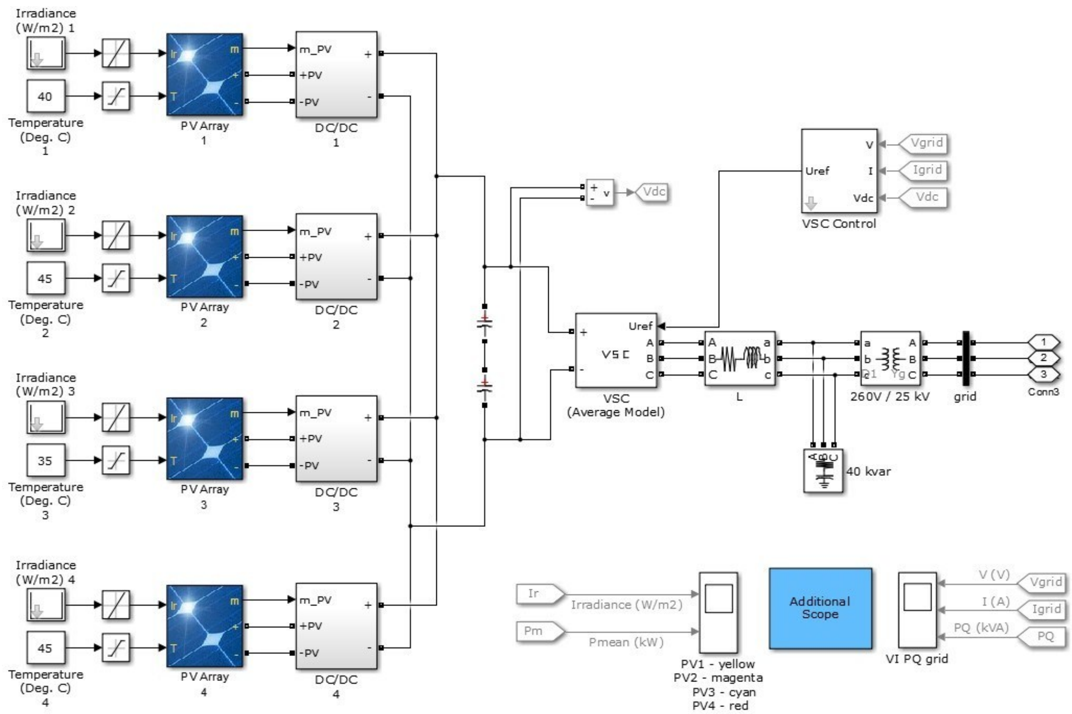

Fig. 3. Solar Farm Model

The main components that effect the power generation from solar energy is the sun irradiance and temperature of the panel. Therefore, this two parameter need to be standardize and included the effect of shading cause by the cloud. Based on Journal of Sustainable Energy & Environment, which publish about Solar and Meteorological Data Relevant to Solar Energy stated that global solar radiation values ranged between 3.73 to 5.11 kWh/(m2d) [12]. Therefore, the irradiance rating that been used for this research 5 kW/m2 for full light condition and 3.85 kW/m2 is used during cloudy condition. This solar farm is demonstrated for three hours and consist of four PV modules to see the various changes of irradiance and panel temperature which might be affecting the total power produced.

The modules that is used for this solar farm is SunPower SPR-315E WHT-D. The maximum power for this module is 315.072W. The maximum voltage and current that can be produced is 54.7V and 5.76A, respectively. Therefore, in order to obtain about 1.5MW, we required 4 set of 64 parallel strings which each strings consist of 5 series modules. Based on this solar farm setup, we can estimate the requirement of 1.5MW solar farm is 1280 units of SunPower SPR-315E WHT-D is required. The temperature of the modules can sustain also important because power generate also affected by the temperature of the module which is around 0.3V and 0.06A different for each degree depending on the optimum operation temperature for the module. The number of units can be reduce depending on the type of module itself and demand power that produce.

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2.3 Power Injection

1.5MW and 1MW are chosen to mimic the uptrend of society to install personal solar panel at their house. This situation will really help community from too depending on network grid, but this action also will give an impact toward the grid itself. Therefore, in this research we can predict the trend on installation PV effecting the network grid. Based on theory, the power distribution will be improved and some line will have increase in power flow and some might drop in the power due to redirect of energy to the other partway. Congestion management is important in order to achieve robust power system and more dynamic voltage stability margin [13-15].

1.5MW and 1MW of solar farm is used to be compared when injected to weak line of 14-buses. The different between 1.5MW and 1MW will be on the sun irradiance and temperature of the solar panel. This is because the sun irradiance and temperature give a major impact power generated by the solar panel. However, in this research, the temperature between 1.5MW and 1MW will be remain the same. The temperature is set between 45° - 35° to demonstrate shading effect.

Based on study, the weakest line in IEEE-14 bus system is line 19 which is connected between bus 12 and bus 13. This location will be used to inject the solar farm system as shown in Fig. 4.

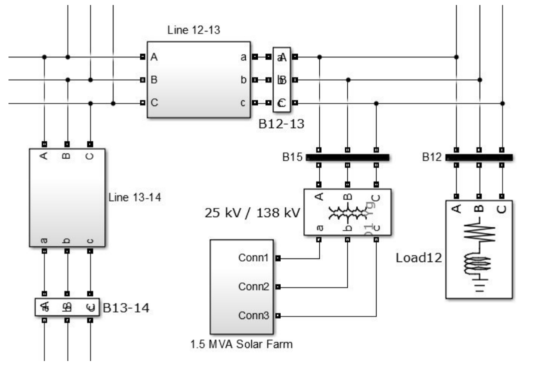

Fig. 4. Location of Solar Farm Implementation

3.0 1.5 MW SOLAR FARM

1.5MW can be generated by set the sun irradiance rating that been used to 5 kW/m2 for full light condition and 3.85 kW/m2 is used during cloudy condition. The expected power that will be generated from those values are 1.5MVA and 1.2MVA respectively.

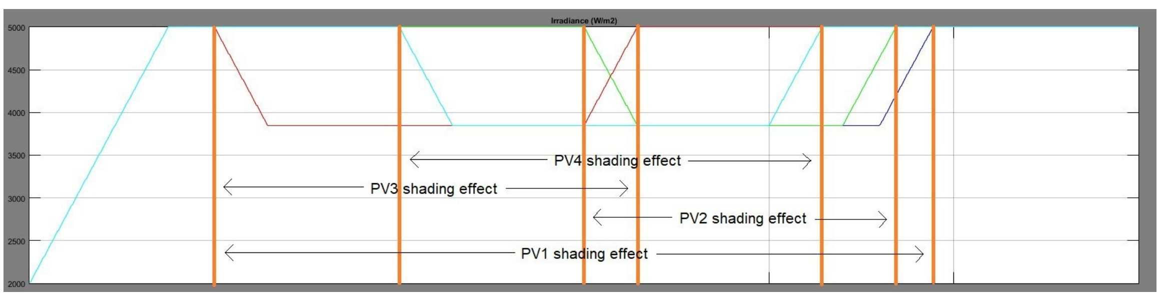

Fig. 5. Sun Irradiance for 1.5MW Solar Farm

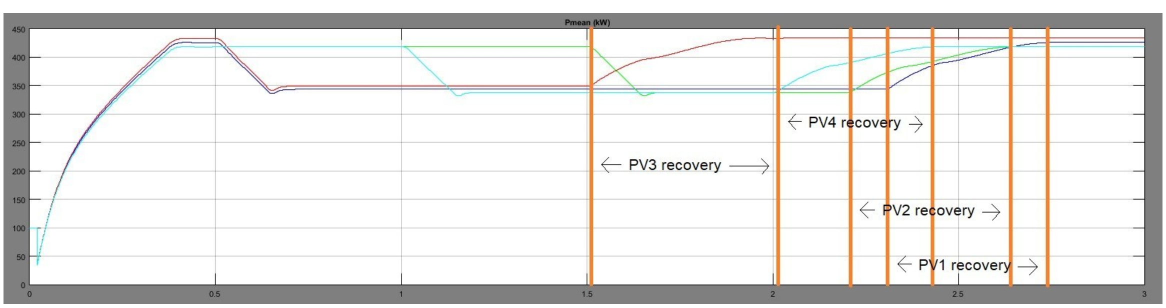

Fig. 6. Power Produced for 1.5MW Solar Farm

Based on Figs. 5 and 6, the power generated by 4 set of solar panel almost similar due to the stability of sun irradiance itself. The power generated is in DC line which is 500V, while the power that required is 260V in AC line. The voltage, current and power produce after passing through inverter and step-up transformer to increase the 260V to 25kV as shown in Fig. 7. The power produced by the solar farm can be obtained by summation of power from blue, green, red & cyan line.

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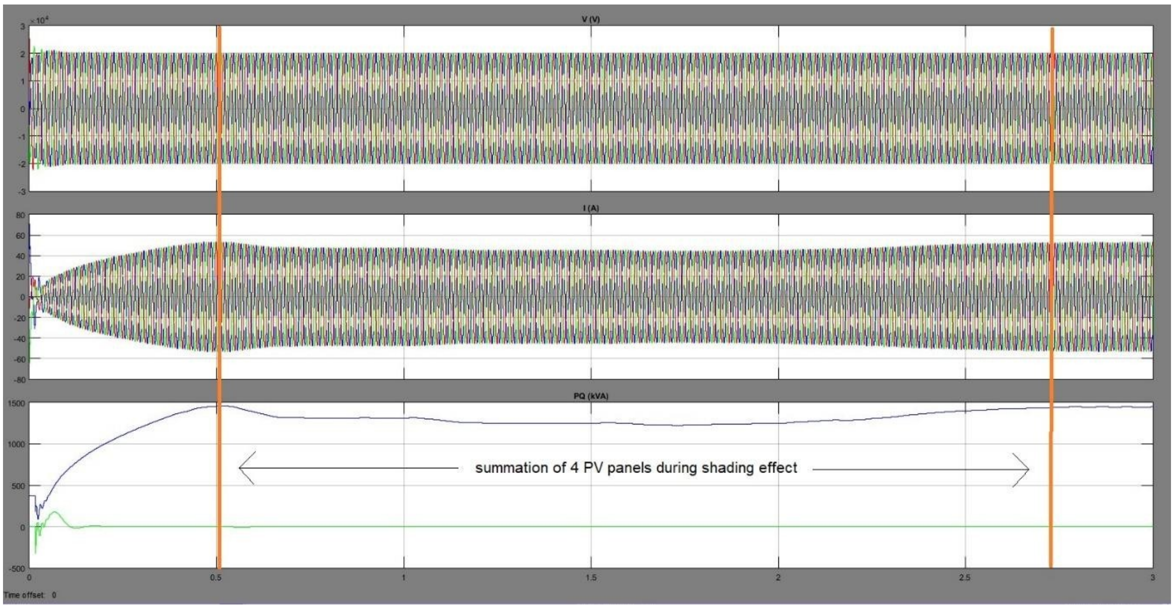

Fig. 7. Voltage, Current and Power for 1.5MW Solar Farm

Based on Fig. 7, the 1.5 MW solar farm only able to provide 20kV which is around 5kV voltage drop. The current produce is in arrange 45A to 54A based on the temperature and irradiance on that moment. Total power that able produce with the model is between 1.225MVA up to 1.460MVA. This injection at line 19 cause changes for power flow and line flow on IEEE-14 Bus network systemas shown in Table I and Table II.

Table I
Power Flow for 1.5MW
Solar Farm

BUS NUMBER	VOLTAGE DROP	LINE POWER	
	(kV)	P (MW)	Q (Mvar)
1	119.70	244.65	-63.01
2	118.45	113.21	-82.82
3	114.30	82.11	66.69
4	128.07	62.08	-42.73
5	126.27	9.54	2.01
6	120.56	169.00	-113.70
7	123.09	36.82	150.26
8	120.24	103.13	229.33
9	123.73	14.30	49.59
10	122.25	10.60	6.83
11	121.03	4.04	2.08
12	119.14	6.82	1.79
13	118.87	15.02	6.46
14	119.39	16.73	5.61
15	119.14	1.50	-0.30

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Table II: Lines Flow for 1.5MW Solar Farm

TAP BUS NUMBER	Z BUS NUMBER	Line	VOLTAGE DROP	LINE POWER	
			(kV)	P (MW)	Q (Mvar)
1	2	1	119.71	136.54	-20.86
5	1	2	119.71	108.11	-42.14
2	3	3	118.45	69.34	6.15
2	4	4	118.45	73.73	-69.27
5	2	5	126.27	74.29	-75.29
3	4	6	114.30	14.84	66.91
4	5	7	128.07	25.06	35.22
4	7	8	128.07	36.59	149.76
9	4	9	123.73	0.09	-37.97
5	6	10	120.56	191.11	-109.20
11	6	11	121.03	0.36	-2.42
12	6	12	119.14	6.60	2.10
13	6	13	118.87	14.95	4.50
7	8	14	123.09	102.93	228.43
9	7	15	123.73	65.90	77.88
10	9	16	123.73	14.39	11.62
14	9	17	123.73	16.03	8.27
11	10	18	122.26	3.70	4.55
13	12	19	119.14	1.16	0.00
14	13	20	119.39	1.05	-1.94

4.0 Design of 1.0 MW SOLAR FARM

1.0MW can be generated by set the sun irradiance rating that been used to 3 kW/m2 for full light condition and 0.15 kW/m2 is used during cloudy condition. The expected power that will be generated from those values are 1MVA and 0.4MVA respectively.

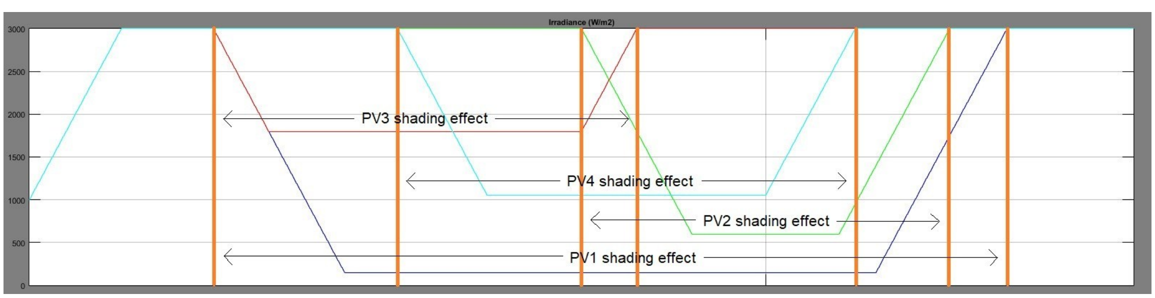

Fig. 8. Sun Irradiance for 1.0MW Solar Farm

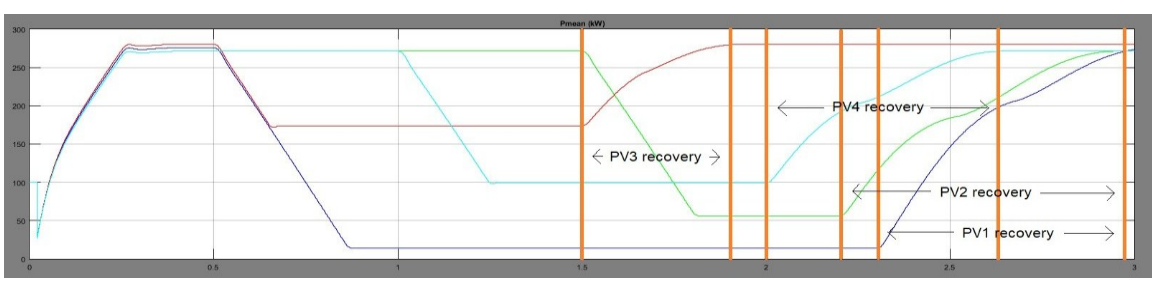

Fig. 9. Power Produced for 1.0MW Solar Farm

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Based on Figs. 8 and 9, the power generated by 4 set of solar panel have various generation time. This is because of low power solar panel will be affected greater with shading effect. The power generated is in DC line which is 500V, while the power that required is 260V in AC line. The power produced by the solar farm can be obtained by summation of power from blue, green, red & cyan line. The voltage, current and power produce after passing through inverter and step-up transformer to increase the 260V to 25kV as shown in Fig. 10. While Fig. 10, the 1MW solar farm able to provide 21kV. However, the current produce is slightly low which is around 14A to 34A. This huge different is caused by the difference at sun irradiance that applied to this model. The total power produced is between 400kVA and 970kVA. This injection at line 19 cause changes for power flow and line flow on IEEE 14-Bus network system as shown in Table III and Table IV. Based on the irradiance affecting power produced, the time interval for power of single PV panel to reach it maximum operation also increased when the gap of irradiance (shading effect) is high. Since we maintained the voltage rating for both cases. The current output will change proportional to the summation of power output for 4 PV panels. Based on PQ graph in Fig.10, the first hours the time is rise which indicate the operation of PV is start. During the second hours, the PV modules undergoes shading effect cause by cloudy atmosphere. Then then third hours the PV modules start to operate as normal back.

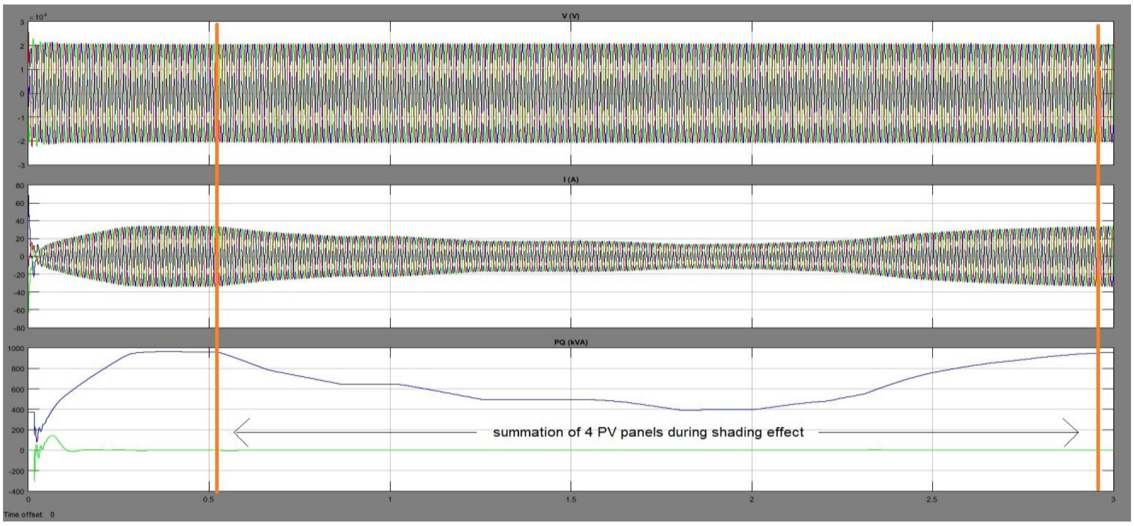

Fig. 10. Voltage, Current and Power for 1.0MW Solar Farm

Table III
Power Flow for 1.0MW Solar Farm

BUS NUMBER	VOLTAGE DROP (kV)	LINE POWER P (MW)	LINE POWER Q (Mvar)
1	119.71	244.65	-63.01
2	118.45	113.21	-82.82
3	114.30	82.11	66.69
4	128.07	62.09	-42.73
5	126.27	9.54	2.01
6	120.56	168.70	-113.50
7	123.09	36.82	150.26
8	120.24	103.15	229.33
9	123.73	14.30	49.59
10	122.26	10.60	6.83
11	121.03	4.04	2.08
12	119.12	6.82	1.79
13	118.86	15.02	6.45
14	119.39	16.73	5.61
15	119.12	1.05	-0.17

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Table IV
Lines Flow for 1.0MW Solar Farm

TAP BUS NUMBER	Z BUS NUMBER	LINE	VOLTAGE DROP (kV)	LINE POWER P (MW)	LINE POWER Q (Mvar)
1	2	1	119.70	136.54	-20.87
5	1	2	119.70	108.11	-42.14
2	3	3	118.45	69.34	6.15
2	4	4	118.45	73.73	-69.27
5	2	5	126.27	74.29	-75.29
3	4	6	114.30	14.84	66.91
4	5	7	128.07	25.05	35.23
4	7	8	128.07	36.59	149.76
9	4	9	123.73	0.09	-37.97
5	6	10	120.56	191.17	-109.21
11	6	11	121.03	0.36	-2.42
12	6	12	119.12	6.77	2.00
13	6	13	118.86	15.05	4.47
7	8	14	123.09	102.94	228.42
9	7	15	123.73	65.92	77.87
10	9	16	123.73	14.39	11.62
14	9	17	123.73	16.05	8.26
11	10	18	122.26	3.70	4.55
13	12	19	119.12	1.00	0.07
14	13	20	119.39	1.02	-1.93

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5.0 RESULTS AND DISCUSSION

The comparison between standalone network and after injection of 1.5MW displayed for better understanding. In addition, 1MW solar farm data also will be used in order to determine the power injection really give an impact toward the grid.

During the analysis, 1.5 MW and 1 MW give significant different power flow at Bus 6 due to the present of synchronous condensers. The changes of real power flow as display at Fig. 11 shown that Bus 6 has different about 0.3MW for every 0.5MW injection different.

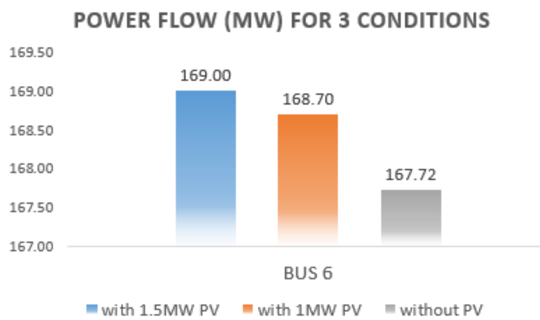

Fig. 11. Different Real Power Flow for Bus 6

While for reactive power flow at Bus 6, there is no significant changes with less than 0.2MVAR different as shown in Fig. 12. This related to the performance of solar farm itself to maintain it efficiency and synchronous condensers to regulate the voltage of the line by absorbing or supplying reactive power.

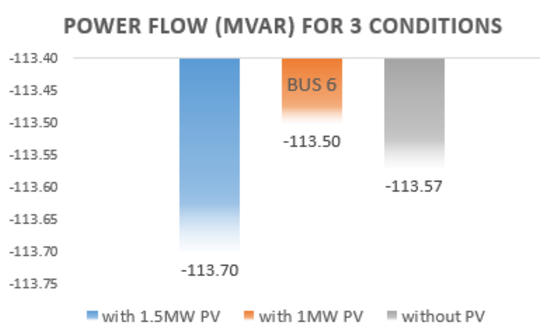

Fig. 12. Different Reactive Power Flow for Bus 6

The solar farm in injected at line 19 which is line between bus 12 and bus 13. The improvement for line 19 can be seen clearly when compared between before the line inject with 1.5MW solar and after the injection. The power flow at line 19 improved 0.57MW and it also improved line 20 by 0.1MW. However, for line 12 and line 13 have a reduction of power around 0.8MW and 0.44MW respectively.

This situation because of the lines are located between bus 6 which has synchronous condensers and line 19 which injected with solar farm cause the power flow of the line is redirect. For every 0.5MW different of solar farm, the different affecting line 19 is 0.16MW. The difference for line 12 and 13 is 0.17MW and 0.1MW respectively as shown in Fig. 13.

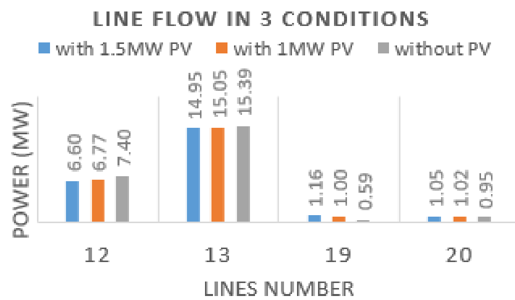

Fig. 13. Different Real Line Flow for Line 12,13, 19 & 20

Power losses of the line is determined by the reactive power of the lines. Therefore, based on Fig. 14, it shows that the power losses did reduce at targeted line which is line 19. While at line 12, 13 & 20 there are only minimal changes.

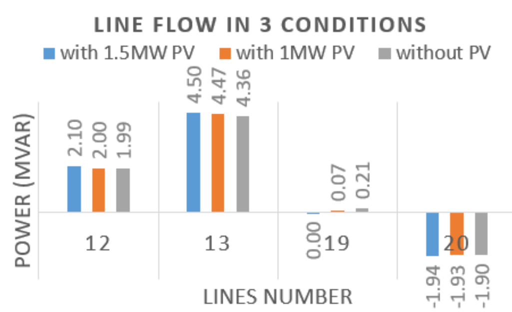

Fig. 14. Different Reactive Line Flow for Line 12,13, 19 & 20

Table V
Power Losses in IEEE-14 Bus System

CASE STUDY	REAL POWER LOSSES (MW)	REACTIVE POWER LOSSES (MVAR)
without PV	13.4	5
with 1.0MW	13.31	5.24
with 1.5MW	13.14	5.18

From Table V, it can be observed that without additional power injection, the active and reactive power loss were 13.4MW and 5MVAR respectively. 1MW able to reduce real power losses by 0.672% and for 1.5MW reduced by 1.940%. Reactive power losses effected by behavior of synchronous generator especially at bus 6. 1MW increase in reactive power losses by 4.8% while for 1.5MW increase by 3.6%. The voltage drops for all bus show no changes except

Bus 12. This is because the addition Bus 15 which is Solar Farm. The location of Bus 12 is between solar farm and synchronous condenser. This position causes 0.1kV for 1.5MW power injection as shown in Fig. 15. The additional power obtained from Bus 15 while the power losses is control by Bus 6.

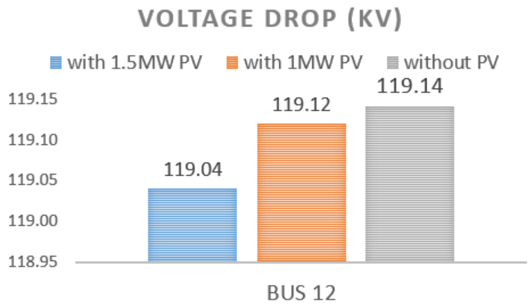

Fig. 15. Different Voltage Drop for Bus 12

Bus 6, line 19 and line 20 will improved in power flow proportional to the power that injected at line 19. While for line 12 and line 13 will decrease in the power flow indirectly proportional to the injection power. The greater the power injection, there is probability that more lines and buses will be affected as well.

6.0 CONCLUSION

The power quality of the IEEE14-bus system has been improved after connected to solar farm. The improvement in line flow at line 19 and line 20 proved that for every additional power generation into the network grid will increase the active power flow and it also can reduce stress line such as line 12 and line 13. The improvement for real power flow are about 50% while reactive power flow reduced about 20% at weakest line. The different of voltage drop is just around 1%, it shows that voltage still stable. However, for overall system performance, the real power performance and reactive power performance has minimal changes. 1MW able to reduce real power losses by 0.672% and for 1.5MW reduced by 1.940%. Reactive power losses effected by behavior of synchronous generator especially at bus 6. 1MW increase in reactive power losses by 4.8% while for 1.5MW increase by 3.6%.

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