Analysis of the Effect of Installing Capacitor Bank in the Photovoltaic On – Grid 122 kWp for Power Factor Correction

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***Abstract*— Photovoltaic (PV) on – grid is one of solution to reduced consumption of conventional power plants, mainly in tropical countries. In general, the inverter used in the PV on-grid only can transmit active power while the reactive power requirements in system PV are obtained from the electricity grid. This can cause the power factor in the grid to decrease and it can cause overvoltage in the system. Voltage Source Converter (VSC) is a control on the inverter PV that can transmit active and reactive power to the grid. Capacitor bank installed in parallel with PV on-grid can be used to compensate reactive power locally. This paper discusses the impact of using VSC controls on the inverter and capacitors bank installed in parallel on the PV on – grid 122 kWp which interconnected with a local load of 150 kVA and has a power factor of 0.7. Analysis using Simulink MATLAB 2016b with variations of capacitor banks under STC conditions (radiation 1000 W/m^2 and temperature 25^{O}C). The simulation results indicated VSC control in the inverter can transmit active and reactive power, which can be seen from the phase difference between voltage and current waveform in the inverter. Capacitor capacity 3x18 kVAR can improve the power factor of the inverter, which was originally 0.749 to 0.919. The VSC control on the inverter can make the inverter set the power factor sent to the grid into 0,99.**

Keywords—PV on–grid, VSC control, capacitor bank, pf correction

I. Introduction

Photovoltaic (PV) is one of the renewable energy most widely developed especially in tropical countries. This is because the efficiency of solar panels increased, convenient of operation and maintenance, low operating costs, and produces environmentally friendly energy[1]. Application of PV interconnected with low and medium voltage electricity Network systems is also more possible and easier, because power electronics technology that supports is also increasingly sophisticated[2].

The disadvantage of generating electricity using PV is that the power generated intermittent, depends on atmospheric conditions, especially the radiation and temperature received by solar panels[3]. DC-DC converter with control Maximum Power Point (MPPT) can produce optimal power in PV with the variation of radiation and temperature received in solar panels[4]. Solar panel generated DC voltage whereas if PV interconnected with electricity network which mostly used AC voltage can cause problems. Inverters can be used to convert DC voltage to AC voltage, so that the power generated by solar panels can be connected to the electrical network system or directly used by AC loads[5].

PV which connected to the electricity network system, must fulfill the requirements conditions i.e voltage, frequency and phase equal to the voltage and frequency of the interconnected power system[6]. Inverter is a power electronic equipment that can controlled voltage and frequency PV equal with the voltage and frequency in electrical network system. In general, inverters used in the PV on-grid only can transmitted active power [7] while the reactive power requirements in system PV are obtained from the electricity grid.

Reactive power compensation to power factor correction in PV on-grid can use an inverter with Voltage Source Converter (VSC) control [8][9] and a capacitor bank that is installed in parallel with the PV system[10]. VSC control can transmit active and reactive power in the grid, meanwhile, the capacitor bank can compensate reactive power locally. This paper discussed the effect of installing the capacitor bank parallel in PV on-grid as a reactive power compensation to power factor correction. Analysis of the effect installed capacitor bank parallel in PV on-grid supported by using Simulink MATLAB 2016b with PV on grid 122 kWp modeling that is interconnected with a local load of 150 kVA power factor 0.7 and connected to a 3-phase low voltage network 260 V / 25 kV[11].

II. System Design

A. Photovoltaic

Solar panels are made of semiconductor material that can convert solar energy into direct electrical energy. In this modeling of PV on grid 122 kWp using SunPower SPR-305-WHT.

TABLE I. SOLAR PANEL SPECIFICATION

Parameter	
Number of cells per module	96
Maximum value of Power (Pmp)	305 W
Open circuit voltage (Voc)	64,2 V
Short circuit current (Isc)	5,96 A
Voltage at MPP (Vmp)	54,7 V
Current at maximum power point (Imp)	5,58 A
Temperature coefficient of Voc (Toc)	-0,177 V/°C
Temperature coefficient of Isc (Tsc)	0,003516 A/°C

PV modules are arranged in series with 5 units and arranged in parallel with 80 units. I-V and P-V curves of the solar module can be seen in Fig. 1 and 2 below.

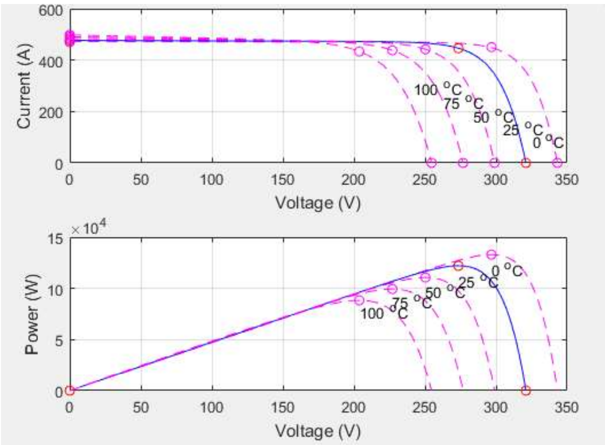


Fig. 1 I-V and P-V solar module curve at radiation 1000 W/m^2

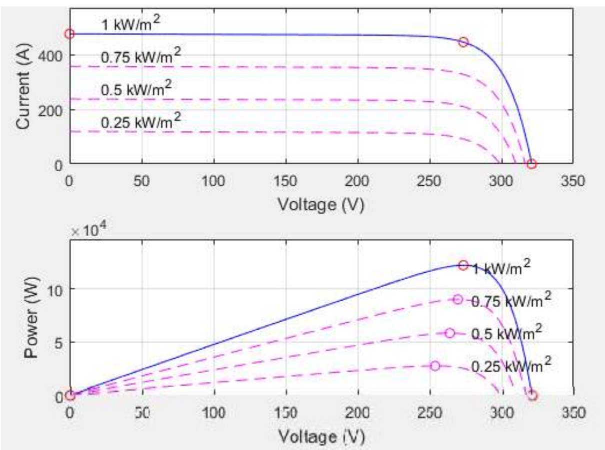


Fig. 2 I-V and P-V solar module curve at temperature 25^{O}C

B. MPPT and DC – DC converter

MPPT (Maximum Power Point Tracking) is a control that is used to optimize the output power of solar panels, by calculating, tracking, and controlling the system in photovoltaic so that it can operate in the area of Maximum Power Point (MPP) on the I-V and P-V curves[12][13]. MPPT produces a duty cycle used as input to the DC-DC converter. The MPPT algorithm used in this PV on-grid modeling is InCond. DC-DC converter used is a boost converter to increase the output voltage PV convenient with the DC voltage reference. The DC voltage reference of this system is 500 Vdc.

C. Inverter[14]

Inverter is a power electronic equipment used to convert DC voltage to AC voltage. The inverter used is 3 phase inverter with Voltage Source Converter (VSC) control. VSC control can transmit active and reactive power in the grid, this can be used to compensate for reactive power in the PV system[15][9]. Filter installed on the system to refine the waveform of the output inverter.

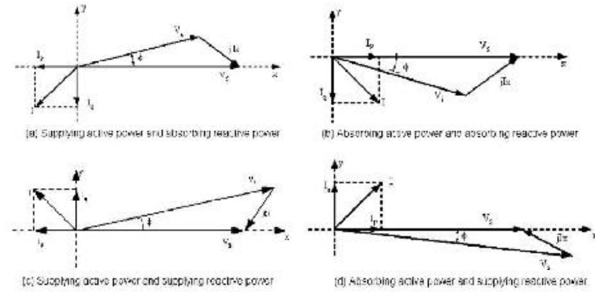


Fig. 3 Phasor diagram of VSC control inverter

Control of the inverter to transmit active and reactive power by controlling the voltage and current vector Ip and Iq on the inverter. Active and reactive power sent to the grid can be calculated using the equation below[8].

$$P = \frac{V_i}{2\pi f L_C}\sin\varphi = P_{MAX}\sin\delta \qquad (1)$$

$$Q = \frac{V_i^2}{2\pi f L_C} - \frac{V_i V_s}{2\pi f L_C}\cos\delta \qquad (2)$$

Vi is voltage in terminal inverters, Vs is voltage grid, Lc is inductance of coupling inductor, δ is phase phase difference between Vi and Vs, f is frequency of the system.

Active power increases if the radiation received by solar panels is high, for example during the day. Reactive power increases at night, when the radiation received by the solar panel is low. The VSC control on the inverter can make the inverter set the power factor sent to the grid into unity.

D. Capacitor bank

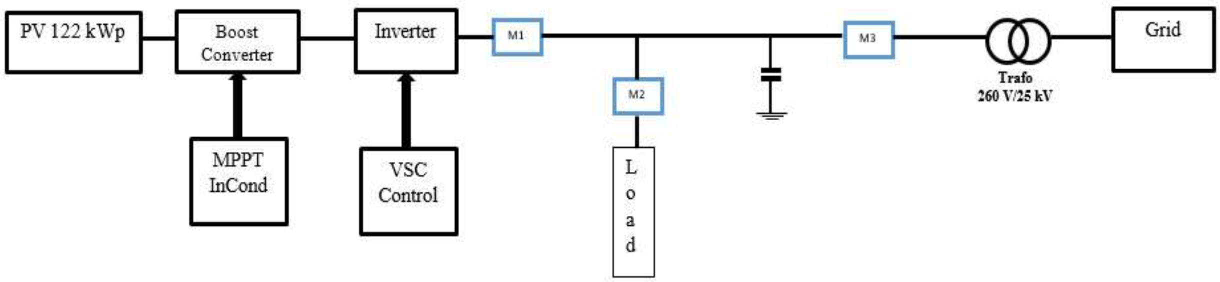
Capacitor banks can compensate reactive power requirements locally. Capacitor bank installed parallel to the PV on-grid to compensate reactive power of the load and the power electronic equipment used in the PV on – grid[10]. The capacity of the installed capacitor bank must be suitable with the requirements in order to work optimally, if capacity less than the rated can cause under voltage in system, while if capacity larger it can cause waste in terms of investment[16]. Reactive power compensation can be calculated using this equation.

$$\Delta Q = P\,(\tan\theta_1 - \tan\theta_2) \qquad (3)$$

ΔQ is the reactive power compensation needed (kVAR), P is the active power system (kW), θ_1 is the desired phase angle after repair, θ_2 is the phase angle before repair.

E. Local load

Interconnected local load capacity of PV on – grid 122 kWp is 150 kVA. Local loads are inductive and have a power factor 0.7. PV is connected to the grid using a 3 phase distribution transformer with a capacity of 100 kVA 260/25 kV.



Note :

M1 = Multimeter 1

M2 = Multimeter 2

M3 = Multimeter 3

Fig. 4 Block Diagram of PV on – grid 122 kWp

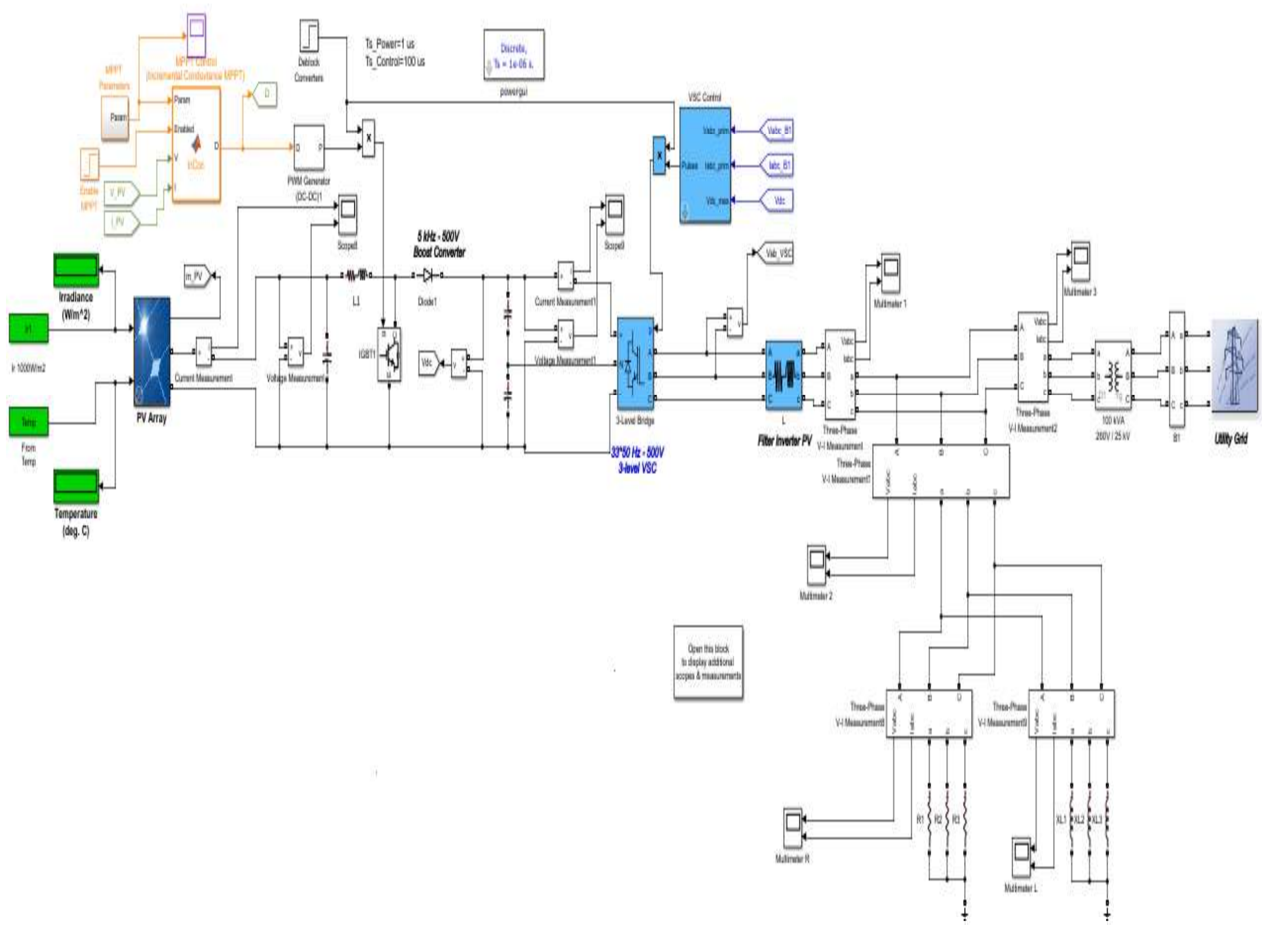


Fig. 5 Simulink modeling PV on – grid 122 kWp

III. Method and Analysis

Analysis of capacitor bank installed on PV on – grid 122 kWp to power factor correction used Simulink MATLAB with modeling that can be seen in Fig. 5. The results observed were voltage and current waves contained in multimeter 1 (inverter output), multimeter 2 (load input), and multimeter 3 (power sent to the grid). The power and power factors contained in each multimeter are calculated using the equation :

$$S_{3phase} = S_R + S_S + S_T \quad (4)$$

$$P_{3phase} = P_R + P_S + P_T \quad (5)$$

$$Q_{3phase} = Q_R + Q_S + Q_T \quad (6)$$

$$\cos\theta = \frac{P_{3phase}}{S_{3phase}} \quad (7)$$

Solar panel input used in STC conditions (1000 W/m^2 radiation and 25^{0}C temperature). The analysis used variations in the capacitor bank capacity on PV on-grid to view the effect of capacitor capacity installed in system towards power and power factor generated in multimeter 1, multimeter 2, and multimeter 3.

A. Multimeter 1

Voltage and current output of filter inverter 3 phase measured in multimeter 1. The results voltage and current waveform in multimeter 1 can be seen in Fig. 6

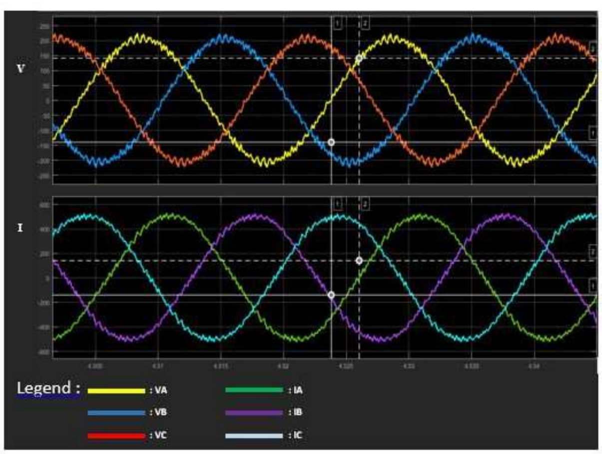


Fig. 6 Output in multimeter 1

Fig, 6 indicated voltage and current waveform in multimeter 1 have phase differences, current lagging to voltage waveform. The different phases of voltage and current waveform indicated VSC control can produce active and reactive power in the PV system, which differs from conventional inverters on PV which can only transmit active power.

TABLE II. Power and Power Factor in Multimeter 1

Capasitor Bank	S (kVA)	P (kW)	Q (kVAR)	PF
NON	158.45	118.63	103.87	0.749
3x3 kVAR	152.99	116.97	101.41	0.765
3x6 kVAR	147.82	118.69	88.07	0.803
3x9 kVAR	142.39	119.19	78.87	0.834
3x12 kVAR	138.45	118.01	72.02	0.853
3x15 kVAR	134.38	119.35	61.70	0.888
3x18 kVAR	130.75	120.22	51.37	0.919

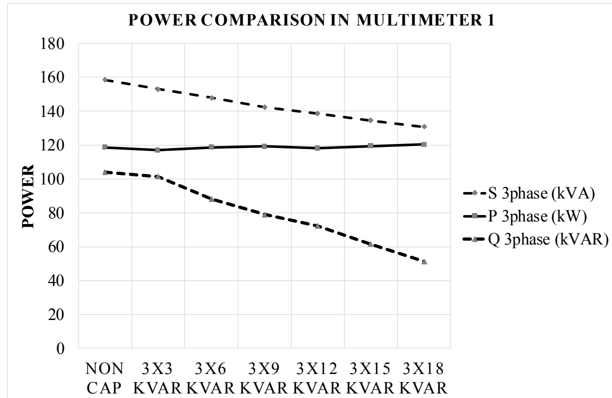


Fig.7 Power comparison in multimeter 1

Installation of capacitor bank capacity affects the active power and reactive power generated by the inverter. Installation of capacitor banks can increase active power to the system and can reduce the reactive power of the system. It because the installation of capacitor banks compensated the load reactive power requirements so the active power increased and reactive power reduced.

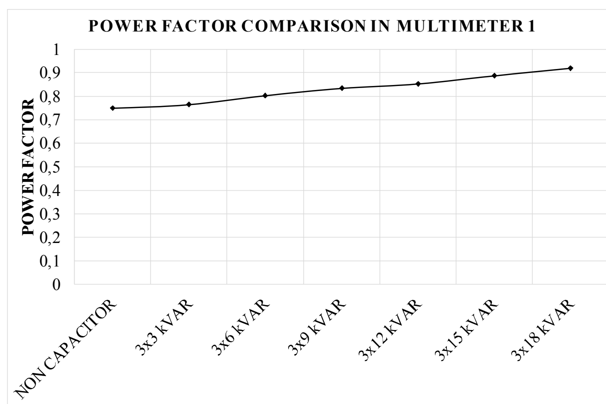


Fig. 8 Power factor comparison in multimeter 1

Installed capacitor bank in PV on-grid can improved power factor correction of output inverter 3 phase. The power factor generated without capacitors is 0.749 according to the power factor of the load. Installation 3x18 kVAR capacitors can improved power factor to 0.919.

B. Multimeter 2

Voltage and current in the load was measured using multimeter 2. The waveform of voltage and current of load can be seen in Fig. 9.

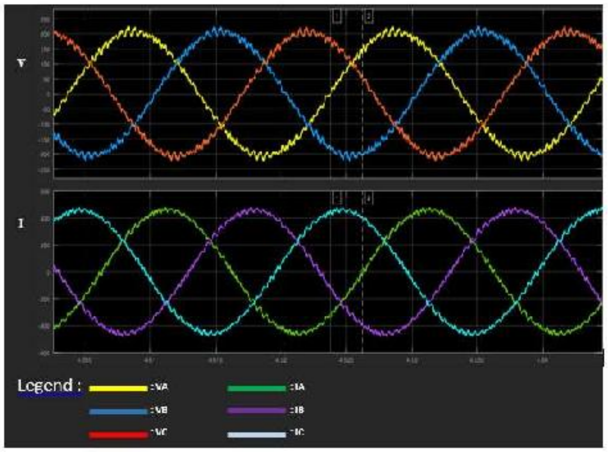


Fig. 9 Output in multimeter 2

Voltage and current waveform measured in multimeter 2 have different phases, current waveform lagging to voltage waveform. This is suitable for the characteristics of the local load used. The effect of capacitor installed in PV on – grid for power and power factor in multimeter 2 can be seen in table 3.

TABLE III. POWER AND POWER FACTOR IN MULTIMETER 2

CAPASITOR BANK	S (KVA)	P (KW)	Q (KVAR)	PF
NON	142.79	98.51	102.79	0.690
3X3 KVAR	142.65	99.07	103.99	0.695
3X6 KVAR	142.64	98.71	102.96	0.692
3X9 KVAR	142.62	98.52	103.12	0.691
3X12 KVAR	142.64	98.71	102.96	0.692
3X15 KVAR	142.65	98.76	102.93	0.692
3X18 KVAR	142.65	98.62	103.07	0.691

Installed capacitor bank in PV on-grid system hasn't effect to power and power factor in load. Active and reactive power measured for capacitor capacity variations tend to be the same as well for the power factor in load.

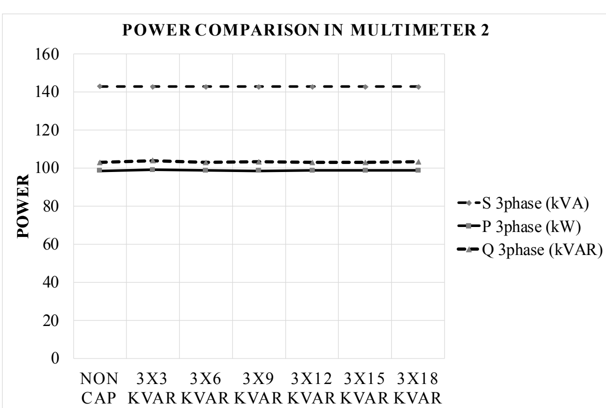


Fig.10 Power comparison in multimeter 2

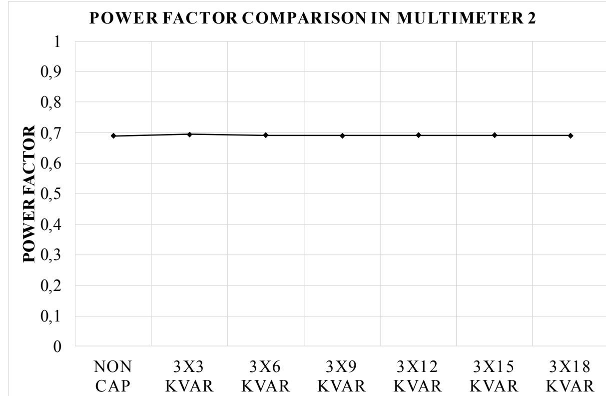


Fig. 11 Power factor comparison in multimeter 2

C. Multimeter 3

Multimeter 3 was measure voltage and current waveform sent by PV to the grid. Multimeter 3 was placed after capacitor bank and before distribution transformers 260/25 kV.

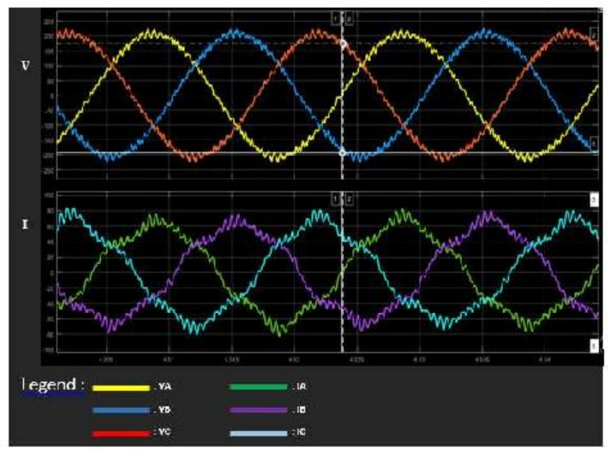


Fig.12 Output in multimeter 3 with non capacitor bank

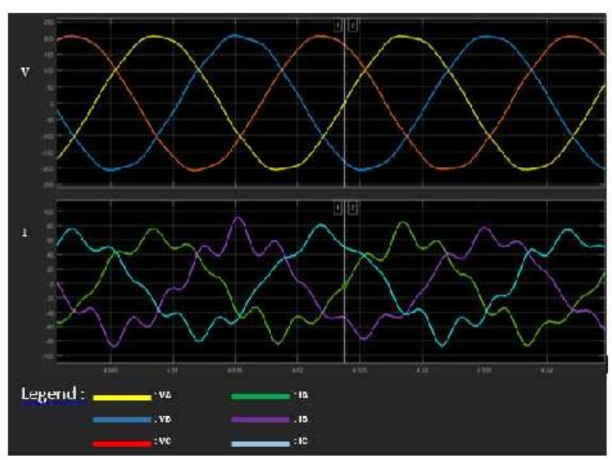


Fig.13 Ouput in multimeter 3 with capacitor bank 3x18 kVAR

The phase difference between voltage and current waves in multimeter 3 was very small. The trend of power factor measured in multimeter 3 was constant, which is equal to

0.99. Capacitor bank can reduced ripple in the current waveform on multimeter 3. this can be seen from the difference of current waveforms in Fig. 12 and 13. Installed capacitor bank in PV on-grid can be used as an additional filter in the system.

TABLE IV. POWER AND POWER FACTOR IN MULTIMETER 3

CAPASITOR BANK	S (KVA)	P (KW)	Q (KVAR)	PF
NON	29.98	29.94	1.23	0.99
3X3 KVAR	29.43	29.39	1.04	0.99
3X6 KVAR	28.91	28.90	0.85	0.99
3X9 KVAR	28.41	28.40	0.50	0.99
3X12 KVAR	27.93	27.92	0.81	0.99
3X15 KVAR	27.31	27.28	1.02	0.99
3X18 KVAR	27.27	27.19	1.78	0.99

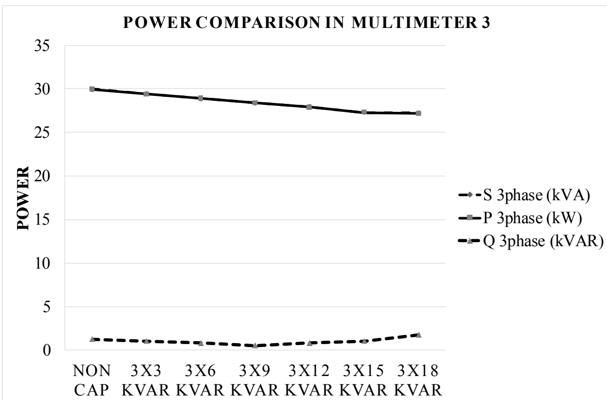


Fig. 14 Power comparison in multimeter 3

The trend of active power measured in multimeter 3 tends to decrease with the increase of the installed capacitor bank capacity, this can be caused by the capacitor bank also absorbed active power of PV.

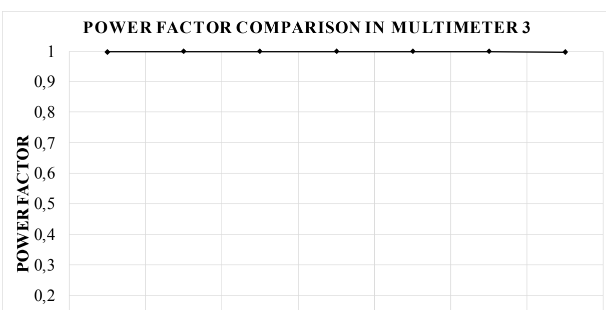


Fig. 15 Power factor comparison in multimeter 3

The power factor generated in multimeter 3 tends to be constant and is not affected by the additional capacitor capacity. This can be caused by the VSC control in the inverter can set power factor of power sent to the grid into unity.

IV. CONCLUSION

The effect of installed capacitor banks in PV on – grid 122 kWp only affects improve power factor correction in output inverter PV. Inverters with VSC control can transmit active and reactive power to the grid. The VSC control in the inverter can set power factor of power sent to the grid into unity. Power flow in PV on-grid system and the effect of installing a capacitor bank for a large scale in PV on-grid penetration further research is needed.

REFERENCE

[1] M. Farhoodnea, A. Mohamed, H. Shareef, and H. Zayandehroodi, "Power Quality Analysis of Grid-Connected Photovoltaic Systems in Distribution Networks," no. 2, pp. 208–213, 2013.

[2] G. M. Masters, *Renewable and Efficient Electric Power Systems*. United States of America: A John Wiley & Sons, Inc, Publication, 2004.

[3] P. D. Larasati, Hermawan, and Karnoto, "Analisis Pengaruh Sudut Kemiringan Panel Surya terhadap Radiasi Matahari yang Diterima oleh Panel Surya Tipe Array Tetap," 2013.

[4] S. Handoko and S. Tejo, "Maximum Power Point Tracking for a Photovoltaic System," *Proc. 2015 2nd Int. Conf. Inf. Technol. Comput. Electr. Eng. (ICITACEE), Indones.*, pp. 266–270, 2010.

[5] W. Peng, Y. Baghzouz, and S. Haddad, "Local Load Power Factor Correction by Grid- Interactive PV Inverters," pp. 1–6, 2013.

[6] B. Singh, D. T. Shahani, and A. K. Verma, "Power balance theory based control of grid interfaced solar photovoltaic power generating system with improved power quality," *2012 IEEE Int. Conf. Power Electron. Drives Energy Syst.*, pp. 1–7, 2012.

[7] S. I. dkk Rasel, "Design & Simulation of Grid Connected Photovoltaic System using Simulink," pp. 15–19, 2015.

[8] J. Moraes, G. C. Guimara, F. L. Albuquerque, M. R. Sanhueza, and A. R. Vaz, "Photovoltaic solar system connected to the electric power grid operating as active power generator and reactive power compensator," vol. 84, pp. 1310–1317, 2010.

[9] M. M. Hussein, "Control of a Grid Connected PV Inverter for Supplying Powers with Different Power Factors," *2018 Twent. Int. Middle East Power Syst. Conf.*, pp. 440–445, 2018.

[10] A. Kalyuzhny, B. Reshef, G. Yehuda, G. David, P. Koulbekov, and T. Day, "Design of capacitor bank in parallel to photovoltaic power plant," no. July 2013, 2014.

[11] A. Fb, "Simulation of Grid Tied Photovoltaic System Based on Solar Irradiance and Temperature Data in Semarang," 2019.

[12] O. Ezinwanne, F. Zhongwen, and L. Zhijun, "Energy Performance and Cost Comparison of MPPT Techniques for Photovoltaics and other Applications," *Energy Procedia*, vol. 107, no. September 2016, pp. 297–303, 2017.

[13] N. Karami, N. Moubayed, and R. Outbib, "General review and classification of different MPPT Techniques," *Renew. Sustain. Energy Rev.*, vol. 68, no. September 2016, pp. 1–18, 2017.

[14] G. Tsengenes and G. Adamidis, "Investigation of the behavior of a three phase grid-connected photovoltaic system to control active and reactive power," *Electr. Power Syst. Res.*, vol. 81, no. 1, pp. 177–184, 2011.

[15] R. Albarracín and M. Alonso, "Photovoltaic reactive power limits," no. November 2015, 2013.

[16] G. S. Energy, "Power Factor and Grid-Connected Photovoltaics." pp. 1–4, 2015.