Single Phase Inverters for Mitigating Phase Voltage Unbalancing of Micro Grids

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Abstract : **The production of electrical energy from renewable energy resources has lead to the development of the microgrid. One of the major power quality issue associated with the operation of these microgrids are the phase voltage unbalancing caused by single phase or unbalanced loads connected to it. All the existing technologies demands the use of an external element for the purpose of mitigating these unbalances by the application of complex controllers. In order to overcome this drawback here we come across a new inverter topology where the three phase compact unit interfacing inverter is rebuilt in the form of three single phase inverter units. Each of these are controlled independently to achieve microgrid phase voltage balancing. The distributed generation's active and reactive power will be divided among the inverter phases with different ratios in accordance to an algorithm verifying the micro grid phase voltage balancing. In the proposed model a modification to the old inverter is given to implement the new inverter control. The proposed inverter control is very simple and highly economical attractive.**

Key words: Phase Voltage, Inverter, Microgrid.

I. INTRODUCTION

The drastic increase in the production of electrical energy has lead to the development of microgrid. Microgrid enables the penetration of a huge amount of renewable energy resources and thus is an active distribution system. The incorporation of the large number of distributed generation systems has improved the power quality at end users. The distributed generation systems are attaining a greater attention from the power engineers due to their lower environmental impacts. One of the advantage of the microgrid is that they can operate in two different modes out of which one is the grid connected mode and other is the islanded mode or standalone mode. In normal operative conditions the microgrid is connected to the utility grid and it can be switched over to standalone mode whenever there occurs a power quality issue within the interconnection.

Microgrid has their own individual characteristics and power quality issues as compared to conventional power grid. This is mainly due to the various power sources in cooperated and the working mode of the grid. The power quality issues found in microgrid are more complex in nature. Basically due to the intermittent operation of the renewable energy resources such as wind, PV, etc, whose output cannot be justified, the current and voltage harmonics injected by interfacing inverter and due to the insertion of single phase or unbalanced loads connected to the three phase system which result in high unbalance. The

previous literatures had described about various methodologies for mitigating the power quality issues mentioned above but all those included a supplementary circuitry for the same which has added to the cost and complexity of the system. Here we come across a new methodology which concentrates upon the mitigation of phase voltage unbalancing.

II. STRATEGIES FOR IMPROVING PHASE VOLTAGE BALANCING

The distribution voltage levels are low in microgrids as compared to the utility grid. As a result the voltage unbalances created by the single phase /nonlinear loads and the interfacing inverter are high in such systems as they inject a large amount of current and voltage harmonics into the system. Different schemes were proposed which enables the mitigation of these phase voltage unbalancing. A combination of Static VAR Compensator (SVC) and Series Active Power Filter (SAPF) has been employed to enhance the power quality of the standalone MG system. The filter is placed near the source to eliminate the source harmonic voltages whereas the SVC is connected at the user side to compensate reactive power which will suppress the load voltage variations. Employing both SVC and SAPF simultaneously reduced the Current Total Harmonic Distortion (ITHD) from 7.25% to 1.77%. Also, the Voltage Total Harmonic Distortion (VTHD) dropped from 11.43% to 0.94%. The Unified Power Quality Conditioner (UPQC) has been used to improve the MG power quality. The UPQC is a combination from series and shunt controllers linked by a common DC bus . The shunt controller has the capability of either generating or absorbing reactive power at the point of connection. The series controller is connected with the MG line in series for controlling the line parameters. Fuzzy logic controller has been applied upon UPQC to mitigate the current and voltage harmonics. Employing the fuzzy logic controller suppressed the total harmonic distortion to 3.34% compared with 8.93% when using the conventional PI controller.

All the previous described techniques and schemes for MG voltage balancing require additional and new hardware to achieve and verify their goal (MG phase voltage balancing). In this paper, we come across a new scheme able to completely mitigate the MG phase voltage unbalancing. The proposed scheme does not require any additional hardware. This feature makes the proposed

technique highly economically attractive. The proposed technique will be implemented by only modifying the DG interfacing inverter control.

III. DGS INTERFACING INVERTER DESIGN

Usually DG units are interfaced to the grid by means of a three phase inverter which converts the DC input to AC output. These three phase inverters does not account any importance in improving the voltage profile of the three phase system and also introduces harmonics. In order to overcome this drawback here we come across a new inverter topology where the compact three phase inverter is replaced by three single phase inverters with the same dc source where each of them are controlled separately in such a way that three of them work with variable power factor. The voltage profile is maintained by controlling the absorbed and injected reactive power. The layout of the proposed model is as shown in fig 1
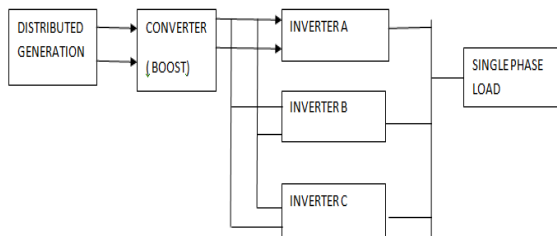

Figure 1: proposed system

Fig.2. shows the single line diagram of the investigated microgrid. As shown the microgrid consists of 4 buses. The microgrid is dominated with photovoltaic array at bus 1, 2, 3 and 4. Bus 1 represents a reference bus (slack bus) if the MG transfer to standalone mode. The ratings of all MG DGs are displayed through the fig.
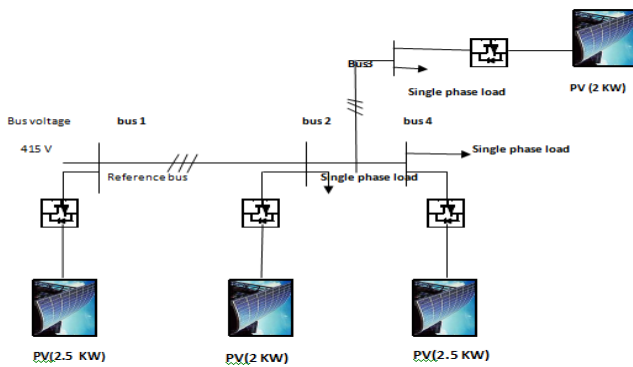

Figure 2. Investigated microgrid

As shown in the figure all DGs (the PV arrays) are interfaced with the MG through power electronic inverters. Using the power electronics inverter is necessary to converter the DC generated power to the AC power with 50 Hz frequency. To prove the effectiveness of the proposed inverter controller in balancing the MG phase voltages, all the MG loads are assumed single phase loads to create very high unbalanced operating condition Sizing of coupling inductance, inverter voltage and power angle Each DG needs a power electronic block to perform the DC/AC conversion and to interface with the MG where it

is installed. The inverter terminals are connected to the AC system (MGbus) through a coupling inductance X_L. Fig. 3 shows the details of the interface with the MG .Measurements are taken from both sides of the coupling inductance X_L and the controller generates desired values for V and δ_v to track the externally commanded values for active power (P) injection, and voltage magnitude (E) at the point of connection
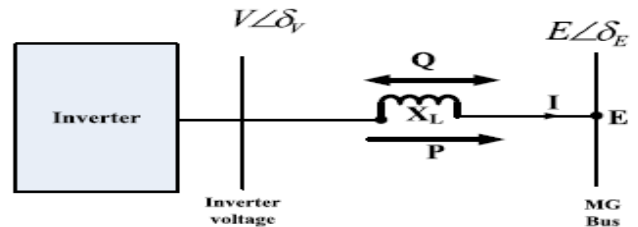

Figure 3. Single line diagram of interfacing inverter

with the MG. The values of active power and reactive power are given by the following equations;

$$P = (VE/ XL) \sin (\delta_V - \delta_E)$$

$$Q = V(V\text{-}E \cos (\delta_V\text{-}\delta_E))/ XL$$

The size of the coupling inductance X_L is derived from the inverter voltage ratings (V_{Max}), MG bus voltage (E) and the limits on the power angle. The power angle is the angle difference between the voltage at the inverter terminal (V) and the MG bus voltage (E) ($\delta P = \delta V - \delta E$). Typical limits can be as follows: (1) Limits on V: This condition is dictated by the value of the voltage at the DC bus and the kind of the used power electronic bridge in the inverter. (2) Limits on δP : This condition derives from the need for controller to operate in the linear portion of the power-angle characteristics.

A. New inverter topology and control for balancing the MG phase voltages

Usually, the DG interfacing inverter is designed as a compact three-phase unit. The active and the reactive powers are divided equally among the three phases (phaseA, phaseB, and phaseC). Each phase injects one third of the total DGs active and reactive powers. In this paper, the DGs active and reactive powers will be divided among the inverter phases with different ratios. The injected active and reactive powers have been divided among the inverter three phases according to an algorithm verified the MG phase voltage balancing.

Fig.4. shows the configuration of the proposed DG interfacing inverter. As shown, the conventional compact three phase inverter unit has been split to three single phase units. The DG active power will be divided equally between the three single phase inverter units. On the other side, the injected or the absorbed reactive power of each single phase inverter unit will be separately controlled to balance the phase voltages. With other words, each single phase inverter unit runs at a power factor differs than the two other single phase inverter
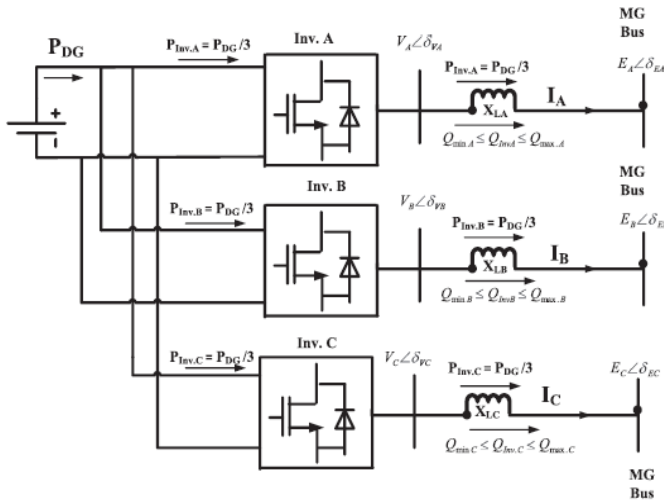
Figure.4. New interfacing inverter configuration.

units. Also, some single phase inverter unit may be operate at lagging power factor (absorbing reactive power), while the other single phase inverter unit runs at leading power factor (injecting reactive power). Amount of the injected or the absorbed reactive power by each single phase inverter unit is determined according to the MG bus voltage. The value of the single phase inverter unit reactive power is limited by its apparent power rating. The active and reactive powers of each single phase inverter unit are determined according to the following procedure. Apparent power of each single phase inverter unit is given by

$$S_{inv.A} = S_{inv.B} = S_{inv.C} = \frac{S_{3-phase\ inv.}}{3}$$

The injected active power by each single phase inverter unit is given by

$$P_{inv.A} = P_{inv.B} = P_{inv.C} = \frac{P_{DG}}{3}$$

Reactive power capability of each single phase inverter unit is determined by

$$Q_{inv.A} = \pm\sqrt{S_{inv.A} - P_{inv.A}}$$

$$Q_{inv.B} = \pm\sqrt{S_{inv.B} - P_{inv.B}}$$

$$Q_{inv.C} = \pm\sqrt{S_{inv.C} - P_{inv.C}}$$

The positive reactive power represents the capacitive (injected) reactive power (leading power factor), while the negative reactive power represents the inductive (absorbed) reactive power (lagging power factor). The reactive power capability of each single phase inverter unit lies between the following two limits:

$$-\sqrt{S_{inv.A} - P_{inv.A}} \leq Q_{inv.A} \leq +\sqrt{S_{inv.A} - P_{inv.A}}$$

$$-\sqrt{S_{inv.B} - P_{inv.B}} \leq Q_{inv.B} \leq +\sqrt{S_{inv.B} - P_{inv.B}}$$

$$-\sqrt{S_{inv.C} - P_{inv.C}} \leq Q_{inv.C} \leq +\sqrt{S_{inv.C} - P_{inv.C}}$$

By controlling the injected or the absorbed reactive power of each single phase inverter unit, the phase voltages balancing at each MG bus can be achieved if the required reactive power lies with the inverter reactive power capability. Both the value and the direction (injected or absorbed) of each single phase inverter unit reactive power depend on its phase voltage magnitude. The reactive power direction (injected or absorbed) of each single phase inverter unit will be determined as follows:

If $|EA| \geq$ Rated Voltage (220 V),there active power Q is negative (absorbed) reactive power. At this condition, the single phase inverter unit A will operate with lagging power factor. If $|E_A| \leq$ Rated Voltage, there active power Q_A is positive (injected) reactive power to raise the phase A voltage. The single phase inverter unit A will run with leading power factor to raise the phase A voltage. The same situation is applicable for both the phase B and the phase C inverter units. The reactive power control block diagram of each single phase inverter unit is shown in Fig. 5.
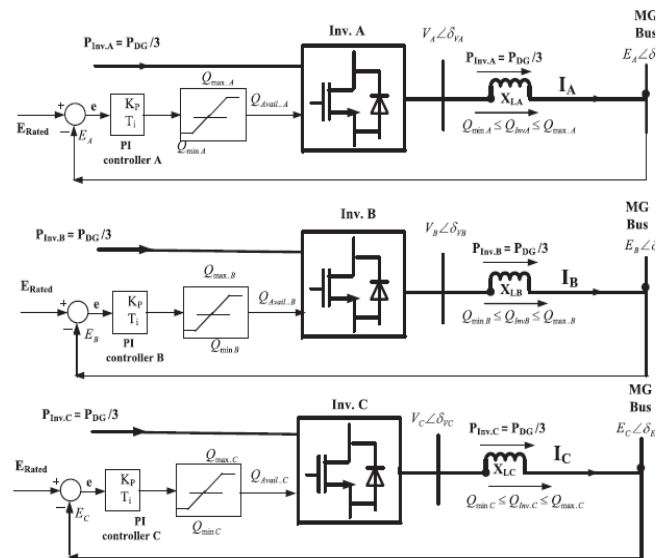

Figure 5. proposed controller for the new inverter configuration

IV. SIMULATION AND RESULTS

In order to confirm the operation of this new topology, a simulation model has been realized in Mat lab/Simulink using the SimPowerSystems toolbox and its parameters are given in Table 1. A conventional inverter is used first in the model to show the unbalance created by single phase loads. Further the same system is replaced by the new proposed inverter control to show its effectiveness

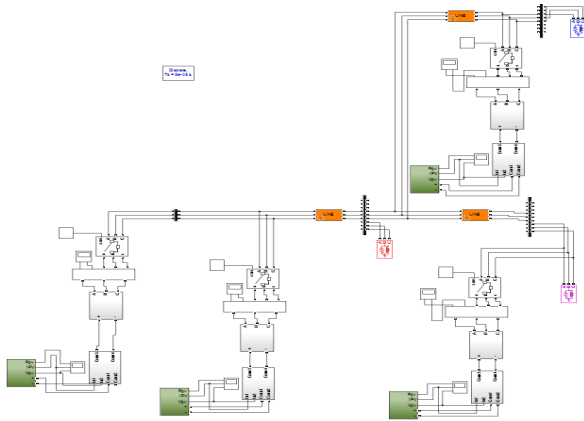| Bus no	DG Rating	loads
Bus1	PV(2.5 KW)	There is no load at bus 1
Bus 2	PV(2 KW)	Single phase load (phase A)
Bus 3	PV(2.5 KW)	Single phase load (phase B)
Bus 4	PV(2 KW)	Single phase load (phase C)

Table .1. system parameters

Figure 6. simulation diagram of investigated MG

A. *Solar panel*

Simulation diagram of a solar panel is shown in fig.7 . The simulation time for the model is taken as 0.5 sec. the parameters of the simulated solar panel is shown in the table 2 .the rating of the DG is taken as 2 KW say the DG of bus 3

Parameters	Values
Power rating	2.5 KW
Voltage output of single cell	.62V
No. of series connected panels	3(each with 12 cells)
No. of parallel connected panels	3 ||3
o/p voltage	44.45 V

Table. 2. Solar panel parameters
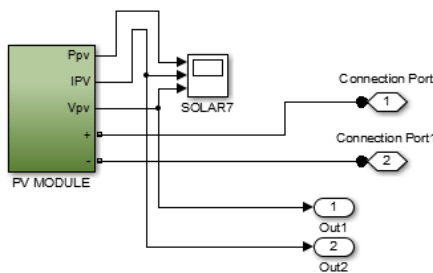
Figure 7.Simulation diagram for solar panel
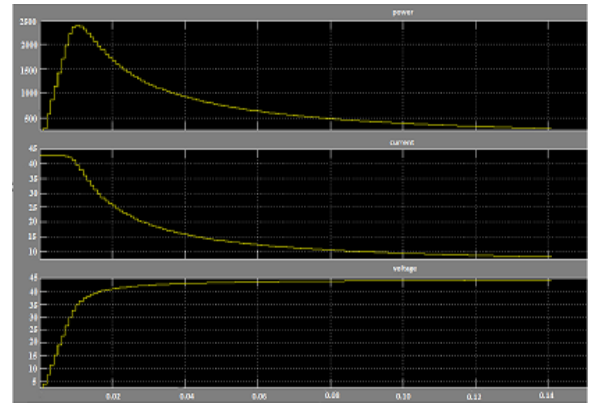
figure 8.solar panel output characteristics

B. *Boost converter*

The boost converter is connected at the output terminals of the solar panel with an output voltage of 44.45V which is the input of the boost converter. The parameters of the components are shown in table. 3. fig.9 . shows the simulation circuit of the boost converter

Parameters	Values
Input voltage	44.45
Output voltage	324
Duty cycle	.7
Inductor	5.253 mH
capacitor	6000μF

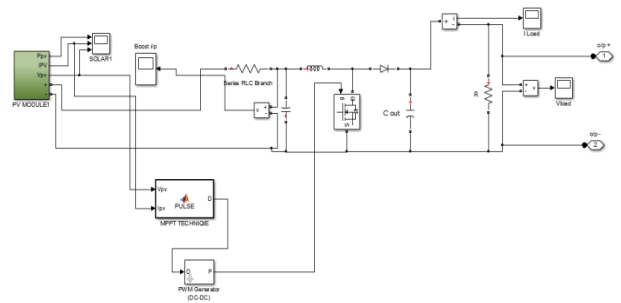Table 3. boost converter parameters

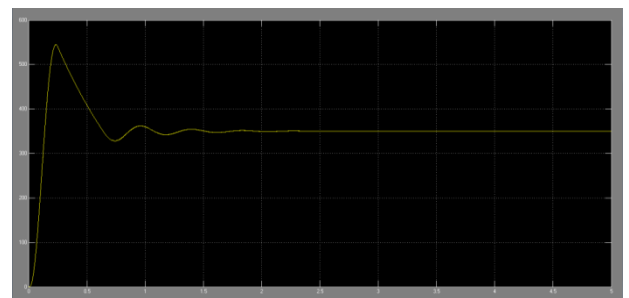Figure 9.Boost converter circuit

Figure. 10.Output voltage waveform of boost converter

C. System with voltage unbalance

Simulation of one of the buses with conventional three phase system with an inductive load is shown in fig.11 . The output of the simulation circuit was observed with a voltage unbalancing among the three phases where the voltages of each phase felled down from the reference value of 230V.
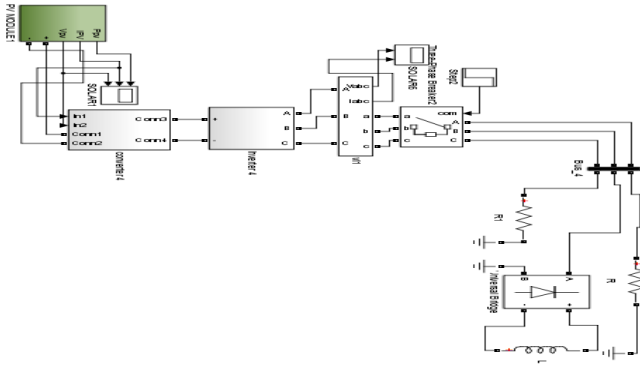

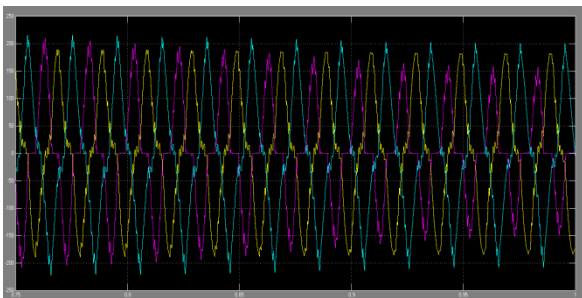
Figure 11. system with voltage unbalance

Figure 12. Inductive unbalance

D. New inverter configuration

The simulation diagram for the new inverter configuration is shown in fig.13.The input given to the new configuration is same as that of the three phase inverter. i.e, 324 V the output from the boost converter.
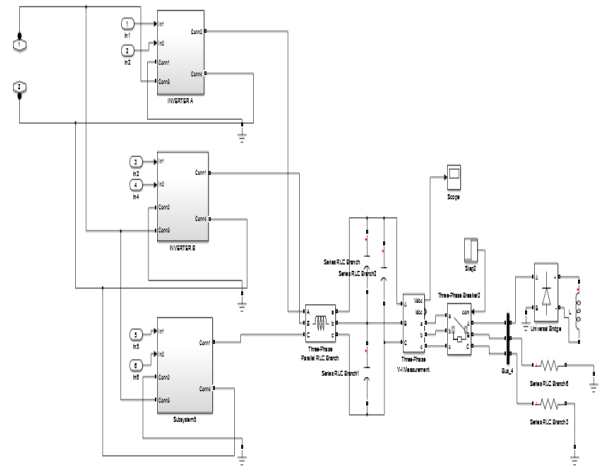

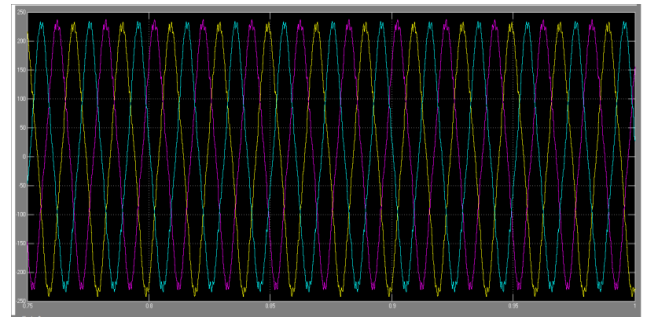Figure 13. Simulation diagram for new inverter configuration

Figure 14.Balanced waveform

E. Control circuit

The values of voltage magnitude of each phase at the output is fed back as the input of the control such that it is compared with the reference value 230 V and corresponding signals are generated which is further used for the PWM generation for switching of inverter
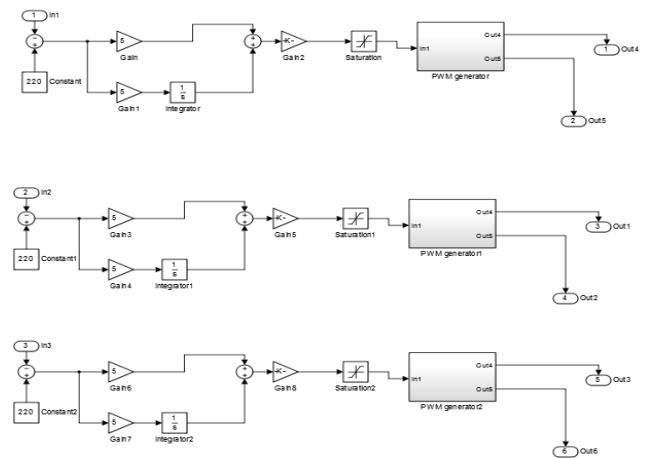

Figure. 15. Control circuit for new configuration

F. Capacitive loaded system

The simulation diagram for system with capacitive load is shown in fig. 16. the unbalanced voltage shown in fig. . shows that there is an increase in the values of phase voltage magnitudes from the reference value of 230 V. The compensated voltage waveform by the application of new inverter configuration is also shown in fig. .
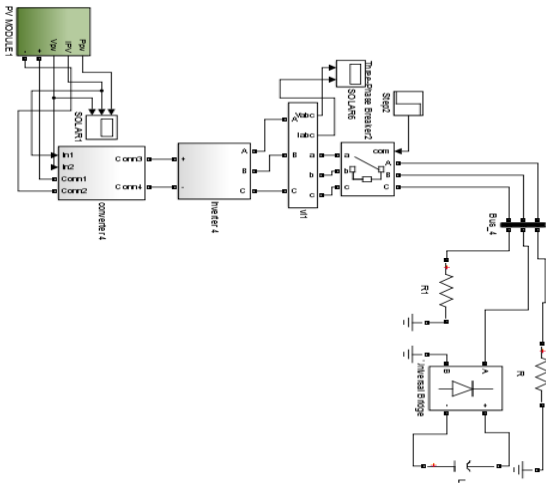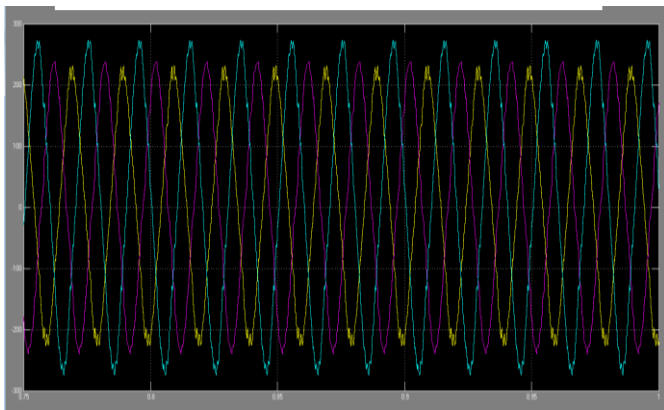

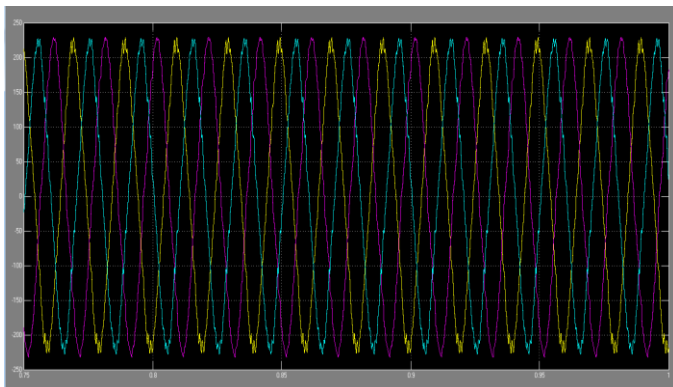Figure. 16. Capacitive loaded system

Figure. 17.Capacitive unbalance

Figure 18. Balanced waveform

V.CONCLUSION

This study presented a comprehensive survey about the MG power quality issue. The paper reported the available techniques and schemes for improvement the standalone MG power quality. Also, this paper proposed and employed a new configuration and control for the DG interfacing inverter. The proposed inverter configuration and control is highly effective in balancing the MG phase voltages under different load conditions. It is found that, by employing the proposed inverter control, the perfect balancing between three phase voltages can be achieved at all MG buses The proposed control shows a superior performance on MG phase voltage balancing if it is compared with the two other inverter control. The proposed control has a local control effect. This feature represents the main drawback of the proposed inverter control. With other words, the proposed inverter control able to balance the phase voltages at the bus which the inverter is connected. It has no ability to balance the phase voltages at other MG buses (especially the far buses). The proposed inverter control is not a central control. It can improve the voltage at other buses but it cannot balance those voltages In conclusions, by including the proposed inverter configuration and control, the phase voltage balancing and the overall MG power quality will be dramatically improved.

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