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Modeling and Simulation of a Microgrid with PV and wind Energy Resources

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ABSTRACT : This work presents the modeling, control and operation of a microgrid with three power sources and a storage system. The sources are solar photovoltaic and wind turbine. The objective of this work is to describe useful models of typical sources, the calculation of its parameters and control design of the power electronic converters of the energy sources. The modeling of the full system including all the stages of the converters is performed using MATLAB software package. The microgrid was designed to operate connected to the main network. The microgrid operated appropriately for different steady state operating conditions.

KEYWORDS: Solar Photovoltaic(SPV), Voltage Source Inverter(VSI), Maximum Power Point Tracking(MPPT), DFIG(doubly fed induction generator.

I.INTRODUCTION

Microgrid is a concept that involves one or more energy resources, loads, control and protection and management system making it operational whether connected or isolated from the main network. The development and increase in DG penetration with electrical proximity to one another have supported the concept of the microgrid. The microgrids are, in general, based on renewable energy resources or of low environmental impact. Energy resources refer to generation and storage units. The most commonly used power generation technologies are solar photovoltaic, wind power, micro turbines, combustion turbines, Stirling engines, geothermal systems, fuel cells and small hydropower . The energy storage sources include battery, super-capacitor, low- and high-speed flywheel systems and Superconducting Magnetic Energy Storage (SMES) systems. Each of these resources has its own characteristics, and most of them require power converters for the connection to the network. The power electronic interfaces play a crucial enabling role of regulating the voltage, frequency, and power to integrate the energy source to the grid. The control applied to converters makes it possible an efficient operation of each individual energy resource and the management of the entire microgrid, whether operating connected to the main network or in isolated system is evolving in the form of Microgrid.

II. MATHEMATICAL MODEL OF PV/WIND MICROGRID

At following models of the energy resources for computer simulation are presented. The control of each energy resource operating connected to the main network is given

A. MODELLING OF PV MODULE

The photovoltaic system consists of photovoltaic modules, a boost converter and an inverter. The dc-dc boost converter is responsible for search for maximum efficiency of the PV system and the inverter controls the suitable operating conditions to meet the ac load demand.

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1) PV Array: The PV cell is represented by a controlled current source with equivalent circuit as shown in Fig.1.

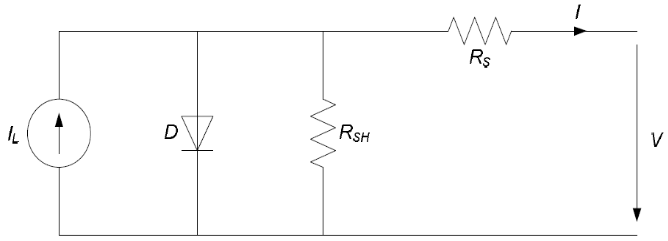

Fig.1 Equivalent Circuit of Solar Cell

A solar cell can be represented by a current source parallel with a diode, ahighresistanceandserieswithasmall resistance. Figure 1 shows the equivalent circuit of a solar cell.
The output current-voltage characteristic of a PV panel is expressed by equation (1), where $n_p$and $n_s$are the number of solar cells in parallel and series respectively.

$$I = n_p\, I_{PH} - n_p\, I_O\,(e^{\frac{q(V-IRs)}{AkTns}} -1) \qquad (1)$$

$$I_{PH} = [I_{SC} + K_i(T-T_{ref})]\,\frac{B}{1000} \qquad (2)$$

I is the load current, I_{PH} / I_L is the photocurrent , I_S / I_O is the diode current , q is the electron charge , V is the terminal voltage of the cell , N is the diode ideality factor , K is the Boltzmann constant, T is the cell temperature , R_S and R_{SH} is the series and shunt resistance respectively. Where Isc is the short circuit current of the PV cell, T is the current atmospheric temperature and T_{ref} is the temperature at nominal condition (25oC and 1000W/m2), G is the current irradiancelevel. Maximum power capacity of array is 7 kW to drive a 6 kW pump. A 250 W PV module is simulated and the modules are connected in series and parallel to attain a 7 kW PV array. Table I shows the parameters of the pv module.

TABLE I
PV MODULE PARAMETERS

ELECTRICAL PARAMETERS	VALUE
Maximum Power (P_{max})	250 W
Open Circuit Voltage (V_{OC})	37.6 A
Short Circuit Current (I_{SC})	8.66 A
Number of Series Cells (N_s)	60

We make use of maximum power point techniques to utilize the trapped power from the available power from the sun. The implementation of technique can be done on the dc-dc converter to change its duty ratio, so as to obtain the required voltage at the output of converters. Of the different MPPT techniques, beta method is used here. Beta is a variable used to find the intermediate value between current and voltage. Beta is calculated by
using the following equation.

$$\ln (Ipv / Vpv) - C.\ Vpv = \ln (I0.C) = \beta \qquad (3)$$

Where Ipv denotes panel output current, Vpv denotes panel output voltage. C denotes conductance, is calculated by using

$$C = q / (\eta\ K\ T\ Ns) \qquad (4)$$

Where q denotes the electron charge (charge carried out by single electron or photon 1.602176565 $^{(35)}$ X 10^{-19} coulombs), η denotes the quality factor of the junction panel, K denotes the Boltzmann constant (1.380648813x 10^{-23} J/K), T represent the temperature, and NS represent number of cells in series. It may be

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noted that β is independent of insolation but depends on temperature

The method senses voltage and current of the PV panel. The initial step of the algorithm is to reading the output voltage (Vpv) and current (Ipv) measured from Photovoltaic panel. After getting the value Vpv and Ipv the β value is calculated. Check β value is in steady state or not. If β is in the steady state, then β is checked whether it is within range of steady state or not. if β in that range then it is switched to Hill climbing or other methods. After that same process repeated again from the initial state. If the β is not in steady state, it starts processing from initial steps. If the βa is not in the steady state range and then error value is calculated. βg , the value of β corresponding to the most probable array temperature is used as the guiding value.

The steady state value is calculated by a fixed temperature, the difference in the magnitude value of β at maximum power point lies smaller, from that β Min and β Max ranges are fixed. Smaller changes irradiation level made changes in wide range. β Max is taken from maximum irradiation in maximum temperature. β Min is taken in minimum irradiation and in minimum temperature. Both values β Min and β Max calculated at maximum power point. Error values are calculated from the difference between β g and β a. From that new duty is calculated, by summing the old duty cycle with the product of error and Boltzmann constant.

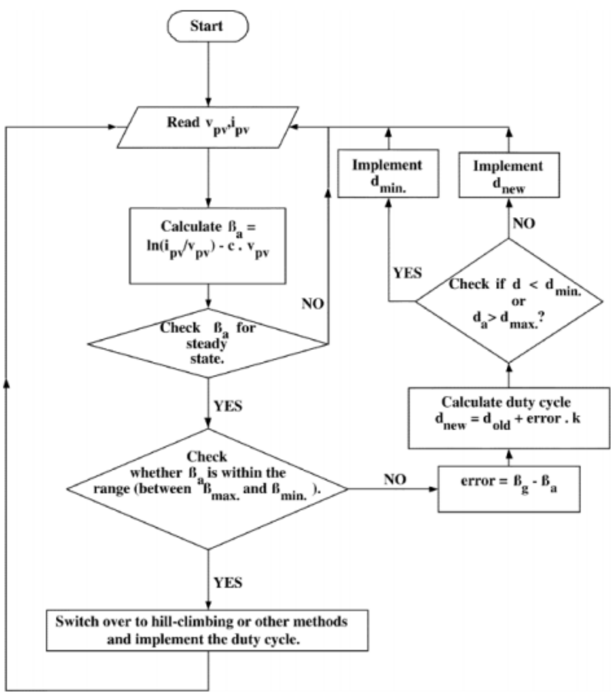

Fig.2.flowchart of Beta method.

B.WIND POWER SYSTEM

The wind power source is based on a three-phase doublyfed induction generator (DFIG). The DFIG stator is directly connected to the low-voltage side of the transformer, so it must have a steady output voltage and frequency. The rotor is connected to the microgrid through a back-to-back converter that comprises a rotor-side converter (RSC), a grid-side converter (GSC) with an intermediate dc voltage link. By controlling the converters in both sides, the DFIG can capture maximum energy from the wind with high efficiency. The traditional control method of DFIG is based on stator field orientation. In the stator flux oriented control (FOC) the d-q frame rotates at synchronous speed and is aligned to the synchronously rotating reference frame such that the stator flux is aligned with the d-axis and the stator voltage vector with the q-axis as represented in Fig.3

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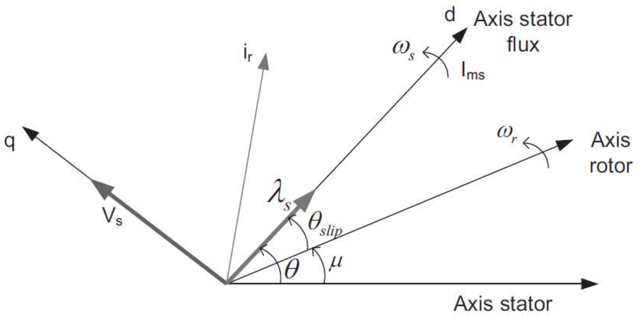

Fig 3

The mathematical model of the DFIG is written in (5)- (8), which considers the generator´s variables in the d-q synchronous reference frame

$$V_{ds} = R_s i_{ds} - \omega_s \lambda_{qs} + L_{ls}\frac{d(ids)}{dt} + L_m\frac{d(ids+idr)}{dt} \quad (5)$$

$$V_{qs} = R_s i_{qs} - \omega_s \lambda_{ds} + L_{ls}\frac{d(iqs)}{dt} + L_m\frac{d(iqs+iqr)}{dt} \quad (6)$$

$$V_{dr} = R_r i_{dr} - (\omega_s - \omega_r)\lambda_{qr} + L_{lr}\frac{d(idr)}{dt} + L_m\frac{d(ids+idr)}{dt} \quad (7)$$

$$V_{qr} = R_r i_{dr} - (\omega_s - \omega_r)\lambda_{dr} + L_{lr}\frac{d(iqr)}{dt} + L_m\frac{d(iqr+iqs)}{dt} \quad (8)$$

where the sub index ds and qs refer to either voltage, current or flux stator related variables in the d- and q-axis, respectively, the sub index dr and qr refer to either voltage, current or flux rotor related variables in the d- and q axis, respectively, Rs is the stator resistance, Rr is the rotor resistance, Lls , Llr and Lm are the stator, rotor dispersed and magnetizing inductance, respectively, ωs is the synchronous speed of the rotating magnetic field and ωr is the rotor angular velocity.

The electromagnetic torque and the active and reactive power at the stator windings can be calculated by:

$$T_e = \frac{3}{2}\, p\, \frac{Lm}{Ls}\, \lambda_{ds}\, i_{rq} \quad (9)$$

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs}) = \frac{3}{2}(V_{qs} i_{qs}) \quad (10)$$

$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) = \frac{3}{2}(V_{qs} i_{qs}) \quad (11)$$

where p is the machine number of pairs of poles and Ls is the proper inductance of the stator. Therefore, considering the magnetic flux constant and controlling the quadrature component of the rotor current, the electromagnetic torque of DFIG is controlled. Making use of the same torque control strategy, one can control the flow of active and reactive powers of stator through the converter on the side of the machine.

The block diagram of the control of the RSC is shown in fig4

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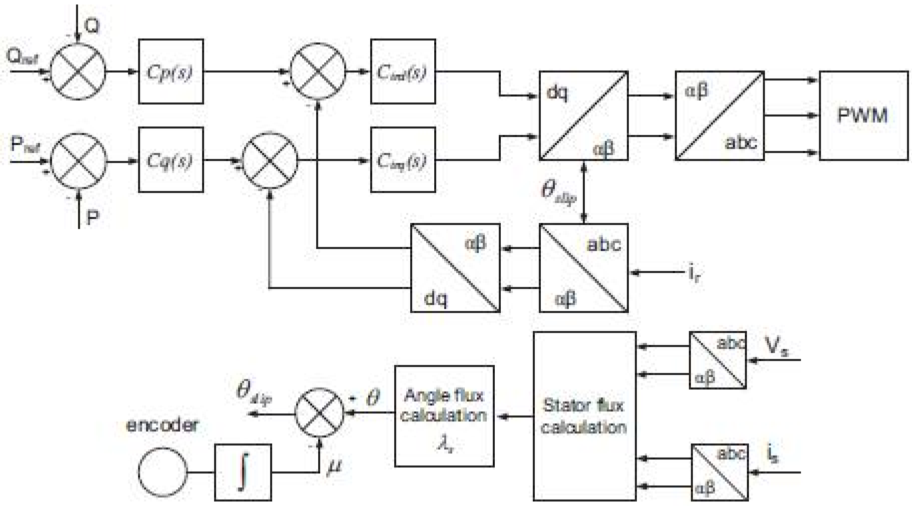

Fig. 4. Control diagram of the rotor-side converter.

The GSC converter is an inverter connected to the electric network whose main function is to keep the DC bus voltage independent of the direction of flow of power through the rotor [14]. Different from the RSC control, the stator voltage on the grid-side converter control is aligned with the d-axis. The equations that will set the GSC converter are defined in (12)-(13).

$$V_{ds} = V_s = R_f i_{fd} + L_f (di_{fd}/ dt) - \omega_g L_f i_{fq} + v_d \quad (12)$$

$$V_{qs} = 0 = R_f i_{fq} + L_f (di_{fq} / dt) - \omega_g L_f i_{fd} + v_q \quad (13)$$

where Rf and Lf are the resistance and inductance of output filter of GSC, ω_g is the angular frequency of the network, i_{fd} and i_{fq} are the current d-q components that flows through the filter, and finally, v_d and v_q are the voltage components at the inverter output.

Using equation of active power of the GSC and active power in the DC link shown in (14), it should be noted that the voltage on the capacitor can be controlled through the filter d-axis current.

Conversely, the q-axis current controls the reactive power that the GSC processes (15); setting the ifq reference to zero when in steady state regime the power factor of the converter is unity.

$$V_{cc}I_{cc} = 3/2 (V_{ds}\, i_{fd}) \quad (14)$$

$$Q_r = 3/2 (V_{ds}\, i_{fq}) \quad (15)$$

The block diagram of the GSC control is shown in Fig. 11.The wind turbine designed to the generator 12.8kVA/10kW was modeled according to [15].

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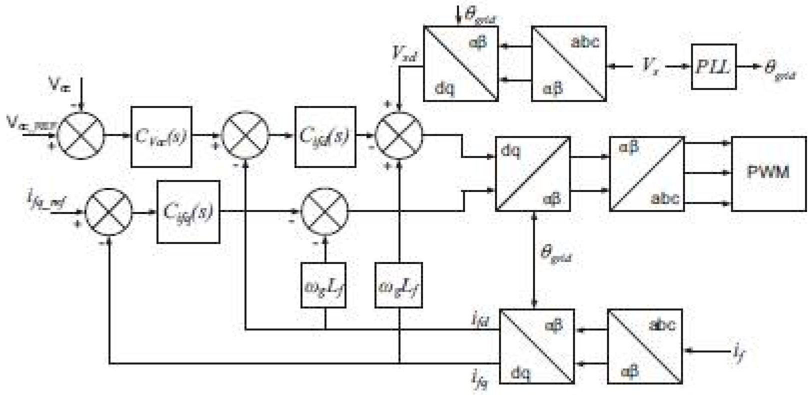
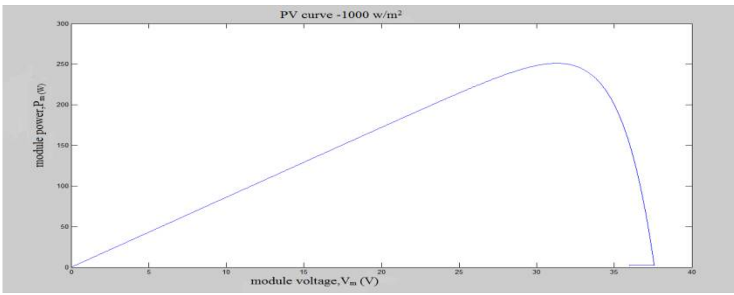


Fig. 5. Control diagram of the grid-side converter.

III. RESULT AND DISCUSSION

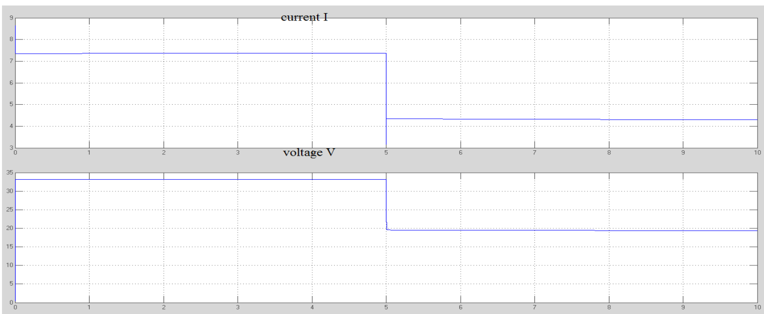
The modelling of proposed system with compensation capacitor is carried out inMATLAB/SIMULINK. The simulation is carried out for an irradiance of 1000 W/m^{2}and a wind speed of 12m/s. The P-V are plotted for the standard test condition at an irradiation level of 1000 W/ m2 and temperature of 298K. The maximum peak point of the P-V curve gives the maximum power obtained from the PV module and it is 250W.

P
O
W
E
R



VOLTAGE

Fig.6. P-V curve at standard test condition of 1000 W/ and 298K



TIME

Fig 7 .Current and voltage waveform PV

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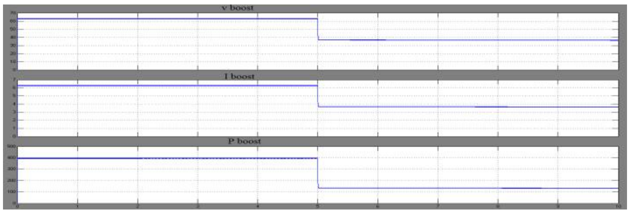
Fig 7 shows the current and voltage waveform with time in x-axis with a step input of irrandiance 1000W/$m^2$and at 5 seconds irradiance of 500W/m^2 is applied.

A boost converter is modeled using the equations. The values used for inductor and capacitor in the converter are L= 5µH and C = 840 µF and switching frequency is 5 kHz. The switching pulses to the boost converter are provided by the MPP algorithm. Fig.8 shows the output voltage waveform of boost converter at different irradiation levels 500 W/ , 1000 W/ respectively



Time

Fig. 8 Output voltage waveform of boost converter at irradiation level of

1000W/ and 500W/

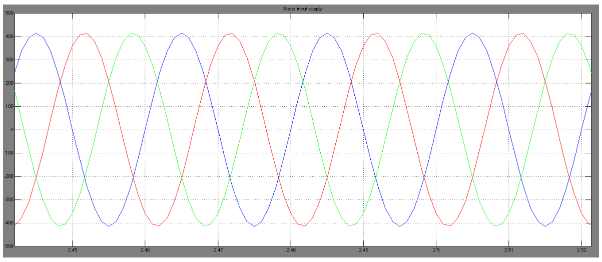


Fig 9 .Stator input voltage of DFIG with wind speed 12 m/s

Fig 9 shows the stator input voltage waveform of doubly fed induction generator for a input of wind speed 12 m/s.the input voltage is 415 v magnitude.

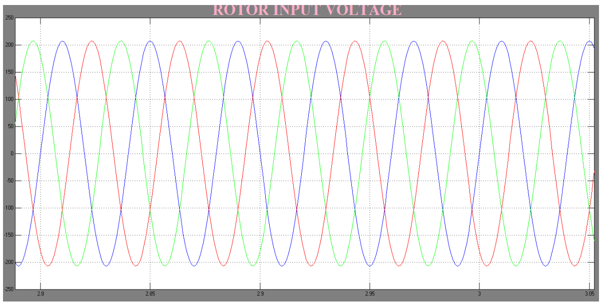


Fig.10 rotor voltage of DFIG with constant wind speed 12m/s.

Fig 10 shows the rotor side voltage of DFIG which is of 200 V in magnitude.

Fig.11 shows the Simulink model of grid control. The grid control circuit mainly consists of DC regulator, ABC to dq conversion, Current regulator and reference generator. The output of the control circuit is a reference sine wave. This reference wave is then compared with the carrier wave to produce the pulses to the three phase inverter. Fig. 12 shows the output voltage waveform of three phase inverter .

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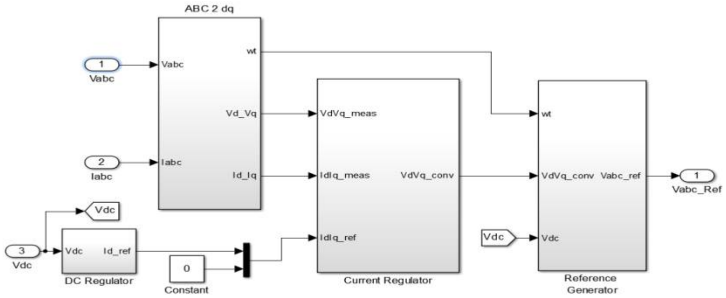

Fig :11 grid control of microgrid

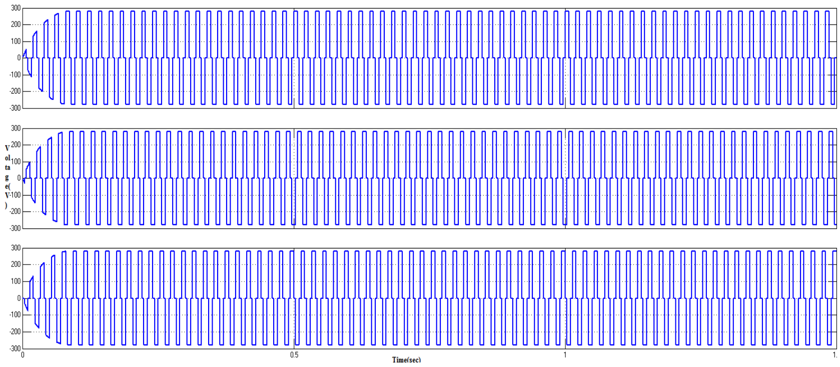

Fig 12. Inverter waveform for a microgrid

Fig 12 shows the inverter line voltage waveform for the microgrid with 280V amplitude

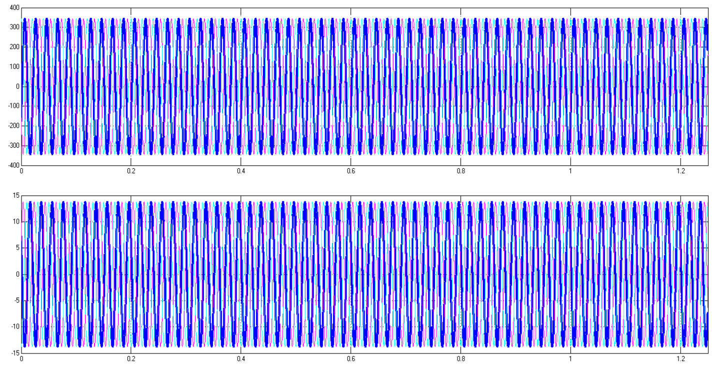

Fig.13.voltage and current waveform of the micro grid

Figure 13 shows the votage and current waveform at grid which is of 440 rms V and 15 A. The power at grid is of 7 KW

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IV.CONCLUSION

The paper has presented useful models of three phase micro sources of a microgrid. The simulation results based in MATLAB software environment were presented The parameters of the models of the energy resources were obtained using the datasheet and operating curves as given b manufactures of the equipment that are to be used as part of the microgrid The energy resources are connected to the network through power converters such as boost converter, high voltage gain boost converter and single- and three-phase inverters The microgrid was designed to operate connected to th main network. The converters operation was tested for different operating point changes, which responded suitably The results showed that the inverters have a higher efficiency low current harmonic distortion, when operating close to it rated power. However, the stochastic power sources, such a PV array and wind turbine, most of the time generate less than the rated power, therefore measures should be taken in the control of these sources in order to improve performance o their converters..

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