Proceedings of 11th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: March Volume: 11

Power Sharing Among Parallel Connected Photovoltaic Inverters with Droop Control in Microgrid

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Abstract

Microgrids are considered as the major part of the modern power plant where the power from different distributed generations are accumulated and provides supply to specific local communities rather than vast regions. Microgrid removes the necessities of large transmission lines and huge protection devices with better control and greater security. Microgrid increases reliability of the system and makes design flexible. Renewable energy sources such as photovoltaics and wind energy are more preferable due to deplition of fossil fuels and global warming. Photovoltaic energy source is becoming best choice world wide among other renewable energy sources due low emission, absence of fuel cost and little maintenance despite of its initial high investment. In this paper an islanded mode of operation of two parallel connected photovoltaic inverters with battery storage system is modeled. Different power electronic interfacing circuits are used such as; DC-DC boost converter with MPPT, charge controller and voltage controller which provide quick response to the system. Conventional droop controller with proportional integrator compensation is used for the proper power sharing among the parallel connected inverters. Common Load is given to parallel connected inverters through the point of common coupling. Maintaining the voltage and frequency within the acceptable limit at point of common coupling when both reistive and inductive load is supplied to the system is given major concern. MATLAB/Simulink is used for the simulation of the microgrid and the controllers.

Keywords

Photovoltaic energy, Microgrid, Droop controller ,PID controllers,Islanded mode

1. Introduction

Many countries in the world are focusing on the encouragement for the use of renewable energy sources with less emissions to reduce the greenhouse effect and decrease the consumption of non-renewable energy sources. In an electric power system microgrids are most preferred due to its characteristics of having controllable set of loads and generations. Microgrid consists of distributed generations, storage system and loads where these renewable energy resources are connected to distribution level to produce a large sum of power. To connect the renewable energy sources parallel the most important component is current control voltage source inverters that can enhance the generating capacity [1]. As photovoltaic energy is most prefered renewable energy souces worldwide due to its advantages such as: absence of fuel cost, little maintenance, little emissions, no noise and absence of moving parts, although its unpredictable nature and high installation cost being of most concern. Photovoltaic cells are generally made up of silicon based semiconductor thin flim which converts the light energy that falls upon it into electric energy using electron hole pair theory. The photovoltaic cells have special current voltage (I-V) characteristics which must be taken into consideration when designing a photovoltaic system where these characteristics is a short circuit current and open circuit voltage. [2].

Microgrid requires proper control strategy and controllers configuration to meet with standard voltage and frequency requirement under different conditions such as fault, overload, unbalance and non-linear load present in system. Many power electronic converters such as DC-DC boost converter with MPPT control for photovoltaic system, droop controller, LC filters for inverters etc. are required for obtaining proper performance of the system. The DC-DC converter is used to control the DC link voltage, trying to keep it at a constant voltage to the invetrer input terminal and MPPT main purpose is to operate PV system at its maximum power point. Inverter converts the dc power obtained from the boost converter into ac[3].In order to design the appropriate power converter topology into the microgrid, the basic control requirements are: frequency control, power control, voltage support and black start capacity. The microgrid control methods are basically divided into two types: control of microgrid with and without communication. The microgrid control method with communication requires the communication line or connection between parallel converters whereas, the control method without communication is also referred as droop control. This type of control scheme does not require any communication between the parallel connected converters[4].

The non-communication based methods control power sharing between parallel inverters is based on droop control. When two or more number of distributed generation inveters are connected in parallel for the proper power sharing of common load at point of common coupling it depends on the droop characteristics. The major advantage of power sharing without usage of communication leads to higher reliability, cost reduction and reduce complexity [5].

2. Methodology

2.1 Overall System Structure

As shown in 1 block diagram below two photovoltaic energy sources with mppt and dc-dc boost converter with battery storage system are used to feed power to the parallel connected voltage source inverters that are connected to common load.

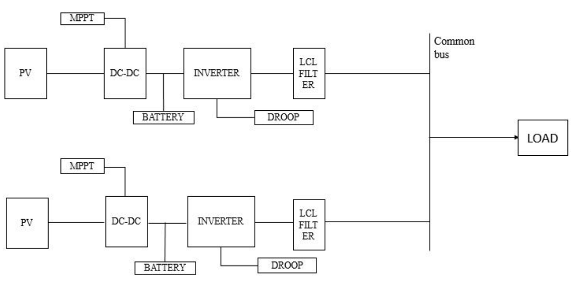

Figure 1: Overall system structure block diagram

2.2 Photovoltaic system modelling

For basic understanding of the performance of a solar cell it can be relatable to the equivalent circuit diagram shown below which consists of a current source, diode and series and parallel reistance for the losses associated with some leakage current. It works on the principle that when light falls on diode it generates appropiate electron hole pair that are seperated by elecric feild.

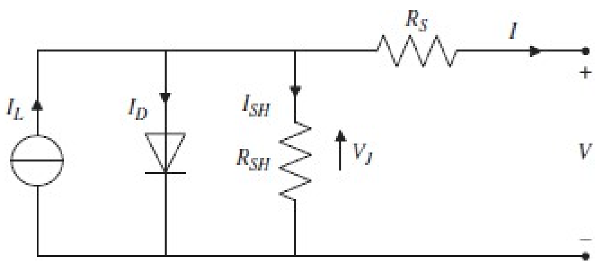

Figure 2: Equivalent Photovoltaic System Circuit Diagram

The photovoltaic cell can be modeled as shown in circuit diagram above as a diode in parallel with a constant current source and a shunt resistor or series resistor according to consideration of losses. The output terminal current I is equal to [2]:

$$I = I_{ph} - I_D - I_{sh} \tag{1}$$

Where; I_{ph} is the generated current, I_D is the current in diode, I_{sh} , shunt leakage current. In this paper two photovoltaic energy sources with 10KW and 15KW ratings are used. Photovoltaic module power and current curve for 15KW system considering two irradiation conditions is as shown in figure:

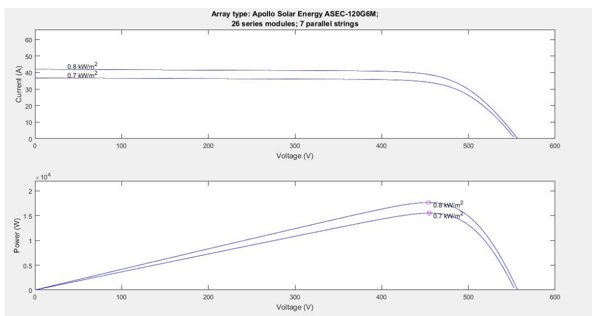

Figure 3: PV module power and current curve for 15KW

Table 1: Specification of PV module used

PV cell specifications	ASEC-120G6M
open circuit voltage	21.06V
short circuit current	7.49A
Voltage at maximum power point	17.33V
Current at maximum power point	6.93A
Maximum Power per array	120.0969 W

For 15 kw system:

parallel array =7 and series array =26.

Similar calculations are done for 10KW system.

2.3 DC-DC boost converter.

In a photovoltaic system the boost converter system is used that transmits the output voltage from PV to the higher voltage which is controlled by the duty cycle value obtained from mppt. The main purpose of boosting the voltage is to provide appropriate voltage level to the input terminal of the photovoltaic inverter so that appropriate ac voltage obtained from inverter output. This semiconductor device consists of diode, inductor, capacity elements and MOSFETS/IGBT as switch. In the circuit of dc-dc boost converter, when the switch is closed then the inductor is charged or energy is stored as the circuit forms the closed path and capacitor current also increases. When the switch is open then the charging current and inductor stored charge is passed through the diode towards the capacitor and load. The duty cycle obtained from the MPPT algorithm is converted into pulse and signal and given to the gate signal of the MOSFET of the converter [2].

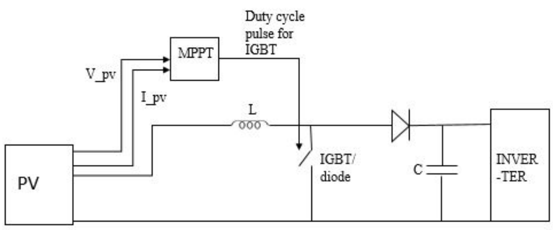

Figure 4: DC-DC boost converter

Calculation of inductor and capacitor value of boost converter of 10 KW PV system: let us assume output voltage of boost converter be 650V dc. Then: V_{in} = 450volt, V_{out} = 650 volt , I_{out} = 23.08A

$F_s(switching frequency)$ = 55 KHZ(assume)

$$Dutycycle(d) = 1 - \frac{V_{in}}{V_{out}}$$

Hence, duty cycle obtained is d=0.307.

$$Capacitance(c) = \frac{d * I_{out}}{\Delta V * F_s}$$

hence capacitane value is 9.39 microfarad

$$Inductance(L) = \frac{V_{out} * (1-d) * d}{\Delta I * F_s}$$

L = 8.39 mH

Similar calculaitons are done for 10 KW pv system.

2.4 Considering MPPT

In this modeling Perturb and Observe algorithm is used to track maximum power by continuous observation of the increment or decrement of the reference voltage or current to track the maximum power based on previous sample value. With the increase in system voltage and current if the change in power is positive then we are going through the correct path in tracking the maximum power. When the further increment of current or voltage causes negative change in power then we are away from the direction of maximum power point and the sign of perturbation has to be changed. MPPT algorithm maintains the duty cycle of converter within range to provide gate pulse to the dc-dc converter switch to boost the voltage to appropriate level. To check the maximum power point we can increase or decrease the voltage level of PV module, with the further increase in voltage decreases power then maximum power point is obtained [6].

2.5 Battery Storage System

Due to unpredictable nature of photovoltaic energy sources proper storage system should be designed. For the islanded mode of operation battery storage system plays an important role to supply the emergency load and backup during the blackout of system.Battery storage system can be used to maintain the balance between the supply and demand. When there is high generation than consumption power can be stored in battery and when there is scarcity of supply occurs then battery can be used to fulfil demand, this assures the stability of the system. To protect the batteries from overcharge and discharge proper charge controller should be modeled with necessary controllers. The required battery capacity is given by [7].

$$B_{size} = \frac{E_{load} * Days_{off}}{DoD_{max} * \eta_{temp}}$$

where, E_{load} is the load need to supplied during unability of power in ampere hour

$Days_{off}$ is the storage days

DoD_{max} is the maximum depth of discharge of battery

η_{temp} the temperature corrector factor

The purpose of microgrid is not obtained until the customer is served with nominal voltage and frequency by a stable system during all modes of operation. The engineering data for the certain Ah li-ion secondary battery can be used for the development of battery that could work in charging and discharging modes. In order to not overcharge or over discharge batteries a charge controller can be used to protect the batteries. By knowing the state of charge and voltage of a battery, a charge controller can regulate when to disconnect the battery to protect from over discharge and how to properly charge a battery [6].

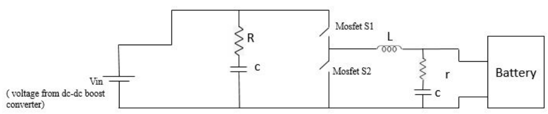

Figure 5: Charge controller for pv connected battery

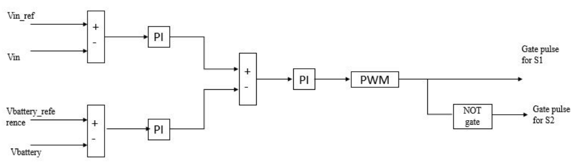

Figure 6: Voltage and Current regulation control block with PI controller

PID controller is used for the charge controlling mechanism in this model. By using the battery current and discharge current to input parameters to PID controller pulse is generated that is given to the MOSFETs connected in the circuit. This helps in charging and discharging of the battery. Other two controllers are that are used for maintaining the constant voltage to the load side and the battery side. One switch is used which is closed and supply power to the battery when the supply is available and is at off state when source is not available and load has to be supplied through the battery. Here for two photovoltaic systems two same capacity of battery bank are used that are used to supply load of maximum 8kw when photovoltaic supply is not available: Battery bank system voltage is assumed to be 120 volt:

Let us take lithium battery of nominal capacity 12volt and 200Ah. Now from the calculation it is obtained that:

No of batteries in parallel:5

No of batteries in series:10

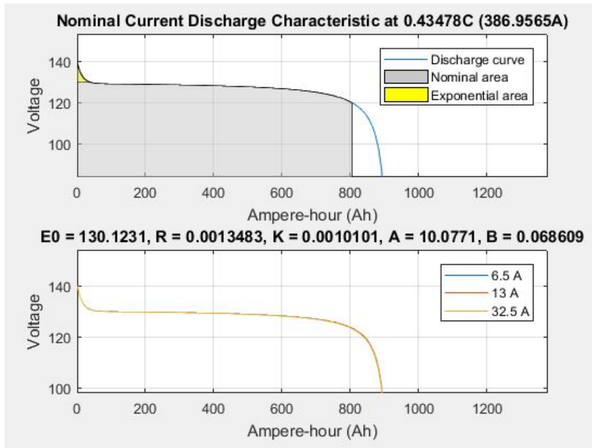

Figure 7: Nominal current and voltage characteristics of a battery

Similar calculations are done for battery of 15KW solar system.

2.6 Three phase Voltage Source Inverter (VSI)

Inverter are playing important role in renewable energy application as they are used to link a photovoltaic to a power grid that converts the dc power obtained from boost converter to ac power. Inverter plays major role in power conversion. The dc-ac inverters usually operates in phase width modulation way and switch between a few different circuit topologies, which mean that the inverters is a nonlinear Three phase inverter used in the system uses six MOSFET switches. The MOSFET's gate pulses are provided by the gate pulse, which controls the switching of the inverter switches such that distortions in output AC waveform is reduced[8].

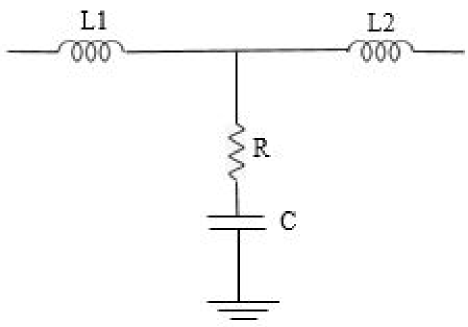

Figure 8: LCL type filter for inverter output

For 15KW system:

Calculation:

Let us assume no load frequency (f)=50Hz

Switching frequency (Fs)= 15KHz

Zb = base impedance

$$Capacitance(c) = \frac{0.05}{2 * \pi * F_s * Z_b}$$

c = 55.29μF

The maximum ripple current occurs at modulation index =0.5

$\Delta I_(max)$ = 10 percent of maximum current

$$I_{max} = \frac{power * \sqrt{2}}{3 * phasevoltage}$$

$$Inductance(L1) = \frac{V_{(in)}}{6 * \Delta I_{(max)} * F_s}$$

$L1$ = 0.84mH

Similarly, $L2$ =0.0122 mH and damping resistance R=0.186 ohm and 10kw inverter filter parameters are calculated.

2.7 Droop Controller

Droop control is the primary control with non-communication based internal control loops such as voltage, frequency. Droop controller is known as primary control that should maintain the most important requirements for the stable operation of the islanded mode. In islanded mode maintaining the voltage and frequency is the major requirement as small difference in these values cause huge circulating current to flow in the system and effect the performance of system. Individual inverters requires the individual control in the non-communication mode of operation this increases the system reliability and stability [1].

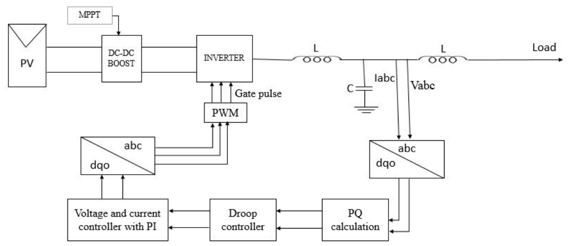

Figure 9: Block diagram for inverter control using droop controller

The output voltage and current from the inverter filter output is taken as feedback and abc phase of the current and voltage is converted to the d axis and q axis and the average value of active and reactive power is calculated by the formulae given below[5]

$$P = \frac{3}{2}(V_d * I_d + V_q * I_q)$$

$$Q = \frac{3}{2}(V_q * I_d - V_d * I_q)$$

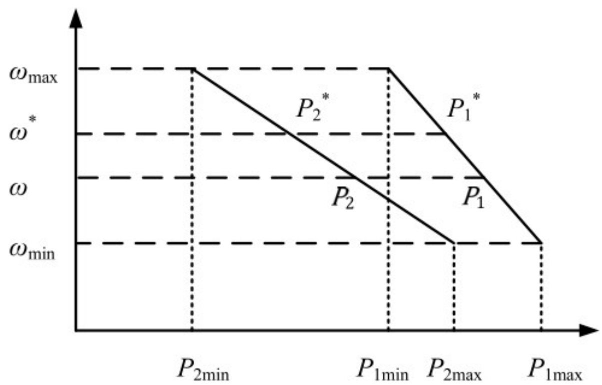

Figure 10: Active power and Frequency droop characteristics

Figure above shows the P-w droop characteristics. In droop control method, the changes in load can be taken up by the distributed generations in a predetermined manner and the communication less control of parallel inverters is achieved with the utilization of system frequency as a communication link within a microgrid. There is use of widely known P-Q droop control in voltage source inverter control where the analytical presentation is as follow[9]

$$W = W_{(ref)} - m * P$$

$$V_d = V_{(ref)} - n * Q$$

Where the corresponding values for inverter m and n are given by:

$$m = \frac{\Delta w}{P_{(max)}}$$

$$n = \frac{\Delta v}{Q_{(max)}}$$

Here, Pmax and Qmax are nominal active and reactive power supplied by system.The corresponding value of m and n for the 10kw system inverter are (2*pi)/10000 and 1/1000 respectively.

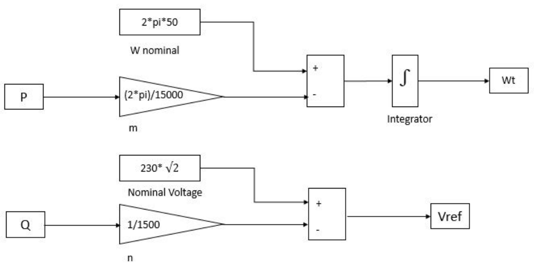

Figure 11: Droop Controller

The frequency output of droop controller is passed through the integrator. Thus the droop controller gives the phase and magnitude of reference voltage signal which is used to control the inverter. It means both inverters share load according to their droop coefficients and are controlled independently. In this way, droop control doesn't require any communications between parallel inverters/DGs.

2.8 Voltage Controller

The reference value of the voltage obtained from the droop controllers are used for the dq controller .The actual d axis voltage is compared with reference d axis voltage obtained from droop controller and error is passed through the PI controller similarly q axis voltage is compared with zero magnitude and error is passed through PI controller. The output from these controller is sent for dq to abc transformation so as to obtain necessary gate signal for three phase inverter[8]. The value of PI controllers is obtained from heat and trail method;

Table 2: PI controller value for d and q axis of inverter

d axis	q axis
k_P=0.4	k_p=0.4
k_i=80	k_i=80

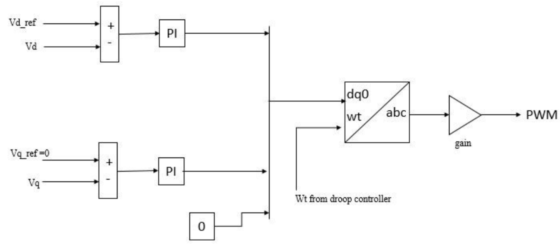

Figure 12: Voltage controller

3. Result and Discussion

3.1 Photovoltaic System, Mppt and dc-dc Converter Output

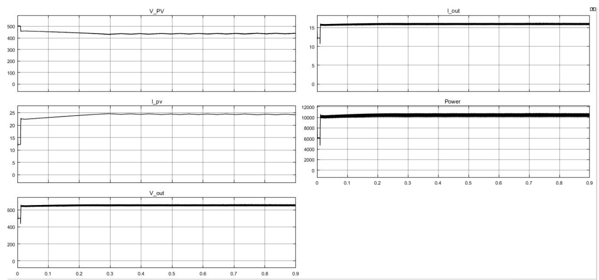

Figure 13: PV system with 10 KW output curve

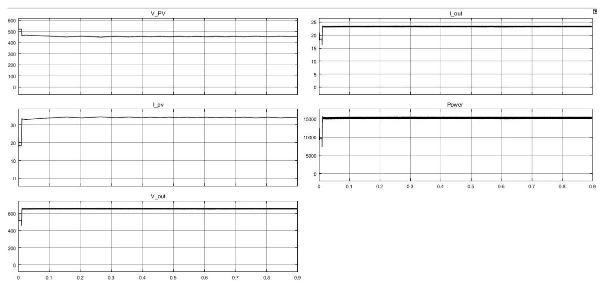

Figure 14: PV system with 15Kw output curve

From above graph we can say that output from PV is obtained as per design and dc dc boost converter has boosted voltage from solar PV panel 350 volt to 450 volt approximately.

3.2 Performance of charge controller

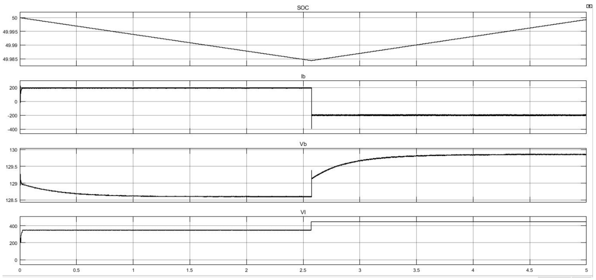

Figure 15: Simulation graph of charge controller

As shown in graph above the battery is charging and discharging current according to the available power condition. Here upto 2.5 seconds battery is in discharging mode i.e it is supplying load . we have assumed initial state of charge as 50 percent. After 2.5 seconds the battery is in charging mode.

3.3 load sharing among inverters when 9kw for 5 second, 4.5kw for 1-2 second and 4.5kw and 5kvar both are supplied for 2-2.6 second

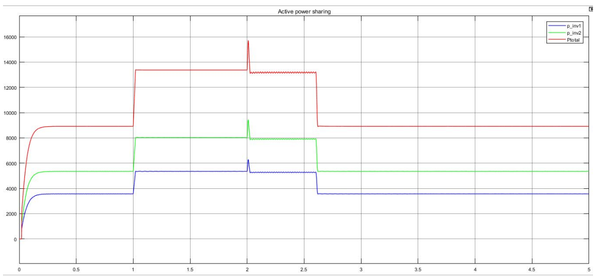

Figure 16: Active power shared by inverters

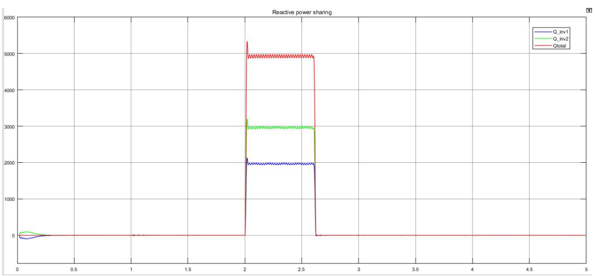

Figure 17: Reactive Power shared by inverters

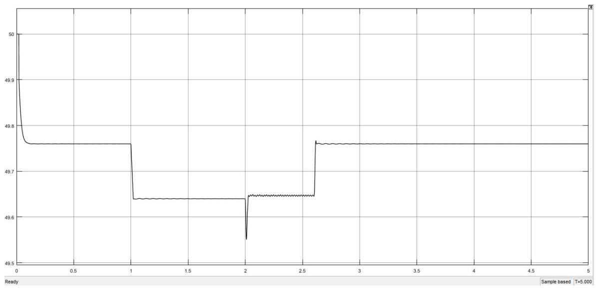

Figure 18: frequency curve for inductive load

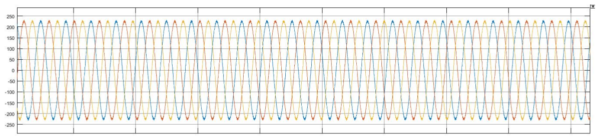

Figure 19: voltage curve for inductive load

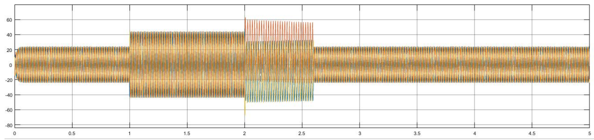

Figure 20: Current curve for inductive load

3.4 load sharing among inverters when resistive load of 9kw supplied for 5 second and 4.5kw for 1-2.6 second

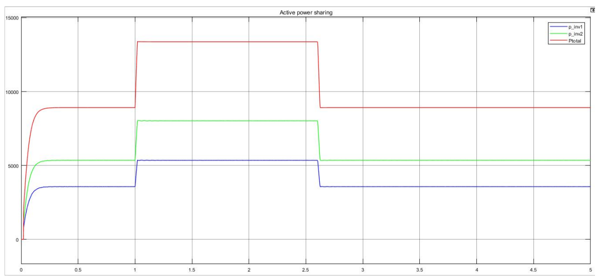

Figure 21: Power shared by inverters

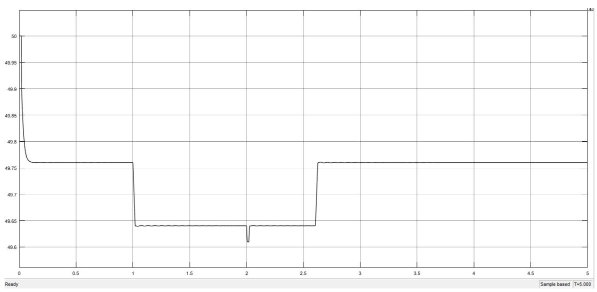

Figure 22: Frequency curve for resistive load

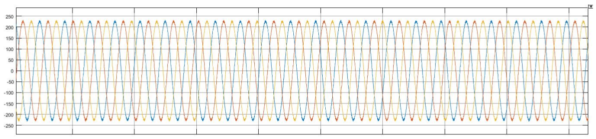

Figure 23: voltage for resistive load

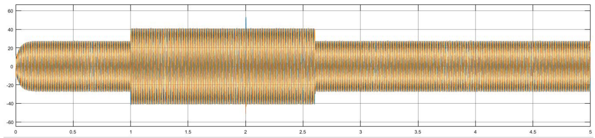

Figure 24: current for resistive load

4. Conclusion

The paper shows the load sharing among the parallel connected inverters using the droop control strategy. Photovoltaic source of energy is used as the major source of energy for the inverts. MPPT is used for the maximum power tracking of the power output from pv system and dc-dc boost converter is used for the boosting the voltage generated. Charge controller is used for charging and discharging of the battery in both the PV systems. And the resistive and inductive load is given to the invertes and proper sharing of the power by two inverters according to their rating is obtained.

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