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MPPT Enabled Solar Photo Voltaic Generators With V-f and P-Q Control in Microgrids

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ABSTRACT: The distributed energy sources are the small energy generating sources. Combination of these small energy sources will form microgrid to act in a interrelated manner to provide a required amount of active power. The control approach shows efficacious coordination between participating micro resources while considering the case of charging irradiance and charging battery state constraint. Micro grids could be controlled as a single dispatch able load which can respond in seconds to meet the needs of the transmission system. The crucial contribution and novelty of the control technique lies in the coordination between MPPT control technique which is used at the PV side or DC supply side, battery controlling technique and V-f and P-Q control algorithm which are use at inverter side. The PV system is designed with a battery back-up at the condition of emergencies. This arrangement helps to keep the microgrid voltage and frequency constant and also reliable supply to the critical loads. A coupling inductor is placed in between PV system and grid, for the elimination of ripples in the PV output current. The PV source is attached with the input of the inverter through a capacitor. This capacitor injects reactive power to PV system. This presents a perspective of interrelated and integrated control of solar PV generators with MPPT technique and battery storage technique to give support to voltage and frequency (V-f) maintain in islanded condition. And more over active and reactive power (P-Q) constraint along with MPPT and battery storage is suggested for the grid connected condition. The results are verified with the matlab simulink software.

KEYWORDS: distributed energy resources, maximum power point tracking, voltage and frequency control, charging battery state, active and reactive power.

I.INTRODUCTION

Now a day the improvement in power electronics gives us the possibility to use the renewable energy sources in various configurations. Using power electronic devices the renewable sources can be added with distribution grid or interconnected with other renewable (Solar Photovoltaic, Fuel cells, etc.) and non renewable generators (Thermal, Nuclear etc.), storage (Battery) systems and loads in mirogrids. Micogrid [1] is a small grid. It is the integration of large number of distribution generators. Microgrids are combination of generating units and energy storage units located close to the load centres. In a microgrid [2], at point of common coupling (PCC) microresources and storage devices are attached to medium level voltage utilities. In grid connected mode microgrid work as a PQ bus. In islanded mode microgrid will be operate on its own, there is no scope of grid. Its own control voltage and frequency of the microgrid, on that condition it will acts as PV bus. Distribution resources like solar PV are capable of providing ancillary services in the form of reactive power through power electronics interface, in addition to the active power. Non active power provided by DER can be used to operate the voltage at weak electrical buses in distribution systems. Capacitor is installed in distribution system as a cost effective approach for voltage control.

The control of voltage and frequency [3], active and non active power from inverter based DER’s to improve the system performance is a come out area of research. Even so, there are not many research works performed on V-*f* or P-Q control using PV in addition with MPPT and battery system. The previous works in this topic either lack the implementation of an energy storage component of the voltage control objective along with frequency control or the incorporation of control transition in various stages. Complete these gaps by taking all of these objectives.

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In past decade solar PV microgrid is used for either grid connected mode or islanded mode separately. In this project coordinated the voltage, frequency and active, non active power control. In this several control algorithm are implemented through which the solar capability of PV generators for voltage and frequency (V-f) control and active and non active/reactive power (P-Q) control in islanded and grid connected microgrid[9] could be harnessed. The locations of controllers are arranged as MPPT controlling technique is used at PV side, battery controlling technique and V-f or P-Q controlling technique used at inverter. These controlling techniques at three places are jointly linked with the power equating objectives at the DC as input of the inverter and AC as output of the inverter. The traditional synchronous generator frequency control, droop control techniques [4], abc-dqo technique are used for the voltage and frequency algorithm, active and non active power control. The used control methods are developed using the RMS/average values of voltage and active and reactive power.

The remaining paper deals the rough explanations of modelling of the solar cell and characteristics in next section. After that next section describes the modelling of the control algorithms of MPPT, voltage and frequency and active and reactive power

II.SOLAR PV MODELLING

Solar cells are the building blocks of a PV array [5]. The commonly used solar PV cell model is single diode model. Solar cells are the building blocks of a PV array. Basically solar cell is a P-N diode. When sun light strikes solar cell it generate electricity. The circuit diagram of solar PV cell is shown below fig: 2. it is one diode equivalent circuit. In this circuit I_{ph} is the electricity generated by P-N Junction diode of solar cell from sun light i.e. current source. R_{sh} & R_s are shunt and series resistances of solar cell respectively. These cells are connected in series and parallel to form module.

The mathematical representation equations of solar cell are shown below.

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \lambda / 1000 \qquad (1)$$

Reserve saturation current of module is

$$I_{rs} = I_{scr} / [\exp(qV_{OC} / N_s kAT) - 1] \qquad (2)$$

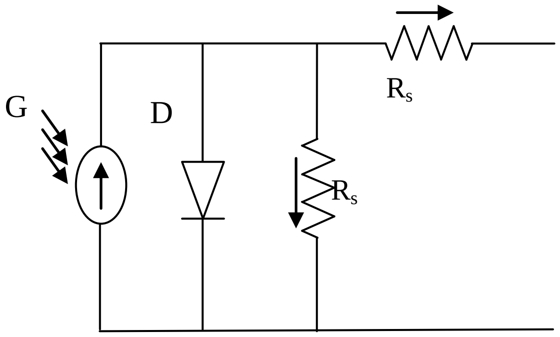

Fig1. Equivalent circuit of solar PV

Table I

Solar module specification

Maximum power (P_{MPP})	200W
Voltage at maximum power (V_{MPP})	26.30V
Current at maximum power (I_{MPP})	7.61A
Open circuit voltage (V_{OC})	32.90V
Short circuit voltage (I_{SC})	8.21A

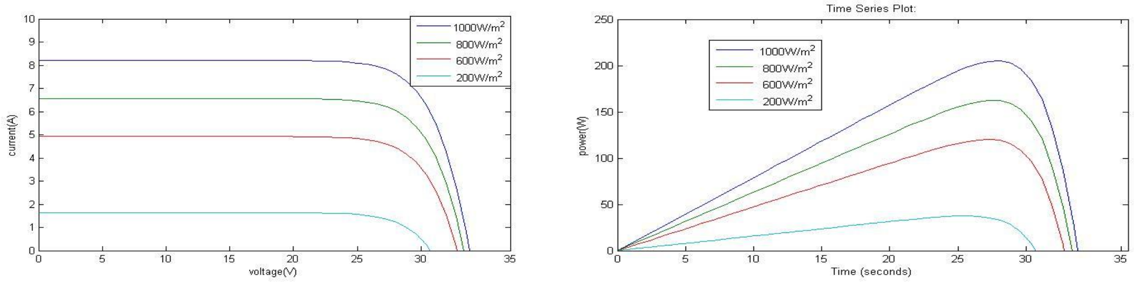

Fig2. I-V&P-V characteristics of solar module

The saturation current I_0 is

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q*E_{g0}}{Bk}\left\{\frac{1}{T_r}-\frac{1}{T}\right\}\right] \quad (3)$$

The PV Module output current is

$$I_{PV} = N_P*I_{ph} - N_p*I_0\left[\exp\left\{\frac{q*\left(V_{PV}+I_{PV}R_s\right)}{N_s AkT}\right\}-1\right] \quad (4)$$

Where B is irradiation, T_{ref} is Reference temperature E_{go} is Energy band gap (for Si =1.1ev), Ns is series connected cells, N_P is Parallel connected cells, V_{OC} is Open circuit voltage, I_{SC} is short circuit current, k is Boltzmann constant (1.3806503×10^{-23} J/K), A is Ideality factor, K_i is the short-circuit current co-eff is 0.017A per deg centigrade, q is Charge of electron ($1.060217646\times10^{-19}$ C), Rs is series resistance, R_{sh} is shunt resistance.

III.SYSTEM DESCIPION

A. *PV System Configuration*:

Fig3 presents the PV system arrangement for V-f and P-Q technique with MPPT inclusive of battery backup. It is a two-stage arrangement where a DC-DC boost converter is used for MPPT control. The battery backup will maintain the system voltage and frequency constant and also trying to supply the critical loads. A battery system is arranged in parallel to the PV at the inverter input to inject or to take active power through a bidirectional DC-DC converter. When the battery is absorbing power, the converter operates in the buck mode and when battery is injecting power to the grid, it operates in the boost mode.In between the solar PV system and grid a coupling Inductor (L_c) is placed which is filter out the ripple in the PV output currents. The node point between inductor and grid is known as the point of common coupling (PCC). The node voltage is denoted as v_t. The rest is connected with the inductive load. The generated PV power is connected through the C_{dc} to inverter. Here the capacitor is acts as the reactive power generator to the system.

B. *Battery Modelling*:

In this paper, the battery model is taken from the MATLAB simpower system library which will be used for the proposed V-f and P-Q controls. Because of the fluctating and uncertain nature of solar power and more over the high varying load demands, lead acid batteries are used. These are the more efficacious type of batteries system used in microgrid executions. These batteries will give the maximum capacity when utilized. So, in the modeling of system, a battery is taken as a lead acid battery with suitable choice of parameters for deep cycle utilization. LA (Lead acid) battery can charge up to SOC of 80% and can be discharged up to SOC of 20%.

The scientific modelled battery has two equations representing the battery discharge and charge model for a LA battery is given bellow

$$V_{battey} = V_0 - R*i - K\frac{Q}{Q-it}\left(it+t^*\right) + Exp\left(t\right) \quad (5)$$

$$V_{battery} = V_0 - R*i - \left[K\frac{Q}{it-0.1Q}\right]i^* - \left[K\frac{Q}{Q-it}\right] + Exp\left(t\right) \quad (6)$$

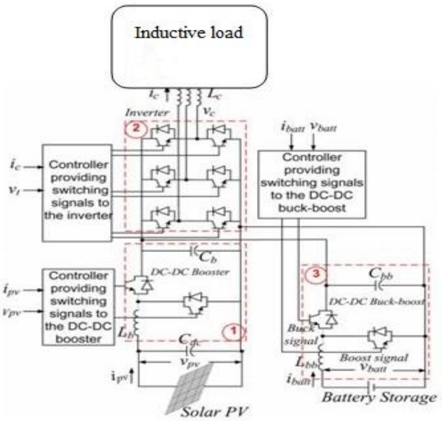

Fig3 schematic diagram of PV system

Where $V_{battery}$ is the battery voltage (V), V_0 is the battery constant voltage (V), K is polarization constant (V/Ah) or polarisation resistance (Ω), Q is battery capacity (Ah), R is the internal resistance (Ω), i is battery current (A), and i^* is filtered current (A). The capacity of the battery is chosen as to provide a maximum backup power to recompense for the PV output if and only if a very small or no irradiance level. In the simulation model the system is designed with MPP of PV model at STC is 100 kW. From this, the battery capacity is taken as to give this amount of power at most of 1 hour with an energy content of 100 kWh. The battery backup is considered for short duration operations like control of frequency of system and critical loads power supplying in the position of emergency conditions. One hour of battery backup is taken as sufficient for other backup sources to take over the controls in the microgrid emergency situations.

IV.CONTROL METHODS

A. MPP Tracking Method:

As we know power conversion efficiency of solar module very low. To increase efficiency of solar module proper impedance matching requires increasing efficiency of solar module. Different types of MPPT method are developed by researchers in recent years. Every method has its advantage and disadvantage. MPPT algorithms are varying due to simplicity, efficiency, tracking speed, sensor required and cost. It is seen that the V-I characteristics of the solar module is nonlinear and extremely affected by the solar irradiation and temperature. To maximize the output power of solar module, it has to be operated at fixed value of load resistance. This requires a separate power converter circuit for the MPPT. In this model design, a Boost type DC–DC converter is utilized to take the maximum power from solar module. There are different methods are there to implement MPPT algorithm these are Perturb and observer method, Proportional integral method and Incremental conductance[6] method etc.

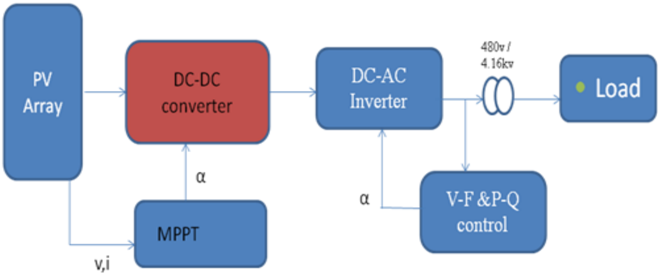

Fig4. block diagram of MPPT and V-f and P-Q controlling

- ***Incremental conductance method***:

This method is based on the slope of the PV curve of solar PV Module. The slope of the curve is zero at MPP, Positive at left side and Negative at right side as given by

$$\left.\begin{aligned}&\frac{dP}{dV} = 0,\ \text{At MPP}\\&\frac{dP}{dV} => 0, \text{Left Side of MP}\\&\frac{dP}{dV} =< 0, \text{Right Side of MPP}\end{aligned}\right\}\ \text{Step (1)}$$

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \qquad \text{Step (2)}$$

From (1) and (2), we get

$$\left.\begin{aligned}&\frac{dI}{dV} + \frac{I}{V} = 0,\ \text{At MPP}\\&\frac{dI}{dV} + \frac{I}{V} > 0,\ \text{Left of MPP}\\&\frac{dI}{dV} + \frac{I}{V} < 0,\ \text{Right of MPP}\end{aligned}\right\}\ \text{Step (3)}$$

By differentiating instantaneous conductance to the incremental conductance the MPP can be tracked as shown in following flowchart. In this method to sense the output voltage and output current uses the voltage and current sensors

The duty cycle generated in this MPPT algorithm is given to the DC to DC controller switches. The inductor and capacitor values are L_s=0.91µH, C_1=9mF, C_2=0.9F. This boost controller will give maximum power from solar PV generator to invert.

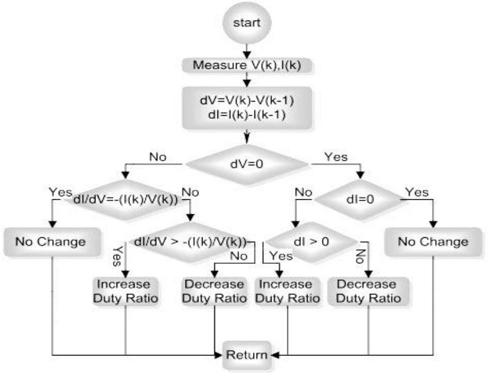

Fig5. Flow chart of MPPT INC method

B. ***V-f controlling method*** :

This control method contains two method containing two loops one loop for voltage control and another loop for frequency control. From fig6 the down loop for voltage control which has feedback PI controller PI_2. In this loop PCC voltage is counted and the rms value of $v_t(t)$ is computed. Then this value is differentiated with reference voltage $V_t^*(t)$ which is given by grid and the difference given to the PI controller. Then the output voltage of inverter is in phase with the PCC voltage, and the magnitude of the inverter output voltage is jurisdiction with respect to the reference voltage. The mathematical expression is given as bellow

$$v^*_{c1} = v_{t(t)}\left[1+K_{P2}*\left(V_t^*(t)-V_t(t)\right)+K_{I2}*\int_0^t\left(V_t^*(t)-V_t(t)\right)dt.\right] \quad (7)$$

Where K_{P2} and K_{I2} are the controller gain constants. In above equation 1 has been added to the right-hand side such that when there is no injection from the PV generator, the PV output voltage is exactly the same as the terminal voltage. The frequency is controlling by controlling the active power output at the inverter side which is shown in the first loop. 60Hz is taken as the reference frequency for microgrid. It is checked with measured value for error if any error exists, it is given to the PI controller PI$_3$. It provide phase shift angle α_1^*. Then the voltage waveform in time scale is shifted. Here active power is injected to maintain the reference frequency. The equations are given bellow.

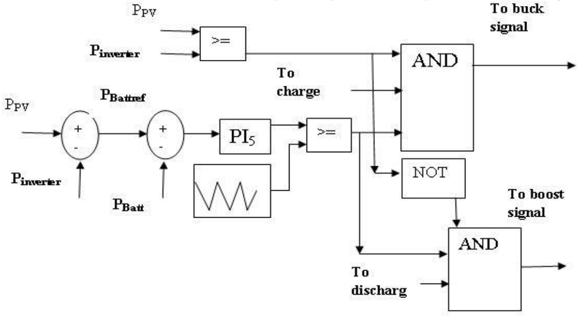

Fig7. Battery SOC controlling schematic diagram

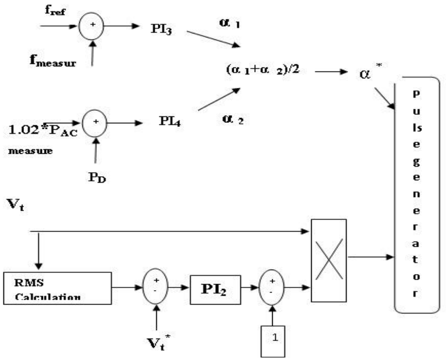

Fig6. V-f controlling method schematic diagram

$$\alpha_1^* = K_{P3}\left(f_{ref} - f_{measured}\right) + K_{I3}\int_0^t\left(f_{ref} - f_{measurd}\right)dt \quad (8)$$

$$\alpha_2^* = K_{P4}\left(1.02*P_{AC} - P_{DC}\right) + K_{I4}\int_0^t\left(1.02*P_{AC} - P_{DC}\right)dt \quad (9)$$

The phase shift contributions respectively from DC and AC sides, $\alpha_1{}^*$ and $\alpha_2{}^*$ are then averaged as given in bellow to obtain the final phase shift, α^* of the voltage, v_{c1} which, then, generates the voltage reference signal v_{c*} for the inverter PWM. Measured AC power is multiplied with the factor 1.02 due to the active DC power is 102% of AC active power. Here inverter is having 98%. The DC active power is compared with the AC active power. The resultant signal is given to the PI$_4$ controller. The equation for this controller is given bellow.

$$\alpha^* = \left(\alpha_1^* + \alpha_2^*\right)/2 \quad (10)$$

The average of these two phase shift signals are given to the PWM pulse generator. This is coupled with voltage control loop. To control the DC side voltage based on AC side voltage. To support frequency control and supply or absorb active power, battery with power control system is incorporated with PV system. Whether there is excess solar power and for frequency control required active power is less than PV$_{MPP}$, charging of battery will start. If there is required amount of solar power solar power availability is less and also for the frequency control the active power requirement is more than PV$_{MPP}$, then the deficit power will supplied by the battery to system.

TABLE II
V-f Control gain parameters

Voltage control loop	K_{p2}	0.00041
	K_{i2}	0.0050
Frequency control	K_{p3}	9.9×10^{-4}
	K_{i3}	0.3×10^{-8}
P_{DC} loop	K_{p4}	0.8×10^{-9}
	K_{i4}	0.8×10^{-8}
Battery loop	K_{p5}	1.5×10^{-8}
	K_{i5}	1.5×10^{-7}

maintain system frequency 60Hz. These control mechanism is shown in figure7.

C. ***P-Q Controlling Method***:

The inverter side P-Q control is similar to that of V-f control. This control loop is total works on the association of active and non active power [7] at PCC with inverter. The output phase and voltage magnitude equations are given blow and corresponding control loop fig shown above. Based on figures down loop the measured reactive power injection at PCC is subtracted with the mentioned reactive load and the resultant signal is passed to the PI controller, PI_2. Then, the output obtained is multiplied with the terminal voltage v_t to obtain the reference voltage v^*_{c1} which is in phase with v_t. The control loop 3 in Fig8 handles active power control through the controller, PI_3 to generate the phase shift contribution α^*_1 and at the same time insure the active power balance between AC and DC sides through the controller, PI_4. The equations for P-Q control are given below.

$$v_{c1}^{*} = \left(K_{p2}\left(Q_{ref} - Q_{actual}\right) + K_{I2}\int_0^t \left(Q_{ref} - Q_{actyal}\right)dt. + 1\right)v_t \qquad (11)$$

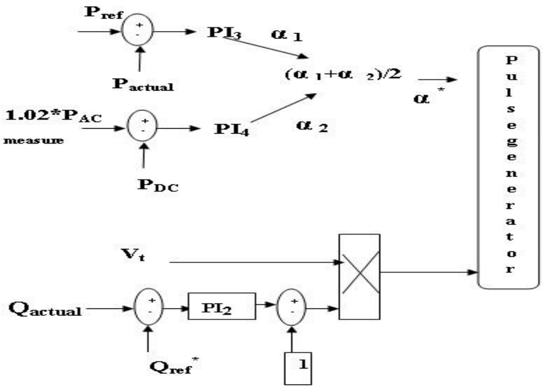

Fig8. P-Q controlling method schematic diagram

$$\alpha_1^{*} = K_{P3}\left(P_{ref} - P_{actual}\right) + K_{I3}\int_0^t \left(P_{ref} - P_{actual}\right)dt. \qquad (12)$$

$$\alpha_2^{*} = K_{P4}\left(1.02*P_{ACmeasu} - P_{DC}\right) + K_{I4}\int_0^t \left(1.02*P_{ACmeasu} - P_{DC}\right)dt. \qquad (13)$$

$$\alpha^{*} = \left(\alpha_1^{*} + \alpha_2^{*}\right)/2 \qquad (14)$$

Equation (10) denotes the reactive power control loop. (11) Denotes the active power control loop, and (12) denotes the active power balance between the input DC side and output AC side of the inverter. Equation (13) averages the phase shift contribution obtained from the active power control at the AC and DC sides such that the active power control at AC side and power balance objective are taken into account. The battery control algorithm is same as above section.

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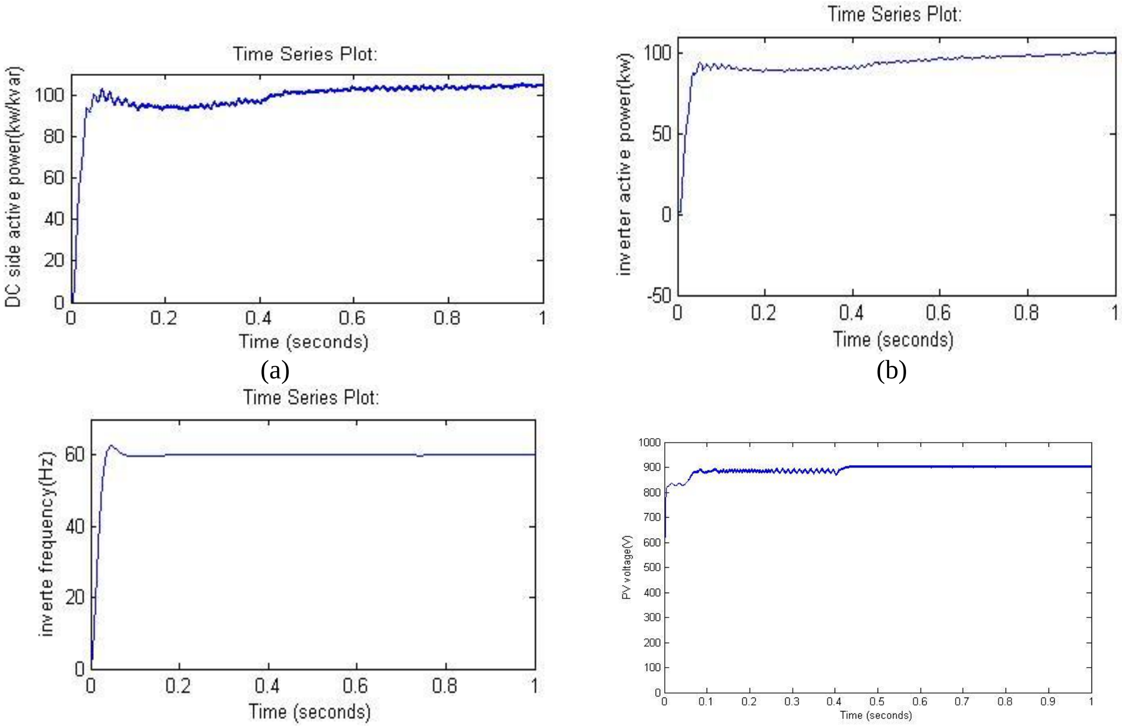
TABLE III
P-Q CONTROL GAIN PARAMETERS

Voltage control loop	K_{p2}	4.99×10^{-8}
	K_{i2}	4.99×10^{-7}
Frequency control	K_{p3}	2.5×10^{-9}
	K_{i3}	2.5×10^{-8}
P_{DC} control loop	K_{p4}	2.5×10^{-9}
	K_{i4}	2.5×10^{-8}
Battery control loop	K_{p5}	0.02×10^{-8}
	K_{i5}	0.02×10^{-7}

V. SIMULATION RESULTS

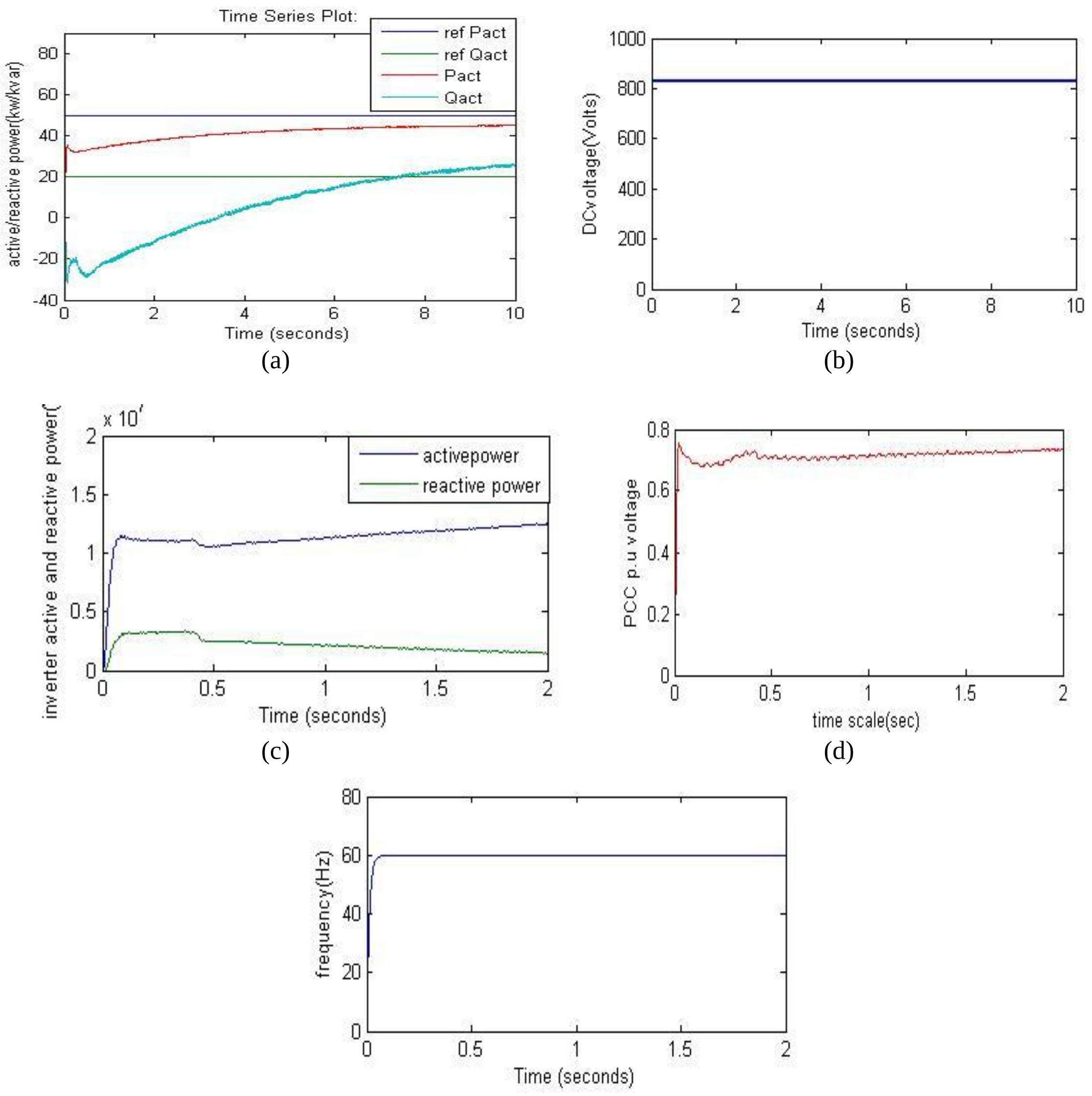
Figure9. Shows the results at the islanding mode of operations and at this condition microgrid only supply the power to load. Figure10. Shows the results at grid connected mode. At this condition system active and non active power controlling are given



(a) (b)

(c) (d)

Fig9. V-f Controlling graphs. (a) Inverter input power, (b) inverter output power, (c) frequency of the system, (d) PV generator output voltage.



(a) (b) (c) (d) (e)

Fig10. P-Q Controlling graphs. (a) active and reactive power with references, (b) generated DC voltage, (c) active and reactive power of gride, (d) per unit PCC voltage, (e) grid frequency.

VI.CONCLUSION

This paper presents various controlling methods for microgrid with battery storage system. In the controlling method MPPT controlling is used at PV side, V-f/P-Q, battery control algorithm at inverter side. PV generator gives maximum power through MPPT control. Smoothened power will be given as input to the inverter. The mentioned control strategy gives a flat transform from P-Q control in grid mode which is operated in grid connected condition to V-f controlling mode in islanded condition. Comparing to traditional methods these methods gives very acceptable performance.

This paper gives in showing the control strategy with efficacious coordination between inverter V-f/P-Q control, and energy storage.

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