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Noval Control Strategies For Distributed Energy Resources

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Abstract: Distributed energy resources, such as solar photo voltaic & diesel generators are used to form microgrids that provide active & reactive power when required. All the generators work in a coordinated manner, if any of them fails to work other will be made equal to the load. This project, mainly proposes three control strategies they are inverter V-F (or P-Q) control, MPPT control and energy storage charging & discharging controls. The controls are done in the grid connected mode as well as in islanded mode conditions. Coordinately solar PV generators are being controlled by using MPPT & V-F are provided by controlling battery storages. This project also shows coordination between distributed energy resources in different irradiance and state of charge constraints of battery. Simulations are done with IEEE 13 bus feeder test system in both the modes such as grid connected and islanded conditions. The proposed method is implemented, trained, and tested using MATLAB and Simpower systems. The results show the effectiveness of the proposed system in controlling three strategies.

Key Words: Solar photo voltaic (PV), Wind energy conversion system (WECs), Fuel cells (FC), Central controller (CC), Micro sources (MCS), Point of common coupling (PCC), Insulated gate bipolar transistors (IGBTs), State of charge (SOC).

I. INTRODUCTION

Distributed energy resources or micro sources are those which are used to generate a small amount of power less than 100 kW[1]. They are categorized into renewable energy resources & non renewable energy resources. Most commonly used renewable energy resources are solar photo voltaic (PV), wind energy conversion system (WECS), fuel cells (FC) & biomass and biofuels. Non renewable energy resources are those such as diesel generators, gas turbines etc. By connecting distributed energy resources, energy storage devices & loads form a micro grid. Coordination between renewable micro sources & non renewable micro sources are carried out by the central controlle ((CC). Microgrids are connected to feeders through micro sources (MCS) & connected to the medium voltage level utility grid at the point of common coupling (PCC) through the circuit breakers[2]. When microgrid is connected to the main grid, all the control strategies such as voltage, frequency are controlled entirely by the grid. Even though it supplies power so, it acts as a PQ bus. In an island condition, micro grid has to operate on its own, to control the voltage, frequency & hence act as a PV bus[3]. Control strategies that are carried out in this paper are voltage, frequency,active power and reactive power. In islanded condition, micro grid voltage & frequency can be controlled by using a droop control method[4][5]. This paper provides a fast response characteristics for voltage & frequency. But there is a necessity of having referenced voltage & frequency signals for inverter control because if there is any occurrences of error signal that can be controlled by PI controller. It is really a challenge to make frequency & voltage to an acceptable range with this micro sources such as solar photo voltaic & diesel generators.

The active & reactive power of the system in islanded condition is carried out by the abc-dqo transformation & vices versa that are provided in this pape[6]r. Power modulation of solar pv generators with an electric double layer capacitor as energy storage is considered for frequency control[7][8].

There are several control algorithms that are carried out in this paper in which the capability of pv genertors for voltage-frequency control & active-reactive power control in islanded & grid connected nodes. Detailed study of PV cells, diesel generators, battery inverters& controller are required[9]. The major proposed control methods are 1) MPPT control at the PV side, 2) battery control & 3) V-f/P-Q control algorithm at inverter side. All this control algorithms are jointly carried out through a power balance objective at the DC & the AC side of the inverters. So that voltage along DC side is indirectly controlled at the desired level. The control is one with ABC-reference frames by the rms value of active & reactive power and voltage[10].

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II. DERs TO GRID

DERs that are used in this paper are solar photo voltaic cell, diesel generated integrated with a battery storage. The high penetration of DERs in the modern electricity grid can provide many potential positive benefits through their integration, but they can have many negative impacts on the network if power output and voltage at the Point of common coupling (PCC) is not properly regulated through controls. The challenge mainly lies in the integration of varying renewable sources like Solar PhV. DERs can provide a technical relief to the grid in the form of reduced losses, reduced network flows and voltage drops, however, there are several negative impacts due to the high penetration of these variable resources which include voltage swell, voltage fluctuations, reverse power flow, changes in power factor, injection of unwanted harmonics, frequency regulation issues, fault currents and grounding issues and unintentional islanding. The electricity generated by DERs can be either directly connected to the area EPS through synchronous or induction generators or indirectly connected with the help of static power electronics (PE) interface.

There are many DER technologies which generate the electrical voltage not in synchronism to the area EPS or a grid. The DERs like solar PhV, fuel cell, storage batteries generate DC power while wind generators produce the AC power from an asynchronous generator and micro-turbines produce a non-synchronous AC. Hence, an intermediate power conversion stage is required in order to convert the power generated by the DERs to the power with voltage magnitude and frequency in synchronism to the area EPS. The power electronics (PE) interface performs this task of connecting any type of DER systems to the grid by providing either DC - AC or AC - DC conversion stages.

PE interfaces comprise of semiconductor switches with the devices like thyristor, diodes, and insulated gate bipolar transistors (IGBTs) or MOSFETs with proper control of the duty cycle of these switches to fulfil the desired objectives. With the proper controls of switches, PE interfaces may be capable of regulating voltage at the point of PCC.

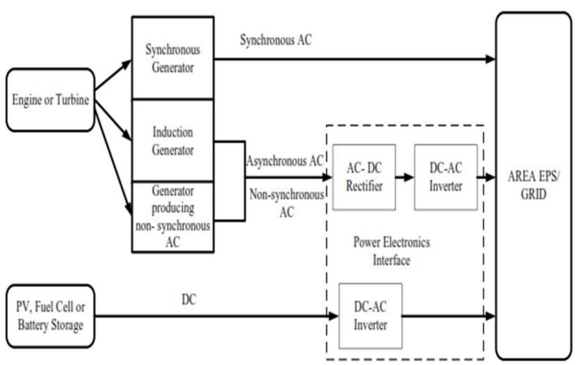

Fig 1:Interconnection interfaces of DERs to the grid

III. SOLAR CELL AND BATTERY DESIGN

A. Solar cell design

Solar cell proposed in this paper is one diode model. Schematic diagram of one diode model is shown in fig 2.

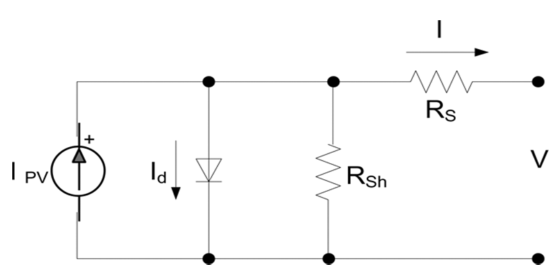

Fig 2 : One diode model

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The V-I characteristics of the solar array are shown in fig 3 & it is represented by the equation (1).

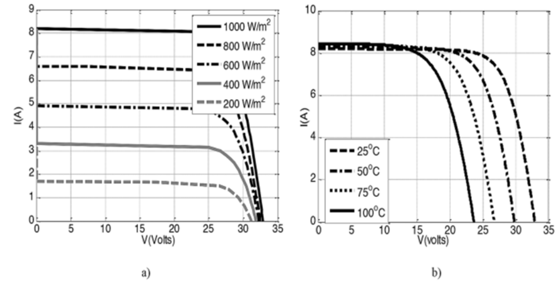

Fig 3:The V-I characteristics of solar cell from simulation with (a) varying irradiance at a cell temperature of 25^0 c and (b) varying cell temperature at $1000W/m^2$.

$$I = I_{PV} - I_0\left[exp\left(\frac{V + R_s I}{V_{therm}\alpha}\right) - 1\right] - \frac{V + R_s I}{R_{sh}} \quad (1)$$

Where I_{PV} is the photo current, I_0 is diode saturation current, $V_{therm}=(N_s kT/q)$ is the thermal voltage, N_s being the cells connected in series for greater output voltage, k is the boltzmann constant,T is the temperature and q is the electron charge, R_s and R_{sh} are the equivalent series and shunt resistances,α is the ideality factor.

B. Battery Design

Because of the intermittent & the uncertain nature of solar power output and also highly fluctuating load demands, deep cycle lead acid batteries are the most common type of battery storage in microgrid applications. Lead acid batteries give the maximum capacity of battery storage when compared without battery storage devices & can be charged up to SOC of 80% & can be discharged up to SOC of 20%.

Charging & discharging of lead acid batteries is represented by the following equations (2)-(3)

$$V_{Batt} = V_0 - Ri - K\frac{Q}{Q - it}(it + t^*) + \exp(t) \quad (2)$$

$$V_{Batt} = V_0 - Ri - \left[k\frac{Q}{it - 0.1Q}\right]i^*\left[K\frac{Q}{Q - it}\right]it + \exp(t) \quad (3)$$

V_{Batt} is the battery voltage (V), V_0 is the battery constant voltage (V), K is polarisation constant ,Q is battery capacity, R is the internal resistance(Ω),i is the battery current (A) and i^* is filtered current (A).

IV. CONFIGURATION OF THE SYSTEM

A. System Configuration

The System is mainly designed with diesel generator, pv cell & battery storage. The system also considers a diesel generator back-up in case of emergencies while maintaining the voltage & frequency of the microgrid or while trying to supply the critical loads. The Solar system is connected to the grid through an inverter, which converts DC to AC power. Diesel generator is connected in parallel to solar system, the ripple content is reduced by the inductor L_C which is connected at the point of common coupling. Reactive power is generated from the capacitor $c_{dc.}$ The Battery is connected in parallel with a solar system to inject or absorb the active power through a bidirectional DC-DC converters. When converter operates in a buck mode, then battery starts to absorb the power. In boost mode, the battery starts to discharge the active power. The operation mode is maintained through the control signals provided to the converter switches.

The schematic diagram of a system is shown in MATLAB & Simulink.

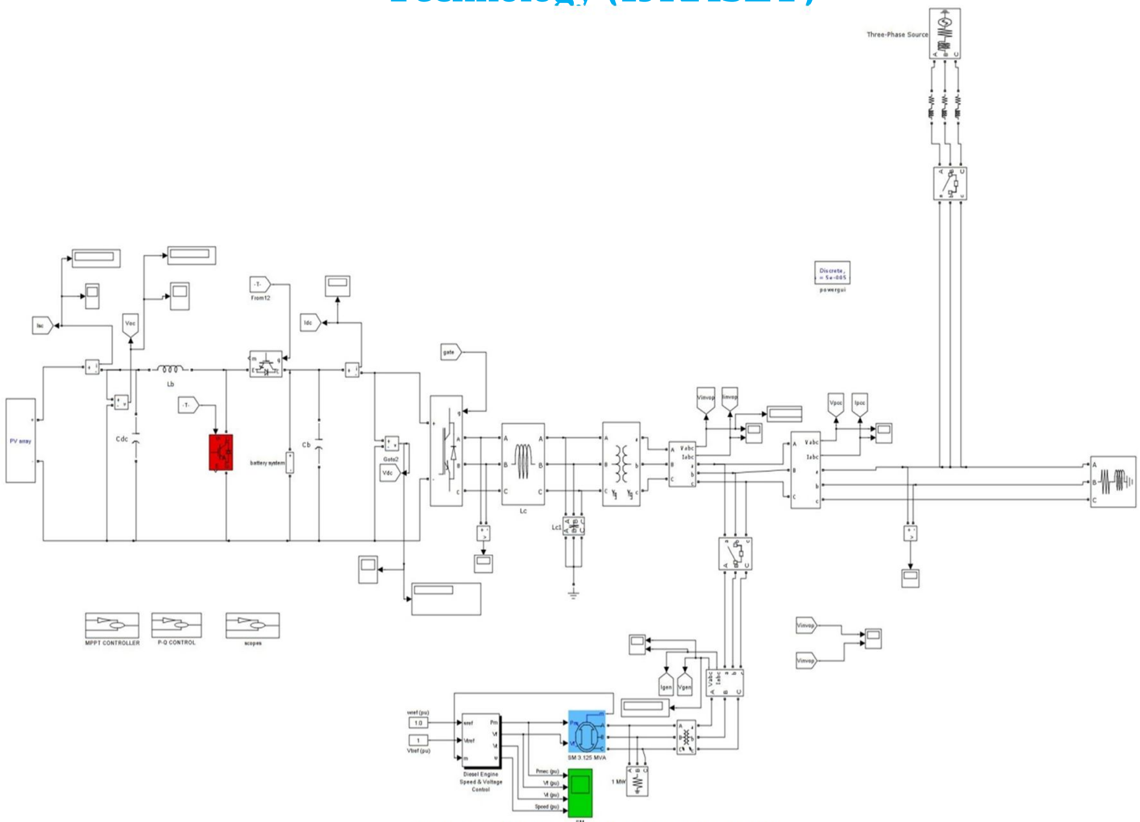

Fig 4: system descripiton diagram

The average active power is given as p(t) & reactive power is given as Q(t) .

$$P(t) = \frac{V_t(t)V_C(t)}{\omega L_c}\alpha \qquad (4)$$

$$Q(t) = \frac{V_t(t)}{\omega L_c}\left(V_t(t) - V_c(t)\right) \qquad (5)$$

C. MPPT Control

Power from solar cell (pv) is compared with P_{MPPref} ,an error signal is sent to the PI controller. The output generated from the PI_1 controller is given as the equation (6)

$$\delta^* = K_{P1} * \left(P_{MPPref} - P_{PV}\right) + K_{I1} * \int_0^t \left(P_{MPPref} - P_{PV}\right) dt \qquad (6)$$

Here K_{P1} and K_{I1} are the controller proportional and integral gains respectively.

V. PROPOSED METHODS

A. For Controlling V-F Control

The measured rms voltage at PCC is given as $V_t(t)$. This value is compared with refences voltage $V^*_t(t)$ & the error is fed to a PI controller. The generated output voltage is given in equation (7)

$$V_{c1}^* = V_t(t)\left[1 + K_{P2}\left(V_t^*(t) - V_t(t)\right) + K_{I2}\int_0^t \left(\left(V_t^*(t) - V_t(t)\right)dt\right)\right] \qquad (7)$$

Frequency can be controlled by controlling active power at inverter side, the measured frequency is compared with the 60hz & the error signal is fed to the PI_3 controller. Which gives the phase shift contribution α^*_1 which shifts the voltage waveform in time scale such that the active power injected will be enough to maintain the frequency at 60 Hz. The equation is given as (8)

$$\alpha_1^* = K_{P3}(f_{ref} - f_{measured}) + K_{I3}\int_0^t (f_{ref} - f_{measured})\,dt \qquad (8)$$

There is an another controller PI_4 , which maintains active power balance between the AC & the DC side of the inverter. The reference signal for PI_4 is obtained from the dynamically changing active power injection from the inverter at the Acside as determined by the output of PI_3. Measured active power $P_{Acmeasured}$ is multiplied by a factor 1.02. The DC side active power is compared with the values of AC side power & error is fed to PI_4 to obtain the phase shift contribution from this loop as α_2^*. The equation for this is given as (9)

$$\alpha_2^* = K_{p4}(1.02 * P_{AC} - P_{DC}) + K_{I4}\int_0^t (1.02 * P_{AC} - P_{DC})\,dt \qquad (9)$$

The final phase shift is given as (10)

$$\alpha^* = \frac{\alpha_1^* + \alpha_2^*}{2} \qquad (10)$$

Simulation diagram of V-f control method is shown in fig 5.

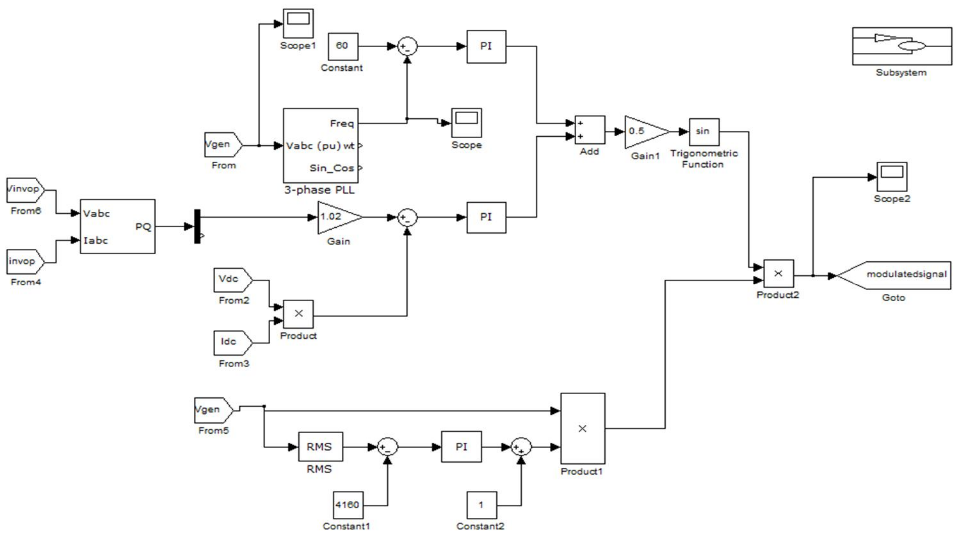

Fig 6: V-f control diagram

B. For Controlling P-Q Control

P-Q control is slightly different from V-f control. It is entirely based up on the relationship between active & reactive power at PCC with inverter output phase and voltage magnitude. Active power injected at the PCC is measured and compared with a reference value and the error signal is passed to PI controller. Then the output obtained is multiplied by the terminal voltage V_t to obtain references, voltage V^*_{c1} which is in phase with V_t.

The reactive power control loop is given by this equation (11)

$$v_{c1}^* = \left(K_{P2}(Q_{ref} - Q_{actual}) + K_{I2}\int_0^t (Q_{ref} - Q_{actual})dt + 1\right)v_t \qquad (11)$$

Simulation diagram of a P-Q control method is shown in fig 6.

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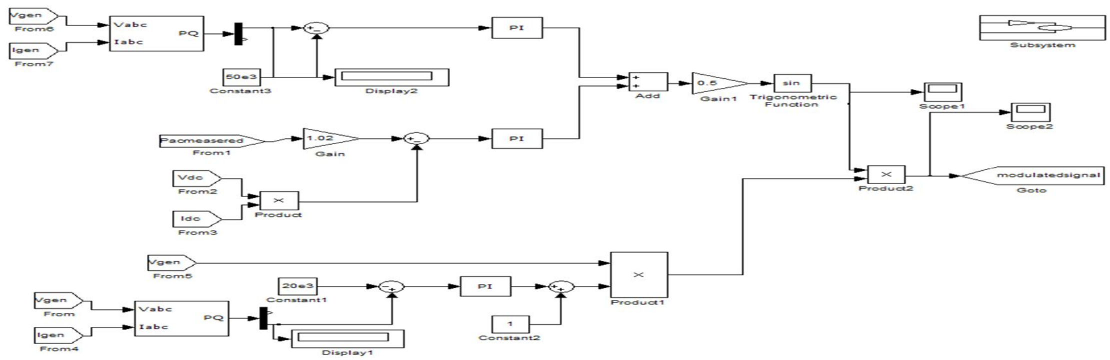


Fig 6: P-Q control diagram

Active power is controlled by PI_3 to generate the phase shift contribution α^*_1 & at the same time ensures the active power balance between AC & the DC side through the controller PI_4. The Active power control loop is represented by the following equations (12)-(14)

$$\alpha_1^* = K_{P3}(P_{ref} - P_{actual}) + K_{I3}\int_0^t (P_{ref} - P_{actual})\,dt \quad (12)$$

$$\alpha_2^* = K_{P3}(1.02 * P_{ACmeasured} - P_{DC}) + K_{I4}\int_0^t (1.02 * P_{ACmaeured} - P_{DC})dt \quad (13)$$

$$\alpha^* = \frac{\alpha_1^* + \alpha_2^*}{2} \quad (14)$$

VI. SIMULATION RESULTS & ANALYSIS

This section provides the results obtained from the above control methods

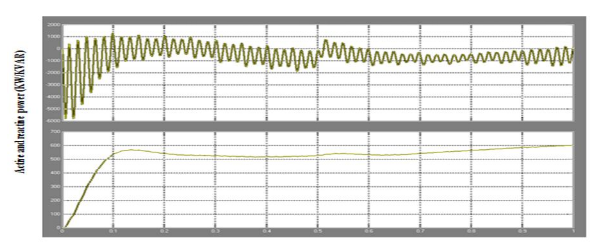
A. Results For V-F Control Method

By considering the irradiances = 1000w/m^2 & the controller gain parameters for v-f control is given in the below table 1.

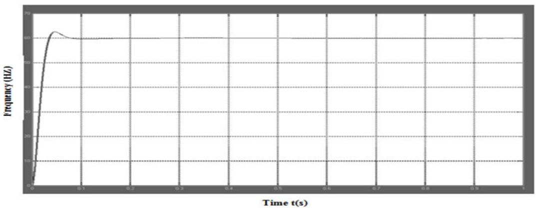
Fig 7 (a)-(h) show the results for V-F control with solar power including MPPT control

MPPT Control Loop	K_{p1}	6×10^{-8}
	K_{i1}	6×10^{-6}
Voltage Control Loop	K_{p2}	0.0004
	K_{i2}	0.005
Frequency Control Loop	K_{p3}	9.9×10^{-4}
	K_{i3}	5×10^{-3}
P_{DC} Control Loop	K_{p4}	0.8×10^{-9}
	K_{i4}	0.8×10^{-8}
Battery Control Loop	K_{p5}	1.5×10^{-8}
	K_{i5}	1.5×10^{-7}

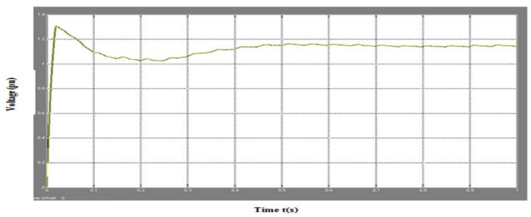
Table 1: controller gain parameters for v-f control



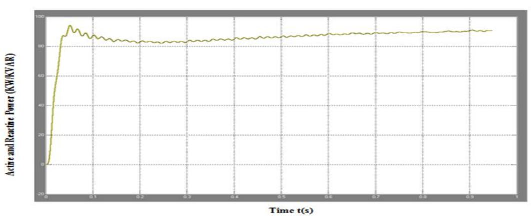
a)Active and Reactive Power of Diesel Generator



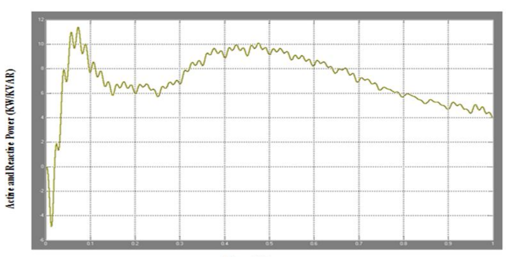
b)Microgrid Frequency



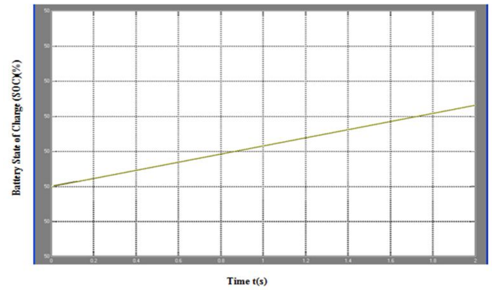
c)PCC voltage



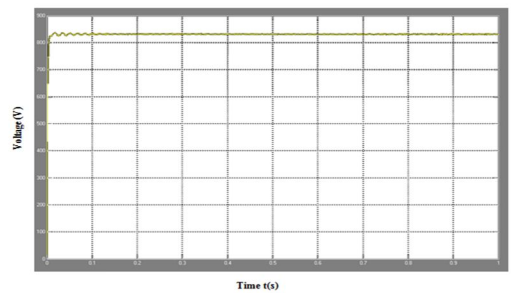
d)P inverter



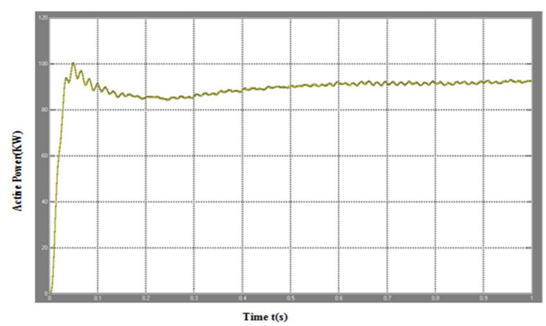
e)Q inverter



f)Battery State of Charge(SOC)(%)



g)Inverter DC side voltage



h)DC side inverter power

Fig 7: Results of coordinated v-f control with solar power including MPPT control

B. Results For P-Q Control Method

By considering the irradiances =1000w/m^2 & the controller in parameters for p-q is given in the below table 2.

Fig 8 (a)-(f) show the results for P-Q control with solar power including MPPT control

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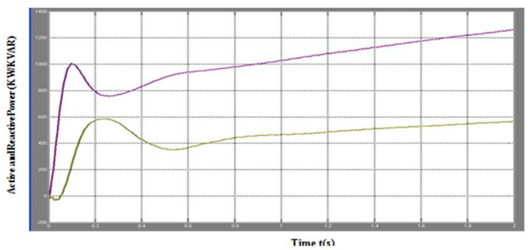
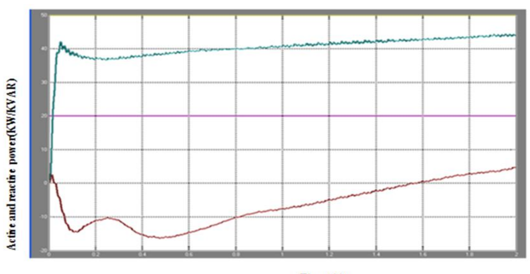
MPPT Control Loop	K_{p1}	6×10^{-8}
	K_{i1}	6×10^{-6}
Voltage Control Loop	K_{p2}	5×10^{-8}
	K_{i2}	5×10^{-7}
P_{AC} Control Loop	K_{p3}	2.5×10^{-9}
	K_{i3}	2.5×10^{-8}
P_{DC} Control Loop	K_{p4}	2.5×10^{-9}
	K_{i4}	2.5×10^{-8}
Battery Control Loop	K_{p5}	0.02×10^{-8}
	K_{i5}	0.02×10^{-7}

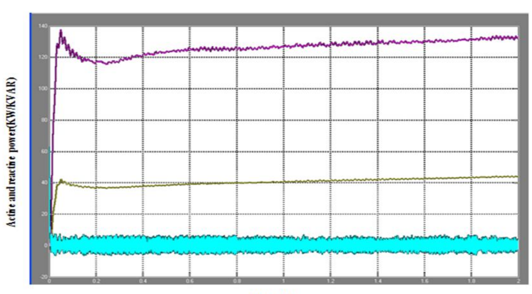
Table 2: controller gain parameters for p-q control



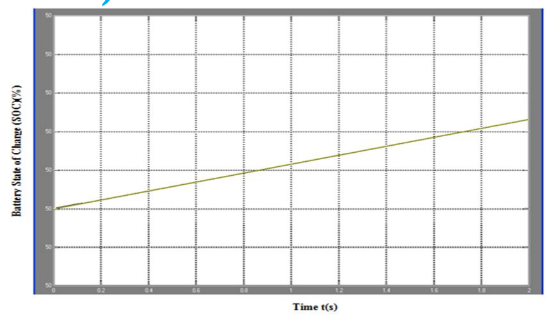
a)Active and reactive power of diesel generator



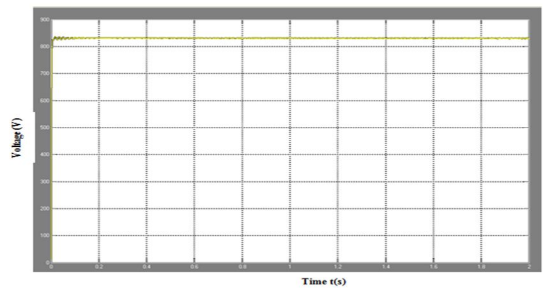
b)Actual active and reactive power of PV inverter



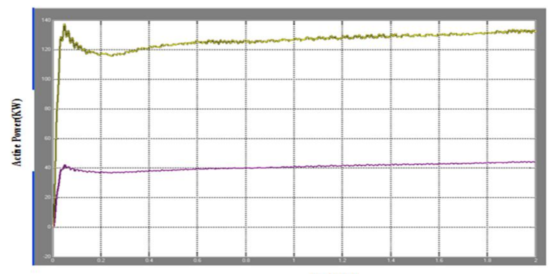
c) Active power from the PV generator, inverter injection and active power to and from the battery



d)SOC of a battery.



e)DC side voltage at the inverter input



f)Active power of inverter ac & dc sides

Fig 8: Results of coordinated P-Q control with solar power including MPPT control

VII. CONCLUSION

This paper shows the better coordination between the solar cell ,diesel generator & battery storage . By this proposed method, solar cell operates at MPPT. The proposed v-f control method shows satisfactory performance in voltage & frequency, come back to the nominal values in a matter of only 2 seconds. By p-q control method, DERs are used to supply some critical loads of a micro grid.

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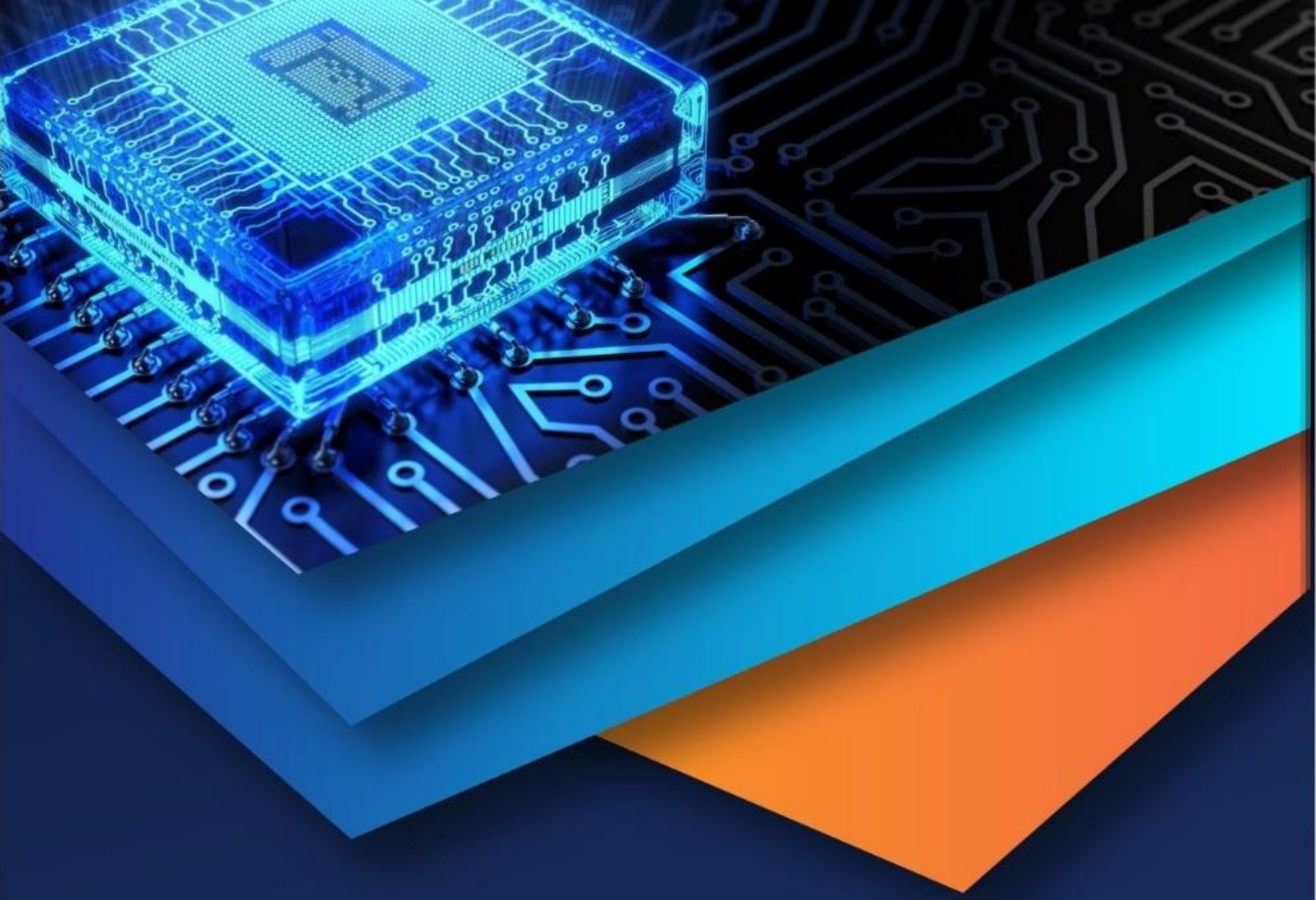

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