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Performance Assessment of Distributive Secondary Control of Microgrid

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Abstract:

Paper proposes a multi agent based distributed cooperative secondary level control of micro grid. Considering DGs in a micro grid as agents which requires only own information and the information of some neighbors. Input–output feedback linearization is used to control tracker synchronization problem and complex communication network used which improve the system reliability. The Secondary control is 0responsible to maintain the voltage and frequency of the micro grid within the acceptable ranges. To achieve a dynamic variation for the output active power ratios among the distributed energy resources, the distributive cooperative secondary control has to adjust the references of frequency for the rated active power and the references of voltage for rated reactive power. The proposed secondary control may lead to unacceptable voltage and frequency in the microgrid and has to adjust the references of the voltage and frequency consequently. A distributed networked Secondary control proposed approach is used in order to avoiding implementation of microgrid central controller and not only able to restore frequency and voltage of the MG but also ensures active and reactive power sharing so that the failure of a single unit will not produce the fail down of the whole system. Distributive cooperative secondary control ensures the stabilization and the synchronization of the inverters frequencies and regulates the frequencies to a rated value. The developed novel solution takes into account the converters parameters as apparent power limit and maximum active power which balance the system and improves reliability. The control parameters and its effectiveness for a desired response speed verified by the simulation of a microgrid test system.
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Keywords **—Distributed generation, Distributed cooperative control, multi-agent systems, synchronization.**

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I. INTRODUCTION

Recent energy development encourages entry of renewable resources and energy storage device in distribution areas. Due to shortage of conventional fuel like coal, gases and other chemical resources their prices escalating day by day and it's create an Energy crisis in modern Era. Also greenhouse gas emission, acid rain and water pollution find environmental issues with use of conventional fuel. Large network of electricity deviate voltage and frequency at consumer end which affect the power quality & reliability of energy. In modern year increase energy demand with increase comfort level and development .due to all these issues efficiency of conventional energy generation is very poor at consumer end so we need to move on green sustainable energy of resources. These notions emerge a new technology micro grid which is pure green and sustainable source of energy[1]. Distribution level of micro grid Improved sustainability with reliability among desired Energy demand. Effective integration of renewable resources realized with micro grids which facilitate the reliable and sustainable power among distribution consumers .Micro grid is combination of single controllable unit of small distributed generators and loads which provide power and heat at same time.The micro grid located downstream of electrical distribution network which encompasses with various variety of renewable energy resources, distributed storage, different types of load and utility grid. Point of common coupling (PCC) is common point which connect to micro grid with utility grid[2] . Distributed energy resources (DER) such as photovoltaic, fuel cells, Wind energy, micro turbines, gas

Turbines integrated into micro grid hub. Emerging potential of distributed generation increase with use of storage devices. Power electronic interfaces direct connect distributed energy resources (DER) to the electrical network. MG central controller (MGCC) is centrally controlled controller which is managed voltage and frequency among all DGs.power electronics and controllers provide properly control and flexibility of micro grid which ensure consumer demand as well as utilities. There is a point of common coupling (PCC) connection to the main distribution utility when a fault occurs a Separation Device disconnect MG to the main distribution utility. a LC (local Controller) control each DG control and exchange information of other DGs with the help from central controller. The central controllers communicate information among all DGs with the help of communication line and also provide a stable voltage and frequency control to individual DGs.

II. CONTROL OF MICROGRID

The primary control is designed to satisfy the following requirements [12]-[13], [15], [21]:

- To stabilize the voltage and frequency: Subsequent to an islanding event, the micro grid may lose its voltage and frequency stability due to the mismatch between the power generated and consumed.
- To offer plug and play capability for DGs and properly share the active and reactive power among them, preferably, without any communication links.
- To mitigate circulating currents that can cause over-current phenomenon in the power electronic devices and damage the DC-link capacitor.

The primary control provides the reference points for the voltage and current control loops of DGs. These inner control loops are commonly referred to as zero-level control. The zero-level control is generally implemented in either active/reactive power (PQ) or voltage control modes [3].In the PQ control mode, the DG active and reactive power delivery is regulated on the pre-determined reference points. The control strategy is implemented with a current-controlled voltage source inverter (CCVSI). H_1controller regulates the DC-link voltage and the active power through adjusting the magnitude of the output active current of the converter, i_P. H_2controller regulates the output reactive power by adjusting the magnitude of the output reactive current, i.e., i_q[4].In the voltage control mode, the DG operates as a voltage controlled voltage source inverter (VCVSI) where the reference voltage, $*v_0$, is determined by the primary control, conventionally via droop characteristics [5]. The nested voltage and current control loops in the voltage control mode are shown in Figure 1-4. This controller feeds the current signal as a feed forward term via a transfer function (e.g., virtual impedance). To fine tune the transient response, proportional-integral-derivative (PID) [5], adaptive [6], and proportional resonant controllers [7] are proposed for the voltage controller.Power quality of small-scale islanded systems is of particular importance due to the presence of nonlinear and single-phase loads and the low inertia of themicro grid [8]. To improve the power quality for a set of energy sources connected to a common bus, the control structure is used. $H_{LPF}(s)$ denotes the transfer function of a low-pass filter. Each converter has an independent current control loop, and a central voltage control loop that is adopted to distribute the fundamental component of the active and reactive powers among different sources. The reference point for the voltage control loop is determined by the primary control. The individual current controllers ensure power quality by controlling the harmonic contents of the supplied currents to the common AC bus [9]. The DG's control modes are usually implemented using the droop characteristic techniques [3].The droop control method has been referred to as the independent, autonomous, and wireless control due to elimination of intercommunication links between the converters. The conventional active power control (frequency droop characteristic) and reactive power control (voltage droop characteristic) are used for voltage mode control. Principles of the conventional droop methods can be explained by considering an equivalent circuit of a VCVSI connected to an AC bus. If switching ripples and high frequency harmonics are neglected, the VCVSI can be modelled as an AC source, with thevoltage. In addition, assume that the common AC bus voltage is V_{com} and the converter output impedance and the line impedance are lumped as a single effective line impedance of Z.

Primary control, as discussed, may cause frequency and voltage deviation even in steady state. Although the storage devices can compensate for this deviation, they are unable to provide the power for load-frequency control in long terms due to their short energy capacity. The secondary control, as a centralized controller, restores the micro grid voltage and frequency and compensate for the deviations caused by the primary control. This control hierarchy is designed to have slower dynamics response than that of the primary, which, justifies the decoupled dynamics of the primary and the secondary control loops and facilitates their individual designs [6].the block diagram of the conventional secondary control with a centralized control structure. Frequency of the micro grid and the terminal voltage of a given DG are compared with the corresponding reference values, $F_{ref}$and v_{ref}, respectively. Then, the error signals are processed by individual controllers as in [1,5]; the resulting signals (f and E) are sent to the primary controller of the DG to compensate for the frequency and voltage deviations. Frequency controller in [7] to facilitate synchronization of the micro grid to the main gird. In the islanded operating mode, this additional term is zero. However, during the synchronization, a PLL module is required to measure [4]-[8]. During the grid-tied operation, voltage and frequency of the main grid are considered as the references in [9].The secondary control can also be designed to satisfy the power quality requirements, e.g., voltage balancing at critical buses [10].

Tertiary control is the last (and the slowest) control level that considers the economic concerns in the optimal operation of the micro grid, and manages the power flow between micro grid and main grid [12]. In the grid-tied mode, the power flow between micro grid and main grid can be managed by adjusting the amplitude and frequency of DGs voltages.. First, active and reactive output powers of the micro grid, $P_G$and Q_G, are measured. These quantities are then compared with the corresponding reference values, ref P_G and ref Q_G , to obtain the frequency and voltage references.

The conventional control explorations a centralized control structure which capability globally on the bring together system-wide information and want a complex sparse two-way communication network .that badly disturbs system controllability and configurability which increases the dependability concerns by posing single point of failure. The single point of failure means overall Central controller failure and complete control system fails down. The distributed structure of the control structure improves the system reliability. In this control structure, the control protocols are distributed on all DGs [13]. Therefore, the requirement for a central controller is prevented and the control system does not stop down subsequent to failure of a single unit. Based on literature survey following conclusions can be drawn [15-17]:

- Control techniques should incorporate stochastic behaviour of RES.
- Droop control is used to ensure attainment of main control objectives as well as flexible plug-and-play operation and minimization of communication needs.
- Hierarchical control structure is used to regulate the microgrid frequency and voltage in large-scale power networks.
- Centralized and decentralized frequency-control algorithms are used to ensure stabilization and frequency regulation.
- A robust secondary control framework should be developed which is able to appropriately operate with minimum communication requirement.
- Appropriate load sharing mechanism between DG units should be developed for efficient and economical operation.
- Power quality issues in grid connected mode need to be addressed properly.

III. PROPOSED METHODOLOGY

The proposed control is based on large-signal nonlinear dynamical model of the DG. The block diagram of an inverter-based DG is contains a primary dc power source (e.g., photovoltaic panels or fuel cells) connected to an inverter bridge shown in Fig.1.The control loops which is set output voltage and frequency of the inverter bridge including the, voltage, current and power controllers[13].

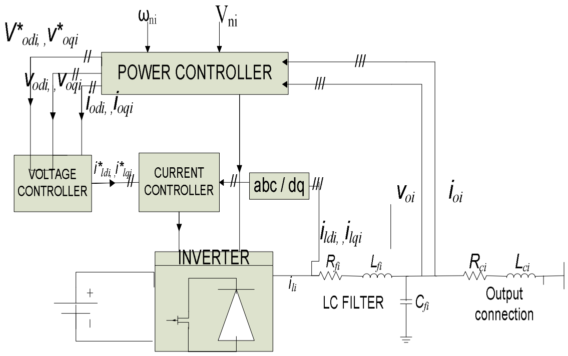

Fig.1. Block diagram of inverter-Based DG

The nonlinear dynamics of each DG are formulated in its own direct-quadrature (d-q) reference frame with rotating at the frequency of ω_i.one DG with the rotating frequency of ω_{com} is considered as the common reference frame. The angle denoted as $\delta_i$of the i^{th} DG reference frame with respect to the common reference frame satisfies the following differential equation [14]:

$$\delta_i=\omega_i- \omega_{com}$$

all of the reference frames rotate synchronously at a common angular frequency. Due to the presence of the frequency-droopcharacteristic [15].

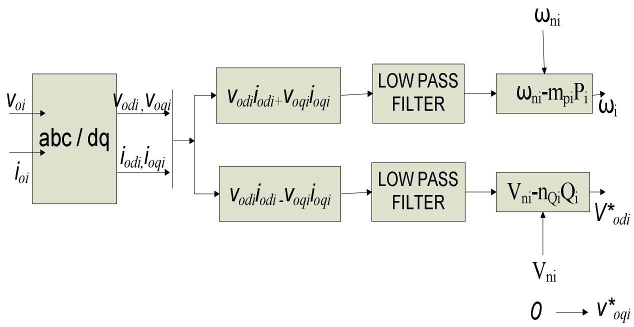

Fig. 2.Block diagram of power controller

The power controller block diagram shown in Fig. 3.with droop technique which provides the voltage references$\upsilon^*_{odi}$and υ^*_{oqi} of the voltage controller and operating frequency ω_i to the inverter bridge. Power controller used two low-pass filters to extract the fundamental component of the output active power(P_i)and reactive power (Q_i) with cut-off frequency ω_{ci} .differential equation of power controller can be written as:-

$$P_{i.}= -\omega_{ci}P_i + \omega_{ci}(\upsilon_{odi}i_{odi} + \upsilon_{oqi}i_{oqi})$$

$$Q_i= -\omega_{ci}Q_i + \omega_{ci}(\upsilon_{oqi}i_{oqi} - \upsilon_{odi}i_{odi})$$

Where υ_{odi}, υ_{oqi}, $i_{odi}$and $i_{oqi}$are the direct and quadrature components ofυ_{oi} and i_{oi} in Fig. the primary voltage control strategy for each DG aligns the output voltage magnitude on the d-axis of the corresponding reference frame [16]:-

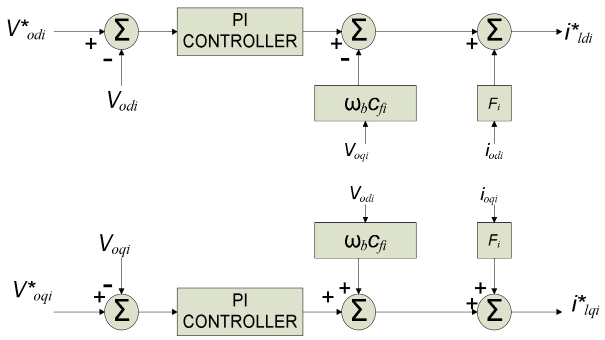

Fig. 3.Block diagram of power controller

The block diagram of the voltage controller is shown in Fig. 3 [17. The differential algebraic equations of the voltage controller are written as

$$\phi_{di} = \upsilon^*_{odi} - \upsilon_{odi}$$

$$\phi_{qi} = \upsilon^*_{oqi} - \upsilon_{oqi}$$

$$i^*_{ldi}= F_i i_{odi} - \omega_b C_{fi}\upsilon_{oqi} + K_{PVi}(\upsilon^*_{odi} - \upsilon_{odi}) + K_{IVi}\phi_{di}$$

$$i^*_{lqi} = F_i i_{oqi} + \omega_b C_{fi}\upsilon_{odi} + K_{PVi}(\upsilon^*_{oqi} - \upsilon_{oqi}) + K_{IVi}\phi_{qi}$$

whereϕ_{odi} and $\phi_{oqi}$are the auxiliary state variables defined for PI controllers in Fig. 3.ω_b is the nominal angular frequency. Other parameters are shown in Figs. 1 and 3. [18].the differential algebraic equations of the current controller are written as

$$\boldsymbol{\Upsilon_{di} = i^*_{ldi} - i_{ldi}}$$

$$\boldsymbol{\Upsilon_{qi} = i^*_{lqi} - i_{lqi}}$$

$$\boldsymbol{v^*_{idi} = -\omega_b L_{fi} i_{lqi} + K_{PCi}(i^*_{ldi} - i_{ldi}) + K_{ICi}\Upsilon_{di}}$$

$$\boldsymbol{v^*_{iqi} = \omega_b L_{fi} i_{ldi} + K_{PCi}(i^*_{lqi} - i_{lqi}) + K_{ICi}\Upsilon_{qi}}$$

whereΥ_{di} and $\Upsilon_{qi}$are the auxiliary state variables defined for the PI controllers and i_{ldi}andi_{lqi} are the direct and quadrature components of in Fig. 1.

IV. DISTRIBUTED COOPERATIVE VOLTAGE CONTROL

The a distributed cooperative control is synchronise the voltage magnitude $v_{o,magi}$ of DGs to the reference voltage v_{ref}.The synchronisation of the voltage magnitude e_{vo} of DGs is equivalent to the direct term of output voltages vodi.Choose an appropriate control inputs Vni , in the secondary voltage control for droop characteristics. The dynamics of the voltage and current controller are much faster than the dynamics of the power controller therefore neglecting the fast dynamics of the voltage and current controller [18].

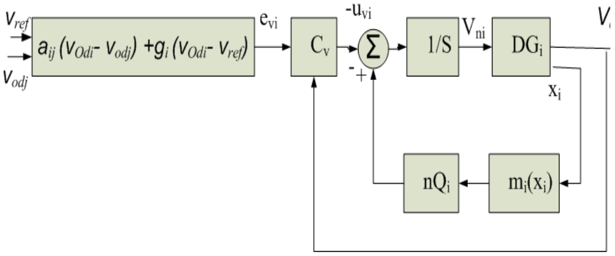

Fig.4-Distributed Cooperative Secondary Voltage Control

The nonlinear dynamics of the i_{th} DG can be written as

$$\boldsymbol{v_{odi} = v_{ni} - n_{Qi} Q_i}$$
$$\boldsymbol{v_{oqi} = 0}$$

Differentiating the above equation

$$\dot{v}_{odi} = \dot{v}_{ni} - n_{Qi} Q_i = u_{vi}$$
$$\dot{v}_{oqi} = 0$$

whereu_{vi} is an auxiliary control. This process is called as input–output feedback linearization.According to a dynamic system the secondary voltage control transformed to the tracking synchronisation problem for a first-order and linear multi-agent system of a micro grid including N DGs.

$$\dot{v}_{od1} = u_{v1}$$
$$\dot{v}_{od2} = u_{v2}$$

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$$\dot{v}_{odn} = u_{vn}$$

it is assumed that all DGs communicate to each other with proper prescribed communication digraph to achieve the synchronisation for void[19] .The auxiliary controls uviare select based on the own information of each DG and its neighbours DGs information in the graph. which as:-

$$\boldsymbol{u_{vi} = -c_v e_{vi}}$$

where the control gain is c_v and e_{vi} is the local tracking error of neighbourhood DGs.

$$e_{vi} = \Sigma\, a_{ij}(v_{odi} - v_{odj}) + g_i(v_{odi} - v_{ref})$$

i_{th} DG is connected to the reference with weight of the edge pinning gain $g_i \geq 0$ and a_{ij} is the coefficients element of adjacency matrix A .

To prove synchronisation of the proposed controller following lemmas and theorem are considered.the global neighbourhood error vector for graph ς are

$$e = (L+G)\,(v_{od} - v_{ref}) = (L+G)\delta$$

where δ is global disagreement vector ,$v_{od}$and e are global variables which is defined as $v_{od} = [v_{o1}\ v_{o2} \ldots\ldots v_{oN}]^T$, $e = [e_{v1}\ e_{v2} \ldots\ldots e_{vN}]$.

Lemma 1 [30]: Let the digraph G have a spanning tree and $g_i = 0$ for at least one root node. Then

$$\|\delta\| \leq \|e\| / \sigma_{min}(L + G)$$

Where e = 0 and $\sigma_{min}(L + G)$ is the minimum singular value of L + G if and only if all nodes synchronise[20][21].

Lemma 2 [28]: Let the digraph G have a spanning tree and $gi \neq 0$ for at least one root node. Let P = diag{1/wi}, where w_i are the elements of a vector w that satisfies Aw = 1N, where $A \equiv L + G$. Then, $Q \equiv PA + ATP$ is positive definite.

Theorem 1: Let the digraph G have a spanning tree and $g_i \neq 0$ for at least one DG. Let the auxiliary control u_{vi} be chosen as in (12). Then, the global neighbourhood error e in (14) isasymptotically stable. Moreover, the DG output voltage direct terms V_{od} is synchronise to V_{ref}.

The block diagram of the secondary voltage control based on the distributed cooperative control is shown in Fig. 5. The control input V_{ni} is written as

$$V_{ni} = \int (u_{vi} + n_{Qi}\dot{Q}_i)\, dt$$

V. DISTRIBUTED COOPERATIVE FREQUENCY CONTROL

Distributed cooperative secondary frequency control is designed to is designed to choose appropriate control inputs V_{ni} to synchronise the frequency of DGs ω_i with the reference frequency ω_{ref}.

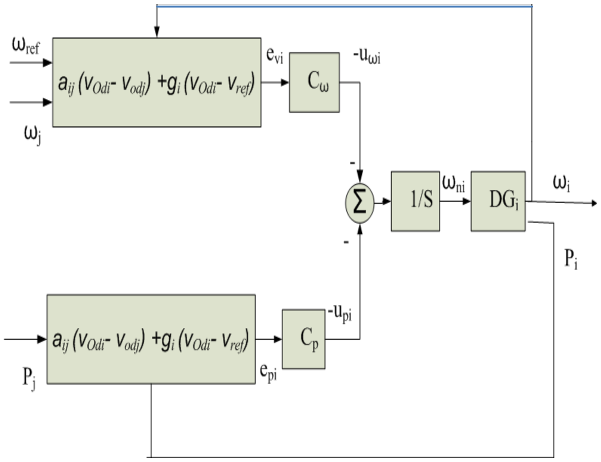

Fig.5-Distributed Cooperative Secondary Frequency Control

The nonlinear dynamics of the i_{th} DG, seen in (7), are considered. Differentiating the frequency droop characteristic in :-

$$\dot{\omega}_i = \dot{\omega}_{ni} - m_{Pi}\dot{P}_i = u_{\omega i}$$

Where $u_{\omega i}$ is an auxiliary control to be designed. Above Equation is a dynamic system for computing the control input $\omega_{ni}$from $u_{\omega i}$. According to the secondary frequency control of a micro grid including N DGs is transformed to a tracking synchronisation problem for a first-order and linear multi-agent system. To achieve the synchronisation, it is assumed that DGs can communicate with each other.

VI. RESULT ANALYSIS

PV array I-V and P-V characteristics are shown in below figure from the model which is used in Simulink model respectively.

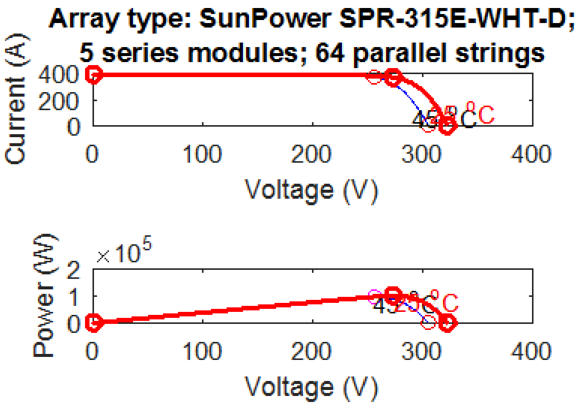

Fig6. I-V and P-V characteristic of PV array

Figure show the I-V characteristic of PV array for different value of temperature and fixed irradiance of 1000 W/m^2.we consider sunny atmosphere with free of cloud PV array show open circuit voltage of 54.7V. at temperature 45^{o}C a point of maximum power tracking occurs it produce maximum power of 100KW.

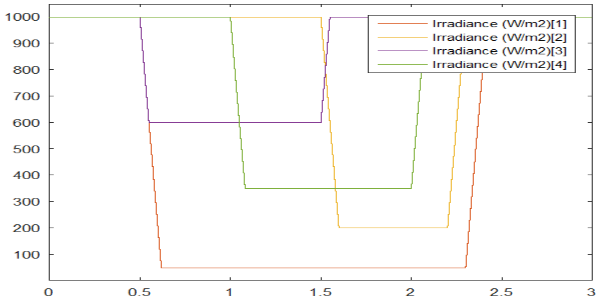

Fig7. Irradiance of PV array

Figure show different irradiance variation of each PV array, PV_1 has different irradiance of 1000, 1000,50,50,1000,1000 at fixed temperature of

40^{o}c., PV$_2$ has different irradiance of 1000,1000,200,200,1000,1000 at fixed temperature of 45^{o}c, PV$_3$ has different irradiance of 1000,1000,600,600,1000,1000 at fixed temperature of 35^{o}c, PV$_1$ has different irradiance of 1000,1000,350,350,1000,1000 at fixed temperature of 45^{o}c.

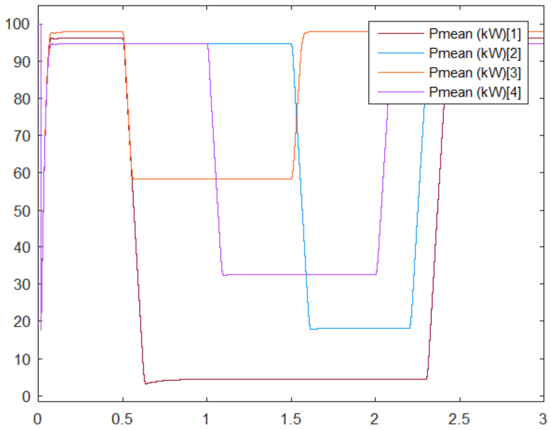

Fig8. Output Power of PV array

Figure show power of each array at different irradiance and different temperature of each array .it show highest peak power of 100 KW each array at 1000w/m^2 irradiance and its goes down with fall in irradiance.as we see at different irradiance we find a constant power in variation of temperature. In maximum irradiance we receive peak power of 400 KW but when variation in irradiance we receive average power 150KW to 100KW.

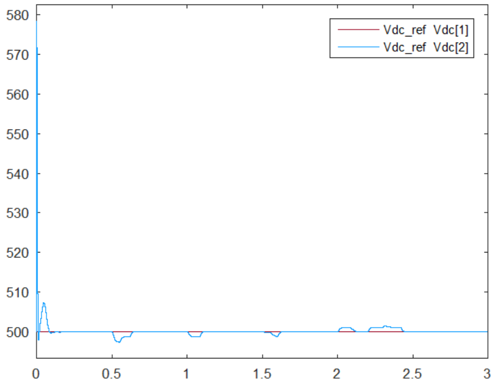

Fig9. Boost dc output voltage

Above figure show Boost dc output voltage with ref dc voltage.it is almost constant but some fluctuation occurs due to variation in irradiance. We take reference value of output dc voltage 500V constant for converter distributed control.

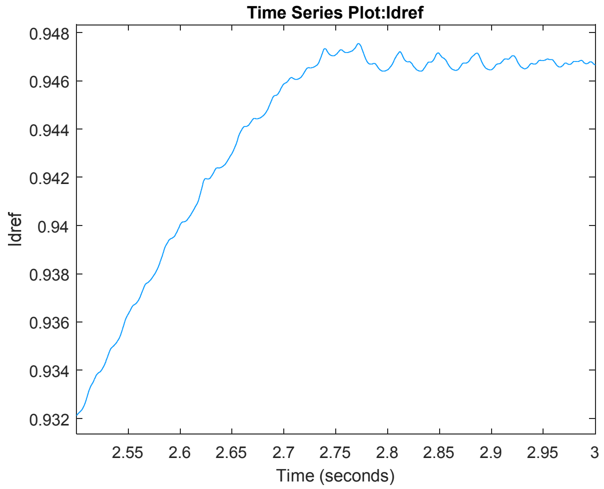

Fig10. I$_d$ reference

I$_d$ reference after secondary control in distributed manner look like shown in fig10.it is all units in per unit values. Then these secondary and

Primary controls generate a reference pulse for full wave converter which is control the output of converter as shown in below fig.

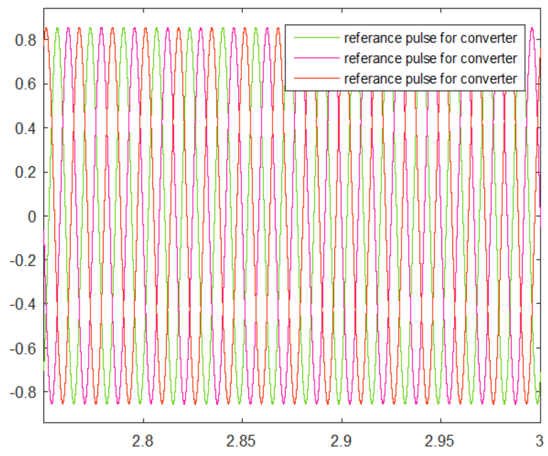

Fig11.Pulse input to converter

After pulse input to converter it produce three phase sinusoidal voltage 230(phase to phase) which is again filter with LC filter . a transformer 230/25KV connected in line which convert voltage from 230Volt to 25KV at connect linefrom a grid .At grid level we measure voltage and power and we find fallowing results.

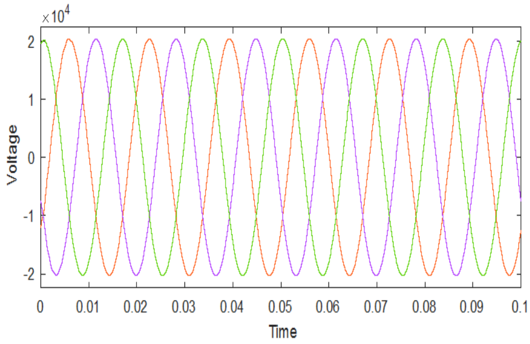

Fig11.Grid Voltage

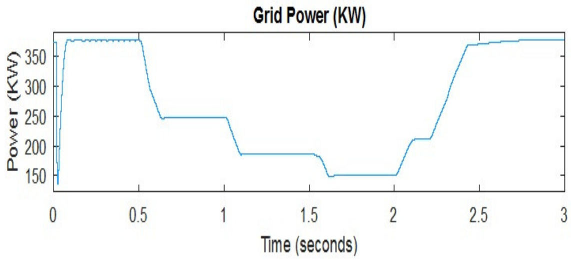

Fig12.Grid Power

As we see from figure voltage at grid point is 25KV and power vary along with irradiance. Therefore we find that after use of distributed control voltage almost constant and also frequency constant. There are no variation in voltage and frequency. Grid power varies with irradiance but it never goes down below 125 KW. All controlling are take care by grid.

VII. CONCLUSION

As above result we find that distributed control is more stable and suitable for grid connected microgrid .all parameter of voltage and current take as a feedback for distributed control and we take Vdc as reference then finalize more conclusions:-

- Hierarchical control strategy is adopted to maintain power balance, voltage and frequency levels and optimal micro grid operation.
- secondary control in micro grids succeed in regulating the inverters frequencies and ensuring proportional power sharing among the inverters.
- The distributed structure obviates the requirements for a central controller and complex communication network which, in turn, improves the system reliability.
- proposed control strategy has a good performance in removing frequency and voltage steady-state errors and can share

reactive power between DG units perfectly.

- It is not only able to restore frequency and voltage of the MG but also ensures reactive power sharing.
- A robust secondary control framework is elementary for smooth functioning of Microgrid.
- Distributed secondary control can significantly reduce communication requirement and result in faster performance.
- Control algorithm should suitably address appropriate load sharing mechanism and power quality issues.
- Conventional controller may not be suitable in Microgrids due to stochastic nature of generating sources..

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