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Droop Control Technique for Parallel Inverters Operation in Lighting Smart Grids Applications

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Abstract - In last few years, many countries are investing in smart grid technologies due to their potential benefits in improving energy efficiency, reliability, and sustainability, to meet demand of electrical power of booming population by integrating renewable energy and reducing the greenhouse gas emission. A Smart-Grid is an advanced, intellectual, localized, small scale grid which can be disconnected from centralized grid and operates autonomously but the integration the renewable energy generations can result in a substantial voltage or frequency deviation in MGs. To enable zero net-energy consumption and optimal power management for future micro-grids, several key technologies and strategies need to be implemented. Therefore, this paper introduces an enhanced finite control set model droop control. Voltage and frequency can be regulated by controlling the active power injection into the system. The effectiveness of the proposed Droop Control is verified by simulation results in the Matlab/Simulink environment. A detailed investigation of voltage regulation of a residential Micro-Grid (MG) is given to demonstrate the effectiveness of the proposed approach.

***Keywords*: Renewable Energy System, Smart Grid, Smart City, Smart Control System, Photovoltaic, Voltage Source Inverter).

1. INTRODUCTION

In recent years, due to the growth of load demand in the entire world and the development of power electronics and information technology, distributed generators (DGs) have attracted attention in a large scale, this DG units form a microgrid (MG) structure with a different architecture. MGs are the trend nowadays in generation of energy power, the integration of renewable energy based generators helps in this kind of studies. The fluctuation and the variation of resources make the challenge bigger in designing and controlling these micro-networks specially in islanding mode. Solar and wind power have been the fastest-growing energy for the last decade in worldwide [1].They play an important role being in architecture in these DGs.

In general, renewable energy sources (RES) are inexhaustible by nature. They give promising solutions in building sustainable and ecofriendly electric power [2].Moreover, they decrease pollution in limiting the emission of carbon dioxide coming from the conventional methods for energy generation based on fossil fuels. RES must work in a complementary way to manage the response for demand of power in any moment. DG units forming the MG can be classified in two categories according to their operation system, the first into a grid forming (voltage controlled) in islanding mode where the micro-sources act as voltage sources. The second into grid following (current controlled) generally operated in grid connected mode [3], many studies discussed control strategies when the MG is connected to the main grid.

In particular, when these DGs are connected to the conventional grid via inverters, several challenging technical problems should be studied in order to manage the energy consumption without any problems. An excellent algorithm management power presented in [4] for a coordinated control of distributed generators integrated to a DC MG in islanded and grid connected modes.

Communication unit. To overcome these boundaries, decentralized controllers are presented, droop controller for a parallel mode operation of different inverters related to DGs forming the MG, has to be used to eases the difficulties in thermal management of power, capable to provide system redundancy and high reliability needed by customers.

Different control techniques for inverters working in parallel mode presented in [8]. Using the conventional droop method, the output impedance and line impedance are considered to be mostly inductive, which is often justified by the large inductor value or by the long distances between DG units [9]. In [10] a universal droop control strategy is discussed witch can be applied to all practical inverters without the need of knowing the impedance angle. In grid-connected mode, the voltage and frequency are maintaining stable due to the grid supply while the current in output of inverters must be controlled. In the opposite hand, when the MG operate in islanding mode , the frequency and the output voltage of DGs doesn't maintain constant due to the nonlinear loads , inverters work in voltage source and we must applied a strategy of control to stabilize the system [11-12].

In the literature, we found multiple studies focused in the droop understanding operation, static droop compensator is utilized for power sharing in [12], a novel droop controller presented in [13] by Yao et al, based on a virtual complex impedance loop for a paralleled inverter system. The proposed controller shows effectiveness in sharing power compared to a conventional droop method witch cannot achieve such results making slow and oscillating transient responses. Same improved droop controller presented in [14], authors mainly utilize error reduction and voltage recovery operation establishing a signal control mechanism to share a reactive power for islanded MG. To improve the active and reactive power decoupling performance, Zang et al in [15] proposed different structures of primary droop control architecture applied on parallel grid inverter supporting AC MG system. In [16] Abdel-Rady and El-Saadany proposed an adaptive droop controller based on a static conventional strategy, the gain adaptive signal uses filtered active and reactive powers as indices, for that a smooth power sharing performance can be obtained. Same thing in [17], where Tuyen et al showed a robust adaptive droop controller for DC-MG implementation. Authors highlighted the control methodology that require a closed-loop model reference adaptive control utilizing a robust projection algorithm for normalization technique. When the communication between parallel inverters is difficult due to the distance location between DG units, the droop control uses local feedback signals to enhance the sharing of power using wireless connection, like presented in [18].

To enable zero net-energy consumption and optimal power management for future smart city or buildings, this paper discusses the (DC) voltage and frequency regulation approach to address the rise/drop of voltage in a Microgrid, equipped with a residential Photovoltaic (PV) system, storage battery (SB), residential load and Smart Control Strategies (SCS) of parallel operated inverter. Voltage and frequency can be regulated by controlling the active power injection into the system. The effectiveness of the proposed Droop Control is verified by simulation results in the Matlab/Simulink environment. A detailed investigation of voltage regulation of a residential Micro-Grid (MG) is given to demonstrate the effectiveness of the proposed approach.

2. GENERAL CONFIGURATION OF MICROGRID

The classical main grid has a limited number of principles generators, a long distribution cables and high maintenance and cost, especially when it deliver power to rural areas [19]. Additionally the depleting of fossil fuels and their negative influences on environment are the main problems for this electrical-network. MGs are created to help incorporate DG units into the existing main grid or in autonomous functioning mode (Figure 1 illustrate the two modes of operation for MG in islanding and grid-connected one).

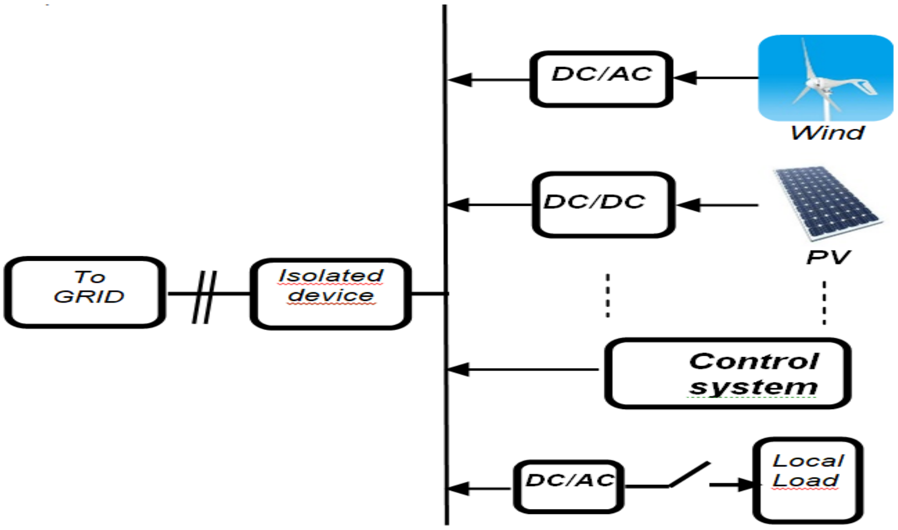


Fig.1 An example of microgrid architecture

They help reducing gas emissions, they are economical and environment friendly. MG is a small network capable for supplying electric power to a local area, antenna-network, and small industry projects. In [20], a study is proposed to help understanding the benefits of MG for electric power supply in rural areas, which gives opportunities to countries to improve the quality of applying energy with the integration of RESs in their generation of power in future previsions. Smart grid (SG) (Fig.2) in the other hand composed from multiple MGs units with the application of an appropriate communication system, connecting all components together from DGs, metering and monitoring system to consumers. It can be defined as an electrical grid that intelligently integrates all this elements to deliver power energy in a reliable secure way with better exploitation of RES.

The advantages of SG based on the integration of RES can be summarized into following points:

• High-level integration of RES in the main grid helping improving power quality.

• Adding consumers to the energy equation through the application of monitoring tools that allows individuals to properly control the energy flow.

• Voltage regulation and frequency stabilization with the application of a demand response program providing better sharing of power between energy service provider and consumer grounded on measuring data.

3. THEORY OF DROOP CONTROLLER TECHNIQUE

There are two categories of methods or techniques for controlling these networks in power sharing mode [4]; [13-14]:

• Methods using centralized control.

• Methods using local control.

Centralized control methods are techniques that use a SCADA (Supervisory Control and Data Acquisition) and the second is power sharing techniques based on a master-slave configuration [4]:

The methods that use local control are designed to share the powers of the various production sources interconnected to the AC bus via the control of the inverters connected in parallel. Several approaches have been proposed, such as Droop Control, which is the most used. In our study, we will use this droop controller for a detailed study. Unlike local controllers, the classic active and reactive power droop allows for power sharing without necessarily requiring a communication link between the control points. Because of its simplicity, Droop Control is the most widely used technique in several research projects for the control of parallel sources, when the power demanded by the load increases the controller gives the order to the generators to vary their frequencies, which produces an acceleration or a slowing down of the rotary machine due to the inertia of the system. [3 to 4.11]

a) MG interface inverter based on hierarchical control

Microgrid is usually composed of DC sources such as PV, fuel cells, batteries. In addition to an AC sources such as micro turbines, wind generator witch need to be rectified. DC voltage source has to be converted using voltage source inverter (VSI) to meet the load demand. These different types of sources can connect or disconnect to the network at any time, though, the dynamic behavior of inertial and non-inertial sources is different, many strategies of VSI control could be applied to manage a better sharing of active and reactive power. The hierarchical control scheme is very promising to achieve a better performance in the operation of a paralleled VSI system. The hierarchical control consist of three levels is shown in Fig.3,[21] :

- The primary control is based on the droop method, including an output-impedance virtual loop, maintains voltage and frequency stability of the MG.
- The secondary control allows the restoration of the deviations produced by the primary control.
- The tertiary control manages the power flow between the MG and the main grid.

b) Droop control

A number of control techniques have been reviewed for proper operation of parallel-connected inverters in MG. Between these methods, voltage and frequency droop control has make reputation and is considered as a well-established method [22]. The conventional droop control is mainly used to realize plug and play features for DGs; the synchronous generators are equipped with P/f droop control witch make a balance in extracted ac power with the use of mechanical power as input[11].

A micro-network (Fig.2) is assumed which includes production sources connected to the PCC point. The droop controller is based initially on these considerations.

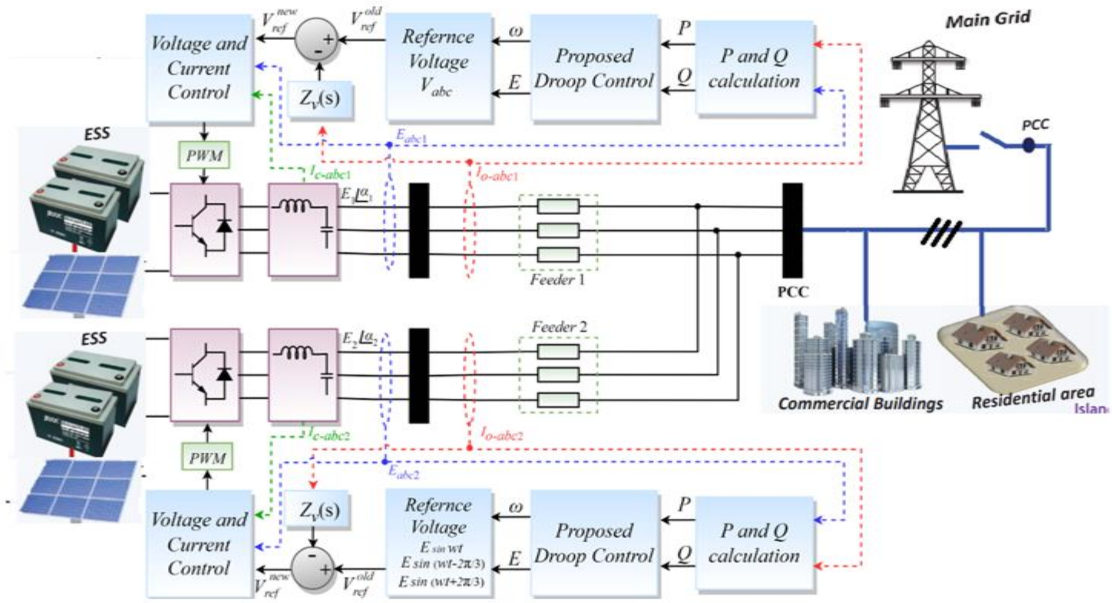


Fig.2. Micro-Grid scheme based Droop Control technique [11].

The generator change their speed related to its inertia. The active and reactive power for each inverter can be expressed as follows:

$$P = \frac{EV \sin \alpha}{X} \tag{1}$$

$$Q = \frac{EV \cos \alpha - V^2}{X} \tag{2}$$

Where E and V are the amplitudes of the inverter output voltage and the common bus voltage, respectively, α is the power angle and X is the output reactance of the inverter.

From equation above, the active power injected from the inverter is influenced by the power angle, and the reactive power is reliant to the amplitude difference between E and V. The equations of the droop characteristics of P related to ω and Q related to E is expressed as follows: Fig.5

$$\begin{cases} \omega_i = \omega^* - m_i * P_i \\ E_i = E^* - n_i * Q_i \end{cases} \tag{3}$$

Where Pi, Qi, are active power output and reactive power output, ω* is the rated frequency and E* is the rate voltage amplitude.

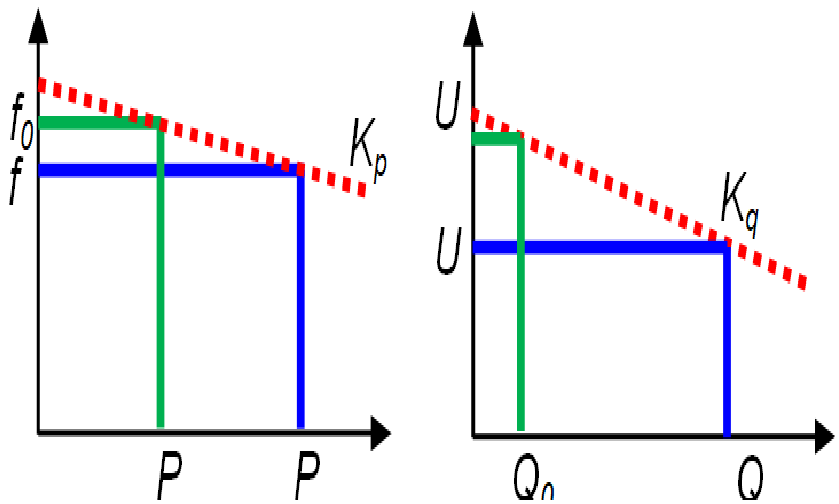


Fig. 3: Frequency and voltage droop characteristics as a function of modified active and reactive power [23]

When the line impedance shifts, the conventional droop control cannot provide a performing sharing of reactive power due to the limitation among parallel-connected inverters. Figure.4 gives the equivalent diagram of the system (source-line-point PCC).

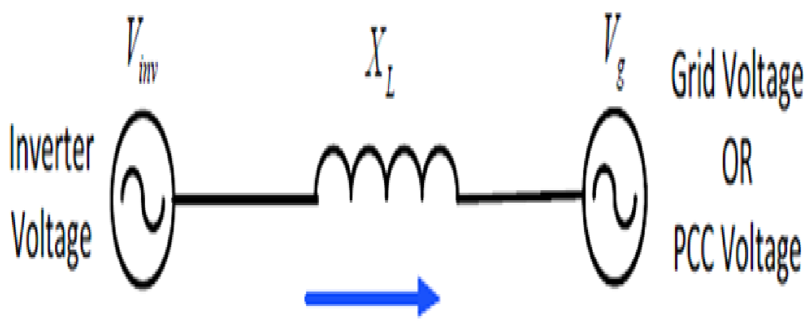


Fig.4. Power Flow between inverter and grid [11]

It is possible to define a relationship between the reactive power with the voltage level and between the active power and the frequency of the system. Equation (4) and (5) [3-4], [11]:

$$P = \frac{V_{inv} V_g}{X_L} \sin(\delta) \tag{4}$$

$$Q = \frac{V_g V_{inv} \cos(\delta) - V_g^{\ 2}}{X_L} \tag{5}$$

d represents the voltage phase generated by the inverter Vinv. XL is the impedance between Vinv and the voltage at the interconnection node Vg. If (d→0), sin (d) ≈d therefore the active and reactive powers are given by:

$$P = \frac{V_{inv} V_g \delta}{X_L} \quad (6)$$

$$\delta = \int (\omega_{inv} - \omega_g) \quad (7)$$

$$Q = \frac{V_g (V_{inv} - V_g)}{X_L} \quad (8)$$

These equations show the link between the active power and the phase angle and between the reactive power and the voltage level. However, low-voltage lines are normally more resistive, and it would be more appropriate to define a relationship between reactive power with phase angle and active power with voltage level [4], [11-12]:

The pulsation of frequency (f) and the level of voltage (V) are given by:

$$f = f_0 - k_\omega.(P - P_0) \quad (9)$$

$$V = V_0 - k_v.(Q - Q_0) \quad (10)$$

- fo and V0 : Nominal values of frequency and voltage level of micro-grid system.
- Kω et Kv : Droop coefficients of displacement.
- P0 et Q0: Active and reactive power values equivalent to the nominal values of the micro-grid voltage.

Figure.5 shows graphically the principle of displacement used in the Droop controller. [12]:

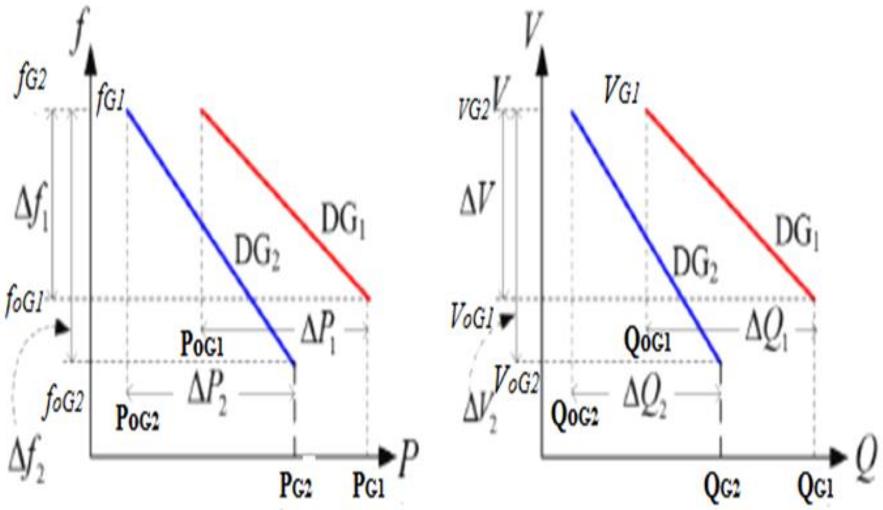


Fig 5. P-F and Q-E droop characteristics

Fig.6, present a different diagram block of droop control strategy based on active and reactive powers calculation.

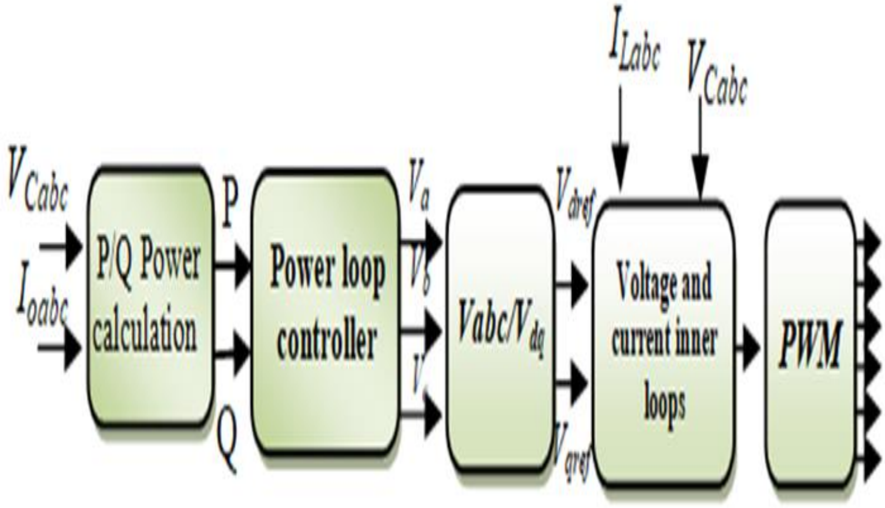


Fig.6: Schematic diagram block of droop control

Using load current and voltage capacitor in output inverter, the first block calculate the active and reactive power (P, Q) Second block generates the frequency and reference voltage values using equations (9) and (10), using these last two quantities, we can make a reconstruction of three voltages Vabc. Who are transformed into two reference voltages (Vdref ,Vqref).

These two voltages values are introduced into the control unit which comprises two loops for regulating the voltage and current, after that we have to switch mode to get the three sinusoidal signals of references. These voltages values are compared with a triangular signal in the PWM block in order to generate six pulses for switching inverter. In this way, the active power of each source can be controlled by varying the frequency (phase angle) and the reactive power can be regulated by varying the amplitude of the output voltage in the inverter.

In the next, numerical simulations will be presented of active and reactive power sharing between three sources which are linked to the AC bus by power interfaces (voltage inverters).

The system structure is represented in Fig.4. this model is summarised as a microgrid with two parallel DGs (DG1, DG2). We perform two simulation tests, the first for a variable load in isolated and connected mode

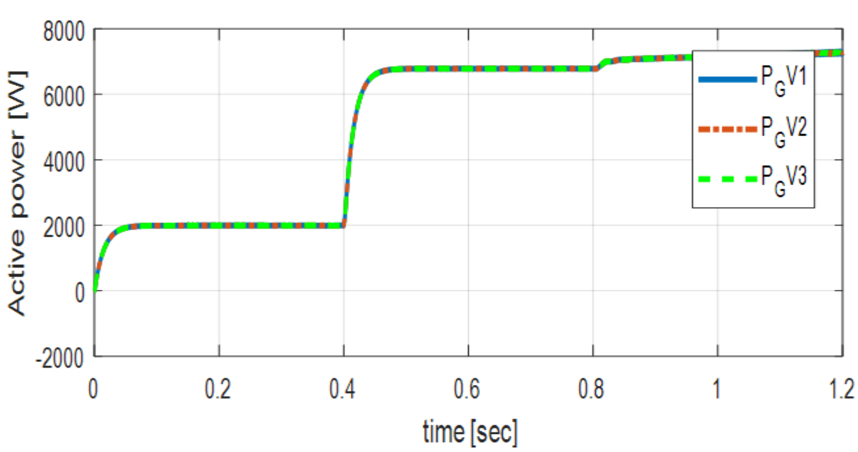


Fig.7 : Active Power

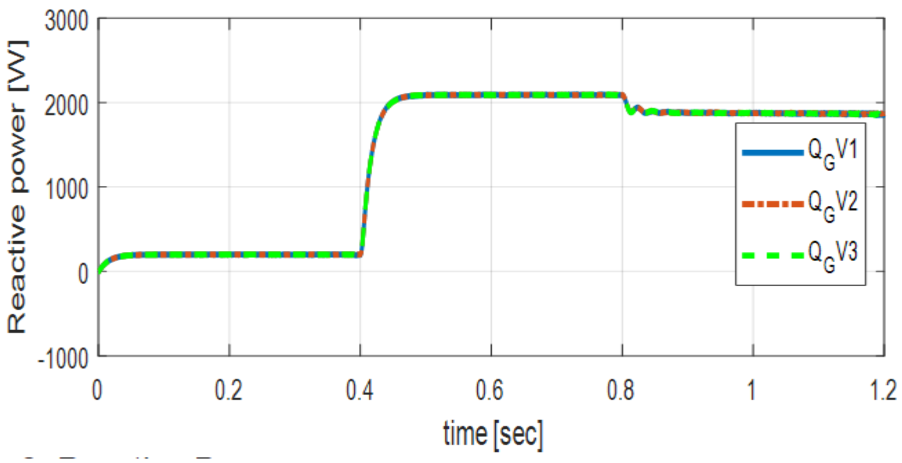


Fig. 8: Reactive Power

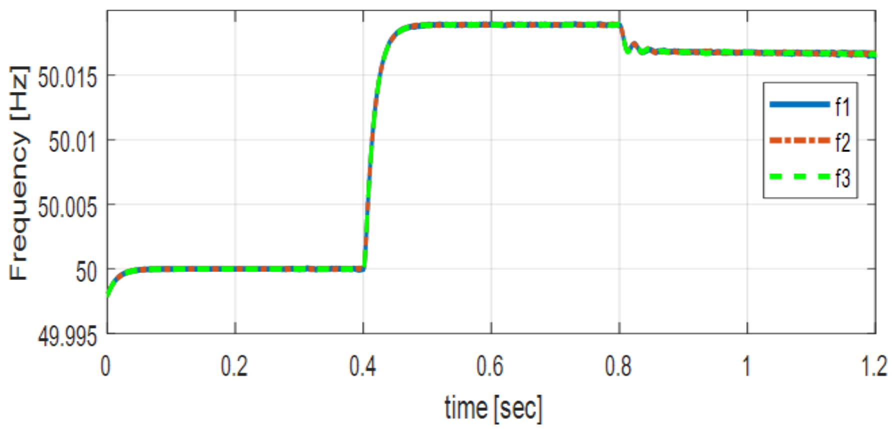


Fig. 9: Frequency

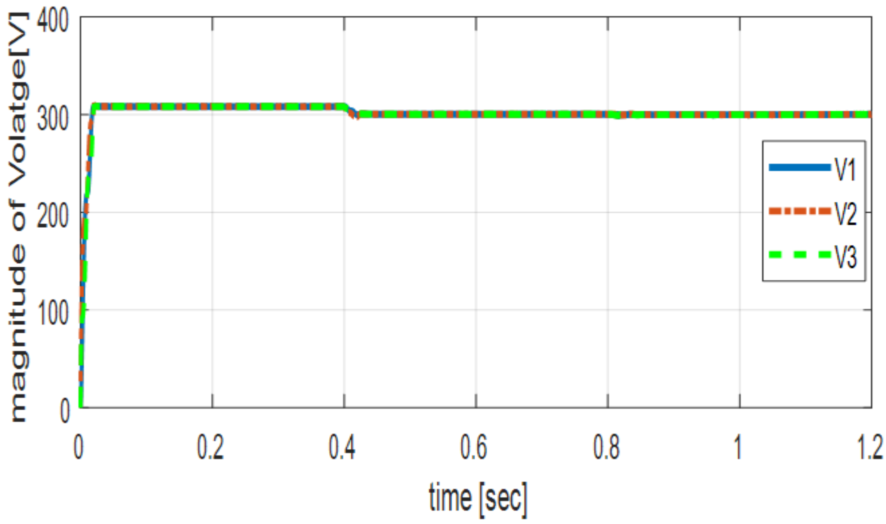


Fig. 10: Magnitude of voltage load

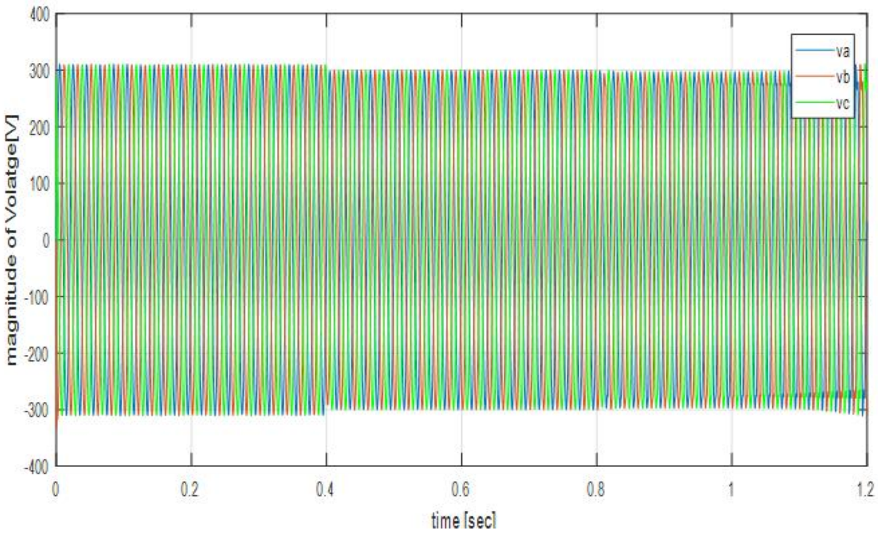


Fig. 11: Three phases load voltage

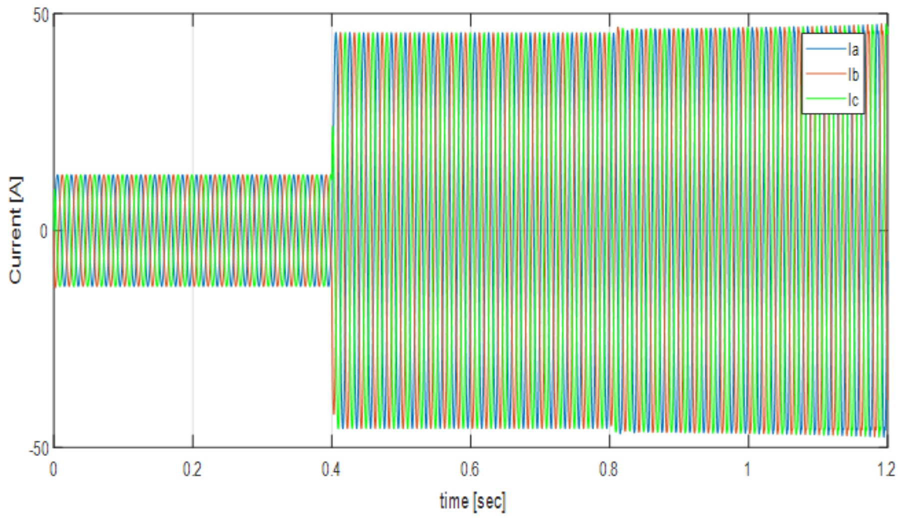


Fig. 12: Three phases load current

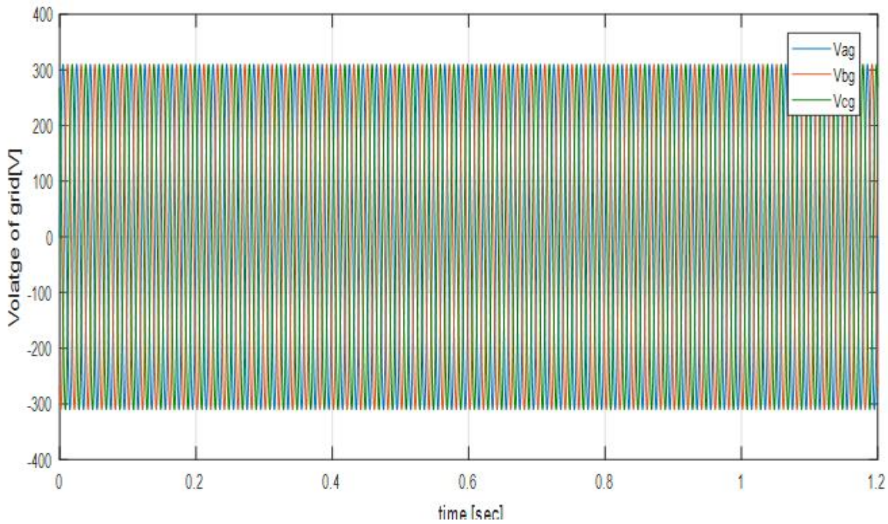


Fig. 13: Three phases grid voltage

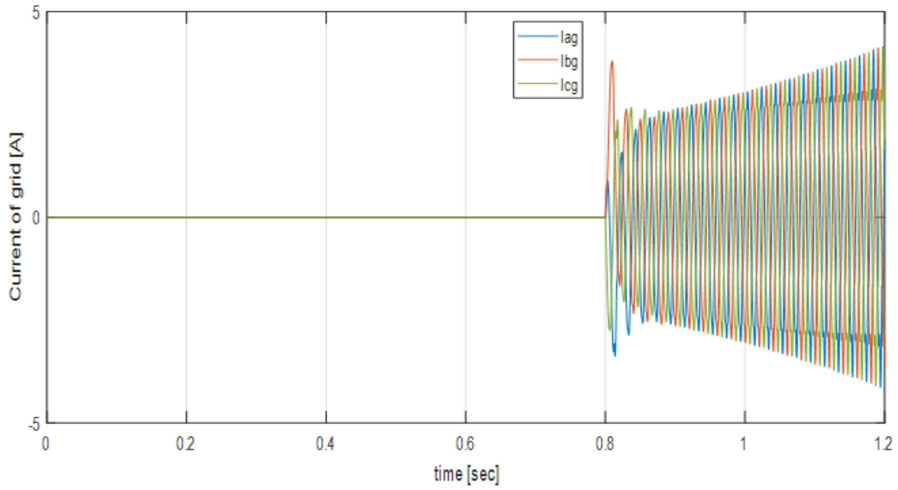


Fig. 14: Three phases grid current

With initial load of 2000W active power and 100VAR reactive power, at the instant 0.4s the load increases to 7000 W for active power and 2000 VAR for reactive power.

According figure(7 and 8), we observe the good sharing of the active and reactive power the load has been shared equitably between two parallel DGs for the first mode, the performance of the proposed power controller is always maintained. It should be noted that the increase in reactive power leads to a decrease in voltage.

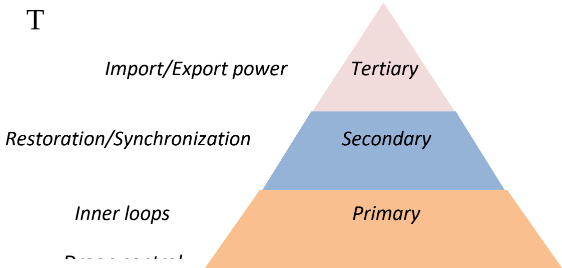
From Figure 9, we observe that the frequency is maintaining stable in 50 Hz (nominal frequency), where the difference between the frequency of voltage generated by each inverter and the nominal frequency is almost zero in both transient and study state, even in load power variations 2000 W to 7000 W, the frequency is 50.015 Hz.

According Fig (7-9) and Figs(8-10) the impact on the voltage and frequency at the inverter output during power sharing. It is observed that the Q-V and P-f droop curve having the same droop coefficient as they are similar responses; On the other hand, both the arctan and angle droop have increased stability over the 5 - 5 droops.

Fig.11 illustrates the corresponding the load voltage waveforms. We observe that the voltage at the terminals of the load has a purely sinusoidal form and is kept stable around the values of the reference voltage generated by the power controller; even in the presence of a variation of the load the voltage keeps its sinusoidal form with a maximum value of 311V. According to figure 12, the current of the load for the first mode takes the value 20A and in the second mode the value 45A, we note that for the two modes the form of the current is purely sinusoidal so with this control technique the quality of the energy is better.

4. CONCLUSION

In this paper, a universal droop control based active and reactive power-sharing techniques using the robust control for Parallel Inverters, to avoid communication and implement robust control principles. In this paper a droop control technique for two parallel voltage source inverters is proposed, using P-f & Q-V droop control for sharing the load power with a stable voltage and frequency.



The simulation results obtained show the good sharing of active and reactive powers. The frequency of DGs in improved method is smooth and consistent, which determines more stable and more accurate active power sharing. Disturbance in loads just changes the value of frequency rather than disrupt the stability. Future research directions are discussed to improvise the block of droop control using advanced control.

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