Original Research Article

Droop Control of Inverter Interfaced Distributed Generation

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ABSTRACT

In recent times, interest in renewable energy-based distributed generation (DG) is increasing rapidly. The paper presents a control strategy for parallel-connected distributed sources. It deals with active power-frequency and reactive power-voltage (P-f/Q-V) droop control strategy for sharing of active and reactive power between parallel-connected DG units. Droop control can be implemented for communication-less control of inverter-based DG units. The control adjusts voltage and frequency of individual generating unit for regulating power flow between parallel-connected units. P-f droop uses real power(P) of the DG unit to decide the operating frequency and reactive power(Q) to decide operating voltage. The simulation is conducted in the MATLAB Simulink and results are analyzed. Results show that droop control is an effective technique for the control of inverters that are interfaced with distributed generation sources.

Keywords: Distributed generation, droop control, inverter control, islanded control

1. INTRODUCTION

The energy demand of the world is continuously growing. In the present scenario, integration of renewable energy-based distributed generation has resulted into evolutionary change in the conventional grid structure. Unlike conventional power system of large capacity and large distance transmission network, the concept of small capacity, low voltage distribution line network, capable of operating independently are marking their presence. These renewable energy-based sources are integrated into the grid structure at dispersed locations and at distribution level are called as distributed generation [1]. Due to flexibility of installation location and better efficiency related to transmission of power, distributed generation can be effectively used as a solution to the problems associated with conventional centralized grid structure. Therefore, microgrids are coming into the picture with the advent of distributed generation. Microgrids consist distributed generation sources supplying power to the loads of a small local area as well as managing and controlling that network as a whole. Microgrids have another feature to operate in grid connected and islanded mode. Due to their capability to operated and control their network independently they can operate in islanded mode. Depending upon the mode of operation the basic functions of a microgrid are;

- To regulate voltage and frequency of the network within acceptable limit during islanded mode.
- To control active and reactive power flow of each DG unit to supply loads during islanded mode.
- To manage power flow between microgrid and main grid during grid-connected mode.

To manage operation of microgrid, proper control actions need to be applied. As most DG units are connected in the network through power electronic converters (via inverter for DC/AC conversion), control strategies are implemented for inverter control to accomplish the energy management and microgrid parameter (voltage, frequency, etc.) regulation [2]. One such control scheme is droop control of individual inverter [3][4].

2. DROOP CONTROL

The droop control strategy in inverter control of DG units simulates drooping characteristic of conventional power system [5].In conventional system, as load increases this extra load is compensated by reduction in rotational speed i.e. via reduction in operating frequency. The droop control of inverter tries to mimic the same characteristics.

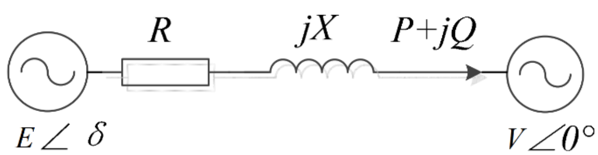


Fig.1: Equivalent circuit of DG connected to AC bus

In Fig.1, $V\angle 0$ and $E\angle\delta$ represent output voltage of inverter and common AC bus voltage respectively and R+jX is line impedance(Z), then active(P) and reactive power(Q) transferred by the source is given by following relation,

$$P = \left(\frac{VE}{Z}\cos\delta - \frac{V^2}{Z}\right)\cos\theta + \frac{VE}{Z}\sin\delta\sin\theta \tag{1}$$

And,

$$Q_i = \left(\frac{VE}{Z}\cos\delta - \frac{V^2}{Z}\right)\sin\theta - \frac{VE}{Z}\sin\delta\cos\theta \tag{2}$$

Where, θ is phase angle of transmission line impedance. Now for highly inductive line $\theta=90^0$ hence, $Z\approx X$ and assuming δ to be small [6]. The active(P) and reactive(Q) power relation for inductive line changes to;

$$P = \frac{VE}{X}\delta \tag{3}$$

$$Q = \frac{VE - V^2}{X} \tag{4}$$

The equation (3) and (4) shows that active power is varying with change in power angle(δ) i.e. change in frequency and reactive power is varying with output voltage(V). Hence it can be derived from these relations that it is feasible to control active and reactive power by controlling frequency and output voltage respectively. Considering same relationship P-f/Q-V droop control is developed for inverter control of DG unit [7]. Control scheme introduces droop in control parameters (voltage, frequency) for the increase in load demand to make inverter responsive to load change. The following relationship between frequency and active power, voltage and reactive power is utilized for droop control of inverter units,

$$f = f^* - m(P - P^*) \tag{5}$$

$$V = V^* - n(Q - Q^*) \quad (6)$$

Where, f^* and V^* are nominal frequency and voltage of inverter operation, P^* and Q^* are nominal active and reactive power respectively and *m* and *n* are frequency and voltage droop coefficients. These coefficients are calculated from following equations,

$$m = \frac{\Delta f}{P_{max}} \quad (7)$$

and,

$$n = \frac{\Delta V}{Q_{max}} \quad (8)$$

Where, P_{max} and Q_{max} are maximum active and reactive power supplied by inverter respectively and Δf and ΔV are maximum allowable deviation in frequency and voltage as shown in Fig.2.

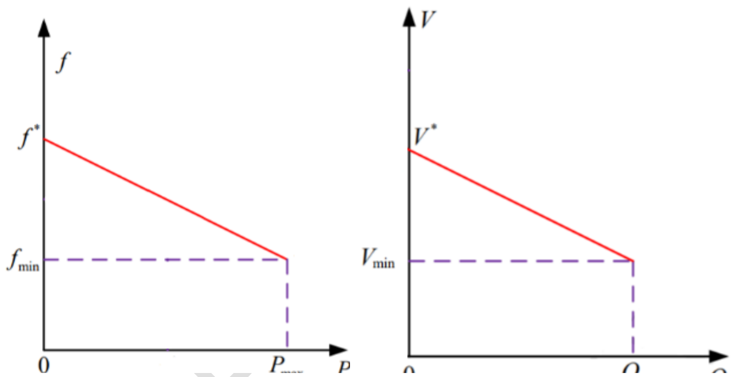


Fig.2:P-f /Q-V droop characteristics

Fig.2 shows active power-frequency (P-f) and reactive power-voltage(Q-V) drooping characteristics respectively. The f_{min} shows minimum allowable frequency deviation and similarly, V_{min} shows minimum allowable voltage deviation [8].

3. SYSTEM DESCRIPTION

Microgrids can operate in grid connected mode and islanded mode. In grid connected mode, inverter operate in constant current mode [9]. The reference voltage and frequency are provided by main grid and then output active and reactive power of inverter is coordinated to its output current respectively. During islanded mode, inverter operates in constant voltage mode. The reference voltage and frequency are calculated from droop controller and then control structure tracks these references.
Fig.3 shows control structure for inverter, the active and reactive power to be supplied is calculated by locally measuring current and voltage. The instantaneous active and reactive powers are calculated through following relation [10],

$$p = V_d i_d + V_q i_q \quad (7)$$

$$q = V_q i_d - V_d i_q \quad (8)$$

V_{dq}, i_{dq} represent dq-transformed quantities of inverter output voltage and current. These calculated values are passed through low pass filter to minimize the effect of harmonics [11] and filtered signals are fed to droop controller. Fig.4 shows block diagram of droop controller, the calculated active(P) and reactive(Q) power are the input for the droop controller and *m* and *n* are constant droop coefficients. Now reference voltage and operating frequency is decided by droop controller. This reference voltage is the input for the next control block that is voltage control block.

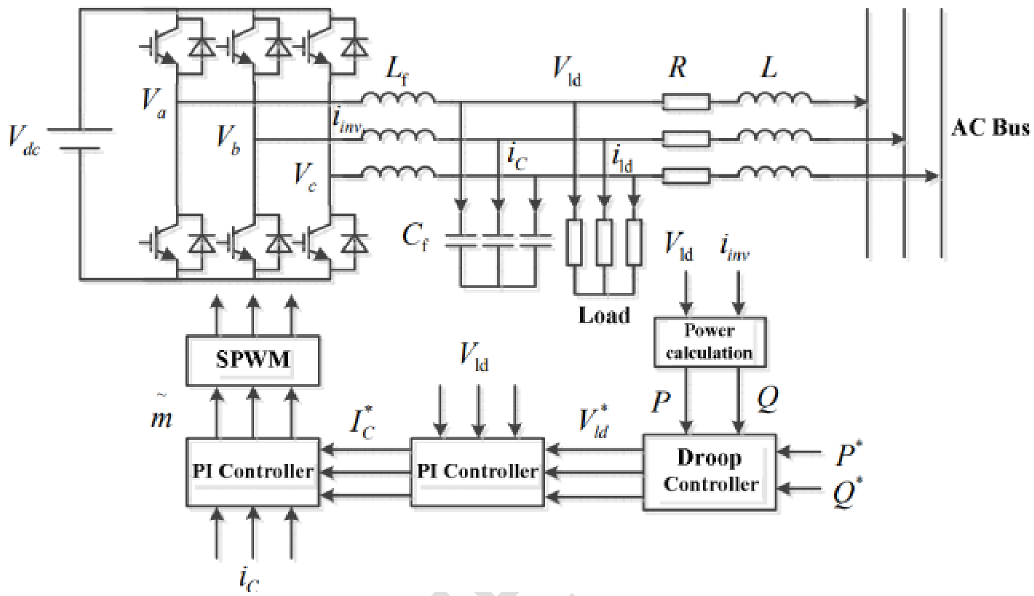


Fig.3: Control structure of inverter

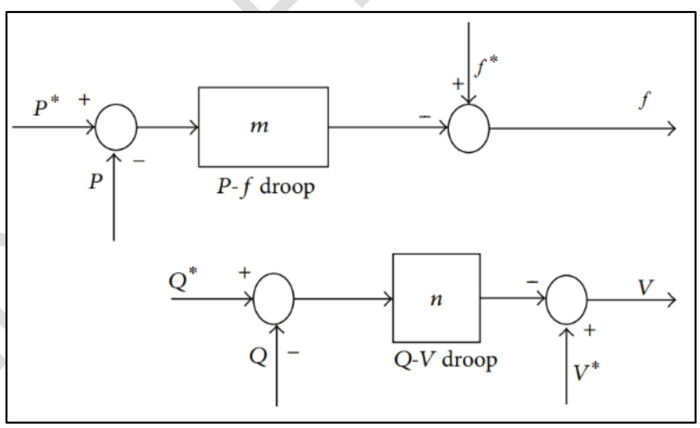


Fig.4: Block diagram of Droop controller

This block consists PI controller to eliminate error between reference and measured voltage signal and generate current reference for next PI control block which is a current control block. Finally, output of current controller block is utilized to generate modulating signals for inverter.

4. RESULTS AND DISCUSSION

In order to analyze the performance of the controller the inverter model is developed in MATLAB/Simulink. Model is built by modelling the dynamical equation of inverter and filter network. Inverter is modelled in off-grid mode and adopts P-f/Q-V droop control scheme. DG structure consisting of one DG source supplying three-phase loads is shown in Fig.5. Standard line voltage at no load is considered to be 380V and frequency is 50hz. Other network parameters are mentioned in Table1. It is considered that for the increase in active and reactive power there is a decrease in operating frequency and voltage from no-load values. Step load of 0.83pf is applied to analyze the response of the controller. Initially a 3KW, 2KVAR load is connected to the network and at t=5sec, another load of the same capacity is added into the network. From the results of Fig.6 it can be seen that increase in active power load is coordinated by a decrease in operating frequency (Fig.6(a), (b)) as per selected frequency droop coefficient and similarly increase in reactive power demand is coordinated by corresponding decrease in output voltage of inverter (Fig.6(c), (d)). Fig.6(e) shows peaks of output voltage of inverter. It shows that at t=5sec when reactive load increases a drop is introduced by controller in the operating voltage to respond to the load change. Fig.6(f) shows steady state three phase current produced by inverter. Result shows increase in current output at t=5sec for the increase in load demand.

Table 1: Network parameters

Parameter	**Value**
Inverter Rating	15kva
Frequency	50hz
Line Voltage	380V
Frequency droop coefficient (m)	6.25e-5
Voltage droop coefficient (n)	0.0021

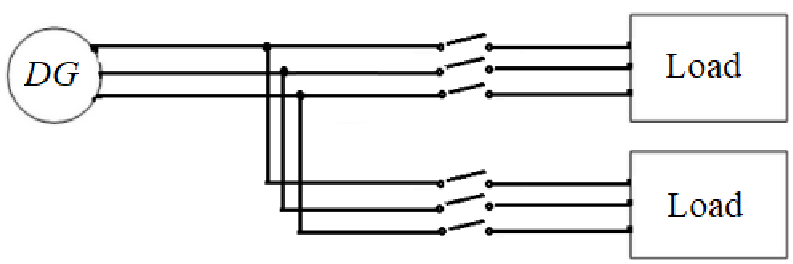
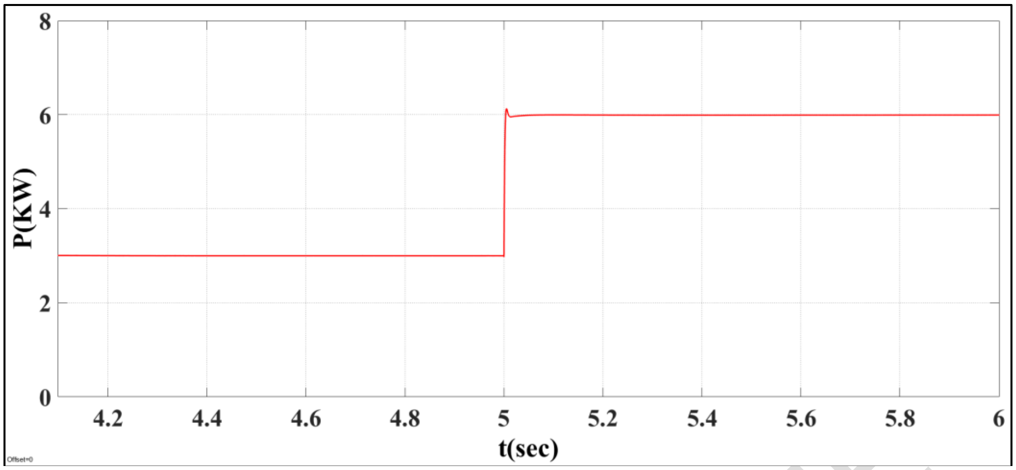
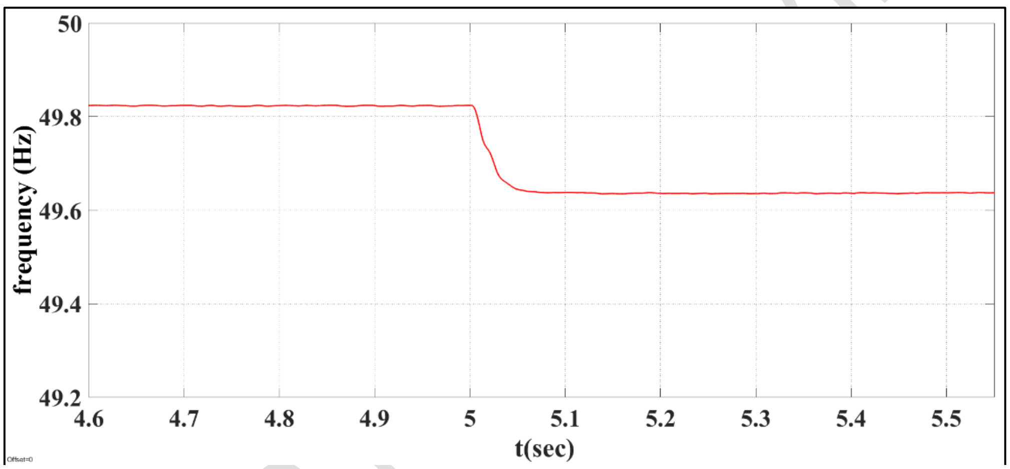
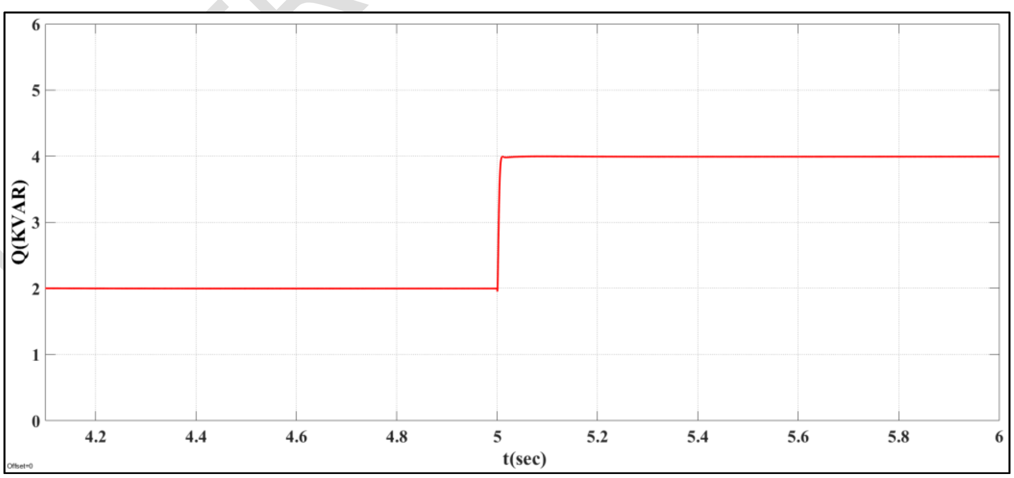
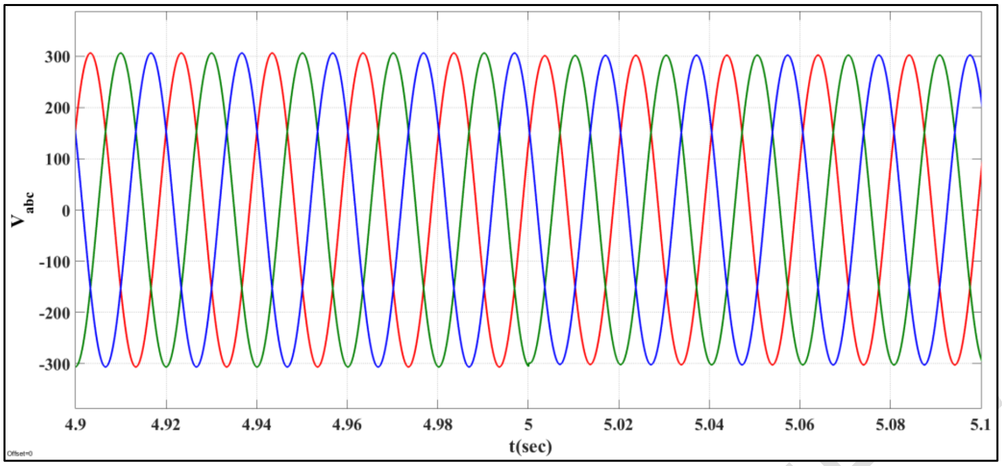


Fig.5: DG structure

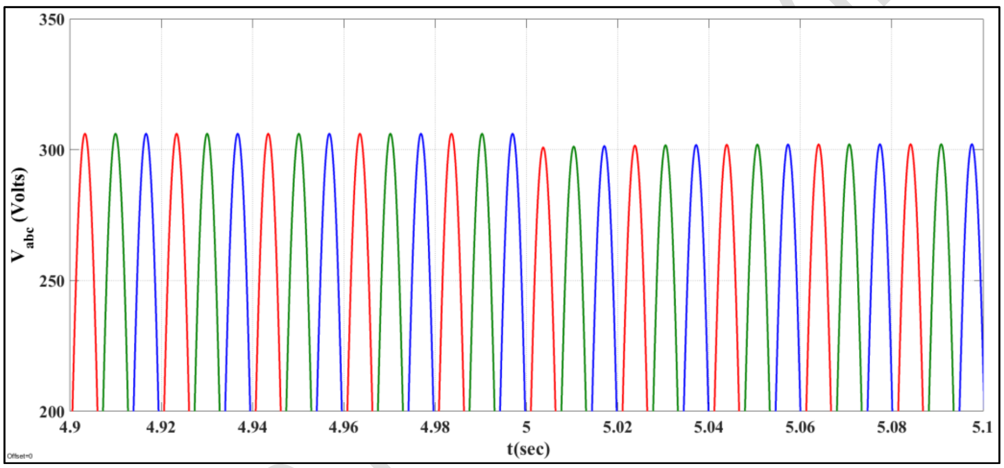

P(KW)
8
6
4
2
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
t(sec)
(a)


frequency (Hz)
50
49.8
49.6
49.4
49.2
4.6
4.7
4.8
4.9
5
5.1
5.2
5.3
5.4
5.5
t(sec)
(b)

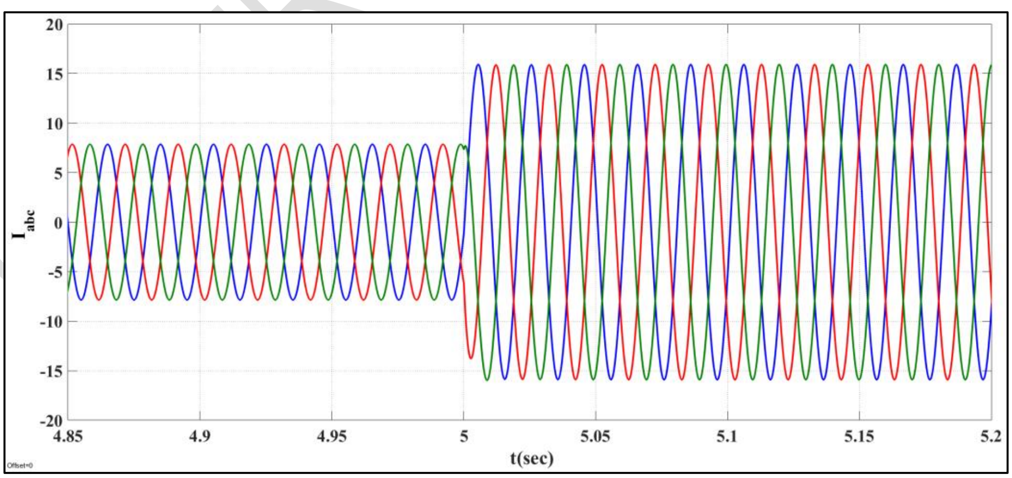

Q(KVAR)
6
5
4
3
2
1
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
t(sec)
(c)



(d)



(e)



(f)

Fig.6: Simulation results of the response of controller to the variation in load

5. CONCLUSION

The paper presents an inverter model for distributed generation based network consisting of droop control scheme. This control scheme makes inverter responsive to the change in load demand by incorporating change in voltage and frequency. To analyze response of controller, stepped loads with active and reactive power demand is applied to the network. It is demonstrated that P-f/Q-V droop introduces droop in operating frequency for increase in active power demand and introduces droop in voltage for the increase in reactive power demand. Results also show that control scheme is capable of maintaining stable operation during the change in load demand and during steady state as well. This control decides operating points for individual inverter based on locally calculated values. Hence this control can also be extended for the inverter control of parallel connected distributed generation network. Each inverter unit locally measures voltage and current values and accordingly decides operating voltage and frequency.

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