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ANALYSIS AND DESIGN OF DROOP CONTROL STRATEGY APPLIED TO PARALLEL OPERATION OF INVERTER

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Abstract: Renewable energy sources are considered as the replacement of conventional energy sources. These RES can use solar light, wind energy, bio waste and in the form of small hydro turbine units. These RES has very poor quality and voltage fluctuations and variable frequency. The conventional droop control technique which was already used in inverter design has difficulty in synchronizing parallel connected inverters with different droop gains. The proposed "Estimated droop control" do not use any predefined droop values for inverters and all inverters are responsible for the estimation of their own droop values with respect to their output power that shares an equal load. The project focuses on analysis of voltage fluctuations and frequency variance of parallel connected inverters, design of estimated droop control strategy and the results are obtained in MATLAB/SIMULINK.

Key words: Single-phase Full Bridge Inverter, Droop coefficients, Sinusoidal PWM, PI Controller, THD.

I.INTRODUCTION

The power handling capacity of a grid connected converter system can be increased by connecting inverters in parallel. Parallel connected inverters are connected to different RES sources at the input side, and to the load at the output side. Power by the parallel connected inverters can be shared equally or unequally which depends on the magnitude and phase difference between the modulating signals of the parallel connected inverters. For the equal power sharing, the phase difference is zero and magnitude of modulating signals of the inverters are equal, but for unequal power sharing, there can be either a non-zero phase difference or unequal magnitude of modulating signals of the inverters. The DG units can operate in autonomous mode which facilitates a commercial consumer in different ways like low cost for transmission systems, reactive power and harmonic compensation, power factor correction and backup generation which may not be possible in a centralized system. These DG units can be easily plugged in or plugged out from the utility grid in case of failure without affecting the system.

II.MODELLING OF SINGLE PHASE DROOP CONTROL

A. DESIGN OF INVERTER

Inverters are being used as an interface between RES and main utility grid. These are responsible to process the output power with controllable voltage amplitude and frequency. This processed output power from different RES is then fed into a microgrid which are either operating in synchronized mode with main utility grid or in islanded mode. This can be achieved when inverters are connected in parallel to one another as shown in the below Fig. 1. In order to supply the power to additional loads to the microgrid and for the DG applications.

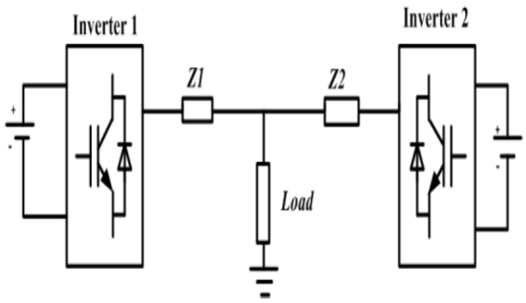


Fig. 1. Two parallel connected Inverters

A LCL filter is connected between the inverter output and the load to reduce the harmonics and to get proper sine waveform. The output voltage and the output current sample have been taken as the input to the droop controlled technique.

B. ANALYSIS OF INVERTERS IN PARALLEL CONNECTED MODE

Two Single phase H-bridge Inverters with same ratings are simulated and observed the readings and compared with the two exact similar rating of Inverters which are connected in parallel as shown in the Fig. 2.

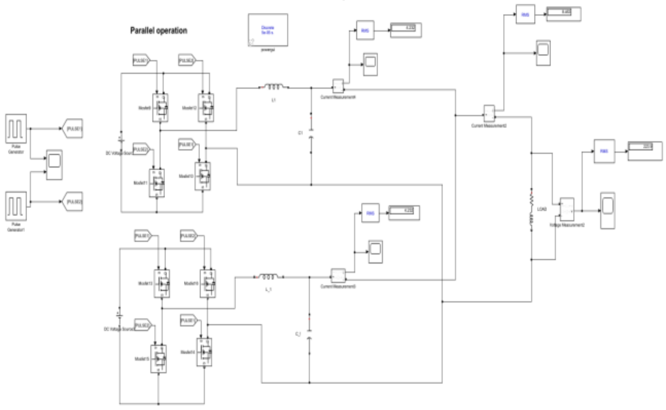


Fig. 2. Parallel operation of Inverters

The analysis is done for both Pulse Generated method and Pulse Width Modulation method. The PWM technique is better in comparison with Pulse generated technique because %THD is less in PWM technique than Pulse Generated Method as shown in Fig. 3.

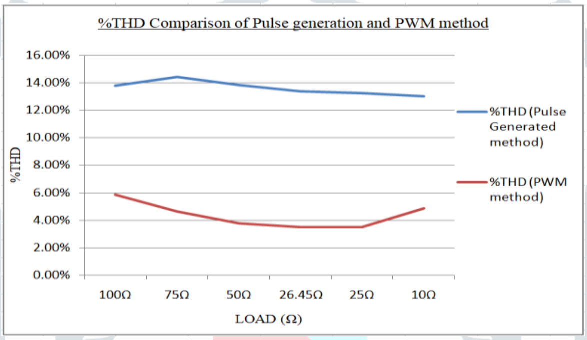
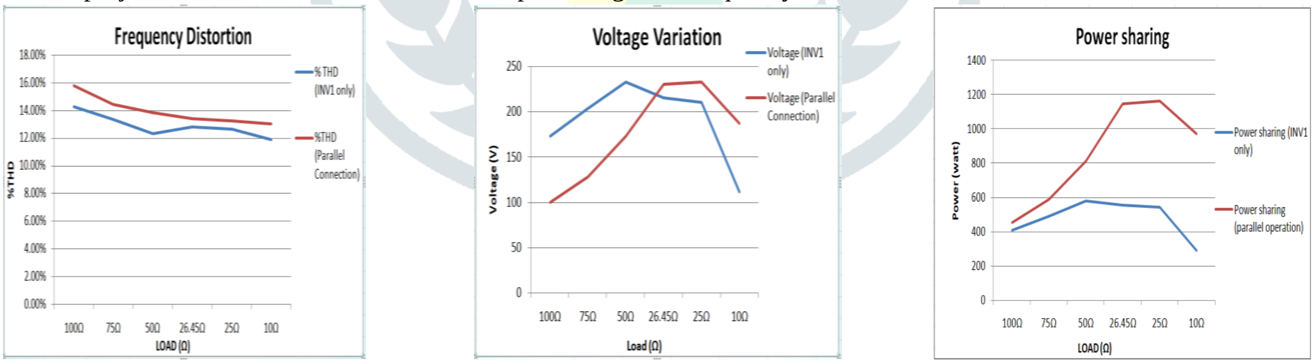


Fig. 3. %THD Comparison of Pulse generated method and PWM method.

In the open loop connection of the Inverters in parallel manner, there is a voltage fluctuation, frequency variation and change in power sharing at the load as shown in the Fig. 4. This arises a problem in the load sharing and may cause damage to the microgrid or to Inverters by short circuit of the sources. So, In order to balance the power sharing and other disturbances a proper droop control technique is adopted in this project to control the variation of the output voltage and frequency.



a. Voltage variation b. Frequency variation c. Power sharing

Fig. 4. Disturbance in microgrid when Inverters are connected in parallel

C. DROOP CONTROL TECHNIQUE

Voltage and frequency control technique is a non-communication based scheme which requires no communication links among the inverters in a microgrid. This technique requires very less computational facilities and a simple microcontroller can be used to perform the task. Due to these advantages droop control not only increases the reliability of a system but also significantly reduces the cost of a system. The idea of a droop control in inverter dominated grid comes from the conventional Synch-Gen power system. In a conventional power system active and reactive power is controlled by regulating the angle difference between the voltage phases of two AC machines and magnitude difference between two voltages respectively. The same principle is followed in this technique to control the flow of active and reactive power by controlling the frequency and amplitude of the output voltage as shown in Figure 6. When the flow of the active power increases due to the increase in load, frequency of an inverter drops, similarly when the flow of the reactive power increases then voltage will drop. A certain acceptable range has defined for the frequency and the voltage droops which is 1% and 4% respectively from their reference values. Adequate operating range is necessary for the sake of maximum quality of service. Droop gains are represented by the slope of the line in Fig. 5.

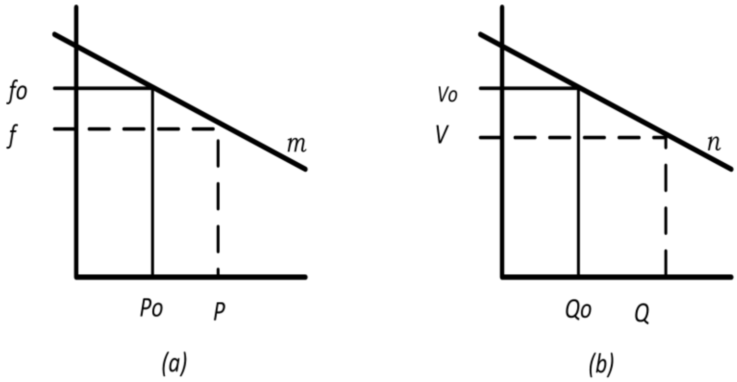


Fig. 5. (a) Frequency and (b) Voltage droop curves.

The fundamental droop equations for an inverter is given by

$$\omega = \omega_0 + m\,(P_0 - P)$$

$$V = V_0 + n\,(Q_0 - Q)$$

Where ω_0, V_0, P_0 and Q_0 are the reference or rated values.

D. PROPOSED DESIGN

Block diagram of the proposed droop control scheme of this project is shown in Fig. 6. as below

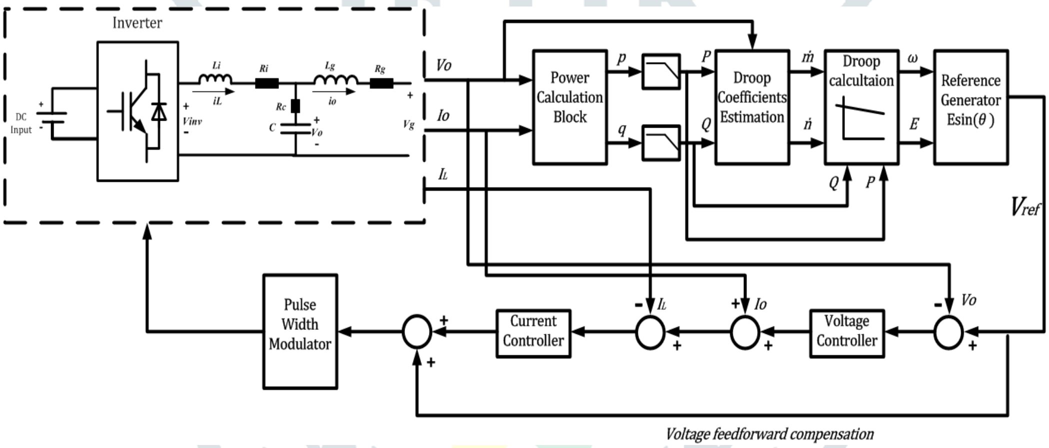


Fig. 6. Proposed model of Single Phase Voltage Source Inverter

The traditional droop control scheme uses only fixed droop values for their droop control mechanism regardless of any change in output active and reactive power demand. While this project work has proposed a new droop control technique and this new estimated droop control block uses an online estimation mechanism for droop values rather than using fixed values (conventional method) and then these values are adopted by droop control block to control active and reactive power flow.

III.SIMULATION AND RESULT

The simulation of the parallel operated inverter is done for a linear load. During the performance, the load is perturbed by adding another load at 0.5 sec.

The power circuit diagram in the simulation is as shown in Fig. 7.

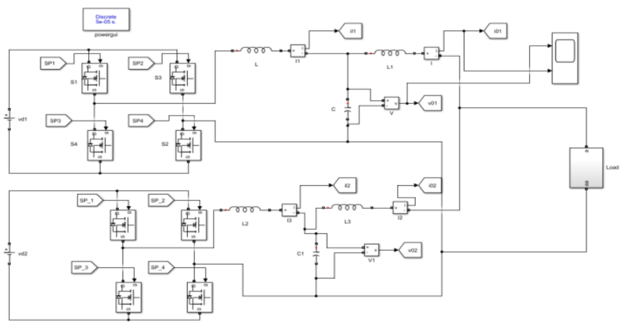


Fig. 7. Simulated diagram of power circuit

The sample of the output voltage and output current of each Inverter is taken out and calculated the active and reactive power and passed through second order filter as shown in Fig. 8.

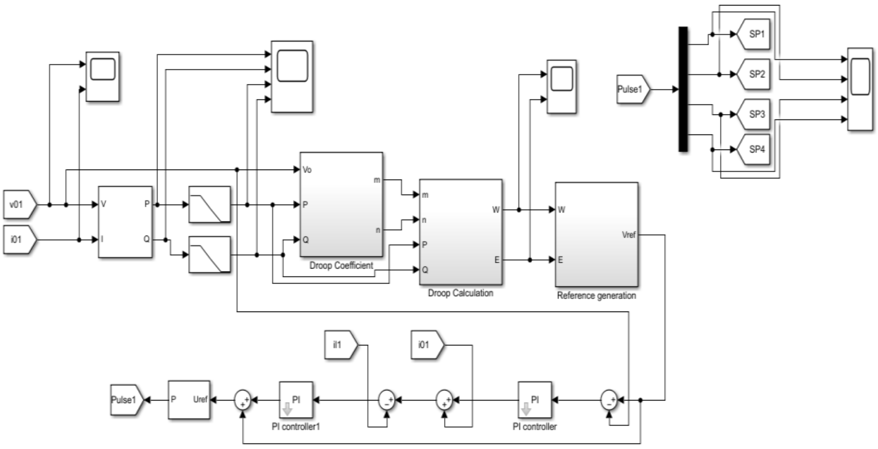


Fig. 8. Simulated diagram of Droop control technique

The single phase voltage is converted to equivalent v_α and v_β and multiplied with theta component in the Droop coefficient calculation block as shown in Fig. 9. Droop coefficients are very important parameters so they should be estimated very precisely with minimum chance of error. Therefore best possible way of estimation is through the Kalman's filter to make the system as much precise as possible.

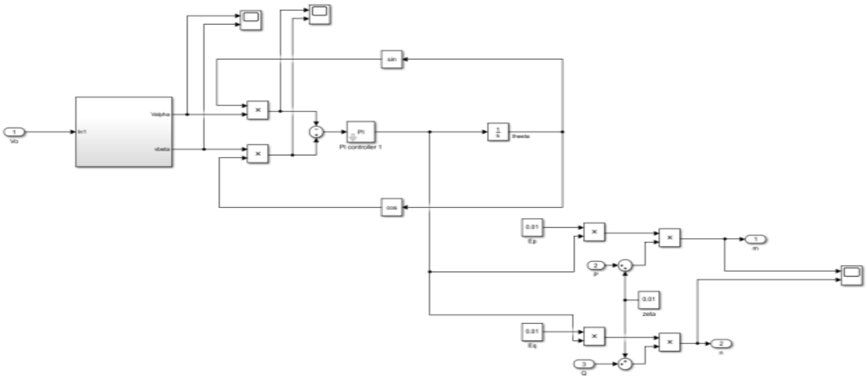
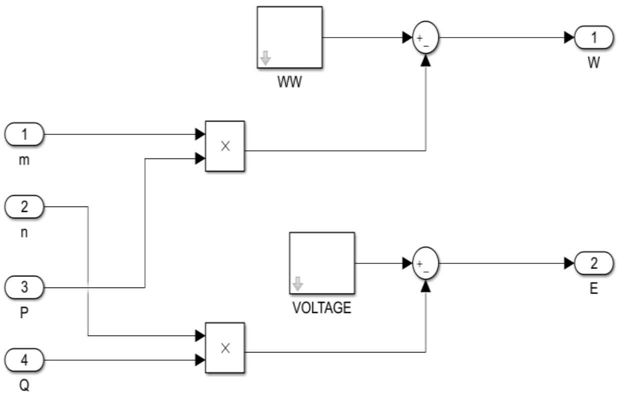


Fig. 9. Droop Coefficient calculation.

The droop values are calculated using the obtained droop coefficients as shown in the below Fig. 10 (a) and generate the reference voltage using amplitude and the frequency as shown in the Fig. 10 (b).



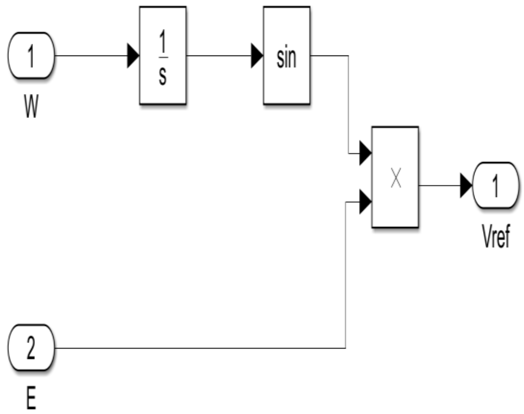


Fig. 10 (a). Droop Value calculation. Fig. 10 (b). Reference voltage generation

Before starting with the estimation of droop coefficients, there are two other parameters need to know ε_p and ε_q. These two parameters belong to frequency and voltage tolerance respectively. It has been observed that during coefficient estimation system encounters with singularity. Therefore to avoid this singularity a pivot with a small value is added with active and reactive power.

$$\bar{P} = P + \xi$$

$$\bar{Q} = Q + \xi$$

The droop coefficients are given by,

$$\hat{m} = \frac{\widehat{\omega}\,\varepsilon_p}{\bar{P}}$$

$$\hat{n} = \frac{\widehat{\omega}\,\varepsilon_q}{\bar{Q}}$$

New droop curve equations are,

$$\omega = \omega^* - \hat{m}P$$

$$E = E^* - \hat{n}Q$$

From ω and E, reference voltage is generated and error voltage is calculated by comparing with the sample of output voltage. PI Controller is used to reduce the error of current and voltage in closed loop. Then the voltage is compared with the carrier voltage signal and generates the pulses which are required to drive the MOSFET's switches.

The active and reactive power is calculated as shown in the Fig. 11.

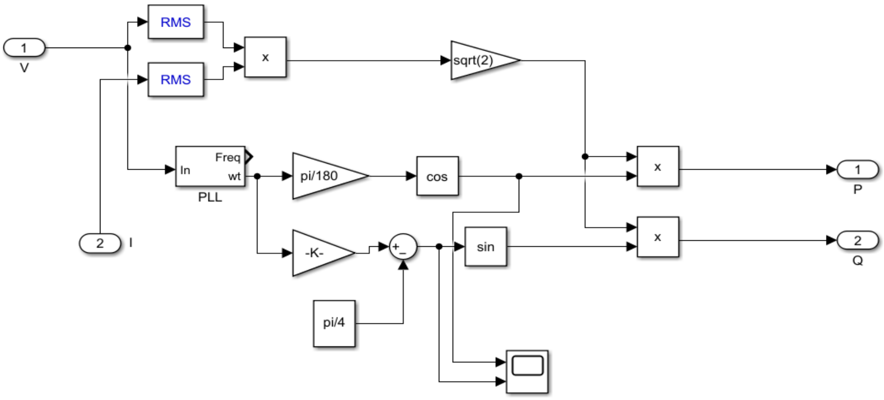


Fig. 11. Simulated diagram of Power Calculation

PI Controller gains and system parameters are listed in table 1 and table 2.

PI Gains for	Parameter	Value
Voltage controller	K_p	5
	K_i	0.1
Current controller	K_p	5
	K_i	0.1
Droop Coefficient controller	K_p	1
	K_i	0.001

Table 1. Controller Gains

Parameter	Value
L_1	1.25mH
L_2	1.25mH
C_f	10µF
ξ	0.01
ε_p	0.01
ε_q	0.01

Table 2. System Parameters and Initial Conditions

The simulation voltage of the system remains almost constant throughout the simulation running time. Simulation results shows there is no overshoot for both voltage and current in linear load during load transition. The system has very smooth transition response during load variation as shown in Table. 3.

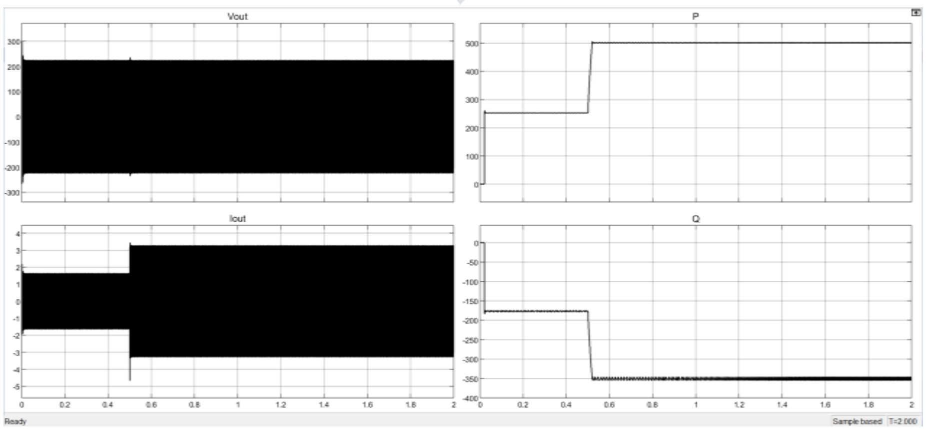


Fig.12. Output waveform of the Voltage, Current, Active power and Reactive power sharing at linear load.

Time duration	Voltage (v)	Current (A)	Active power (watt)	Reactive power (var)
t = 0 sec	0	0	0	0
0 sec ≤ t ≤ 0.5 sec	220	4.85	880	-600
0.5 sec ≤ t ≤ 1 sec	215	9.47	1680	-1180

Table. 3. Table of output result

CONCLUSION

This project work is conducted to improve the stability and reliability of low and medium voltage microgrids consisting of more than one RES. Then the results are shown that the estimated droop control not only improves the stability of the system but also improves the reliability. The reliability is of more concern about how much an inverter is independent in its operations. In the Estimated droop control scheme these droop gains are estimated online and no predefined values are used. This method increases the reliability of a system by making independent operation of each inverter in a system and it is possible only by virtual communication link.

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