Droop Controlled Grid Synchronization Technique for Inverter Based Distributed Generation

T.Bharani Prakash[1], S.Nagakumararaj[2],R.Pavan[3],S.Mohamed Jaffer[4]
[1,2]*Assistant Professor, Electrical and Electronics Engineering*
[3,4]*UG Scholar, Electrical and Electronics Engineering*
Sri Krishna College of Technology (Autonomous), Kovai Pudur, Coimbatore (DT).Tamilnadu,India

Abstract

Renewable energy changes the future world into green energy. In this, Distributed Generation (DG) is getting popular in the recent development of renewable energy technology. The key component in DG is grid connected converters that serve as an interface between DG and power grid. The important factor in power electronic converters is maintaining stability while connecting DG to the main grid. And also to provide electric power with high reliability, the challenging issue of integrating of DG to grid is controlled by some control technique. In this paper, grid synchronization with droop control method, enhanced droop control and decentralized droop control technique are proposed to synchronize two DG units parallel to power grid along with power sharing among them. The primary consideration is that to analyze grid synchronization technique applied to DGs by detecting the phase angle and frequency deviation during abnormal grid conditions and power quality problems. Here, active power will be shared proportionally by the micro sources with the help of droop control which is examined by MATLAB/Simulink model.

Index Terms — *Distributed Generation, grid synchronization, droop control, power electronic converters, decentralized control*

I. INTRODUCTION

The small scale generation of generally 10 MW or less is properly well-known as Distributed Generation (DG). DG is not a central power system and is located close to the load. In other words, it enables collection of energy from many renewable and nonrenewable sources of 30 MW or less. It has lower environmental impacts[1]. DG provides an improvement of power quality. It provides good benefits for the voltage profile and power factor corrections, where voltage support is difficult. But the high penetration of DG may lead to instability of the voltage profile. Additionally, short circuits and under loads are supplied by multiple sources; this leads to large voltage fluctuation in grid side[2].

Mostly renewable energies are good to act as a DG systems. These will become green energy in future worlds. In addition to that, fossil fuel is increasing air pollutants. Thus the renewable energy becomes the essential requirement in this world. DG resources become great part to these concerns[3]. However, the present electricity grid architecture is fully based on centralized power generation where this energy meets both reducing energy demand from the utility grid and greenhouse gas emissions for the environmental regulations. During peak demand, power injection from DG to the grid can optimize the energy consumption and also reduce the stress from the point of common coupling [4].

Generally, voltage source converters (VSC) are used as the central part for interfacing between DG source and the power grid. Compared with two level converters, the multilevel inverter is preferred which has significant advantages such as lower harmonic distortion, lower voltage stress, and lower common mode voltage when connected to large loads. Therefore, by reducing filtering, they not only improve the efficiency but also increase the load power of the converter[5]. Many problems are facing related to integrating DG resources to the power grid. These problems reduce the system stability and cause major fluctuation.

Several studies have been stated in the literature regarding the control of DG resources integrating to the power grid. A neutral point clamped inverter with control topology is provided by buck converter. Here inverter is regulated as a current source by inner inductor loop in the grid - tied operation and voltage controller in islanding mode[6]. The adaptive hysteresis band current controller is used to change hysteresis bandwidth according to frequency and voltage deviations. Thus DG sources act as a Shunt active power filter by sharing load demand appropriately[7]. A multi - objective control technique is used for integration of DG resources to the power grid. Here, grid variables are transformed into synchronous orthogonal reference frame for controlling of the voltage source converter[8].

The flexible control strategy balanced the voltages by sinking negative sequence components during the fault condition. It should inject reactive power when three phases balanced voltage sag condition[9]. The control algorithm is used to withstand inverter in grid abnormalities by the advanced synchronization method. By introducing PLL along with grid synchronization technique, the stability of power grid is improved and maintained constant [10]. The control algorithm discussed in[11] is used to generate the SVPWM pulses for the DG inverter. The technique developed a control strategy for harmonic current filtering in three phase grid without using extra compensating device [12].

The impedance - based small signal model of DG system is presented, and active control technique is proposed to stabilize the system[13]. A Lyapunov stability theory is presented for connection of distributed generation resources to electrical grids via power electronic converters. Here, proper switching state functions of the grid interfacing converter are obtained [14].

The rest of paper is consists of four sections. Following section II, the block diagram of proposed scheme system is introduced. In section III, the detailed explained of proposed system is discussed. In section IV, simulation results are performed to analyze the DG condition and its effect on load sharing. Finally, conclusions are drawn in section V.

II. PROPOSED BLOCK DIAGRAM

Fig 1 shows the block diagram of the proposed common droop control system which consists of three main parts such as grid, load, and DG system. In addition to that, the DG link is integrated into the network in shunt connection type by means three level converter. Two sources are considered as DG systems such as PV system and Fuel cell. To have high efficiency in PV cell, incremental conductance MPPT algorithm is used. The boost converter is used to boost DC voltages from two DG sources. Then the output of boost is used to convert to AC voltage utilizing three phase three level inverter.

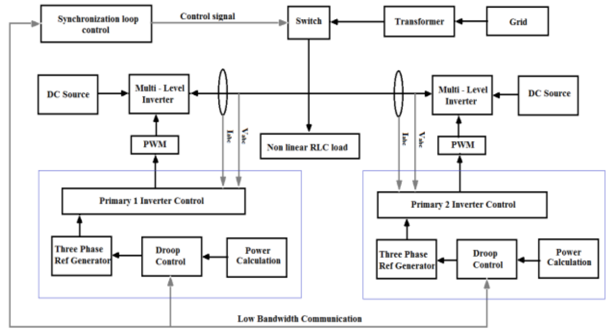

Fig 1: Block diagram of Enhanced droop control system

The proposed DG model is integrated into the grid as a result of control techniques such as enhanced droop control and grid synchronization units with PLL. By connecting DG sources, it injects current components from DG source into PCC. The normal droop control consists of only one Distributed generation sources such as solar energy.

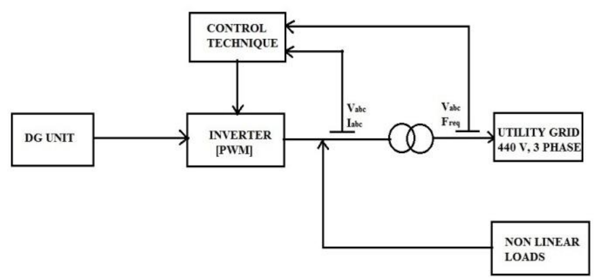

Fig 2: Block Diagram of Droop Control

The normal droop control technique consists of voltage control loops which are shown in figure 2. The Decentralized droop control is similar to enhanced droop control, but it includes high bandwidth communication which is shown in figure 3.

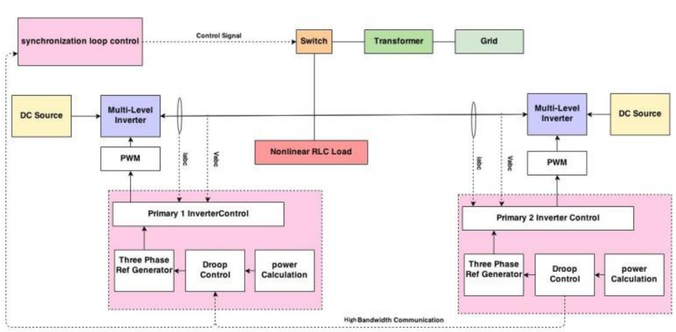

Fig 3: Block Diagram of Decentralized Droop Control

III. ENHANCED CONTROL SCHEME

There are two control techniques which are used to integrate DG converter to the power grid. These control techniques are necessary for stable operation of interfacing converter when subjected to power quality disturbances such as voltage sag, swells, and harmonic distortion. The inverter control and grid synchronization are the two control techniques used in this paper. The inverter control acts as a primary control technique which is known as V/F droop control technique. The grid synchronization method serves as a secondary control technique which is known as synchronous reference frame with PLL (Phase Locked Loop). During the grid synchronization process, the role of droop control is to share the non-linear loads between two DG sources.

A. Primary Control Technique

The primary control technique is a V/F droop control. It consists of virtual impedance, droop control block, and phase calculation block. The virtual impedance is a current feedback loop that adjusts the voltage reference. The voltage regulator limits the speed of this loop. Thus to prevent fast current transients and to accommodate the voltage source to operate together with other voltage sources such as other DG inverters or grid, an ideal physical inductor used. The accuracy of the power-sharing provided by the droop controllers is affected by the output impedance of the Dg units and the line impedances. The virtual impedance is a fast control that can fix phase and magnitude of the output impedance.

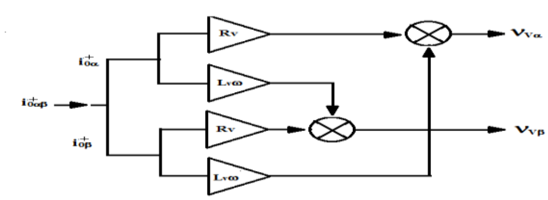

Fig 4: Fundamental Virtual Impedance Loop

Droop control technique is to enhance power sharing, and the V/F synchronization is compensating real power using frequency and reactive power using voltage. When multiple DGs are attached to the grid, the power sharing among them is made correctly with the help of control strategy. PI controller is used to neutralizing the voltage and frequency error. The voltage from PCC is used to convert active and reactive power which is given by

$P_{grid} = U_d\, i_d + U_q\, i_q$
(1)

$Q_{grid} = U_q\, i_d - U_d\, i_q$
(2)

From this, voltage and frequency can be calculated as

$f = f_o + m\,(P_{grid} - P_o)$
(3)

$V = V_o + n\,(Q_{grid} - Q_o)$
(4)

Where droop coefficients are

$m = \frac{\Delta W}{P_{max}}$ $n = \frac{\Delta V \Delta}{Q_{max}}$

The primary control is used to share the load between different DGs. After park transformation, real and reactive power is calculated from voltage and current reference. And that required frequency and voltage are obtained from power deviations which are derived from droop coefficients m and n which is shown in figure 5.

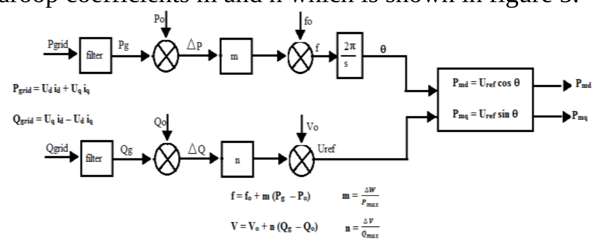

Fig 5: Primary control technique

B. Secondary control technique

The secondary control technique is grid synchronization technique along with PLL. The ideal synchronization is used

1. To track the phase angle of the utility grid.
2. To detect the frequency variation
3. To eliminate disturbances and high harmonic components.

Synchronization is defined as the minimization of the change in voltage, phase angle, and frequency between the DG sources and the grid supply. Such synchronization is achieved by connecting the DG sources into power grid which is done with the help of PLL. It allows the grid and the synchronized power converter to work together.

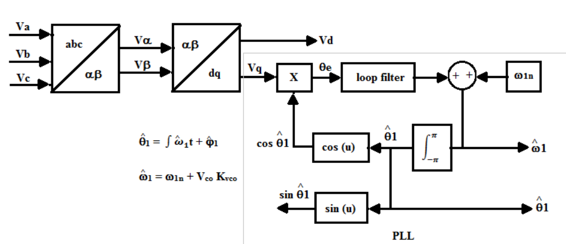

Fig 6: Secondary control technique

The voltage from the converter is transformed to d-q reference frame by means of park transformation. The output of the transferred variables is sent to PLL. It is a control system that generates an output signal whose phase is related to the phase of an input reference signal. It compares the phase of the input signal with the phase of the signal derived from its output oscillator and adjusts the frequency of its oscillator to keep the phases matched which are shown in figure 6.

IV. DROOP CONTROL TECHNIQUE

This Droop Control technique behaves similarly to the normal droop characteristics. After three phase transformation of voltage parameter, it is transformed to two phase transformation to produce phase value for firing the inverter semiconductor switches which is shown in figure 7.

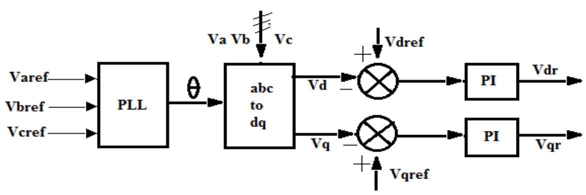

Fig 7: Droop Control technique

V. SIMULATION RESULTS

In order to demonstrate the high performance of the proposed control technique, the complete system is simulated with MATLAB/Simulink model. The Simulink implementation of proposed system is shown in figure 8 and 9. The proposed model consists of two DG unit converter having 200 KW. The grid is operated at 250 KW. The nonlinear loads connected to PCC which consists of 4 loads totally of 180 KW.

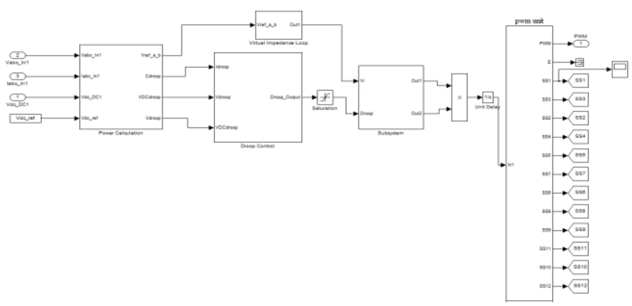

Fig 8: Simulation diagram of Droop control technique

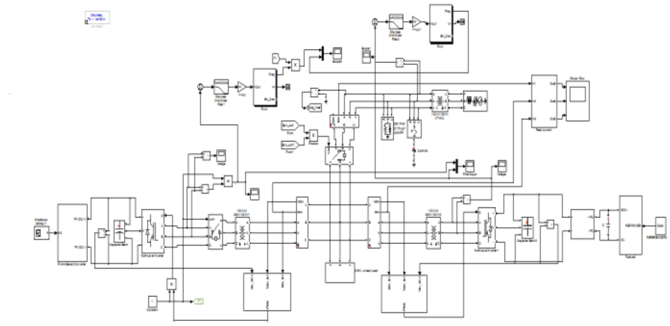

Fig 9: Simulink implementation of Enhanced droop control system

At first, each inverter voltage of two DG converter is examined when subjected to an increase in non-linear load which is shown in fig 10 and fig 11. PV Inverter voltage gets disturbed by voltage sags during an increase in loads at t=0.15 sec. Then the voltage gets restored to normal values at t=0.2 sec. The response of grid and DG voltage is shown in fig 8. Finally, the voltage gets synchronized within 0.05 sec. The frequency gets oscillates during this fluctuation or load increases which are also gets compensated. This control technique can withstand any power quality problems.

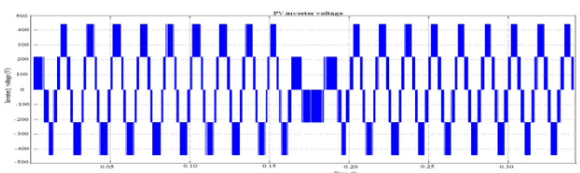

Fig 10: Voltage waveform of PV Inverter

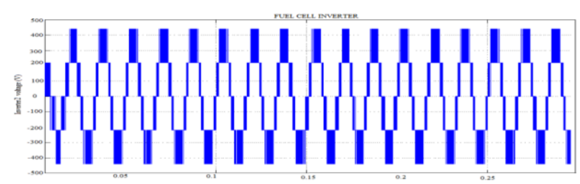

Fig 11: voltage waveform of fuel cell inverter

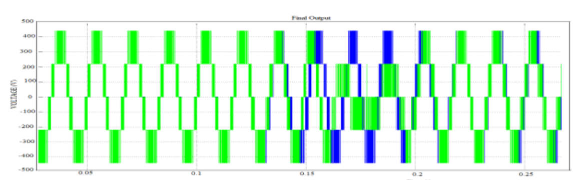

Fig 12: Response of grid voltage and DG voltage when **Non - linear load increases in Enhanced Droop control**

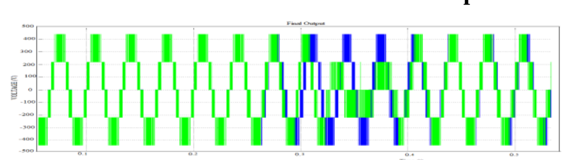

Fig 13: Response of grid voltage and DG voltage during voltage sags in Droop control technique

When comparing Droop control with Enhanced droop control, the time taken to synchronize is 0.05 more than Enhanced droop control. The response of grid and DG voltage during voltage sags in Enhanced Droop control technique and Droop control technique is shown in figure 12 and 13. But compared with Decentralized Droop control, the DG voltage takes only 0.025 sec to synchronize with grid voltage which is shown in figure 14.

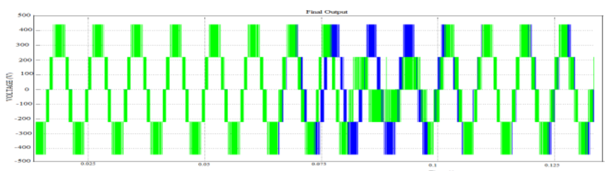

Fig 14: Response of grid voltage and DG voltage during voltage sags in Decentralized Droop Control technique

During load increases, frequency deviation is shown in figure 15. The frequency of the DG inverter varies from 49 to 51 Hz at t=0.15 sec. At t=0.20 sec, the frequency gets synchronized each other to 50 Hz (at normal grid frequency).

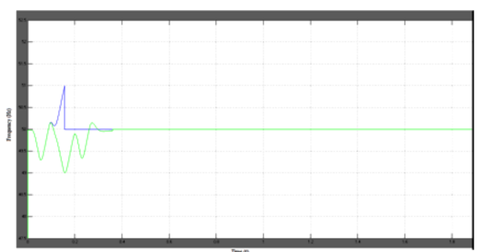

Fig 15: Frequency synchronization graph

At t=0.01 sec, 100 KW load is connected to PCC which is shared by both DG sources. At t=0.8 sec, load is increased by 30 KW and 10 KW. At t=1.6 sec, load is increased rapidly to 40KW which leads to voltage sag in the grid which is compensated by means of the control technique. Due to more load when compared to DG system, 10 KW of the load is shared by power grid which is shown in figure 16.

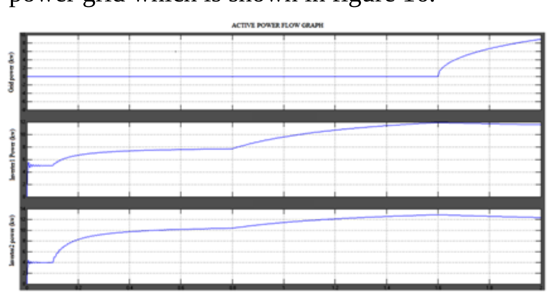

Fig 16: Power sharing graph

Table 1: Comparison of Control Technique with related to quick Synchronization

S.NO	CONTROL TECHNIQUES	FAST RESPONSE TIME
1	Droop Control technique	0.1 sec
2	Enhanced Control technique	0.05 sec
3	Decentralized Control technique	0.025 sec

Table 2: Comparison of THD value

S.NO	CONDITION	THD VALUE		
		DROOP CONTROL	ENHANCED DROOP CONTROL	DECENTRALIZED DROOP CONTROL
1.	Normal operation	37.23%	35.85%	32.56%
2.	During load increases	49.52%	48.01%	47.45%
3.	After load increases	41.92%	40.59%	38.20%

VI. CONCLUSION

In this paper, a grid synchronization technique with droop control is proposed for the integration of DG sources to the power grid. The control technique is based on synchronizing rotating reference frame. Simulation results show the frequency, the phase angle and the magnitude of the PCC voltage are matched to those of the grid voltage without distributing the real and reactive power output of DG converters and then the DGs moves into the grid – connected mode smoothly. The effect of droop control employing load sharing among sources is provided properly. Hence, the DG acts an active power filter. Here, DG is preformed without harmonic content. So installing proper filter harmonic content can be compensated and also THD value is reduced. By comparing all control technique, Decentralized droop control technique has fast response time.

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