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Parallel Operation of Inverters With Droop Control of Voltage and Frequency

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***Abstract*— In distributed generation numerous small generating stations are connected to micro grid by using interfacing inverter. While connecting a various inverters in micro grid, load sharing amongst them in very important factor. This paper presents a novel approach for interfacing parallel inverter, the technique used in this paper is based on P-F/Q-V droop control. This technique is very helpful when micro grid is operating in island mode. The droop control is designed in a such a way that it helps in maintaining the voltage and frequency stability. In this paper method of droop control is implemented and characteristics of proportional load sharing are obtained from each connected inverter. The two inverters operation is shown in this paper. The two inverter scheme with droop control is implemented in MATLAB and results obtained shows significant sharing of load while maintaining the constant voltage and frequency.**

Keywords — Parallel operation of converter, droop control of Voltage and frequency, power grid, proportional power sharing etc.

I. Introduction

In the last decade tremendous growth of load is observed and new generation plant are not added. In most of the cases the capacity addition is done to existing cases. There is shortfall of the electric power as there is a gap between supply and demand. Moreover, if we use fossil fuels for generation of the electricity, the cost of plant will be higher. Moreover, plants uses a fossil fuel are located at far distance so the transmission losses are also increased. It is best to use renewable energy sources like solar and wind, it will not affect the environment and fuel is free of cost from nature, thus the running cost of wind and solar are very minimal. As the necessity and importance of using renewable energy sources grew up the importance of power electronic devices also rose at same rate. The uses of power electronic devices are inherent in renewable energy sources. The power generated by solar and wind is DC so make it useful we have to use converter which uses a power electronic devices. Micro grid can be connected to main grid or it can be also operate in island mode.

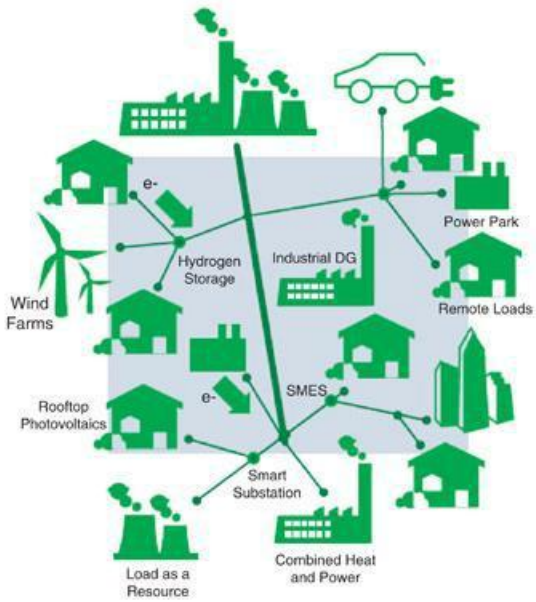

Fig. 1. Distributed Generation System

As shown in Fig. 1. Numerous, various kinds of generators are connected together, which form a distributed generation system is connected together forms a micro grid. when the system is in islanding mode, it utilizes the multiple distributed power inverter in parallel way for achieving the high capacity and redundant power supply which helps in improving the power supply system. When comparison of single power inverters and multiple inverters is carried out for increasing the capacity of the system, parallel operation of the inverters offers many advantages. The main advantage of it has no external communication mechanism will be required for inverters. Another advantage is, it can achieve stable and reliable redundant power.

Parallel operation of the inverter improves the operational reliability and efficiency of both the inverter and widely used in high frequency modular UPS and distributed generation system.

However, in the parallel operation of the inverter it will be difficult so in the parallel operation of the inverter it should be synchronized, if it is not done properly parallel operation of the inverter will be difficult. However, if the synchronization of the inverter is not done properly it may add the burden on the inverter will be more and may cause the system to collapse and it may add to interruption in the system. The parallel operation of the inverter can be classified in three ways centralized control, decentralized control and master slave control; this is classified on the communication technology. Interaction between control and no interconnecting lines and their interaction control.

Droop control is mostly preferred method as it is no contact signal line independent method. Droop control is signal line independent control technology. The best advantage of droop control is it does not require interconnection between the inverters. The most important challenge in case of micro grid is, if supply from grid power utility fails, the micro grid should rely on their own capacity to maintain the regulation of voltage and frequency. The droop control uses Pf/Q-V inverter, as it does not require any kind of communication, amongst the inverters which are operating in parallel. This paper concentrates on implementation of the droop control for parallel operation of the inverters for sharing of the load.

II. Droop Control

Fig. 2. Shows a simple circuit whose active and reactive power flow control to be controlled.

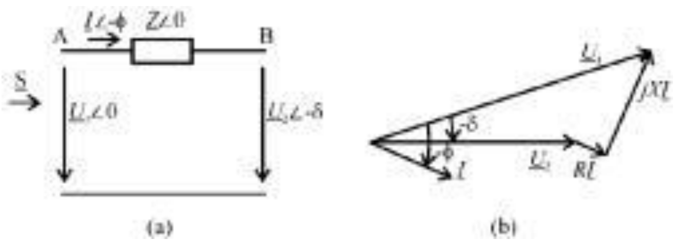

Fig.1 (a) Power flow through line, (b) Phasor Diagram

$$\underline{P + jQ} = \underline{S} = \underline{U1}\,\underline{I1} = \underline{U1} = \left(\frac{\underline{U1} - \underline{U2}}{\underline{Z}} \right)$$

$$= U1 \left(\frac{U1 - U2e^{j\delta}}{Ze^{-j\theta}} \right)$$

$$= \frac{U1^2}{Z} e^{j\theta} - \frac{U1U2}{Z} e^{j(\theta+\delta)} \quad (1)$$

The active and reactive power flowing into the line can be given as follows

$$P = \frac{U1^2}{Z}\cos\theta - \frac{U1U2}{Z}\cos(\theta + \delta) \quad (2)$$

$$Q = \frac{U1^2}{Z}\sin\theta - \frac{U1U2}{Z}\sin(\theta + \delta) \quad (3)$$

As impedance of the line is written as Z= R+jX, equation number (2) and (3) are rearranged as

$$P = \frac{U1}{R^2 + X^2}[R(U1 - U2\cos\delta) + XU2\sin\delta] \quad (4)$$

$$Q = \frac{U1}{R^2 + X^2}[-RU2\sin\delta + X(U1 - U2\cos\delta)] \quad (5)$$

Equation (4) and (5) can also be written as

$$U2\sin\delta = \frac{XP - RQ}{U1} \quad (6)$$

$$U1 - U2COS\delta = \frac{RP + XQ}{U1} \quad (7)$$

For overhead transmission lines X/R ratio is very high, indicating that X is much higher and R is very low. Considering this fact R can be neglected, power angle δ is also very small for overhead transmission line. On the basis of above two assumptions (6) and (7) can be simplified as

$$\delta \cong \frac{XP}{U1U2} \quad (8)$$

$$U1 - U2 \cong \frac{XQ}{U1} \quad (9)$$

As X/R and power angle of overhead transmission line is very low, very small difference between U1 and U2 is observed, it is also shown in (8) power angle only depends on real power. And difference between the two voltages on reactive power. In other words power angle control the real power and output voltage of the inverter is governed by the reactive power. If we control the frequency the control of power angle is possible and real power control is possible. In this way by varying the values of P & Q independently frequency and voltage magnitude of grid are calculated.

$$f - f_0 = -k_p(p - p_0) \quad (10)$$

$$U1 - U0 = -k_q(q - q_0) \quad (11)$$

F_0 and U_0 are abbreviations of frequency and grid voltage respectively and P_0 and Q_0 are assumed to the initial values of active and reactive power. The characteristics of droop control and frequency control are shown graphically in Fig. 2.

III. Modelling of Three Phase Inverter with Droop Control

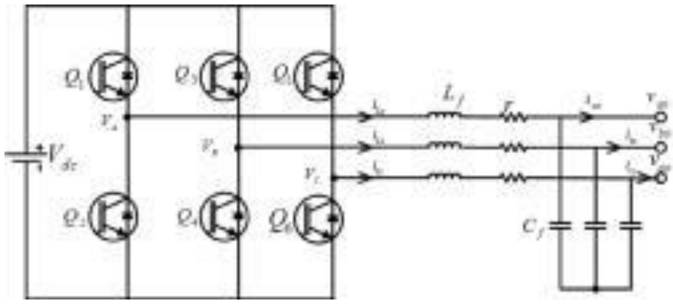

Fig. 3. Three phase voltage source inverter.

V_{dc} → is considered as a input voltage
L_f → Inductor filter
R → Equivalent resistance of Inductor filter
C_f → Filter Capacitor
A, B, C, → Inverter Bridge arms
Va, Vb, Vc → Inverter leg midpoint voltage.

By using kirchoffs current law we can write different voltages and inverters current as follows

$$V_a - V_{a0} = L_f \frac{di_{la}}{dt} + ri_{la}$$
$$V_b - V_{b0} = L_f \frac{di_{lb}}{dt} + ri_{lb}$$
$$V_c - V_{c0} = L_f \frac{di_{lc}}{dt} + ri_{lc}$$
$$I_{la} - I_{ao} = C_f \frac{D_{va0}}{dt}$$
$$I_{lb} - I_{bo} = C_f \frac{D_{vb0}}{dt}$$
$$I_{lc} - I_{co} = C_f \frac{D_{vc0}}{dt} \quad (12)$$

Based on principle of equal magnitude conversion transformation matrix is written as

$$T_{abc-\alpha\beta} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \quad (13)$$

Applying inverse clark transformation

$$T_{\alpha\beta-abc} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \quad (14)$$

Based on the principle of equal amplitude transformation both rotating transformation matrix is written as.

$$T_{\alpha\beta-dq} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \quad (15)$$

Equivalent model of complete inverter can be written as

$$\frac{d}{dt}\begin{bmatrix} V_{od} \\ V_{oq} \\ I_{ld} \\ I_{lq} \end{bmatrix} = \begin{bmatrix} 0 & \omega & \frac{1}{C_f} & 0 \\ -\omega & 0 & 0 & \frac{1}{C_f} \\ -\frac{1}{L_f} & 0 & -\frac{r}{L_f} & \omega \\ 0 & -\frac{1}{L_f} & -\omega & -\frac{r}{L_f} \end{bmatrix} \quad (16)$$

Equation (16) three phase voltage source inverter dq mathematical model with respect to two phase rotating co-ordinate system. .0

IV. Control Diagram of Current and Voltage Loop

Double close loop system is used while designing control system of the droop control voltage source inverter same shown in Fig. 4. The signal derived from the output voltage used for reference tracking loop for controlling the output power. Inner loop is depends on the current drawn from the system, reference taken from this helps in improve steady state and dynamic stability of the system.

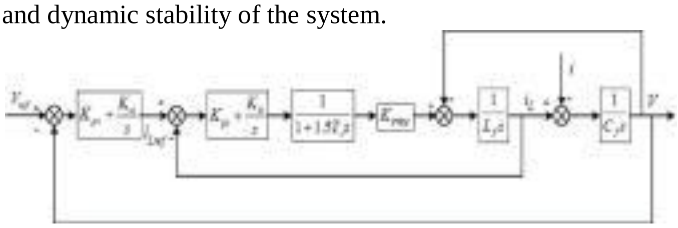

Fig.4. Voltage and current double closed loop control block diagram

In the design of current loop the inner loop controlled two phase rotating co-ordinate system. The system is modeled using two axis system d-axis and q Axis coordinate system. Fig. 5. Shows the block diagram of the same.

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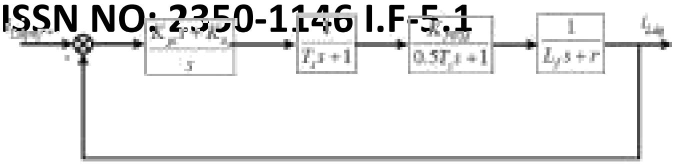

Fig.5 .Current loop control block diagram

V. Simulation Results and Discussions

Above explained method is simulated in the MATLAB simulink software. Two inverters are connected in parallel to share the load. The load of active and reactive type both are applied at point of common coupling(PCC). Two different inverters of 3KW each are connected across each other with droop coefficients of m=0.0015rad/s/W, n=0.001/Var/W, and line impedance of R= 0.642 ohm, X=0.083 ohm. The applied active and reactive power connected is P=2000W and Q = 5VAR. The various waveforms drawn at the PCC are shown in Fig. 6,7 and 8. It is observed that both the inverters shared same amount active and reactive power.

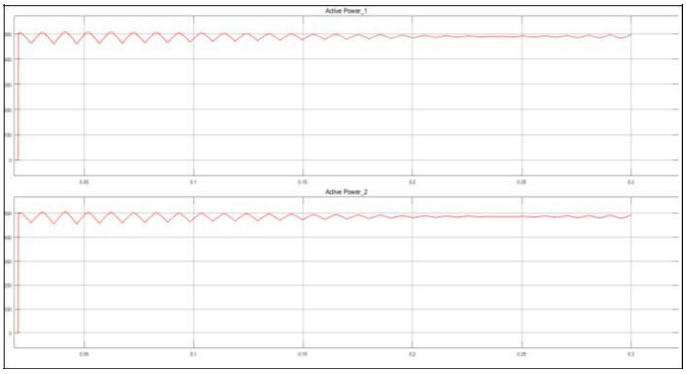

Fig. 6. Active power of inverter 1 and inverter 2

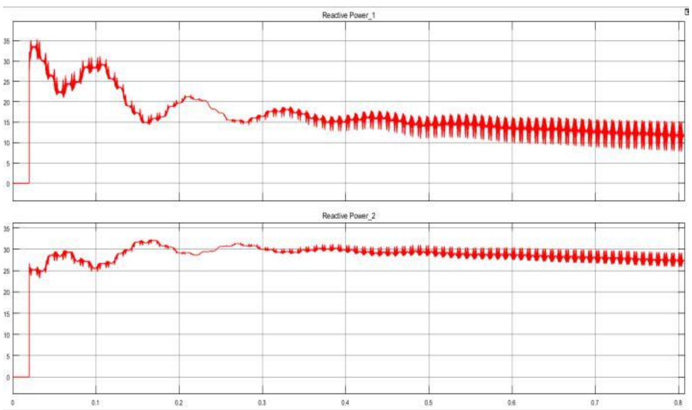

Fig. 7. Reactive power of inverter 1 and inverter 2

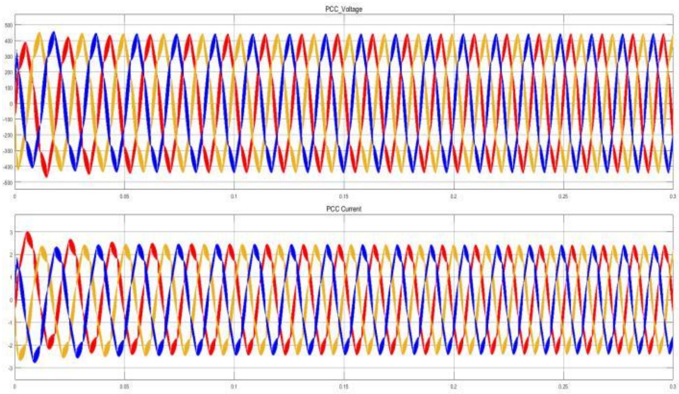

Fig. 8. Voltage and Current waveforms at PCC

VI. Conclusion

The droop control method for the inverters is being mention in great detail and it is implemented for two inverters in the MATLAB simulink environment. Usage droop control method is very effective for using inverters is microgrid. Using droop control method implemented in this paper it is observed that both the inverters shared proportionate results and it proved the effective usage of droop control

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