Power Quality Enhancement for A Renewable Source Connected Inverter with Cascaded Voltage Current Control

E. Manohar[1], M. Ramakrishna[2]

[1]*M.Tech student, EEE, Lords Institute of Engineering and Technology, Hyderabad, India.*

[2]*Associate Professor, EEE, Lords Institute of Engineering and Technology, Hyderabad, India*

***Abstract*- Many of the new types of distributed energy resources (DER) are inverter based, such as photovoltaics (PV), wind, microturbines, and fuel cells. Inverters with energy storage enable new functionality such as peak shaving, energy arbitrage, and seamless islanding, i.e. UPS functionality. Here a cascaded current–voltage control strategy is proposed for inverters to concurrently progress the power quality of the inverter local load voltage and the current switched with the grid. In general control scheme comprises an inner voltage loop and an outer current loop, with both controllers designed using the H^{∞} repetitive control approach. This leads to a very low total harmonic distortion in both the inverter local load voltage and the current exchanged with the grid at the same time. Our proposed control approach can be employed to single-phase inverters as well as three-phase four-wire inverters. It allows grid-connected inverters to inject balanced clean currents to the grid even when the local loads (if any) are unbalanced and/or nonlinear.**

***Index Terms*— H ∞ control, microgrids, power quality, repetitive control, seamless transfer, total harmonic distortion (THD).**

I. INTRODUCTION

The determination of distributed power generation has been increasing quickly in the past decades. Compared to the conventional centralized power generation, distributed generation (DG) units can able to carry spotless and renewable power close to the customer's end [1]. As a result, it can improve the stress of many conventional transmission and distribution infrastructures. If the grid is connected to any distributed generating units by using power electronic converters, they have the opportunity to realize enhanced power generation through a flexible digital control of the power converters. Alternatively, high penetration of power electronics based DG units also introduces a few issues, such as system resonance, protection interference, etc. In order to overcome these problems, the micro grid concept has been proposed, which is realized through the control of multiple DG units. Compared to a single DG unit, the micro grid can achieve superior power management within its distribution networks. In addition, the islanding operation of micro grid offers high reliability power supply to the critical loads. Therefore, micro grid is considered to cover the way to the future smart grid [1].

Microgrids have attracted attention in recent years for their role in integration of distributed-energy resources (DER), delaying transmission investments by adding generation near load centers, and providing islanded operation during outages. A microgrid can be defined as a group of sources and loads that have the ability to operate in parallel with, or intentionally separate from the utility. A conceptual microgrid architecture is shown in Fig. 1. Microgrids can simplify the integration of large numbers of DER with the grid by aggregating the control of multiple DER and allowing the utility to interface with the microgrid as a single entity. By operating in islanded mode, DER has the ability to improve reliability by operating in islanded mode during grid disturbances and outages.

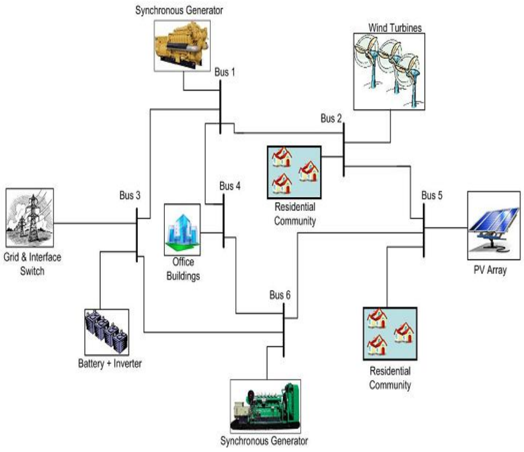

Fig. 1: Conceptual microgrid architecture.

Many types of renewables and distributed generation such as photovoltaics (PV), wind, micro turbines, fuel cells, and energy storage interface to the grid through DC/AC inverters. Therefore much of the existing microgrid literature assumes that microgrids will be dominated by inverter-based sources. However, since internal combustion engine driven synchronous generators (SGs) are the most common type of DER, it is expected that synchronous generators will play a major role in microgrid installations.

Thus it is important to carefully consider the interaction between inverters and generators.

II. PROCEDURE FOR PROPOSED CONTROL SCHEME

As depicted in fig.1 which completely gives information about configuration of grid to which a single phase inverter is connected that contains several blocks like an LC filter, an inverter bridge and a grid interface inductor that is connected with a circuit breaker. Also it is worth noting that local loads are connected in parallel with that of filter capacitor so that current i_1 is flowing through the inductor filter which is termed to be inductor current and similarly current i_2 flowing through the grid interface inductor is termed as the grid current. The main motto of the proposal is to preserve as low as possible THD for the inverter local load voltage u_o and, at the same time, for the grid current i_2.

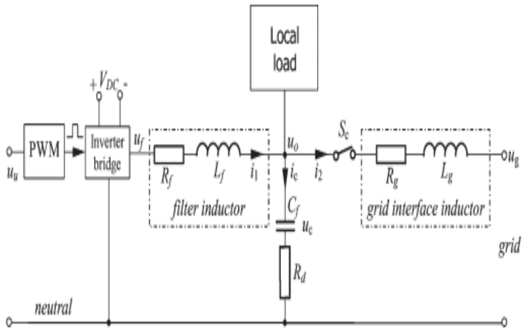

Fig. 1. Sketch of a grid-connected single-phase inverter with local loads.

Generally speaking the system can be treated as two parts which is depicted in fig.2 and fig.3 that were cascaded together so for this reason cascaded controller is employed in the design.

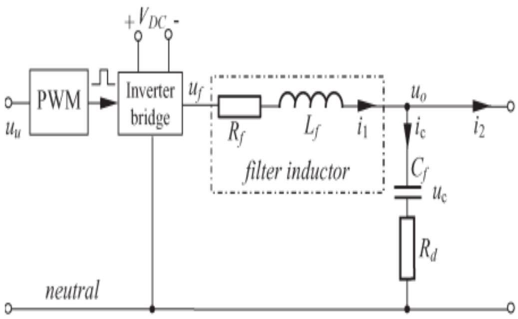

Fig. 2. Control plant Pu for the inner voltage controller.

Here proposed controller, as shown in Fig. 4, comprises of two loops: one is inner voltage loop that's job is to adjust the inverter local load voltage u_o and the other is an outer current loop that's job is to adjust the grid current i2.

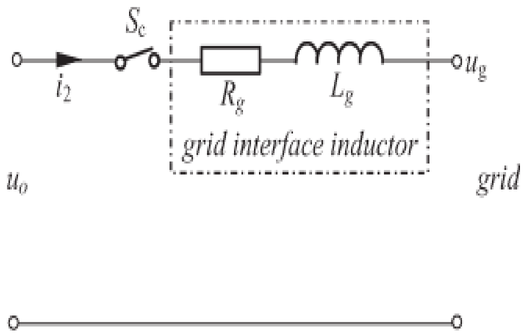

Fig. 3. Control plant *Pi* for the outer current controller.

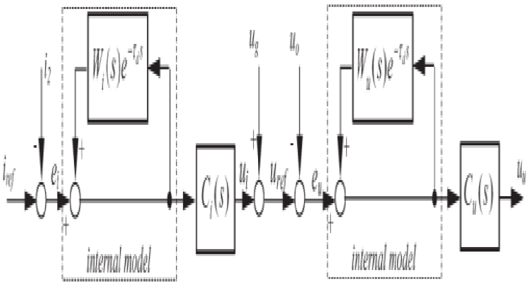

Fig. 4. Proposed cascaded current–voltage controller for inverters, where both controllers adopt the H^∞ repetitive strategy.

Rendering to the elementary principles of control theory that gives details about cascaded control, in which the dynamics of the outer loop is designed to be slower compare to that of the inner loop, subsequently the two loops can be designed distinctly. As a result, the outer loop controller can be designed by take supposition that of the inner loop that is already in the steady state, i.e. $U_o = U_{ref.}$ As before mentioned ii is much stressing that always the current controller is in the outer loop whereas voltage controller is in the inner loop. Now the foremost tasks of the voltage controller are as follows: they have to deal with power quality issues of the inverter local load voltage irrespective of unbalanced and/or nonlinear local loads, to produce and dispatch required power to the local load, and to synchronize the inverter with that of the grid.

III. DESIGN OF THE VOLTAGE CONTROLLER

The design of the voltage controller will be shown in which control plant of the voltage controller is no longer the whole *LCL* filter but just the *LC* filter, as shown in Fig. 2. Moreover, it is absolutely necessary to obtain a linear model that represents the relationship between input and output in order to design the controller [10].

The corresponding control plant shown in Fig. 2 for the voltage controller consists of the inverter bridge and the LC filter (L_f and C_f). The filter inductor is modeled with a series winding resistance. The pi block, together with the inverter, is modeled by using an average voltage approach with the limits of the available dc-link voltage so that the average value of u_f over a sampling period is equal to u_u. The output signal from the plant Pu is the tracking error $e_u = u_{ref} - u_o$, where $u_o = u_c + Rd\ (i_1 - i2)$ is the inverter local load voltage. The plant Pu can be described by the state equation

$x_u = A_{uxu} + B_{u1wu} + B_{u2u}u$…………… (1)

and the output equation

$y_u = e_u = C_{u1x}u + D_{u1wu} + D_{u2uu.}$…….. (2)

with

$$A_u = \begin{bmatrix} \frac{-R_f + R_d}{L_f} & \frac{-1}{L_f} \\ \frac{-1}{C_f} & 0 \end{bmatrix}$$

$$B_{u1} = \begin{bmatrix} \frac{R_d}{L_f} & 0 \\ \frac{-1}{C_f} & 0 \end{bmatrix} B_{u2} = \begin{bmatrix} \frac{1}{L_f} \\ 0 \end{bmatrix}$$

$$C_{u1} = [-R_d - 1]$$

$D_{u1} = [R_d \quad 1]$ $\qquad D_{u2} = 0$

The corresponding plant transfer function is then

$$P_u = \left[\begin{array}{c|cc} A_u & B_{u1} & B_{u2} \\ C_{u1} & D_{u1} & D_{u2} \end{array}\right] \text{……….(3)}$$

IV. DESIGN OF THE CURRENT CONTROLLER

When designing the outer-loop current controller, it can be assumed that the inner voltage loop tracks the reference voltage perfectly, i.e., $u_o = u_{ref}$. Hence, the control plant for the current loop is simply the grid inductor, as shown in Fig. 3. The formulation of the control problem to design the PI compensator C_i is similar to that in the case of the voltage control loop.

The plant P_i can then be described by the state equation

$x_i = A_{ix}i + B_{i1wi} + B_{i2ui}$……………(4)

and the output equation

$y_i = e_i = C_{i1xi} + D_{i1w}i + D_{i2ui}$……(5)

where

$$A_i = -\frac{R_g}{L_g} \qquad B_{i1} = 0 \qquad B_{i2} = \frac{1}{L_g}$$

$$C_{i1} = -1 \qquad D_{i1} = 1 \qquad D_{i2} = 0$$

The corresponding transfer function of P_i is

$$P_i = \left[\begin{array}{c|cc} A_i & B_{i1} & B_{i2} \\ C_{i1} & D_{i1} & D_{i2} \end{array}\right] \text{……………(6)}$$

V. DESIGN OF RENWABLE ENERGY PLANT USING CASCADED CONTROLLER

The designed cascaded voltage-current controller is connected to the renewable energy source such as wind turbine as shown in the fig.5.

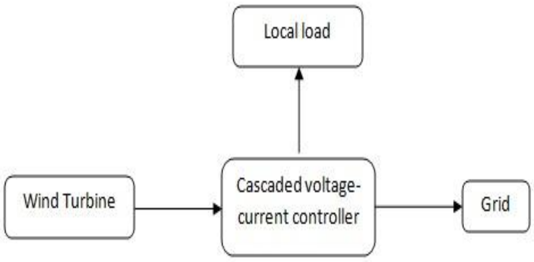

Fig.5 Proposed renewable energy source with cascaded voltage-current controller

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. The PID controller block is reduced to P and I blocks only as shown in fig 6.

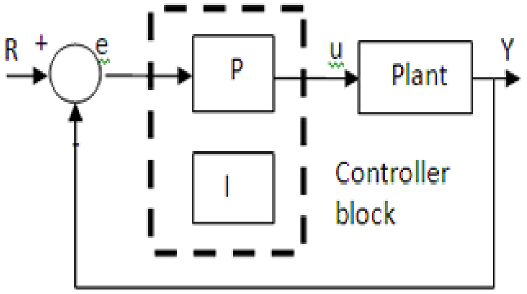

Fig.6: Proportional Integral (PI) Controller block diagram

Three sets of identical controllers were used for the three phases because there was a stable neutral line available. The control structure for the three-phase system is shown in Fig. 7. A traditional dq PLL was used to provide the phase information needed to generate the three-phase grid current references via a dq/abc transformation from the current references I^*_d and I_q^*.

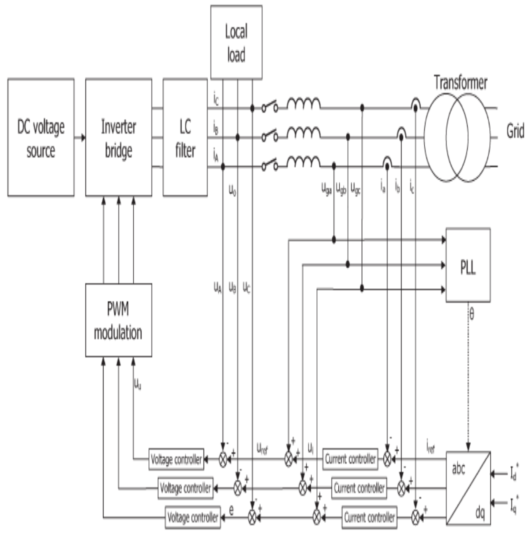

Fig.7. Sketch of a grid-connected three-phase inverter using the proposed strategy.

VI. SIMULATION RESULTS

The above-designed controller was implemented to evaluate its performance in both stand-alone and grid-connected modes with different loads using the MATLAB simulation circuit as shown in the fig.8.

The proportional and integral terms is given by:

$$u(t) = K_p e(t) + K_i \int e(t)dt \ldots\ldots\ldots\ldots..(7)$$

K_p and K_i are the tuning knobs, are adjusted to obtain the desired output.

The unified transfer of the operation modes was also supported out. In the stand-alone mode, since the grid current reference was set to zero and the circuit breaker was turned off (which means that the current controller was not functioning), The PI controller was designed according to the plant used.

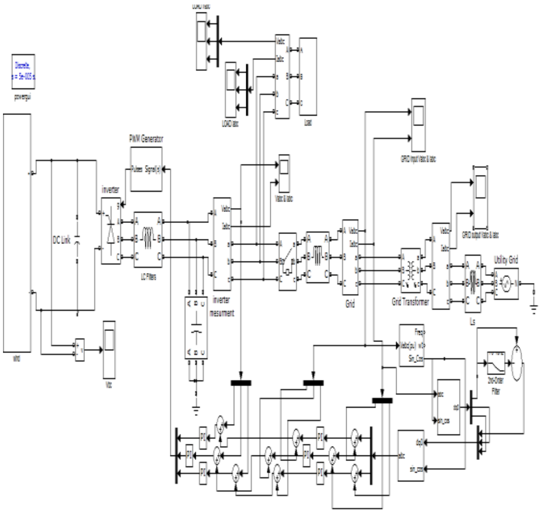

Fig.8.Simulation circuit for the proposed control strategy.

A. In the Stand-Alone Mode

The voltage reference was set to the grid voltage (the inverter is synchronized and ready to be connected to the utility grid).

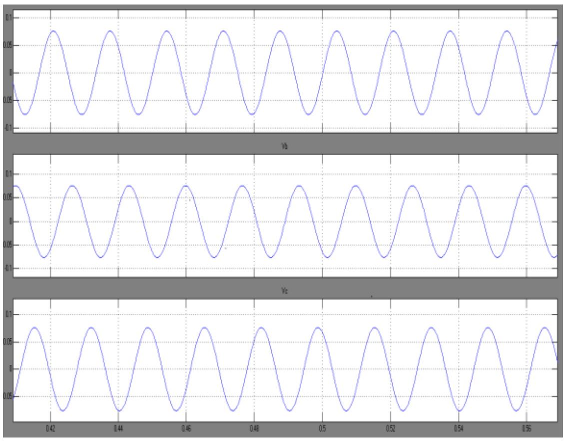

Fig.9 Voltage waveform across load

The evaluation of the proposed controller was made for a resistive load (RA = RB = RC = 12 Ω), a nonlinear load (a three-phase uncontrolled rectifier loaded with an LC filter with L = 150 μH and C = 1000 μF and a resistor R = 20 Ω), and an unbalanced load (RA = RC = 12 Ω and RB = ∞). The output voltage and current waveforms obtained at the load is shown in Fig.9 and Fig.10. Since the proposed control structure adopts separate controllers for each phase, the unbalanced loads had no influence on the voltage controller performance, and the inverter local load voltages remained balanced.

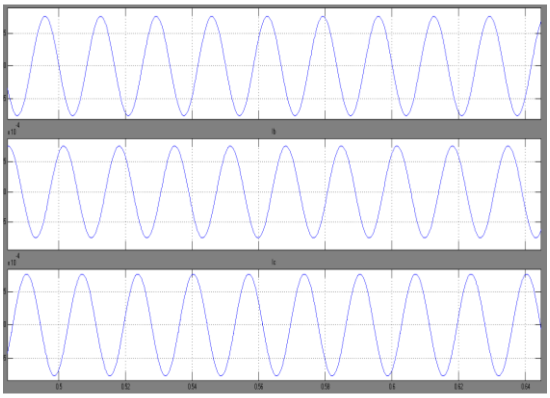

Fig.10 Current waveform across load

B. In the Grid-Connected Mode

The current reference of the grid current $I*d$ was set at 2 A (corresponding to 1.41A rms), after connecting the inverter to the grid. The reactive power was set at 0 var($I*q$=0). The resistive, nonlinear, and unbalanced loads used in the previous section were used again. Moreover, the case without a local load was carried out as well. Finally, the transient responses of the system were evaluated.

The grid output voltage and current waveforms are shown in Fig.11 and Fig.12.

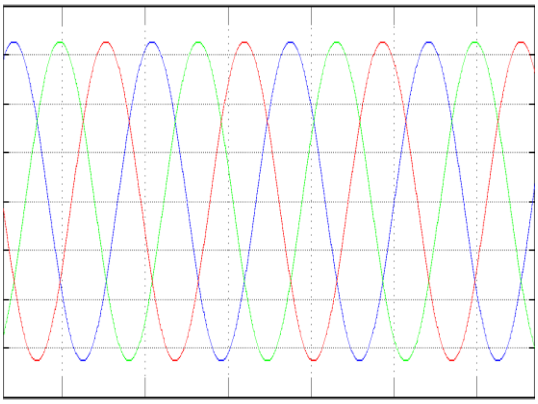

Fig.11 Voltage waveform across grid

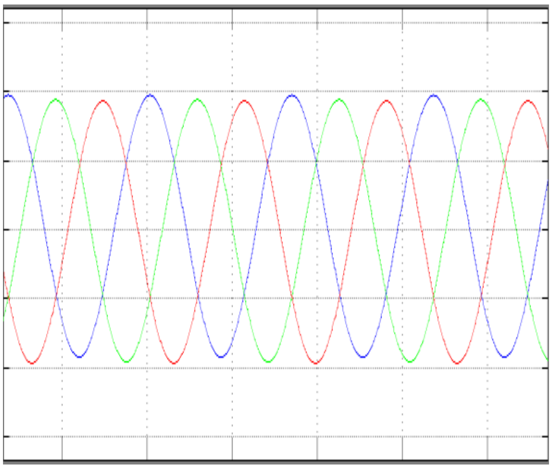

Fig.12 Current waveform across grid

C. Seamless Transfer of the Operation Mode

The transient response of the grid current when the inverter was changed from the stand-alone mode to the grid connected mode and back. There were no noticeable transients in the inverter local load voltage, and seamless disconnection from the grid was achieved. In summary, the proposed control strategy is able to achieve seamless transfer of operation modes from stand-alone to grid connected or vice versa.

VII. CONCLUSION

This paper improves understanding of the transient interactions between grid-supporting-grid-forming inverters and generators, and provides microgrid designers control over the tradeoff between transient load sharing and power quality. The methods proposed in this paper for mitigating inverter overloads will allow for more reliable and cost effective application of inverter based DER with synchronous generators in microgrids. The proposed strategy also achieves seamless transfer between the standalone and the grid-connected modes. The strategy can be used for single-phase systems or three-phase systems. As a result, the nonlinear harmonic currents and unbalanced local load currents are all contained locally and do not affect the grid. Simulation results under various scenarios have demonstrated the excellent performance of the proposed strategy.

REFERENCES

[1] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, "Microgrids," IEEE Power Energy Mag., vol. 5, no. 4, pp. 78–94, Jul./Aug. 2007.

[2] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, "Microgrids management," IEEE Power Energy Mag., vol. 6, no. 3, pp. 54–65, May/Jun. 2008.

[3] C. Xiarnay, H. Asano, S. Papathanassiou, and G. Strbac, "Policymaking for microgrids," IEEE Power Energy Mag., vol. 6, no. 3, pp. 66–77, May/Jun. 2008.

[4] Y. Mohamed and E. El-Saadany, "Adaptive decentralized droop controller to preserve power sharing stability of paralleled inverters in distributed generation microgrids," IEEE Trans. Power Electron., vol. 23, no. 6, pp. 2806–2816, Nov. 2008.

[5] Y. Li and C.-N. Kao, "An accurate power control strategy for power electronics- interfaced distributed generation units operating in a low voltage multi bus microgrid," IEEE Trans. Power Electron., vol. 24, no. 12, pp. 2977–2988, Dec. 2009.

[6] C.-L. Chen, Y. Wang, J.-S. Lai, Y.-S. Lee, and D. Martin, "Design of parallel inverters for smooth mode transfer microgrid applications," IEEE Trans. Power Electron., vol. 25, no. 1, pp. 6–15, Jan. 2010.

[7] J. Guerrero, J. Vasquez, J. Matas, M. Castilla, and L. de Vicuna, "Control strategy for flexible microgrid based on parallel line-interactive UPS systems," IEEE Trans. Ind. Electron., vol. 56, no. 3, pp. 726–736, Mar. 2009.

[8] Z. Yao, L. Xiao, and Y. Yan, "Seamless transfer of single-phase grid interactive inverters between grid connected and stand-alone modes," IEEE Trans. Power Electron., vol. 25, no. 6, pp. 1597–1603, Jun. 2010.

[9] Q.-C. Zhong and G. Weiss, "Synchronverters: Inverters that mimic synchronous generators," IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1259–1267, Apr. 2011. Accurate proportional load sharing among inverters operated in parallel," IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1281–1290, Apr. 2013.

[10] Q.-C. Zhong, "Robust droop controller for accurate proportional load sharing among inverters operated in parallel," IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1281–1290, Apr. 2013.