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QUALITY IMPROVEMENT BY USING WIND AND SOLAR HYBRID SYSTEM WITH NOVEL METHOD

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ABSTRACT

The main aim of this paper is to analysis and improve the power quality (voltage sag, swell and harmonics) performance of smart grid connected inverter used in distributed generation. The structure of the designed controller consists of outer power with harmonic con-trol loop, middle voltage control loop and inner current control loop for real and reactive power control in dq reference frame.The operation of the controller is investigated for vary-ing power demands with linear and non linear loads from the customer side and for varying smart grid impedance along with varying distributed generation source voltage. An increase in reactive power demand at pee would affect the system power factor at pee.The conventional type PI controller for such change in customer load and variation of smart grid imped-ance do not exhibit a satisfactory dynamic behaviour. Alternatively, the proposed controller simultaneously computes current dynamics and harmonics of the pa-rameters for generating the control reference values to meet the current additional reactive power require-ment with reduced total harmonic distortion and is used as new reactive power reference value for power controller. The state space model of the proposed con-troller is developed.The simulation results clearly indicates that the devel-oped controller is able to maintain constant voltage at the point of common coupling (PEC) and exhibits good dynamic response for varying smart grid imped-ance and dynamic load changes besides nullifying the effect of voltage swell, sag and harmonics at pee . The comparisons have been made with the conventional SVPWM based PI controller employed for the same hy-brid scheme with the proposed controller. The results clearly bring out suppleness of the proposed scheme.

I. INTRODUCTION

In recent years there has been a growing interest in moving away from large centralized power generation towards distributed energy resources. Hybrid solar and wind energy generation presents several benefits for use as a distributed energy resource, especially as a peaking power source. In earlier days, one of the draw-backs in the solar energy sources is the need for energy storage for the system to be utilized for a significant percentage of the day.One way to overcome this disadvantages by utilizing the inverter and its controller circuits for PV based DG units during the day and night times for improving the reactive power compensation and harmonic elimina-tion on its neighboring DG units and the grid by proper exchange of reactive power between the sources. For this approach the existing developed linear control-lers, proportional-integral controller (PI) and predic-tive control methods are more dominant in current er-ror compensation.But the conventional type PI controllers normally do not have appropriate compensation from the invert-ers for the grid connected applications. The existing predictive control algorithms are based on deadbeat control in support of voltage source inverters for both power and voltage control, however this method is quite complicated and some digital predicative control strategies suffers from control delay and mainly con-trollers uses the dc link voltage as one of the control parameter but this method is not superior for PV based DG units without dc-dc converters.

II. BLOCK SCHEMATIC OF THE PROPOSED HY-BRID SCHEME

The proposed model consists of a two different Distrib-uted generating units (DG) comprises of PV array and wind power resource integrated to the grid through VSI and filter and control blocks as indicated in Fig. (1). the consumer loads are connected at PCC. The control block consists of abc - dqO conversion block and volt-age, current and power control blocks. Measuring in-struments (voltage and current transformers are con-nected at the point of common coupling) to measure the currents flow through the VSI, induction generator, grid, customer demand. The 11.5Kw of PV array unit is integrated with grid through the VSI. A 2.5Kw of wind driven induction gen-erator is connected to the grid at the point of common coupling. This two units are supply's the local load and the surplus power is injected to the grid simultaneous-ly PV sourced VSI is used for reactive compensation at PCC for avoid the voltage swell and sag. In order for communication between measured units and DG con-trol units through DSC, embedded kit is used The complete dynamic equations of IG, taking satura-tion into account, in synchronously rotating refer-ence frame are represented in matrix form as

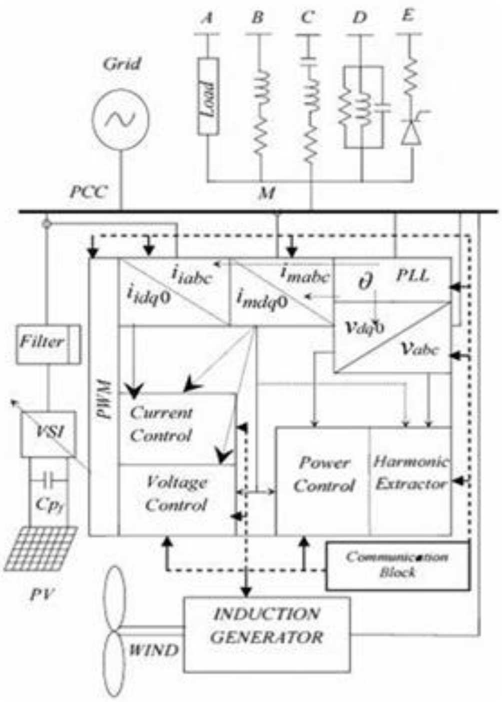

Fig (I) Functional Block Diagram of Proposed Model

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III MODELING OF 3 - SELF EXCITED INDUC- TION GENERATOR

The d-q axes equivalent circuits of an induction generator (IG) in synchronously rotating reference frame are shown in Fig. 2. The complete dynamic equations of IG, taking satura-tion into account, in synchronously rotating refer-ence frame are represented in matrix form as follows

$$\frac{d}{dt}\begin{bmatrix}\lambda_{ds}\\ \lambda_{qs}\end{bmatrix}=\begin{bmatrix}V_{ds}\\ V_{qs}\end{bmatrix}-R_s\begin{bmatrix}i_{ds}\\ I_{qs}\end{bmatrix}-\omega\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\lambda_{ds}\\ \lambda_{qs}\end{bmatrix} \quad (1)$$

$$\frac{d}{dt}\begin{bmatrix}\lambda_{dr}\\ \lambda_{qr}\end{bmatrix}=\begin{bmatrix}V_{dr}\\ V_{qr}\end{bmatrix}-R_r\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix}-(\omega-\omega_r)\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\lambda_{dr}\\ \lambda_{qr}\end{bmatrix} \quad (2)$$

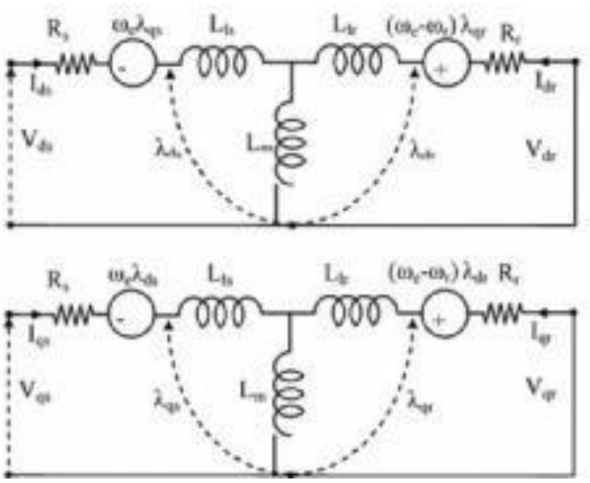

Fig (2) Equivalent Circuit Of IG-d-q Model (a) d-axis (b) q-axis

Where , Rs = Per-phase stator resistance Rr = Per-phase rotor resistance referre to stator iqs = Stator q-axis current, ids = Stator d-axis current iqr = Rotor q-axis current, idr = Rotor d-axis current Vqs= Stator q-axis voltae, Vds= Stator d-axis voltage Vqr= Rotor q-axis voltage, Vdr= Rotor d-axi voltage we = Arbitrary reference frame speed wr = Rotor speed in rad/sec λqS = Flux linkages of stator in q -axis λdS = Flux linkages of stator in d- axis λqr = Flux linkages of rotor in q-axis λdr = Flux linkages of rotor in d-axis LIs = Stator Leakage reactanc

Llr = Rotor Leakage reactance

Lm= Magnetizing inductance of inductance generator

IV. MATHEMATICAL MODELING OF THE PRO- POSED SCHEME

The state space model in dq reference frame for a three phase voltage source inverter (YSI) inte-grated to the grid and powered by PY array and wind driven IG is taken up in this paper. In grid connected mode, both DGs are utilized for supplying pre specified power to load to minimize the power import from the grid. The simplified equivalent circuit of YSI inte-grated to grid in current control mode is indicated in Fig. (3). In Fig.(3),

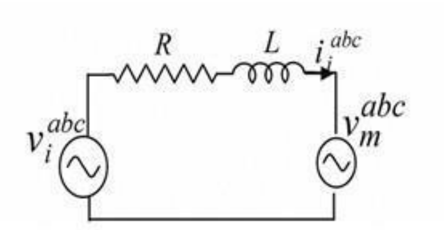

Fig (3) Simplified equivalent model of current con-trol scheme for proposed system

the Vma,Vmb,Vmc &Via,Vib,Vic are the three phase ac voltage at the point of com-mon coupling and voltage on inverter side, the sub-scripts m and i denote at the point of common coupling and inverter

The input to the inverter is a three phase voltage and is given by

Via = Vmax sin (ωt)

V ib = Vmax (ωt - 2Π/3)----- (3) Vic = Vmax (ωt + 2Π/3)

Where Vmax and ω are the maximum phase voltage and angular frequency of the inverter respectively.The voltage and current control model of the grid con-nected are implemented in for voltage and power controls. This developed controller model mostly con-centrates only voltage sag and voltage interruption because the system model is not included in the controller. Accordingly the inverter output voltage is obtained as in eqn. (4)

$$\begin{bmatrix} v_{ia} \\ v_{ib} \\ v_{ic} \end{bmatrix} = R\begin{bmatrix} i_{ia} \\ i_{ib} \\ i_{ic} \end{bmatrix} + L\begin{bmatrix} \frac{di_{ia}}{dt} \\ \frac{di_{ib}}{dt} \\ \frac{di_{ic}}{dt} \end{bmatrix} + \begin{bmatrix} v_{ma} \\ v_{mb} \\ v_{mc} \end{bmatrix}$$

$$\begin{bmatrix} \frac{di_{id}}{dt} \\ \frac{di_{iq}}{dt} \end{bmatrix} = \frac{1}{L}\left[\begin{bmatrix} -R & \omega L \\ -\omega L & -R \end{bmatrix}\begin{bmatrix} i_{id} \\ i_{iq} \end{bmatrix} + \begin{bmatrix} v_{id} \\ v_{iq} \end{bmatrix} - \begin{bmatrix} v_{md} \\ v_{mq} \end{bmatrix}\right] \quad \text{---(4)}$$

$$\dot{X}(t) = AX + Bu(t) + ew(t)$$
$$y = CX(t)$$
$$A = \begin{bmatrix} -R/L & \omega \\ -\omega & -R/L \end{bmatrix}$$
$$B = \begin{bmatrix} 1/L & 0 \\ 0 & 1/L \end{bmatrix}$$
$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad \text{------(5)}$$
$$e = \begin{bmatrix} -1/L & 0 \\ 0 & -1/L \end{bmatrix}$$

X(t)=[iid(t) iiq(t)]T u(t)=[Vid(t) Viq]T w(t)=[Vmd(t) vmq(t)]T

Equations in voltage mode control is given as in (5)

x (t) = [vc fd (t) vc fq (t) iid(t) iiq(t)]T

u (t) = [vid (t) viq (t)]T -----------(6)

w (t) = [imd (t) imq(t)]T

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$$A=\begin{bmatrix} 0 & \omega & 1/C_f & 0 \\ -\omega & 0 & 0 & 1/C_f \\ -1/L & 0 & -R/L & \omega \\ 0 & -1/L & -\omega & -R/L \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1/L & 0 \\ 0 & 1/L \end{bmatrix} \quad C=\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The injected active and reactive power components, p and q, can be represented in terms of the d- and q-axis components of the supply voltage at the PCC and the injected currents as follows: pinv = 3/2(vidi id + viqi iq)qinv = 3/2(viqi id +vidi iq) ---(3) The voltage and current reference values are obtained through general power equation (6). However with this conventional control the dynamic response is poor as the variation of filter capacitance & grid im-pedance occurring due to change in load cannot meet satisfactorily

$$\begin{bmatrix} i_{id}^* \\ i_{iq}^* \end{bmatrix} = \frac{1}{\|v_i^*\|}\begin{bmatrix} v_{id}^* & -v_{iq}^* \\ v_{iq}^* & v_{id}^* \end{bmatrix}\begin{bmatrix} p_i \\ q_i \end{bmatrix} \qquad \text{----(7)}$$

To compensate for this filter-capacitor current compo-nent And the inductor current references are calcu-lated by adding a simple feed-forward compensation term as follows in this proposed model.

$$\begin{bmatrix} i_{id} \\ i_{iq} \end{bmatrix} = \frac{1}{\|v_i\|}\begin{bmatrix} v_{id} & -v_{iq} \\ v_{iq} & v_{id} \end{bmatrix}\begin{bmatrix} p_i \\ q_i \end{bmatrix} + \frac{1}{Z}\begin{bmatrix} v_{id} \\ v_{iq} \end{bmatrix} \qquad \text{----(8)}$$

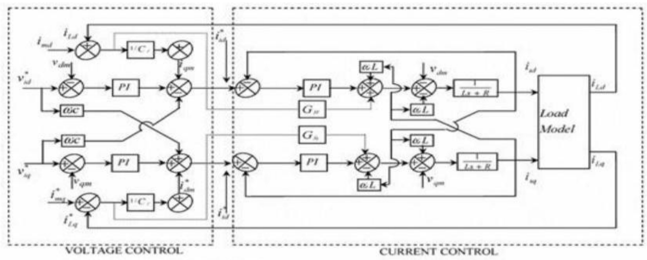


Fig. (4).Proposed voltage and current control loops

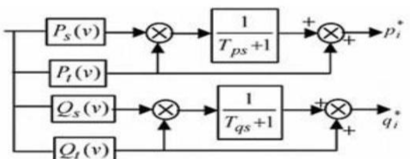


Fig. (4a).Dynamic load model for power references

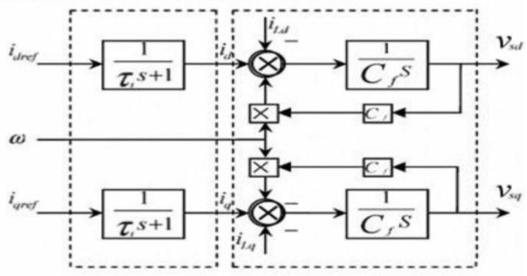


Fig. (4b). Block diagram of dynamic load model with inverter model

V CONTROLLER FUNCTION

Fast load voltage regulation is a necessary requirement in a power distribution system particularly in feeders serving voltage-sensitive loads and Distributed Gener-ating units with renewable energy source.One of the main objectives of the voltage controller is to achieve fast and accurate generation of the reactive current reference for regulating the voltage at PCC. To achieve this objective, the principle of voltage sag and swell mitigations along with harmonic re-duction of DG sourced voltage source inverters are to inject a current into the PCC in order to keep the load voltage at its rated value. Using the voltage-oriented control, the active and reactive power injection can be controlled via a current-controlled VSI. To achieve the objective the required control for operation of i) grid-connected mode ii) islanding mode. In the grid connected mode, both DGs are utilized for supplying pre-specified power to minimize the power import from the grid.

VI. POWER CONTROL LOOP:

$$P_s(v)=P_o\left(\frac{v}{v_o}\right)^{\alpha s} \quad \text{---(9)} \qquad Q_s(v)=Q_o\left(\frac{v}{v_o}\right)^{\beta s} \quad \text{---(10)}$$

$$P_t(v)=P_o\left(\frac{v}{v_o}\right)^{\alpha t} \quad \text{---(11)} \qquad Q_t(v)=Q_o\left(\frac{v}{v_o}\right)^{\beta t} \quad \text{---(12)}$$

With this arrangement, the dynamics of the system changes rapidly in the case of instantaneous load varying situations. A flexible control strategy is re-quired to be developed to handle this dynamics. The proposed multilevel controller comprises of power control loop (external level control), voltage control loop (middle level control) and inner or cur-rent control loop. Outer loop creates reference for inner loop as indicated in Fig. (5). All blocks make use of control variables that are possible to be lo-cally measured

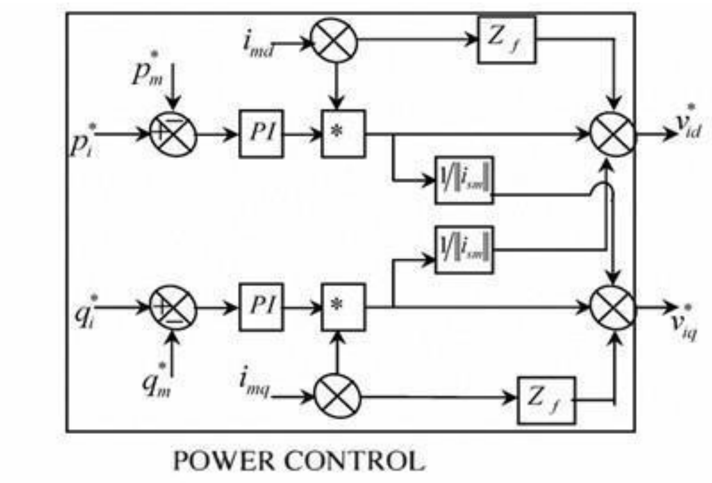


Fig (5) Proposed power control loops

$$\begin{bmatrix} L_s + \frac{K^2}{Cs} & \omega_0 L \\ \omega_0 L & L_s \end{bmatrix} \begin{bmatrix} i_{pn}(s) \\ i_{rn}(s) \end{bmatrix} = \begin{bmatrix} v_{pn}(s) \\ v_{rn}(s) \end{bmatrix} \quad (13)$$

$$V_{pn}(t) = v_n \cos(n-1)\omega_o t \quad \text{---------} \; (14)$$

$$V_{rn}(t) = v_n \sin(n-1)\omega_o t \quad \text{---------} \; (15)$$

$$\left(Ls + \frac{K^2}{Cs}\right) i_{pn}(s) + i_{rn}(s)\omega_0 L = V_{pn}(s)$$

$$-\omega_0 i_{pn}(s) + Ls\, i_{rn}(s) = V_{rn}(s) \text{ for harmonic analysis}$$

$$i_{pn}(s) = \frac{L_s\, v_{pn}(s)}{\Delta(s)} - \frac{\omega_0\, l}{\Delta(s)} v_{rn}(s) \text{-------}(16)$$

$$i_{rn}(s) = \frac{\omega_0\, l}{\Delta(s)} v_{rn}(s) + \frac{\left(L_s + \frac{K^2}{Cs}\right) v_{pn}(s)}{\Delta(s)} \text{-------}(17)$$

$$\Delta(s) = L^2\left[s^2 + \frac{K^2}{LC} + \omega_0{}^2\right]$$

$$i_{pn}(t) = v_n A \sin(n-1)\omega_0 t$$

$$i_{rn}(t) = v_n B \cos(n-1)\omega_0 t$$

$$A = -\frac{(n-2)}{D}; B = -\frac{1}{D}\left[(n-2) - \frac{\omega_n{}^2}{\omega_0{}^2(n-1)}\right];$$

$$D = X_L\left[\frac{\omega_r{}^2}{\omega_0} - n(n-2)\right];$$

$$X_L = \omega_0 L \qquad \omega_r = \frac{K^2}{LC} \qquad K = \sqrt{6}/\pi$$

VI. EXTERNAL LEVEL CONTROL

The external level power control is developed by us-ing (7-12) (Fig.4) is responsible for determining the active and reactive power exchange between the PV system and the utility grid. The proposed external level control scheme is de-signed for performing simultaneously three major control objectives, one is active power control mode (P-CM) and the voltage control mode (Q-CM) and reduce the harmonic at PCC . In this paper voltage mode control is employed. In this mode, the cur-rent reactive power value is measured at point (qm) m this value of qm is compared with qi and error value is fed to the PI control for error minimization and the output of this controller gives dq voltage refer-ence value (Vid *, Viq *) . These variables are fed to the voltage controller for generation of current reference using (7-12). The change of reactive power requirement with respect to change of grid imped-ance value and local loads results in voltage drop across the filter and this drop may affect the system time response and performance. This drawback is nullified in proposed controller by adding z,ie•

VII. VOLTAGE & CURRENT CONTROL

This voltage control loop is developed using (5, 15, 16) for regulating the rated voltage at the PCC con-nected through the VSI. This is achieved by varying the modulation of the reactive component of output current and magnitude of the voltage vector at the PCC. The inverter terminal voltage Vi is calculated from (4) and the compare to Vi. An error signal is produced and then fed to a PI controller. The in-stantaneous values of the three-phase ac bus volt-ages in the dq reference frame permits to design a simpler control system than using abc components. The current control loop developed by using (3, 13, and 14) following the voltage control loop and this loop controls the real and reactive power indepen-dently and good response of the system dynamics and harmonics are ensured due to the inclusion of system modeling and inclusion of instantaneous grid impedance variation due to load variation.

VlII. OPERATION THEORY OF PROPOSED CON- TROLLER

This paper focuses on the control of reactive power for maintaining the rated voltage at PCe. The prin-ciples of voltage swell and sag mitigation during the change of local or grid impedance variation is identi-fied by measuring the value of reactive power flow at PCC (qm). This amount of reactive power requirement is com-pared with the reactive power from the inverter (qi) and the error is used by the controller to bal-ance the present reactive power requirement at PCC for voltage swell and sag.The conventional controllers mostly concentrate on voltage sag and interruption but the proposed controller also compensates the voltage swell by absorbing the Var during this period real power supplied by the inverter is affected by small value absorbing and reduce the values by extracting the harmonics using(13,15) but the power factor is maintained unity at PCC.

IX SIMULATION RESULTS:

To validate the developed model of the proposed controller for the hybrid grid integrated scheme com-prising PV array and wind -driven induction generator, simulations have been using the state model using MATLAB/Simulink by using Sim power system plat-form for different loads and grid impedance varia-tions. The simulations are carried out with different mode of operation first to examine the dynamic response of the controller for local load variation for reactive power requirement and next to vary the grid impedance value along with loads to create a reactive power requirement. The parameter values of the proposed test system model as follows, the power availability from PV array is 14kW and wind power of 600W supplying a load of 7kW in time do-main and the remaining power is injected into the Grid. As evident from Fig. (6). The voltage at PCC drops from rms value of 282.2V to 261 V with an ad-ditional load demand from SkW to 7kW, 2kV Ar at t = O.Ss with the conventional SVPWM based PI control. Similarly the sudden change of grid impedance and local load variation leading to voltage rise beyond its rated value is shown for the same controller is indi-cated in Fig. (7).

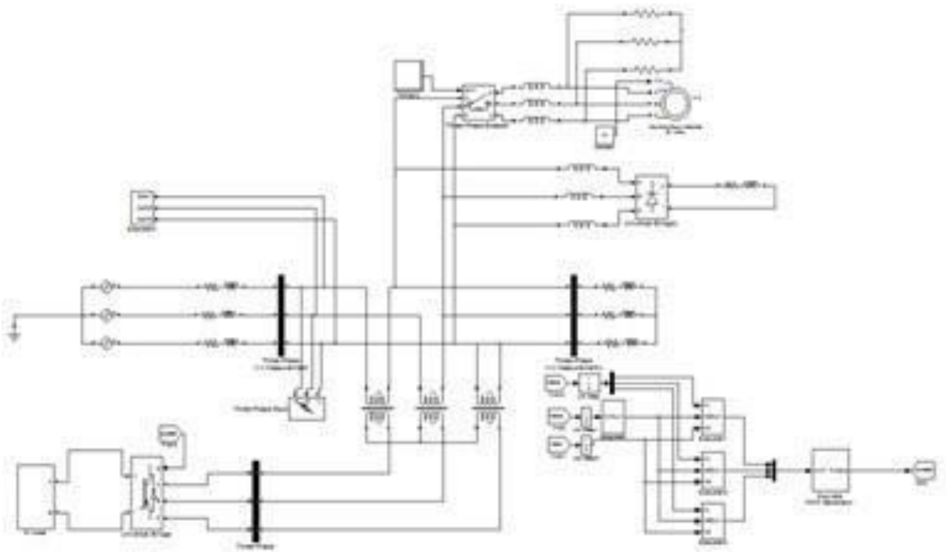


Fig. (6) simulation diagram

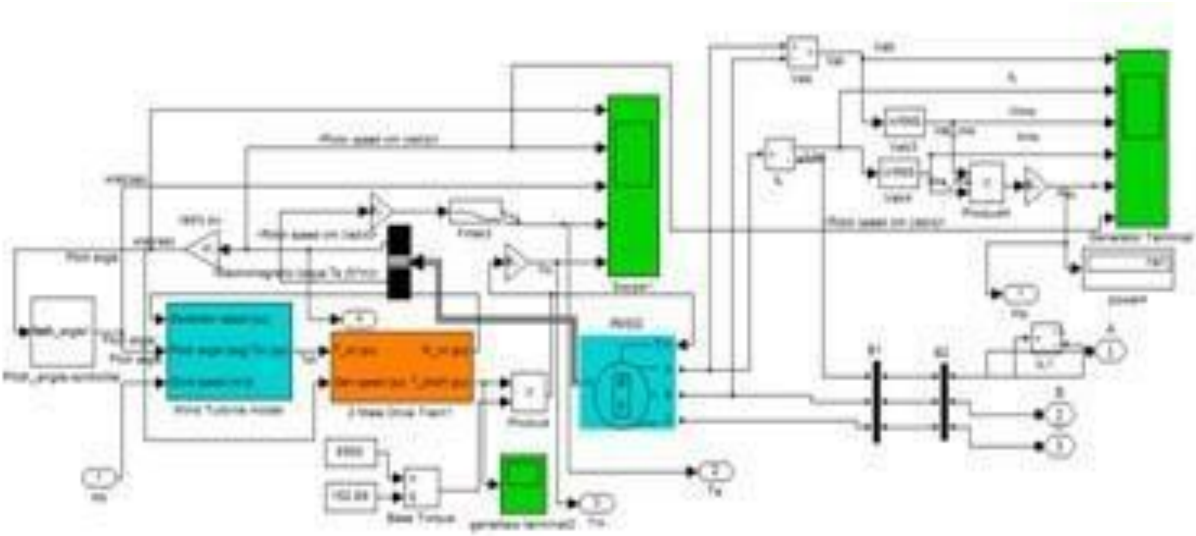


Fig. (7) wind power generation

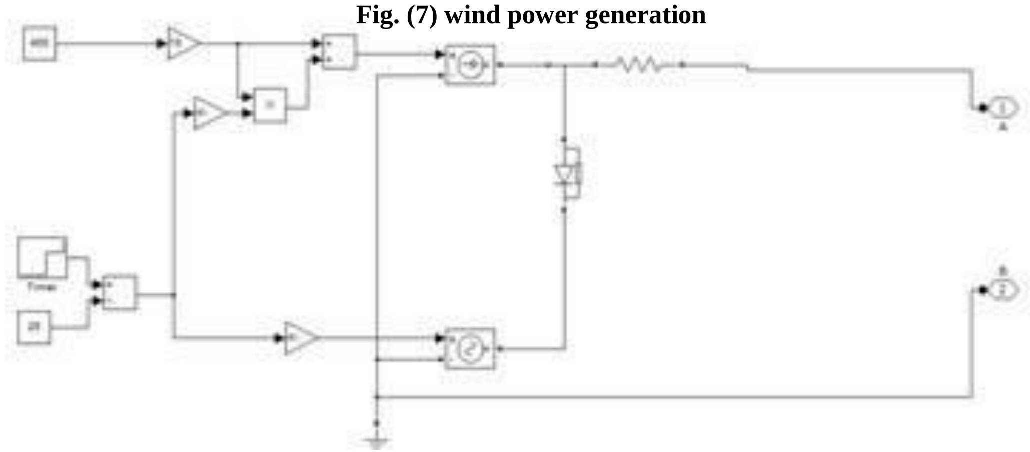


Fig. (8) PV module.

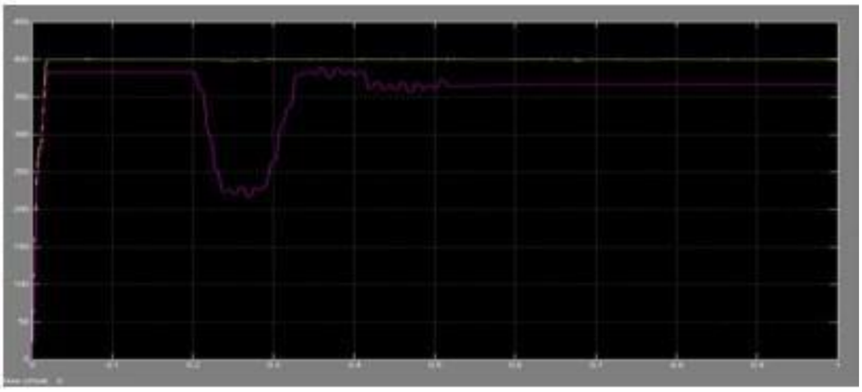


Fig. (9) Line rms voltage at pcc by using proposed con-troller DG source and grid voltages is shown in Fig. (10)

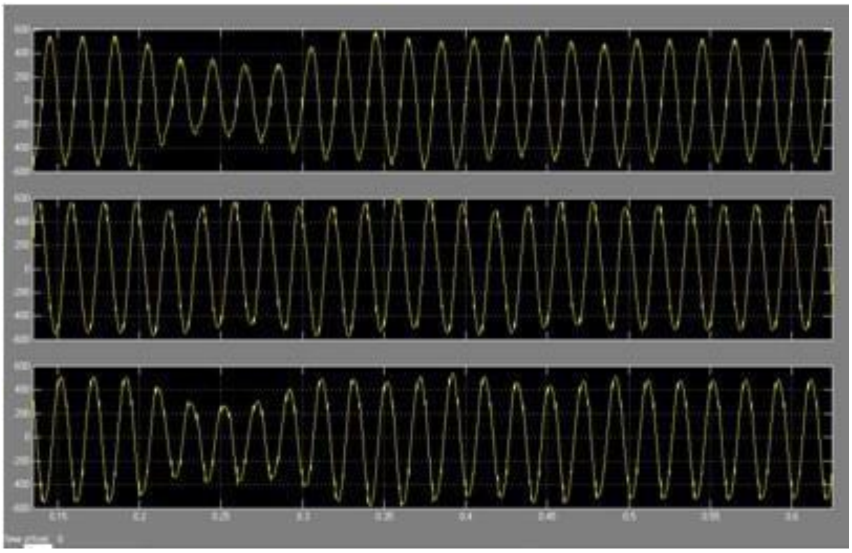


Fig. (10) source voltages

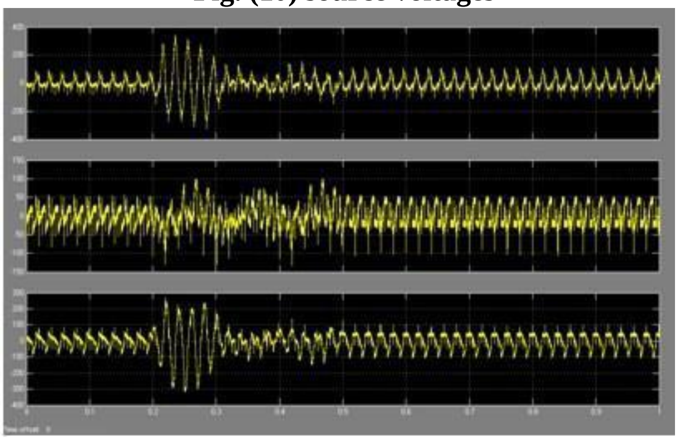


Fig. (11) Real and Reactive power supplied by the DG units with conventional Control (power supplied by PV).

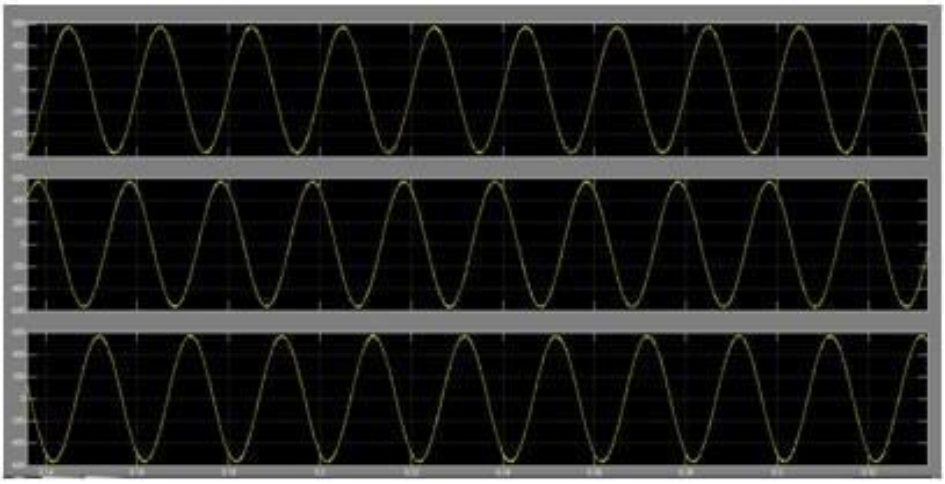


Fig. (12) Real and Reactive power supplied by the DG units with proposed control.

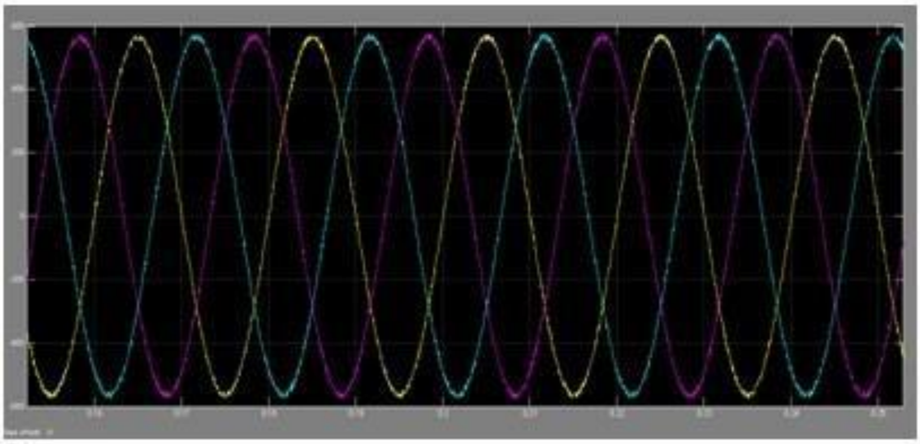


Fig. (13) Dynamically absorbing the real and reactive power by the grid.

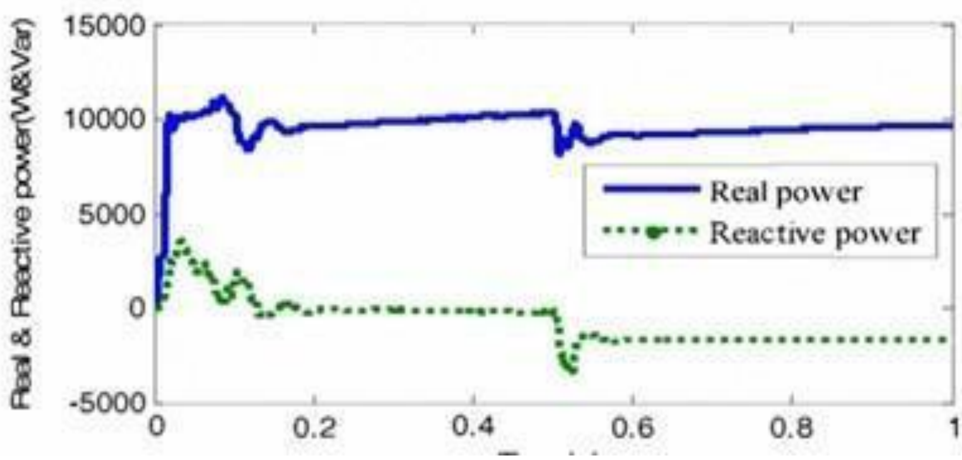


Fig. (14) The real and reactive power delivered by the DG source with conventional power control during dynamic variation of grid power requirement.

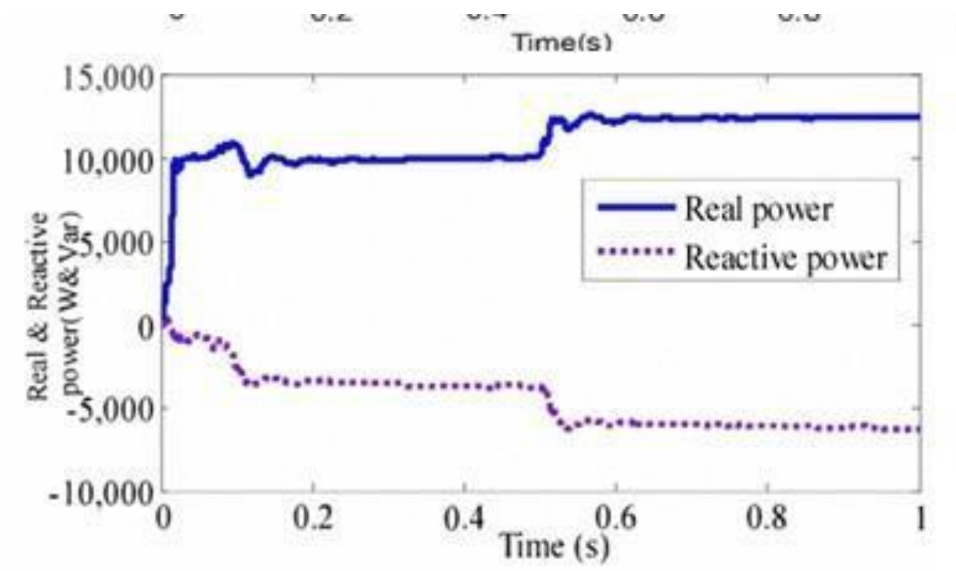


Fig. (15) The real and reactive power delivered by the DG source.

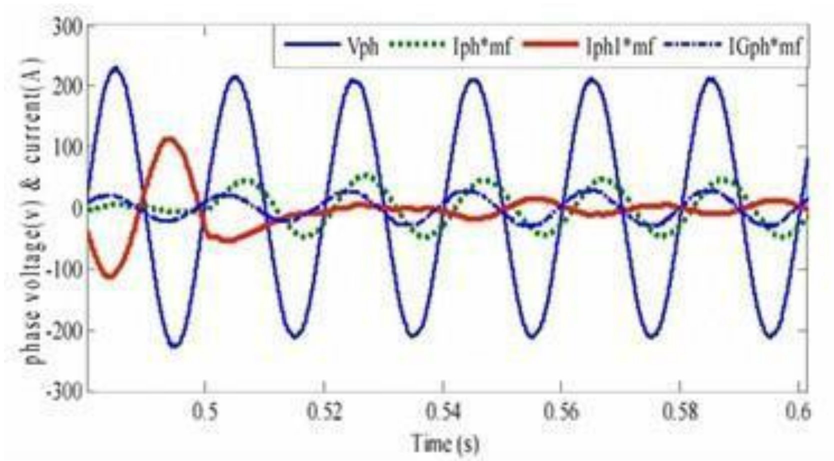
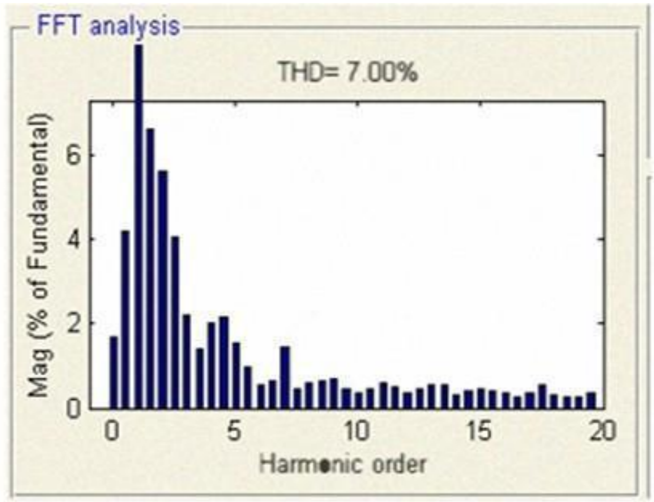


Fig. (17) Phase voltage and Phase current values are at pee during the with proposed control during dynamic variation of grid power requirementcompen-sation for conventional (Jph) and proposed controller (lph)



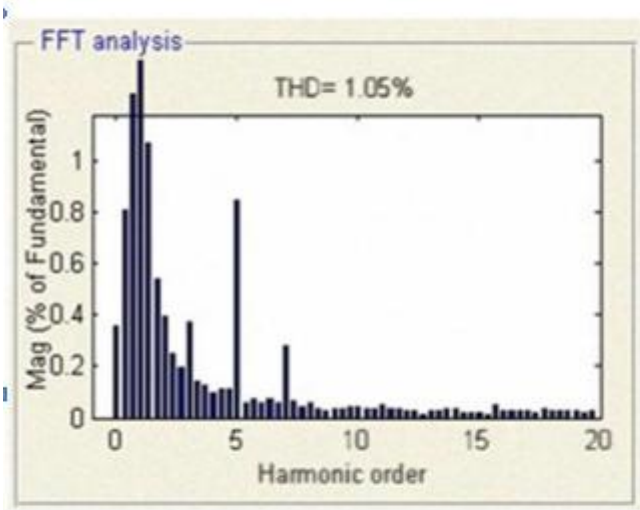
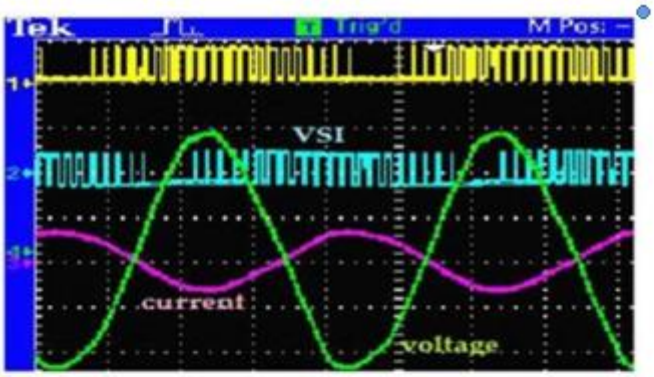


Fig. (18) & (19) Current harmonics at pee with con-ventional control and proposed control (With scale of KHz in Harmonic Order)

X. EXPERIMENTAL SETUP:

The prototype model of two proposed controllers have been developed at the rating of 2.5kw induction generator along with 5kw of PV sourced inverter is integrated with grid and load at the point of com-mon coupling shown in Fig (20) A 2kvar of capacitive bank is connected parallel with induction generator for self-excitation. When the load increases, the am-plitude of induced voltage and current waveforms in induction generator gets reduced and observed experimentally. For sensing variation in load, DSP controller kit is used & to inject voltage for compen-sation.

Fig (20) Experimental Setup for Proposed Model



Xl CONCLUSION

This paper presents analysis and improvement of power quality (voltage sag, swell and harmonics) performance of smart grid connected inverter used in distributed generation.The developed controller controls the real and reactive power supplied by the DOs at the PCe. The controller is designed to deliver current at unity power factor at PCC. An increase in reactive power demand and harmonics at PCC due to change of load and grid impedance variation, would affect the system voltage at PCe. To study the dynamic behavior of the proposed scheme, the state space model in dq reference frame has been developed for the entire hybrid scheme with the controller for validating the proposed with existing conventional SVPWM PI controller through simula-tion. The developed controller has been designed with outer power control loop, middle voltage con-trol loop and inner current control loop. The perfor-mance of the developed controller model is evaluat-ed through MAT LAB/Simpower platform .Simulation have been carried out and the results are presented for both varying local power demand and grid im-pedance variation to evaluate the performance the proposed controller. The simulations indicates that voltage sag and swell and harmonics at PCC due to customer load variation and grid impedance varia-tion is nullified by the designed controller structure and current at unity power factor is delivered to the grid

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