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Power Quality Improvement Of Grid Integrated Type I Wind Turbine Generation System Operating as DSTATCOM by d-q Control Method

In recent years with the excessive consumption of electrical energy, the incongruity between generation and demand, the irrational structure of World's energy as well as the environmental pollution have become progressively more evident. It has become crucial for ecological development to reduce the consumption of conventional energy and to enhance the development and utilization of renewable energy. Wind energy and Solar are unlimited supply of renewable energy and it has no pollution. But this concept suffer from the power quality issues from grid and generator side, this paper presents a control strategy for achieving maximum benefits from these grid-interfacing inverter when installed in 3-phase 4-wire distribution systems. The inverter can be controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid and 2) shunt APF (Active Power Filter) to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously. With such a control, the combination of grid-interfacing inverter and the 3-phase 4-wire linear/non-linear unbalanced load at point of common coupling appears as balanced linear load to the grid. The Paper propose design of 500kW Type I Wind Generation System 250kW each with Four Leg Inverter Controlled by d-q technique operated as DSTATCOM connected to 415V 4 wire Grid and also the results are compared with conventional Unit Vector Control. The proposed d-q method reduces the %THD of system to 1.97% from 24.12% where Unit Vector Control is of 3.94% which was on higher side , this is simulated in MATLAB/SIMULINK.

Keywords: Power Quality, Harmonics, Reactive Power, DSTATCOM.
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1. Introduction

Now a day's power demand is increasing at a faster rate than power generation. Hence the utilities are concentrated on power generation in order to meet the increased demand. Out of total energy demand, 75% load is supplied from fossil fuels. Because of this, there are so many problems related to environment such as air pollution, greenhouse effect, lessening fossil fuels. Hence it is necessary to check for another alternative for power generation i.e. renewable energy sources. From past ten years, many countries have concentrated on these renewable energy sources for power generation. Presently, the government also motivating the people towards the use of renewable energy sources accelerated the renewable energy sector growth. Injecting wind power into the power system grid effects power quality problems such as reactive power compensation, voltage regulation, harmonics produced in the grid. We know reactive problems may come due to non-liner loads balanced and unbalanced loads some kind of power electronic devices such as arc lamps welding machines etc. this all are switching actions harmonics will present in the system so that complete grid effects and also it effects on source side.

Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar

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approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in a control strategy for renewable interfacing inverter based on theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics. The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (wind, solar, etc.); 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system. Moreover, with adequate control of grid-interfacing inverter, all the four objectives can be accomplished either individually or simultaneously. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost.

2. Notations

The notation used throughout the paper is stated below.

P_{wind} = wind power(MW)

ρ = air density (kg/m3)

A = area swept out by Turbine blade (m^2)

V_{wind} = wind speed(m/s)

R = Radius of the blade (m)

c_p = constant value i.e maximum posible efficiency = 16/27

V_{dc} = actual DC − link voltage(V)

I_{dc1} = The current injected by renewable into dc-link

I_{dc2} = The current flow on the other side of DC − link

P_G=grid power

P_{Loss}= inverter power losses

P_{inv}=inverter power in MW

P_{RES} = power across renewable energysource

$V^*_{dc(n)}$ = reference DC − link voltage

$V_{dcerr(n)}$ =DC-link voltage error at n^{th} sampling instant

$I_{m(n)}$ = Active current component at n^{th} sampling instant

$K_{PV_{dc}}, K_{IV_{dc}}$ = Proportional and integral gains of dc-voltage regulator

Ua ,Ub ,Uc =grid voltage vector templates

la^* *, Ib*, Ic*= reference grid currents

$I_{aerr}, I_{berr}, I_{cerr}$ = current errors given to the hysteresis current controller.

i_d = direct axis current component in rotationary synchro nus refrence frame

i_q = quadrature axis current component in rotationary synchronous reference frame

i_α = direct axis current component in stationary synchronous reference frame

i_β = quadrature axis current component in stationary synchronous reference frame

v_α = direct axis voltage component in stationary synchronous reference frame

v_β = quadrature axis voltage component in stationary synchronous reference frame

K = transformation matrix

$\overline{i_d}$ =DC component of direct axis current component in rotationary synchronous reference frame

$\widetilde{i_d}$ = AC component of direct axis current component in rotationary synchronous reference frame
$\overline{i_q}$ = DC component of quadrature axis current component inrotationary synchronous reference frame
$\widetilde{i_q}$ =AC component of quadrature axis current component inrotationary synchronous reference frame
i_{Ld} = reference supply current
$\overline{i_{Ld}}$ = DC component reference supply current.
$P_{L\alpha\beta}$ = Load Power in αβ Quadrents

3. Problem formulation

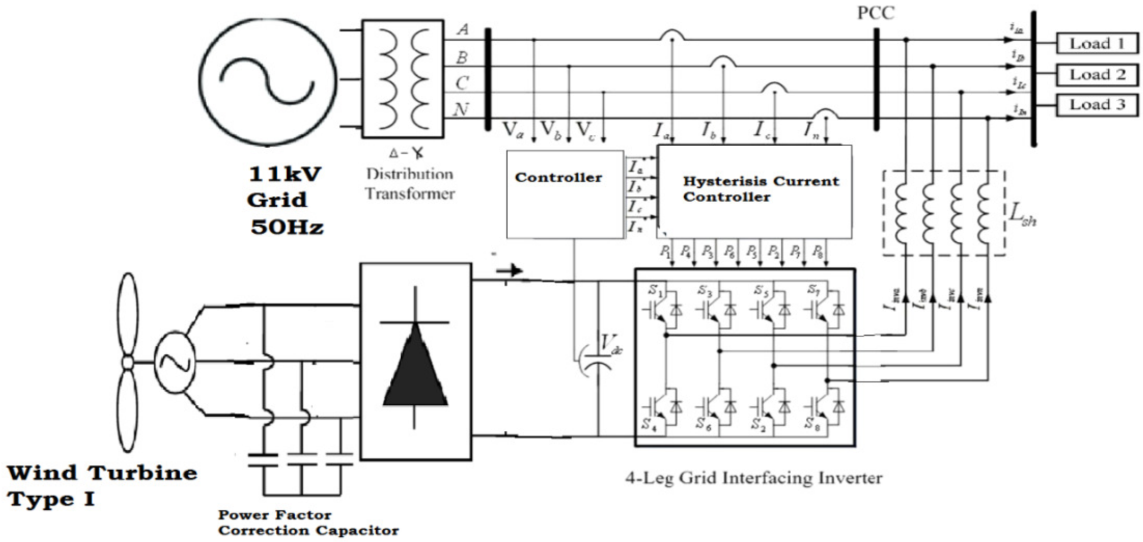

Fig.1.Block diagram of grid connected wind generation system at distribution level.

3.1. System description

The proposed system consists of RES (Renewable Energy Source) of Type I connected to the intermediate circuit of an inverter network-interface as shown in Fig. 1. The voltage source inverter is a key element of a system of DG and interconnecting the source of renewable energy to the grid and provides power generated. The RES can be a DC source or an AC source coupled to rectifier dc-link. Usually energy sources fuel cell and photovoltaic energy generated in lower variable voltage dc, while variable-speed wind turbines generate power in variable AC voltage. Therefore, the energy generated from these renewable power conditioning needs (ie, dc / dc or ac / dc) before connecting the dc-link [6] - [8]. The DC-capacitor-RES decouples the network and also allows independent control of converters on both sides of dc-link

A. Wind Energy Generating System.

In this configuration, the production of wind energy is based on topologies constant speed with ground control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and the natural protection against short circuit. The power available from the wind energy system is presented as:

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^3 \quad (1)$$

It is not possible to extract all kinetic energy of wind. Thus extracts a fraction of the power called power coefficient 'Cp' of the wind turbine, and is given by

$P_{mech} = C_p P_{wind}$ (2)

The mechanical power produced by wind turbine is given By

$P_{mech} = \frac{1}{2}\pi R^2 V_{wind}^3 c_p$ (3)

TABLEI.WINDTURBINEDATA

Characteristic	Value
Generator Type	Type I
TurbineType	3bladehorizontalaxis
Radius	48m
Rotor speed	18rpm
Air density	$1.23 kg/m^3$
Cut in wind speed	4m/s
Rated wind speed	12m/s

TABLEII.WINDGENERATORDATA

Generator characteristic	Value
Nominal power(P)	500kW
Rated voltage(V)	460V
Slip	0.2
Stator to rotor turns ratio	0.3
Rated frequency	50Hz
Stator resistance (Rs)	0.011pu
Stator inductance (Ls)	0.1pu (referred to stator)
Rotor resistance (Rr)	0.0118pu
Rotor reactance (Lr)	0.08pu (referred to stator)
Mutual inductance(Lm)	3.343pu
Lumped Inertia Constant(H)	0.5s

B. DC-Link Voltage and Power Control Operation

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. The current injected by renewable into dc-link at voltage level can be given as :

$I_{dc1} = \frac{P_{RES}}{V_{dc}}$ (4)

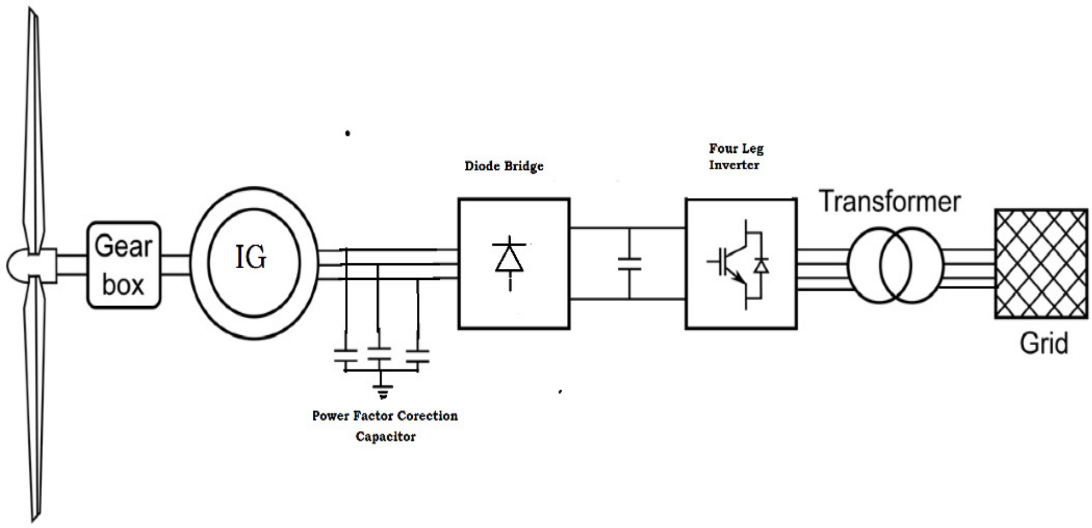

Fig. 2. Type I Wind Generation with DC Link equivalent diagram.

The current flow on the other side of dc-link can be represented as,

$$I_{dc2} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{Loss}}{V_{dc}} \quad (5)$$

If inverter losses are negligible then PRES= PG.

3.2. Unit Vector template control technique

The main aim of the Unit Vector template technical control is to generate reference source currents to control the pulse 8 APF. The block diagram of the control scheme is shown in Fig. 3. The control strategy Applied to the grid side inverter Mainly Consists of two cascaded loops. Usually there is a fast internal current control loop, qui regulates the current grid voltage loop and an external qui controls the DC-link voltage. Conduction Losses and switching of IGBT and diodes in inverters Increase voltage ripple in DC-link qui affects the performance of the filter. The control scheme approach is based on injecting the currents into the grid using hysteresis current controller.

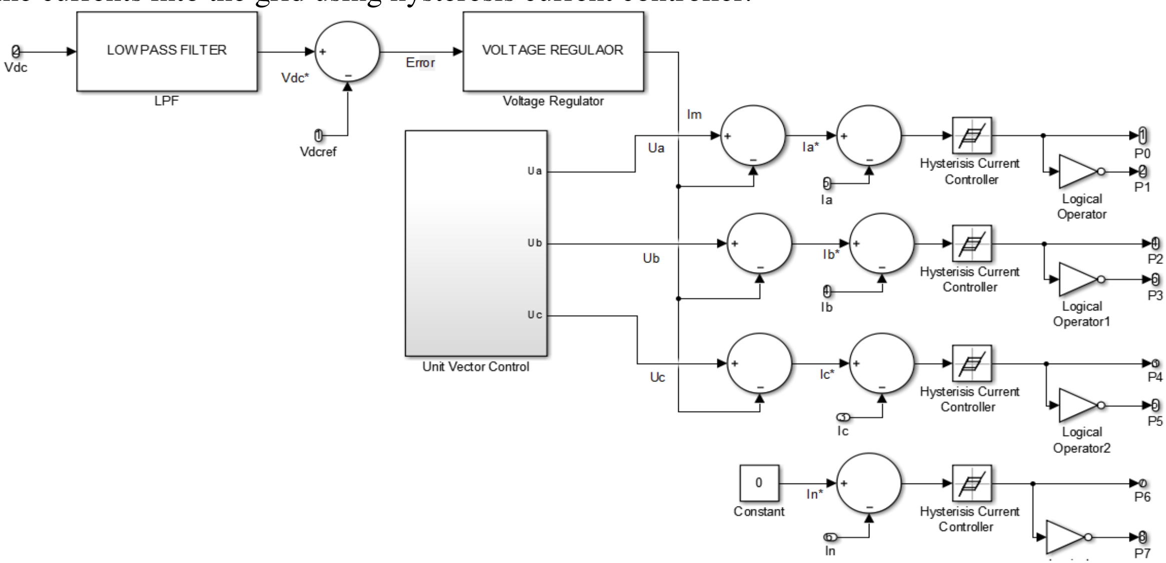

Fig.3 Block diagram representation of Unit vector control scheme

A. Magnitude of the Reference current

A PI controller is used to maintain the DC link voltage at specified value. The DC link voltage is sensed and compared with reference value and the error is passed through a PI controller.

$$V_{dcerr(n)} = V^*_{dc(n)} - V_{dc(n)} \quad (6)$$

Thus the output of dc link voltage regulator results in current I_m.

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{dc}}\left(V_{dcerr(n)} - V_{dcerr(n-1)}\right) + K_{IV_{dc}}V_{d\,cerr(n)} \quad (7)$$

B. Current Control of VSI:

Unit vector templates are generated as

$$\left.\begin{aligned} U_a &= \sin(\theta) \\ U_b &= \sin(\theta - 2\pi/3) \\ U_c &= \sin(\theta + 2\pi/3) \end{aligned}\right\} \quad (8)$$

The multiplication of current I_m with unit vector template (U_a ,U_b ,U_c) generates reference grid currents (I_a^* *, I_b*, I_c*).

The instantaneous values of reference grid currents are computed as

$$\left.\begin{aligned} I_a^* &= I_m \cdot U_a \\ I_b^* &= I_m \cdot U_b \\ I_c^* &= I_m \cdot U_c \end{aligned}\right\} \quad (9)$$

The neutral currents present if any due to the loads connected to the neutral conductor should not be drawn from the grid. Thus reference grid neutral current is considered as zero and can be expressed as

In* = 0

Current errors are obtained by comparing reference grid currents (Ia*, Ib*, Ic*) with actual grid currents (Ia, Ib , Ic).

These current errors are given to the hysteresis current controller.

$$\left.\begin{aligned} I_{aerr} &= I_a^* - I_a \\ I_{berr} &= I_b^* - I_b \\ I_{cerr} &= I_c^* - I_c \\ I_{nerr} &= I_n^* - I_n \end{aligned}\right\} \quad (10)$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses for the gate drives of grid-interfacing inverter

3.3. I_{dq} Control Technique

By using instantaneous active and reactive currents $i_{d\text{-}q}$ control technique reference current can be obtained through the non linear load.

Calculations follow like the instantaneous power theory, but dq load currents are often obtained from equation (11)2 stage transformations make known relation between the stationary and rotating system with active and reactive current methodology. The transformation angle 'θ' is wise to all or any voltage harmonics and unbalanced voltages; as a result dθ/dt might not be constant.

The system d-q (d direct axis, q-quadrature axis) is set by the angle θ with respect to the α-β frame utilized in the p-q theory. The transformation from α – β – zero frame to d–q –0 frame is given by

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \frac{1}{v_{\alpha\beta}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & sin\theta \\ 0 & -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (11)$$

If the d axis is within the direction of the voltage space vector, since the zero-sequence part is invariant, the transformation is given by

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = K \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{12}$$

$$K = \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \tag{13}$$

$$K = \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \tag{14}$$

Where the transformation matrix K, satisfies$\|K\| = 1 \; and K^{-1} = K^T$

Each current component (I_d, I_q) has an average value or dc component and an oscillating value or ac component

$$\left.\begin{aligned} i_d &= \bar{i_d} + \tilde{i_d} \\ i_q &= \bar{i_q} + \tilde{i_q} \end{aligned}\right\} \tag{15}$$

The compensating strategy (for harmonic reduction and reactive power compensation) assumes that the supply should deliver the average of the direct-axis element of the load current. The reference supply current can so be

$$i_{sdref} = \overline{i_{Ld}};\; i_{sqref} = i_{s0ref} \tag{16}$$

In this methodology, the currents magnitude changes its axes and p-q formulation is simply performed on the instant active id and instant reactive Iq parts. If the d axis has constant direction because the voltage space vector v, then the zero-sequence element of current remains invariant. Therefore, the $i_{d\text{-}q}$ methodology is also expressed as follows:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha & v_\beta & 0 \\ -v_\beta & v_\alpha & 0 \\ 0 & 0 & v_{\alpha\beta} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \\ i_{L0} \end{bmatrix} \tag{17}$$

In this strategy, the supply should deliver the constant term of the direct-axis of the load (for harmonic compensation and power issue correction). The reference supply current is going to be calculated as follows:

$$i_{sd} = \overline{i_{Ld}}\;;\; i_{sq} = i_{so} = 0 \tag{18}$$

$$i_{Ld} = \frac{v_\alpha i_{L\alpha} + v_\beta i_{L\beta}}{v_{\alpha\beta}} = \frac{P_{L\alpha\beta}}{\sqrt{v_\alpha^2 + v_\beta^2}} \tag{19}$$

The dc component of the above equation will be

$$\overline{i_{Ld}} = \left(\frac{P_{L\alpha\beta}}{v_{\alpha\beta}}\right)_{dc} = \left(\frac{P_{L\alpha\beta}}{\sqrt{v_\alpha^2 + v_\beta^2}}\right)_{dc} \tag{20}$$

Where the subscript “dc” suggests that the mean value of the expression inside the parentheses. Since the reference supply current should to be sinusoidal and in phase with the voltage at the PCC (and haven't any zero-sequence component), it will be calculated (in α-β-0 coordinate) by multiplying the on top of equation by a unit vector within the direction of the PCC voltage space vector (excluding the zero sequence component):

$$i_{sref} = \overline{i_{Ld}} \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha \\ v_\beta \\ 0 \end{bmatrix} \tag{21}$$

$$\begin{bmatrix} i_{s\alpha ref} \\ i_{s\beta ref} \\ i_{s0ref} \end{bmatrix} = \left(\frac{P_{L\alpha\beta}}{v_{\alpha\beta}}\right)_{dc} \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha \\ v_\beta \\ 0 \end{bmatrix} \tag{22}$$

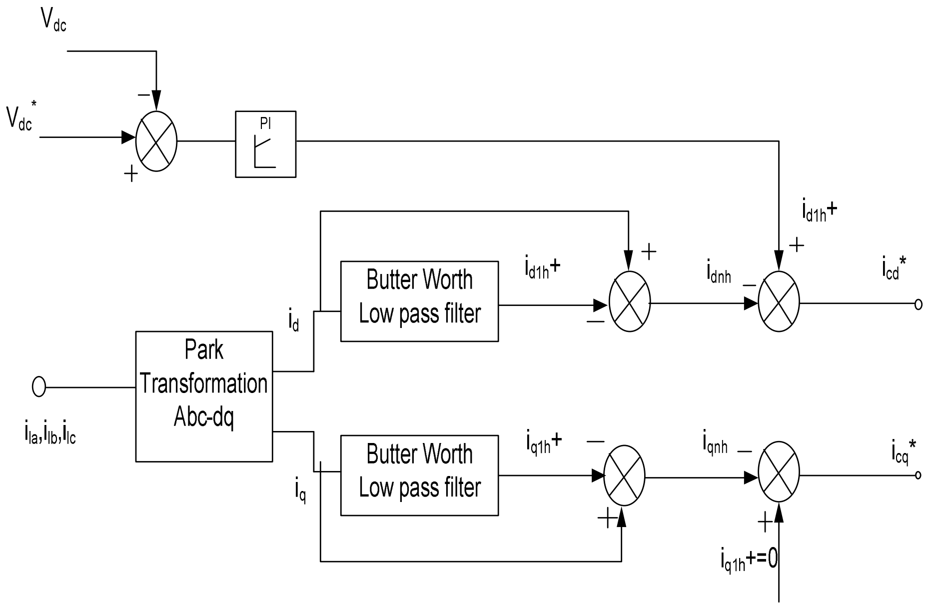

Fig.4. Transformation and injection of harmonic current.

1. MATLAB MODELEING AND SIMULATION RESULTS

Table III: Over all System Parameters:

S.No	System quantities	Parameters values
1.	Source	3 phases, 11kv,50Hz
2.	Grid Specifications	415V, Four Wire
3.	3 phase Δ/Y Winding transformer	11kv Δ/415V Y
4.	Wind Turbine Type I	460V,250kW
5.	Total RES Rating	250kW*2=500kW
6.	Power Factor Correction Capacitor	3kVAr
7.	DC voltage	800Vdc ,1200Vref.
8.	Non-Linear Load	3phase, 4 Wire Diode Rectifier Circuit, L1=(R= 20Ω, L=20mH) L2=(R=20Ω, L=20mH) L3=(R= 20Ω, L=20mH)
9.	Linear Load	3phase, Y Un Balance Load L6=(R=6, L=20mH) L7=(R=15, L=20mH) L8=(R=8)

Case I: Simulink wave forms of the proposed concept with UV control technique.

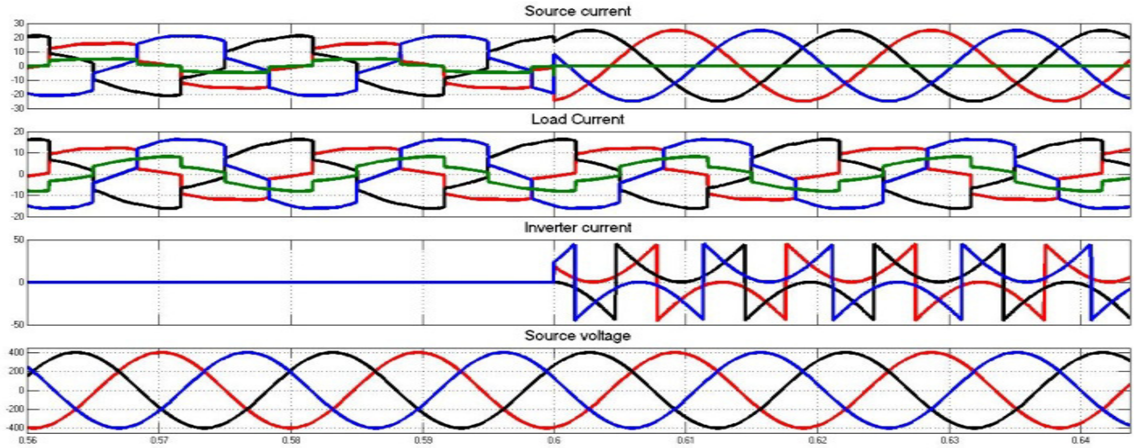

Fig 5: Three phase wave forms of source current, Load current, inverter currents and source voltage

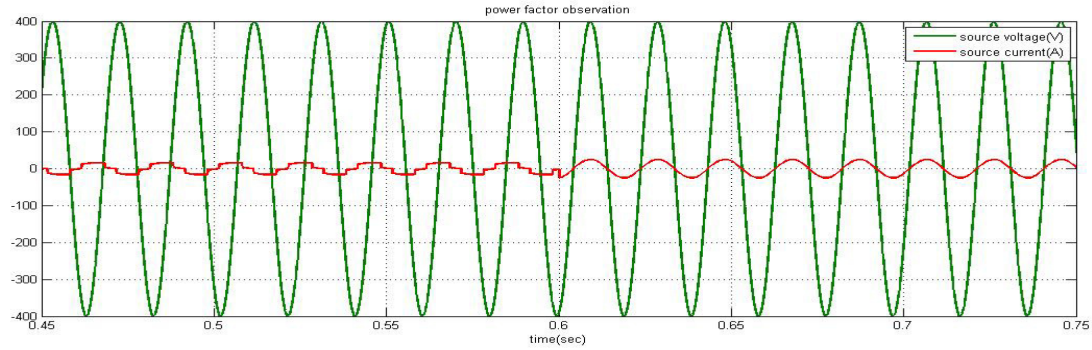

Fig 6: Power factor maintained unity when the inverter is connected from 0.6 sec with Unit Vector controller.

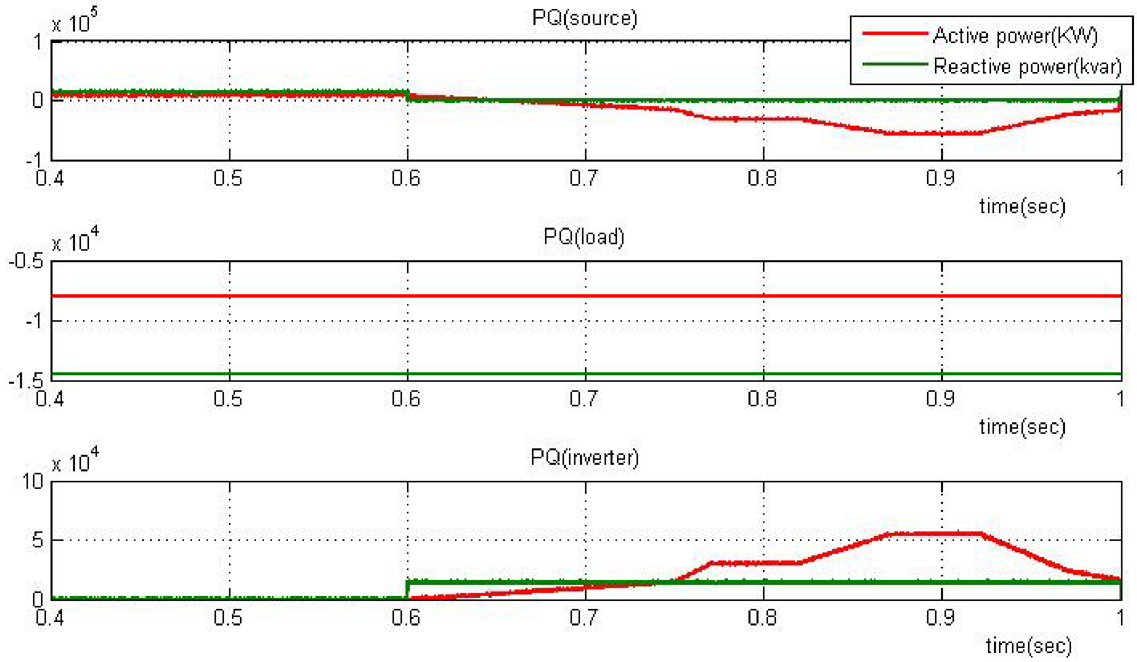

Fig 7: Simulated output wave forms of Source, load and Compensated active and re-active powers with Unit Vector controller.

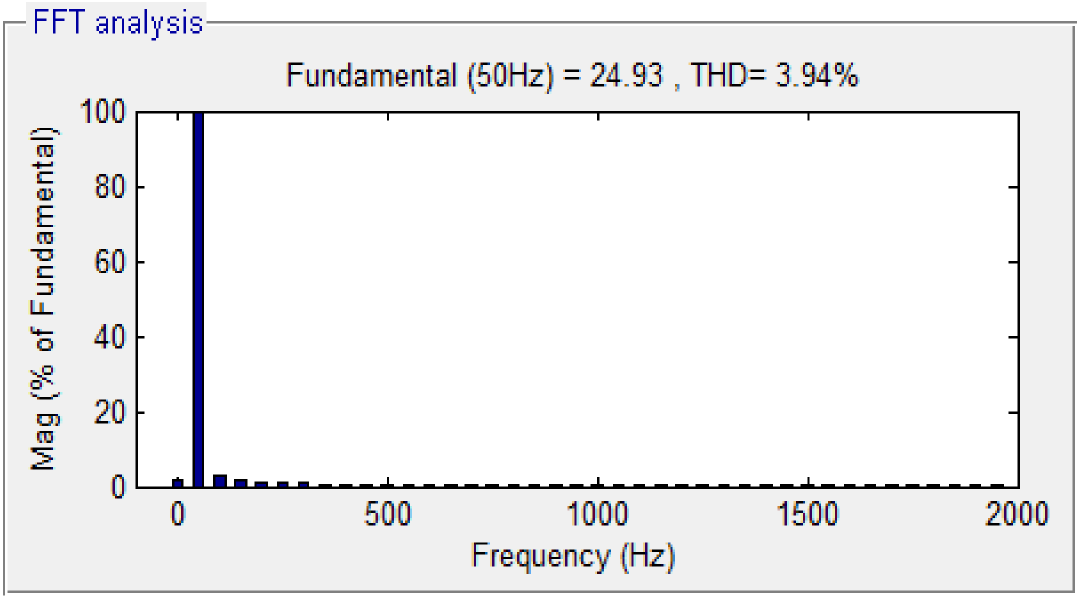

Fig 8: Total Harmonics distortion of source currents.

Case II: Simulink wave forms of the proposed concept with I_{dq} control technique.

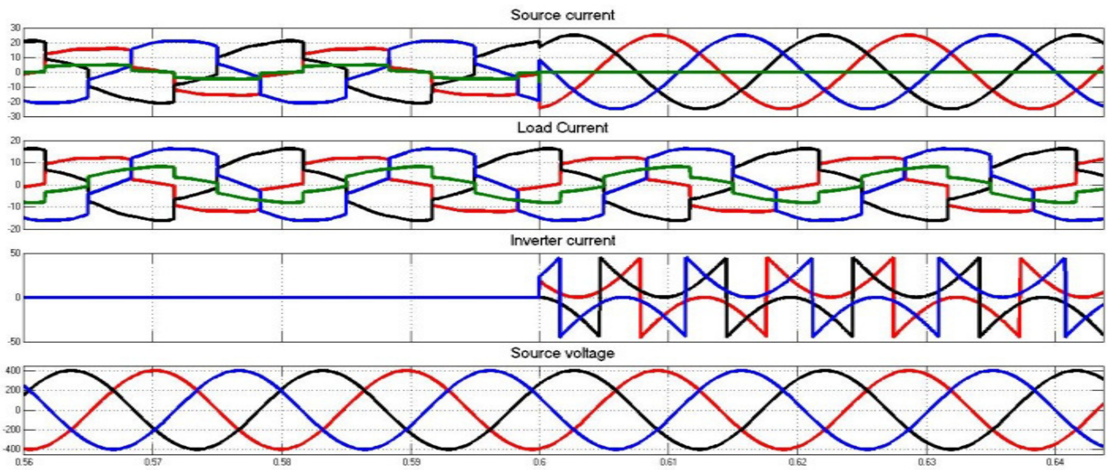

Fig 9: Three phase wave forms of source current, Load current, inverter currents and source voltage

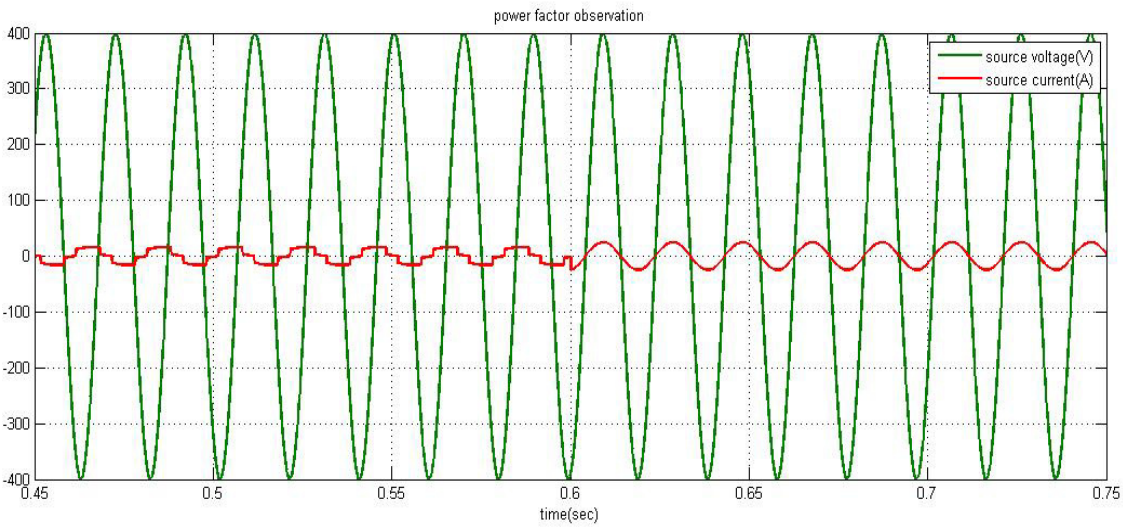

Fig 10: Power factor maintained unity when the Statcom is acting from 0.6 sec with Idq controller.

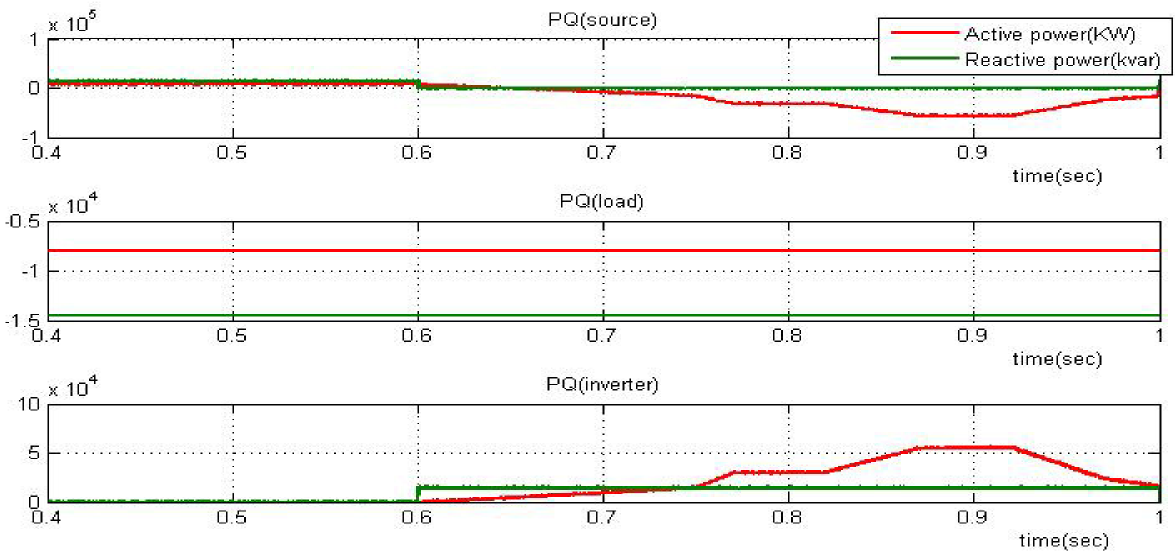

Fig 11: Simulated output wave forms of Source, load and Compensated active and re-active powers with I_{dq} controller.

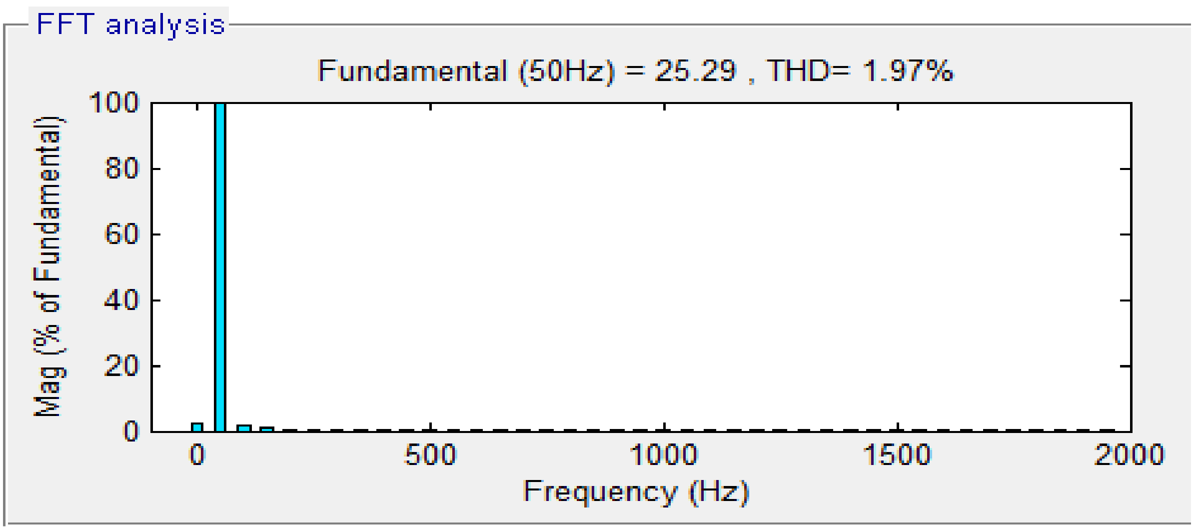

Fig 12: Total Harmonics distortion of source currents.

Analysis from the results

The simulation work is done for 3 phase, four wire grid interface DG system using MATLAB/Simulink. A four-leg hysteresis controlled voltage source inverter is actively controlled to reach fair sinusoidal currents from nonlinear load and varying renewable generating conditions. Fig 5&9 shows grid voltage, grid currents, UN balanced load current and inverter currents. At t=0 s, the controlled inverter is not connecting to the system up to 0.6 s it fallows the grid current profile is similar to the load current profile. At t=0.6 s, the controlled inverter is attached to the system. Right now the inverter start injects the current in such a way that the profile of grid current starts changing from unbalanced non linear to balanced sinusoidal current and Grid side neutral current becomes zero after t=0.6 s.

At t=0.6s, the inverter starts injecting active power from RES. since the generated power is more than the demand the additional power is fed back to the grid. The more amount active power injection from renewable source to the grid is observed at t=0.8 s, this shows the magnitude of the inverter current is more. Treated load demand is remains unchanged. At t=0.92 s, the active power injection from renewable source is reduced. Corresponding grid currents are shown in fig 5&9. Corresponding active and re-active power flows between the inverter, load and grid during increase and decrease of energy generation can be observed in fig. 7&11. Voltage across The DC-Link should be maintained constant at different conditions. From the results we conclude the grid-interfacing inverter can be efficiently used to balance the load reactive power at different control strategies.

10. CONCLUSION

In the presented paper improve the power quality is the main objective for grid connected Type I wind generation system for that choose as a interfacing inverter i.e grid interfacing inverter at PCC for 3-phase 4 wire system from the results it is observed that interfacing inverter works efficiently used for power controlling without effecting the normal operation. The inverter operates as both the functions draws or supplies the active and reactive power from RES to grid. And it is also used as APF when no generation from RES. The advantage of the proposed work is doesn't require additional equipment for improves the power quality. Due to unbalanced and non-linear load, the problems of current unbalance, current harmonics and load reactive power, are eliminated by controlling the inverter gate pulses.

For generating the gate pulses to the inverter two control theories are presented unit vector control theory and I_{dq}(SRF)control theory. For nonlinear load it is observed that the source current is having THD of 24.12%. After compensation, by the results it is clearly observed the THD values are reduced to less than 4%. By unit vector control theory the THD is 3.94% (which is on the higher end and is near to IEEE standard Harmonic of 5% at distribution level). And by the proposed I_{dq} (SRF) control the THD farther reduced to 1.97%, whereas the power Quality is improved.

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