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SOLAR PHOTOVOLTAIC GRID INTERCONNECTION FOR POWER QUALITY ENHANCEMENT AT DISTRIBUTION LEVEL

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Abstract:

Rapid growth in the demand leads to increased integration of Renewable Energy Source to distribution systems through converters of power electronics. Addition of Renewable Energy Sources with grid needs inverters. This paper discusses a proposed organize strategy for completely utilizing these inverters of grid-interfacing when used in a 3-Ph 3-wire distribution system. By including active power filter functionality, the inverter operates as a device of having multi-function. The following are the functions of inverter:1) aids in injecting generated power to the grid from RES 2) Provide compensation for harmonics of load current, unbalance, reactive power necessity of load. This paper proposes using of the hysteresis current controller for grid interfacing inverter's gate drives, the combined 3-Ph 3-wire linear/non-linear unbalanced load and grid-interfacing inverter which is connected to point of common coupling, grid encounters with a linear balanced load. Solar photovoltaic grid interconnection for power quality enhancement is validated by decreasing Total Harmonic Distortion in both the voltage and current by using the proposed control strategy of grid interfacing inverter. The proposed control is manifested by using MATLAB/ Simu-link platform.

Keywords: Renewable energy sources (RES); grid-interfacing inverter; Distributed generation (DG); Power quality (PQ).

1. INTRODUCTION

Today 75% requirement of energy the world is met by using fossil-fuels which is having disadvantages of air pollution, global warming, exhausting fossil fuels; therefore, RES is the next alternative in the coming days. Modern grid is pushed to be integrated with renewable energy sources like solar photovoltaic (SPV) system, wind energy and biomass etc because of rise in the demand of electrical energy and minimize the environmental crash of conventional plant[M. Singh et.al., 2011; E. M. Sandhu and T. Thakur, 2014].By the year 2022 Ministry of New and Renewable Energy (MNRE) Government of India is aiming to complete 2000 MW grid-interactive power by solar[V. Kumar et. al., 2016]. RES aids to meet the current requirement for electricity, but its intermittent behaviour causes power quality problems [M. Yuvaraj and K. Manivannan, 2016]. Integration leads to power quality concerns. Three important issues are voltage dips, rise in steady-state voltage, harmonics and voltage flickering [E. M. Sandhu and T. Thakur, 2014] .The increased utilization of non-linear loads also causing power quality troubles like unbalance, harmonics in the currents of grid and load ,active and reactive requirements of load[M. Singh et.al., 2011; S. Munir and Y. W. Li, 2013]. Without compromising the protection, reliability and efficient operation of the entire network, we should interconnect RES. Intermittent RES can be interfaced with the distribution system with the help of current controlled voltage sources. The main thought is to convert underutilization of inverter rating into maximum utilization [M. Singh et.al., 2011]. In order to develop the system operation in addition to better power quality at the Point of Common Coupling (PCC), active control of RES is required. The grid interfacing inverter has the subsequent key functions:

i. Transmission of active power gleaned of renewable resources

ii. Load reactive power claim maintains

iii. Compensation of unbalanced current.

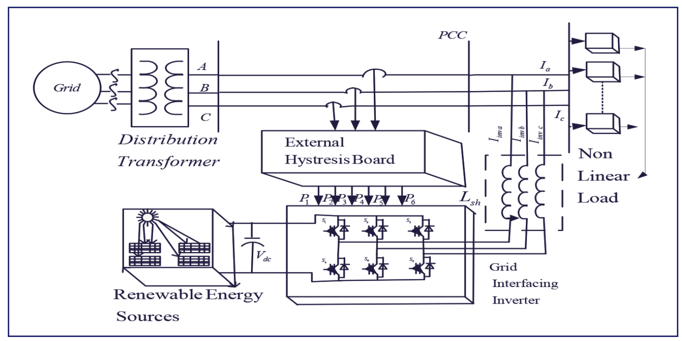
Hence by using interfacing inverter, PQ parameters at PCC can be kept within the standards of utility [M. Singh et.al., 2011]. This shows that the Grid-inter facing inverter is having multi-functions

The evaluation of diverse current controllers with changeable input power is engaged for grid-connected distributed power. This has main aim to set a linear controller for instance Proportional Integral, Proportional Resonant and improved deadbeat (DB)and implement these in the [A. Timbus et. al., 2009]. The grid bringing together with RES and consideration of safe running is given with an overview with simulation and experiment results to evaluate the behaviour of synchronization method with different grid turbulence as harmonics [A. Timbus et. al., 2005]. The integration of solar brings changes in the profile of voltage and response of frequency of the system and the transmission-distribution systems of convenience grid are affected [E. M. Sandhu and T. Thakur, 2014].In the projects having penetration of large photovoltaic (PVs) on rooftops of commercial buildings and houses the problems of quality of power are identified (J. H. R. Enslin and P. J. M. Heskes, 2004). Connecting Distributed Generation (CDG) to the utility system presents some motivating technical issues that have not been formally investigated. Various tribulations linked with the interconnection of DG are addressed by Roger C. Dugan in (R. C. Dugan et. al., 2001). The key in element of PV based system is inverter which controls the power flow between load and dc source. For power Quality enhancement Shunt Active Power Filter (SAPF) is used in solar PV integrated grid system (C. Shiva et. al., 2017). Three-phase three-wire SPV system which is supporting the grid utilizing a boost converter at first stage to do the purpose of MPPT. The extracted SPV (Solar Photo-Voltaic) energy is fed by boost converter besides supporting the distribution system for power quality development (B. Singh and C. Jain, 2017). The significant influence of harmonics is possible when the access level of RES is high. In order to conquer the power quality challenges, the control technology based system helps us (X. Liang, 2017). The changing output nature of an integrated SPV system causes more problems of power quality which are to be solved properly. By using the hysteresis current controller for grid interfacing inverter's control, the combined 3-Ph 3-wire linear/non-linear unbalanced load and grid-interfacing inverter, grid encounters with a linear balanced load. Paper is written with well-planned pattern. The first section is representing the introduction and literature review of the articles with available techniques. The second section gives the brief description of the system use for the article and methodology applied. The third section is of simulation and results. The fourth section is of the discussion and last section concluded the research followed by the references.

2. SYSTEM DESCRIPTION

The key component of a DG system is voltage source inverter as it interfaces the renewable energy sources to the grid and dispatches the generated power. The RES coupled to dc link may be a *DC / AC* source with rectifier. Generally photovoltaic energy sources produce power at changing low dc voltages, while variable AC voltages are generated by variable speed wind turbines. Thus power conditioning (*i.eAC / DC or DC /AC*) is required for power produced from these renewable sources ahead of connecting to dc-link [M. Singh et.al., 2011].In this paper, with a simple three-leg three-wire voltage source inverter system, it is possible to compensate disturbances like THD, voltage unbalance and others. The topology of grid interconnected active power filter (APF) is presented in Fig. 1 (A. Timbus et. al., 2005).

Fig. 1. Schematic of proposed solar PV based distribution generation system



It is having a three-leg, three-wire voltage source inverter whose dc-link is interconnected with SPV. Solar PV array (SPV) is interfaced with the DC-link of UPQC with a simple boost DC-DC converter.

2.1 Voltage of DC Link and Operation of Power Control:

The power produced is of changing nature in RES, because of its intermittent nature. Grid-interfacing inverter's DC-link connected with RES which is represented by current source. Power delivery from the solar PV via DC-link to grid is shown in the fig.2.Renewable injects current into dc-link at V_{DC} voltage level can be represented as

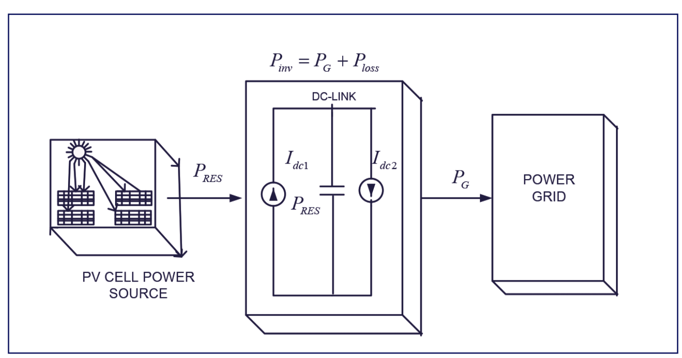


Fig. 2. DC - Link equivalent diagram

$$I_{DC1} = \frac{P_{RES}}{V_{DC}} \quad (1)$$

The dc-link current flow on the remaining side can be represented as

$$I_{dc2} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{loss}}{V_{dc}} \quad (2)$$

Where P_{inv},P_G and P_{loss} are grid-interfacing inverter side's total power available, grid received power, losses of inverter correspondingly .If the losses of inverter are omitted, then $P_{RES} = P_G$

For a 3-Ph 3-wire system and grid-interfacing inverter's control diagram is shown in Fig. 3.

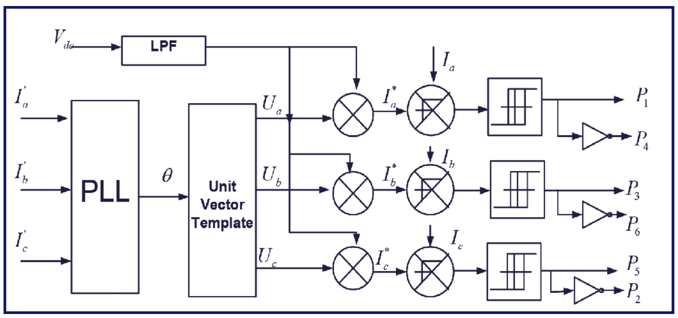


Fig. 3. Block diagram representation of grid-interfacing inverter control.

The inverter is actively managed in such a way that takes/gives fundamental active power from/to the grid. Combined appearance of load and inverter injected power resembles balanced resistive load by varying duty ratio of inverter switches in a power cycle. .The data related to the exchange of active power in between grid and renewable sources is carried by regulation of dc-link voltage. .Active current (I_m) is the result of regulation of dc-link's output voltage. Reference grid currents (I^*_a, *I*b and I*c*) are obtaine d by multiplying active current component (I_m)and vector templates of grid voltages (U_a,U_b *and* U_c) .Phase locked loop(PLL)gives unity vector template with the help of synchronizing angle (θ) of the grid.

$$U_a = \sin(\theta)$$
$$U_b = \sin(\theta - \frac{2\pi}{3}) \quad (3)$$
$$U_c = \sin(\theta + \frac{2\pi}{3})$$

The actual dc-link voltage (V_{dc}) is subtracted from the reference dc-link voltage (V^*_{dc})and the difference is supplied to a discrete PI regulator to have fixed dc-link voltage even though load and generation conditions are changing. At the point of nth sampling, the voltage error of dc-link $V_{dcerr}(n)$

$$V_{dceer(n)} = V^*_{dc(n)} - V_{dc\,(n)} \quad (4)$$

At the point of n[th] sampling, discrete-PI regulator's output is expressed as

$$I_{m(n)} = I_{m(n-1)} + K_{PVdc}(V_{dcerr(n)} - V_{dcerr(n-1)}) + K_{IVdc}V_{dceer(n)} \quad (5)$$

Where K_{PVdc} =10 and K_{IVdc} = 0.05

The three phase grid currents have the following computation formulas

$$I_a^* = I_m.U_a$$
$$I_b^* = I_m.U_b \quad (6)$$
$$I_c^* = I_m.U_c$$

To obtain the current errors, the reference currents of grid (I^*_a ,I^*_b *and* I^*_c) are compared with original currents of grid (I_a,I_b,I_c).

$$I_{aerr} = I_a^* - I_a$$
$$I_{beer} = I_b^* - I_b \quad (7)$$
$$I_{cerr} = I_c^* - I_c$$

The hysteresis current controller is given by the errors of current. Switching pulses are generated by hysteresis current controller for grid interfacing inverter's gate drives which are (P1 to P6). State space equations of 3-leg inverter's average model are

$$\frac{dI_{Inva}}{dt} = \frac{(V_{INVa} - V_a)}{L_{sh}}$$
$$\frac{dI_{Invb}}{dt} = \frac{(V_{INVb} - V_b)}{L_{sh}} \quad (8)$$
$$\frac{dI_{Invc}}{dt} = \frac{(V_{INVc} - V_c)}{L_{sh}}$$

$$\frac{dV_{dc}}{dt} = \frac{(I_{Invad} + I_{Invbd} + I_{Invcd})}{C_{dc}} \quad (9)$$

Where $V_{inva,}$ $V_{invb,}$ V_{invc} and V_{invn} are generated on the inverter's output terminal as ac three-phase switching voltages. Output voltages of the inverter can be represented as a combination of instantaneous dc bus voltage and inverter's switching pulses as below

$$V_{Inva} = \left(\frac{P_1 - P_4}{2}\right) V_{dc}$$
$$V_{Inva} = \left(\frac{P_3 - P_6}{2}\right) V_{dc} \quad (10)$$
$$V_{Inva} = \left(\frac{P_5 - P_2}{2}\right) V_{dc}$$

Each leg of inverter having charging current I_{Invad}, I_{Invbd} , and I_{Invcd} can be represented as

$$I_{Invad} = I_{Inva}(P_1 - P_4)$$
$$I_{Invbd} = I_{Invb}(P_3 - P_6) \quad (11)$$
$$I_{Invcd} = I_{Invc}(P_5 - P_2)$$

The inverter is having IGBTs whose switching pattern is decided based on the difference between actual and reference current of inverter, which are given below

If $I_{Inva} < (I^*_{Inva-hb})$ gives switch off of upper switch S1

(P1=0) and switch on for lower switch S4 (P4=1) in the inverter's phase a leg

If $I_{Inva} > (I^*_{Inva-hb})$ gives switch on of upper switch S1.

(P1=1) and switch off for lower switch S4 (P4=0) in the inverter's phase a leg.

h_b =width of hysteresis band.

Rest of the three firing pulses of the three legs can be derived by the same principle.

3. SIMULATION RESULT

For RES interfaced with grid connected to three phase three wire system, the proposed control method is verified to obtain multi objectives by using MatLab Simu-link, an elaborated simulation study is done. Even though we used highly unbalanced nonlinear load at PCC under change in generating conditions, three-leg current control voltage source converters is managed to obtained sinusoidal grid current with less Total Harmonic Distortion (THD). The DC link of Grid interfacing inverter is connected with a RES having changing output power. The PCC is connected with an unbalanced three-phase three wire nonlinear load of which harmonics, reactive power, unbalanced require to be compensated. The wave forms of grid voltages (V_a, V_b, V_C) grid currents (I_a, I_b, I_c) , unbalanced load currents (I_{la}, I_{lb}, I_{lc}) and inverter currents ($I_{inv\ a}$, $I_{inv\ b}$, $I_{inv\ c}$) are shown in Fig 4. The input and outputs of PV panels are shown in Fig 5.

At first only non-linear load is connected to the PCC and grid interfacing inverter is not connected to the network (the load power demand is entirely supplied by grid alone). Before time 0.166 sec only one non-linear is connected at PCC. After the time the circuit breaker is closed and total two non-linear loads are connected. In those cases when no APF is connected, the PCC voltages and the current resemble grid voltages and currents. Later grid interfacing is connected to the network. Profile of the grid current starts shifting from unbalanced non-linear to balance sinusoidal current after inverter starts injecting current in the network. Active power produced from RES is injected by the inverter. Grid supplies/receives fundamental active power only after inverter starts operating. The Parameters used for designing of proposed system are given in Table 1.
In the next the active power output from RES is increased by increasing the irradiance and temperature of PV system, to check the performance under change in power generation from

.Sr. No	Name of the Parameter	Values
1	3-Phase Supply	Vg=4160V,60Hz
2	DC-Link Capacitance	Cdc=500F
3	Coupling Inductance	Lsh=0.01mH
4	DC-DC boost conveter's Resistace,Capacitance & Inductance	R=5mΩ C3=100μF L1=5mH

Table 1. System Parameters

RES. The constant load power demand is taken for simplicity. The respective variation in the grid and inverter are seen in the Fig.5 and in the Fig.6. FFT analysis of Phase a of grid voltage without grid interfacing inverter & PV integration is shown in Fig.7.

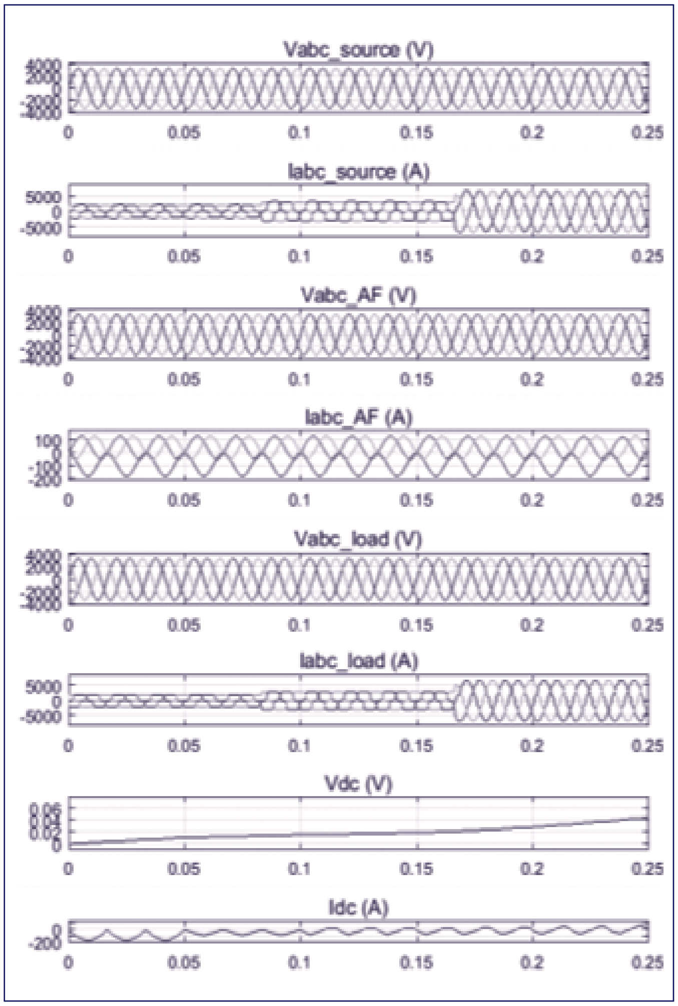


Fig. 4. Simulation results (a) Grid Voltages, Grid Currents, (b) Inverter Voltages, Currents (c) Load Voltages and Currents (d)DC-Link Voltage and Current

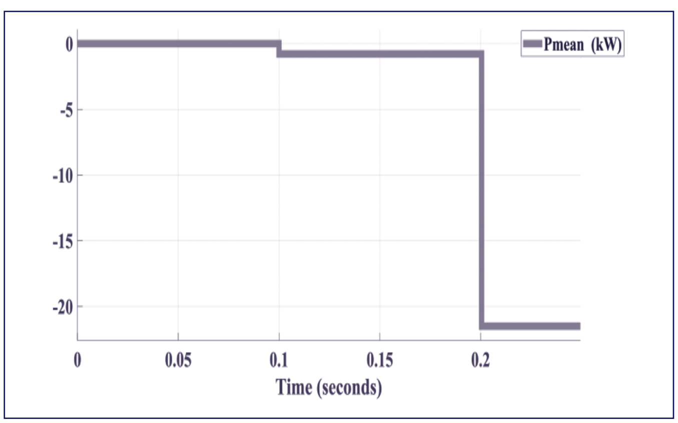


Fig.5. Simulation results (a) Real power output of PV

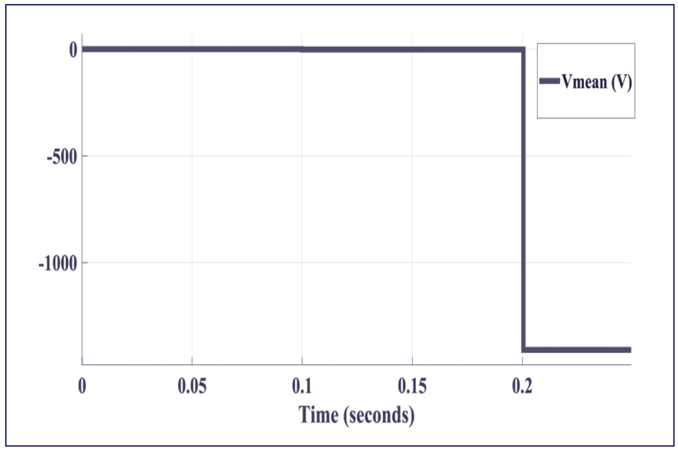


Fig.6. Simulation results (b) Mean Voltage Output of PV

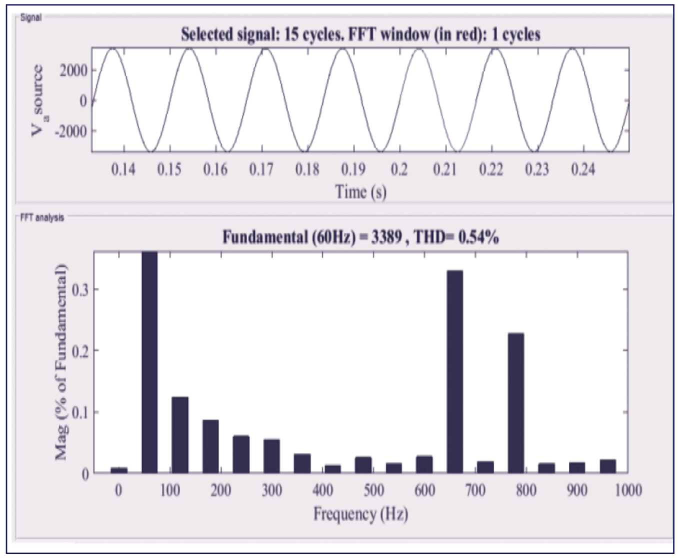


Fig.7. FFT Analysis of Phase a of grid voltage without grid interfacing inverter & PV integration.

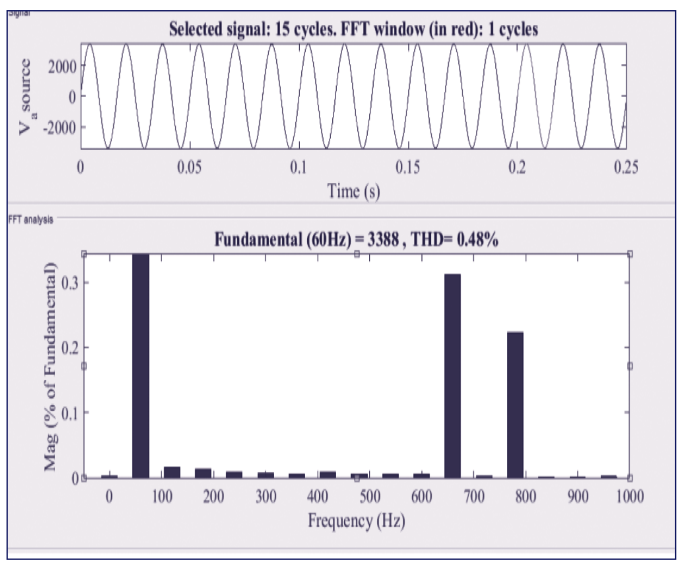


Fig.8.FFT Analysis of Phase a of grid voltage with grid interfacing inverter & PV integration.

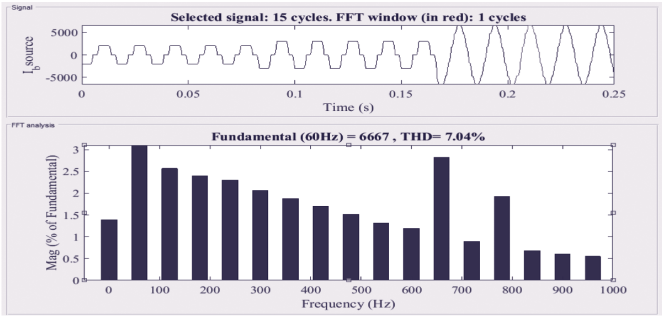


Fig.9. FFT analysis of Phase b of grid current without grid interfacing inverter & PV integration.

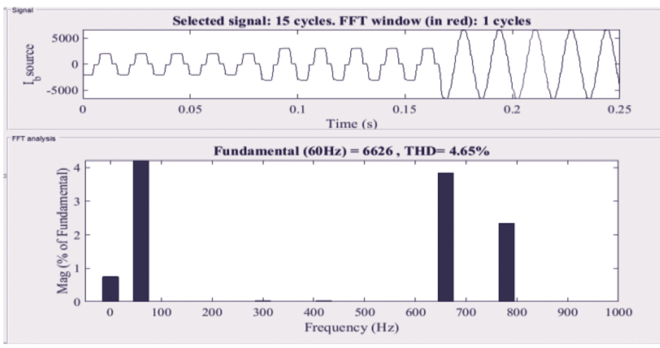


Fig.10.FFT analysis of Phase b of grid current with grid interfacing inverter & PV integration.

During various condition of operation, the voltage across the DC link of grid interfacing inverter is kept constant level to achieve the active and reactive power flow. So, it is clear that load reactive power current harmonics and current unbalanced are compensated by improving power quality by using the power injection from RES. This helps to integrate the RES with grid at distribution level besides power quality enhancement. By increasing the values of irradiance and temperature of PV panel, there is an increase in the charging rate of DC-Link capacitor charging voltage. The enhancement in of power quality and increment in the rate of charging of DC link voltage can be observed from Table 2. The Fig.8.shows FFT analysis of Phase a of grid voltage with grid interfacing inverter & PV integration. The reduction in the current harmonics can be observed by comparing Fig.9. and Fig.10. which shows FFT analysis of Phase-b of grid current without grid interfacing inverter & PV integration and with grid interfacing inverter along with PV integration respectively. Thus reduction in voltage and current harmonics indicates that grid encounters with a linear balanced load in spite of being connected to non-linear unbalanced load.

Variable	THD		
	Grid connected to Non-Linear Load without grid interfacing inverter & PV integration	Grid connected to Non-Linear Load with grid interfacing inverter & PV integration ($Ir=1000 w/m^2, T=25^oC$)	
V_a_Source	0.54	0.48	
V_a_Source	0.54	0.48	
V_a_Source	0.53	0.48	
V_a_load	0.54	0.48	
V_b_load	0.54	0.48	
V_c_load	0.53	0.48	
I_a_Source	4.69	4.66	
I_b_Source	7.04	4.65	
I_c_Source	7.43	4.65	
I_a_load	4.67	4.68	
I_b_load	7.01	4.67	
I_c_load	7.43	4.67	
$V_{dc-Link}$ Charging	------	Slow ($Ir=1000 w/m^2, T=25^oC$)	Faster $Ir=1400 w/m^2, T=35^oC$)

Table 2. Comparative Analysis of Proposed System Without and With Grid Interfacing Inverter & P V Integration

4. CONCLUSION

This paper has illustrated a new control strategy for 3-phase 3-wire DG system's grid-interfacing inverter to enhance the power quality at PCC. Without altering real power transfer operation, the effectiveness of grid-interfacing inverter for conditioning of poweris proved. The presented approach of grid-interfacing inverter is useful to:

- Injection of produced real power from RES to the grid.
- Behaves as a shunt Active Power Filter (APF)
- Enhances the power quality.

The power quality at PCC is improved without using extra equipment for conditioning of power. Simulation is done in MATLAB/Simu-link to justify the proposed approach and proved that grid-inter facing inverter is having multi-functions.

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