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Power-Quality Improvement in Interconnection of Grid for Hybrid Energy Sources at the Distribution Level

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Abstract— *Renewable Energy supply (RES) integrated at distribution level is understood as Distributed Generation (DG). This paper presents a bearing strategy for achieving most edges from these grid-interfacing inverters once put in in 3-phase 4-wire distribution systems. The electrical converter is controlled to perform as a multi-function device by incorporating active power filter practicality. The convertor} will therefore be used as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF and L,C Filter to compensate current unbalance, load current harmonics, load reactive power demand and cargo neutral current. Dynamic Voltage renovator to compensating the Voltage sags and swells. All of those functions is also accomplished either severally or at the same time. With such a bearing, the mixture of grid-interfacing electrical converter and therefore the 3-phase 4-wire linear/non-linear unbalanced load at purpose of common coupling seems as balanced linear load to the grid.*

Keywords— Power quality, Active power filter (APF), Dynamic Voltage Restorer (DVR), distributed generation (DG), distribution system, grid interconnection, power quality (PQ), renewable energy.

I. INTRODUCTION

Power quality (PQ) is incredibly vital to bound customers. For this reason, several utilities may sell current at totally different costs to their customers, counting on the standard of the delivered power. Since most finish users area unit connected to secondary distribution networks, at medium voltage, it can be vital to watch and compensate the most disturbances on the medium voltage. As additional sensitive masses, like computers, automation equipments, communication equipments, medical equipments, and military equipments, have get wide use, power quality has become a big issue to each customers and therefore the utility firms. Since these equipments area unit terribly sensitive in reference to input voltage disturbances, the inadequate operation or the fault of those masses brings concerning Brobdingnagian losses.

Renewable energy sources (RES) integrated at distribution level is termed as distributed generation (DG). The utility worries because of the high penetration level of intermittent RES in distribution systems because it could cause a threat to network in terms of stability, voltage regulation and power-quality (PQ) problems. Therefore, the decigram systems area unit needed to suits strict technical and regulative frameworks to confirm safe, reliable and economical operation of overall network. With the advancement in power physical science and digital management technology, the decigram systems will currently be actively controlled to boost the system operation with improved PQ at PCC. However, the intensive use of power physical science based mostly instrumentality and non-linear masses at PCC generate harmonic currents, which can deteriorate the standard of power [1], [2]. Generally, current controlled voltage supply inverters area unit accustomed interface the intermittent RES in distributed system.

Recently, a number of management ways for grid connected inverters incorporating PQ resolution are projected. In [3] Associate in Nursing electrical converter operates as active inductance at a particular frequency to soak up the harmonic current. however the precise calculation of network inductance in period of time is troublesome and should deteriorate the management performance. the same approach within which a shunt active filter acts as active electrical phenomenon to damp out the harmonics in distribution network is projected in [4]. In [5], a bearing strategy for renewable interfacing electrical converter supported theory is projected. during this strategy each load and electrical converter current sensing is needed to compensate the load current harmonics. The non-linear load current harmonics could end in voltage harmonics and might produce a heavy PQ drawback within the grid network.

Active power filters (APF), LC filters area unit extensively accustomed compensate the load current harmonics and cargo unbalance at distribution level. Dynamic Voltage renovator to compensating the Voltage sags and swells. This leads to an extra hardware value. However, during this paper authors have incorporated the options of APF, LC filter within the, standard electrical converter interfacing renewable with the grid, with none further hardware value. Here, the most plan is that the most utilization of electrical converter rating that is most of the time underutilized because of intermittent nature of RES.

It is shown used to perform following vital 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 just in case of 3-phase 4-wire system. Moreover, with adequate management of grid-interfacing electrical converter, all the four objectives are often accomplished either severally or at the same time. Dynamic Voltage renovator to compensating

the Voltage sags and swells. The PQ constraints at the PCC will so be strictly maintained among the utility standards while not further hardware value.

II. System Description

In this paper, it is shown that using an adequate control strategy, with a four-leg four-wire grid interfacing inverter, it is possible to mitigate disturbances like voltage unbalance. The topology of the investigated grid interfacing inverter and its interconnection with the grid is presented in Fig. 1.

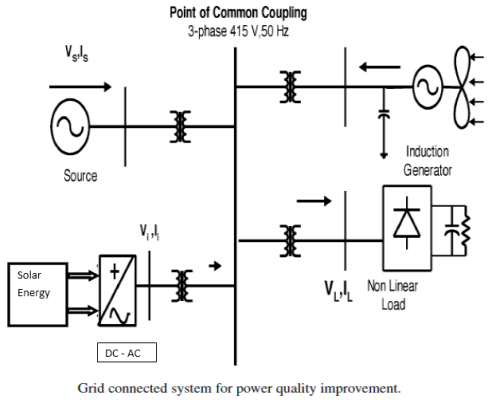


Fig.1 Single line diagram for Hybrid system

It consists of a four-leg four-wire voltage supply electrical converter. The voltage supply electrical converter could be a key part of a decigram system because it interfaces the renewable energy supply to the grid and delivers the generated power. during this form of applications, the electrical converter operates as a current controlled voltage supply. Fourth leg is employed for neutral affiliation. The RES is also a DC supply or Associate in Nursing AC supply with rectifier coupled to dc-link. during this paper wind energy is employed as a RES, the variable speed wind turbines generate power at variable ac voltage. Thus, the facility generated from these renewable sources must convert in dc before connecting on dc-link [8]–[10]. The simulink model of powerhouse is given in Fig. powerhouse generates a variable ac offer; this variable ac supply is born-again into dc by connecting a rectifier at output aspect.

The controller needs the three-phase grid current (Ia,,Ib, Ic), the three-phase voltage at the PCC (Va, Vb, Vc) and therefore the DC-link voltage (VDC). As shown in Fig. 3, the curved undulation and therefore the section of the grid current reference (Ia*, Ib*, Ic*) comes from the road voltage due to a PLL. The management diagram of grid-interfacing electrical converter for a 3-phase 4-wire system. The fourth leg of electrical converter is employed to compensate the neutral current of load. the most aim of projected approach is to manage the facility at PCC during: 1) Pres =0; 2) Pres < total load power (PL); and 3) Pres > PL. whereas playing the facility management operation, the electrical converter is actively controlled in such some way that it perpetually draws/ provides elementary active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the mixture of each, the given management approach conjointly compensates the harmonics, unbalance, and neutral current.

The duty magnitude relation of electrical converter switches area unit varied in an exceedingly power cycle specified the mixture of load and electrical converter injected power seems as balanced resistive load to the grid. The regulation of dc-link voltage carries the knowledge concerning the exchange of active power in between renewable supply and grid. therefore the output of dc-link transformer leads to an energetic current .The multiplication of active current part with (IM) unity grid voltage vector emplates (UA,UB,UC) generates the network currents (IA,IB, and IC). The network neutral current is about to zero, being the fast total of balanced grid currents. The grid synchronizing angle obtained from section barred loop (PLL) is employed to get unity vector example.

$$UA = \sin(\Theta) \quad \text{---------- (1)}$$

$$UB = \sin(\Theta - 2\pi/3) \quad \text{---------- (2)}$$

$$UC = \sin(\Theta + 2\Pi/3) \quad \text{---------- (3)}$$

The actual dc-link voltage is perceived and more established a first-order low pass filter (LPF) to eliminate the presence of switch ripples on the dc-link voltage and within the generated reference current signals. The distinction of this filtered dc-link voltage and reference dc-link voltage is given to a separate PI regulator to keep up a relentless dc-link voltage underneath varied generation and cargo conditions. The dc-link voltage error at ordinal sampling instant is given as:

$$Vdcerr(n) = V^*dc(n) - Vdc(n) \quad \text{-- (4)}$$

The output of discrete-PI regulator at th sampling instant is expressed as

$$Im(n) = Im(n-1) + Kpvdc(Vdcerr(n) - Vdecrr(n-1)) + KIVdcVdecrr(n) \quad (5)$$

Where Kpvdc=10 andKIVdc=0.05 are proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$Ia^* = Im.Ua \quad \text{---------- (6)}$$

$$Ib^* = Im.Ub \quad \text{---------- (7)}$$

$$Ic^* = Im.Uc \quad \text{---------- (8)}$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$$I^*n = 0 \quad \text{---------- (9)}$$

The reference grid currents (Ia*,Ib* and Ic*) are compared with actual grid currents (Ia Ib and Ic) to compute the current errors as

Iaerr =I*a -Ia ---------- (10)

Iberr =I*b –Ib ---------- (11)

Icerr =I*c –Ic ---------- (12)

Inerr=I*n–In ---------- (13)

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P1 to P8) for the gate drives of grid-interfacing inverter. The average model of 4-leg inverter can be obtained by the following.

(dI inva)/dt = ((Vinva-Va))/Lsh ---------- (14)

(dI invb)/dt = ((Vinvb-Vb))/Lsh -------- (15)

The three-phase ac switching voltages generated on the output terminal of inverter. These inverter output voltages can be modelled in terms of instantaneous dc bus voltage and switching pulses of the inverter as

(dI invc)/dt = ((Vinvc-Vc))/Lsh --------- (16)

(dI invn)/dt = ((Vinvn-Vn))/Lsh ------- (17)

(dVdc)/dt=((Iinvad+Iinvbd+Iinvcd+Iinvnd))/Cdc --- (18)

Similarly the charging currents Iinvad,Iinvbd and Iinvcd on dc bus due to the each leg of inverter can be expressed as

Iinvad=Iinva(P1-P4) ---------- (19)

Iinvbd=Iinvb(P3-P6)---------- (20)

Iinvc=Iinvc(P5-P2)---------- (21)

Iinvad=Iinva(P7-P8)---------- (22)

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter.

B.VOLTAGE SOURCE CONVERTER (VSC)

A Voltage supply device (VSC) could be a power device that connected in shunt or parallel to the system. It will generate a curved voltage with any needed magnitude, frequency and point. It conjointly converts the DC voltage across storage devices into a group of 3 section AC output voltages. it's conjointly capable to get or absorbs reactive power. If the output voltage of the VSC is bigger than AC depot voltages, is claimed to be in electrical phenomenon mode. So, it'll compensate the reactive power through AC system. the kind of power switch used is Associate in Nursing IGBT in anti-parallel with a diode. The 3 section four leg VSI is sculpturesque in Simulink by exploitation IGBT.

C. SWITCHING CONTROL

The physical phenomenon management has been accustomed keep the controlled current within an outlined band round the references. The standing of the switches is set in line with the error. once this is increasing and therefore the error exceeds a particular positive price, the standing of the switches changes and therefore the current begins to decrease till the error reaches a particular negative price. Then, the switches standing changes once more. Compared with linear controllers, the non-linear ones supported physical phenomenon ways enable quicker dynamic response and higher hardiness with relevance the variation of the non-linear load. A downside [13] [14] of the physical phenomenon ways is that the switch frequency that isn't constant and might generate an outsized aspect harmonics band round the switch frequency.

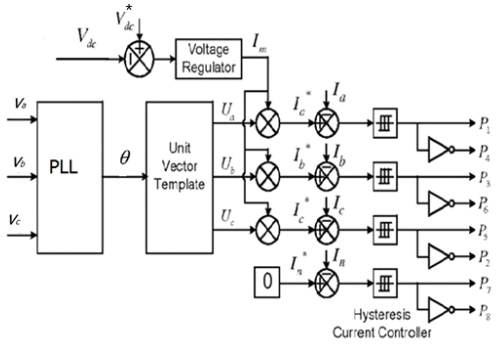


Fig 2.Control Scheme

III.HYSTERESIS CURRENT CONTROL

The physical phenomenon current management (HCC) is that the best management methodology to implement; the shunt APF is enforced with 3 section current controlled VSI and is connected to the ac mains for compensating this harmonics. The VSI gate management signals area unit brought out from physical phenomenon band current controller. A physical phenomenon current controller is enforced with a closed-loop system system and waveforms area unit shown in Fig .3. miscalculation signal is employed to manage the switches in an exceedingly voltage supply electrical converter. This error is that the distinction between the required current and therefore the current being injected by the electrical converter. If the error exceeds the higher limit of the physical phenomenon band, the higher switch of the electrical converter arm is turned off and therefore the lower switch is turned on. As a result, this starts decaying.

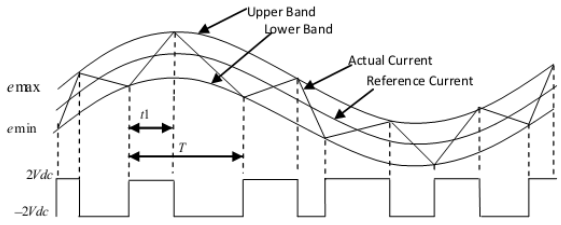


Fig 3.Waveform of Hysteresis current controller

If the error crosses the lower limit of the physical phenomenon band, the lower switch of the electrical converter arm is turned off and therefore the higher switch is turned on. As a result, this gets back to the physical phenomenon band. The minimum and most values of the error signal area unit emin and emax severally. The vary of the error signal emax-emin directly controls the quantity of ripple within the output current from the VSI.

IV MODELING THE PV ARRAY

The direct conversion of the alternative energy into wattage is obtained by star cells. A PVG consists by several strings of star cells asynchronous, connected in parallel, so as to produce the required values of output voltage and current. Fig. four shows the equivalent circuit of a PVG, from that non linear I–V characteristic are often deduced.

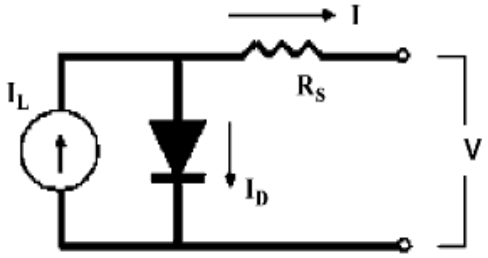


Fig 4.Solar-Cell Equivalent Circuit.

The cells are connected in series and in parallel combinations in order to form an array of the desired voltage and power levels.

V WIND TURBINE SYSTEM MODELLING

Although there area unit many varieties of wind turbines, either synchronous or asynchronous, the scope of this Investigation is restricted to asynchronous wind turbines that area unit presently and wide utilized in wind turbines because of their low value and convenient maintenance. Generally, a whole turbine model consists of Associate in Nursing mechanics model, mechanical drive model, and induction generator model. The mechanics rotor extracts the kinetic power from the wind and exchanges this power into mechanical power. The relation between the wind speed and mechanical power is given by Equation

$$Pw = (1/2)\ \rho\pi\ R2\ Vw\ 3\ Cp\ (\theta, \delta)$$

where, Pw is the power extracted from wind (W), ρ is the air density (kg/m3), R is the radius of the rotor of wind turbine (m), Vw is the wind speed (m/s), θ is the pitch angle of the rotor (deg) , λ =Wrot R/Vw, λ = the tip speed ratio, where, Wrot is the rotor speed of wind turbine (rad/sec), Cp is the aerodynamic efficiency of the rotor which can be expressed as a function of the tip speed ratio (λ) and the pitch angle (θ) by the following equation [11]:

$$Cp= 0.22(116/\beta -0.40\theta-5)\ e\ 12.5/\ \beta$$

Produced mechanical power is transferred into the electrical energy by generator and is fed into the grid.

VI CONTROL OF WIND FARM SIDE CONVERTER

The main scope of the powerhouse aspect device during this investigation is to manage the reactive power generated or absorbed by the VSC. This reactive power is controlled by the magnitude of the device AC voltage, that in PWM conversion is set by modulation index. The simplified management diagram of the powerhouse aspect device is additionally enclosed in grid aspect. Shift signal is that the point order in degrees derived from open loop power controller. it's the angle by that the voltage across the causation finish electrical device is section shifted so as to manage the facility flow. The firing unit uses the PWM reference signals at first harmonic. The magnitude of the reference signal is controlled by the signal r m and its section is controlled by the signal shift. Firing pulses area unit generated with comparison between reference signals and triangular Signals [14].

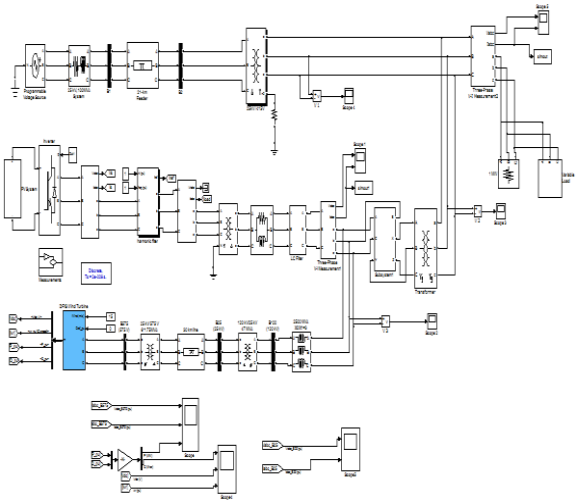


Fig 4.1 Simulation Diagram for Hybrid systems

VII CONTROL OF GRID SIDE CONVERTER

The main schematic of this controller is discovered in too. This management aims to regulate the point of receiving finish device at the AC aspect. Also, once the DC link voltage is above traditional condition, the point is adjusted to push power into the receiving finish AC system. If the DC link voltage tends to be not up to reference price, the angle is altered in an exceedingly thanks to receive the facility from receiving finish AC system so as to charge the DC link. The mi is that the modulation index of the output of controller so as to manage the voltage magnitude of the grid aspect device. The firing unit acts as similar as cited in powerhouse aspect device controller [14].

VIII POWER QUALITY IN POWER DISTRIBUTION SYSTEMS

Most of the additional vital international standards outline power quality because the physical characteristics of the electrical offer provided underneath traditional in operation Conditions that don't disrupt or disturb the customer's processes. Therefore, an influence quality drawback exists if any voltage, current or frequency deviation leads to a failure or in an exceedingly dangerous operation of customer's instrumentality. However, it's vital to note that the standard of power offer implies primarily voltage quality and provide dependability. Voltage quality issues relate to any failure of kit because of deviations of the road voltage from its nominal characteristics, and therefore the offer dependability is characterised by its adequacy (ability to provide the load), security (ability to face up to abrupt disturbances like system faults) and accessibility (focusing particularly on long interruptions). Power quality issues area unit common in most of business,

industrial and utility networks. Natural phenomena, like lightning area unit the foremost frequent explanation for power quality issues. switch phenomena leading to oscillating transients within the electrical offer, for instance once capacitors area unit switched, conjointly contribute well to power quality disturbances. Also, the affiliation of high power non-linear masses contributes to the generation of current and voltage harmonic elements. Between the various voltage disturbances that may be made, the foremost vital and important power quality issues area unit voltage sags because of the high economical losses that may be generated.

Short-term voltage drops (sags) will trip electrical drives or additional sensitive instrumentality, resulting in pricey interruptions of production [10]. For of these reasons, from the buyer purpose of read, power quality problems can become Associate in Nursing more and more vital issue to think about so as to satisfy smart productivity. On the opposite hand, for the electrical offer trade, the standard of power delivered are going to be one in every of the identifying issue for guaranteeing client loyalty during this terribly competitive and deregulated market. to handle the requirements of energy customers attempting to enhance productivity through the reduction of power quality connected method stoppages and energy suppliers attempting to maximise in operation profits whereas keeping customers glad with offer quality, innovative technology provides the key to cost-efficient power quality enhancements solutions. However, with the assorted power quality solutions out there, the apparent question for a shopper or utility facing a specific power quality drawback is that instrumentality provides the higher resolution.

IX SOLUTIONS TO POWER QUALITY PROBLEMS

There area unit 2 approaches to the mitigation of Power Quality issues. the primary approach is named load learning, that ensures that the instrumentality is a smaller amount sensitive to power disturbances, permitting the operation even underneath vital voltage distortion. the opposite resolution is to put in line learning systems that suppress or counteracts the facility system disturbances. a versatile and versatile resolution to voltage quality issues is obtainable by active power filters. presently they're supported PWM converters and hook up with low and medium voltage distribution system in shunt or asynchronous. Series active power filters should operate in conjunction with shunt passive filters so as to compensate load current harmonics. Shunt active power filters operate as a governable current supply and series active power filters operates as a governable voltage supply. each schemes area unit enforced desirable with voltage supply PWM inverters, with a dc bus having a reactive part like a condenser. Active power filters will perform one or additional of the functions needed to compensate power systems and up power quality. because it are going to be illustrated during this paper, their performances rely on the facility rating and therefore the speed of response.

X SIMULATION RESULTS

The total active and reactive powers of grid, load and electrical converter within the APF mode of operation, the electrical converter consumes a little quantity of active power to keep up the dc-link voltage and to beat the losses related to electrical converter, whereas most of the load reactive power want is supported by electrical converter effectively. Thus, this mode of operation validates the idea of utilization of grid-interfacing electrical converter as shunt APF once there's no power generation from the RES. The experimental results demonstrate the effective compensations of load current unbalance, harmonics and reactive power.

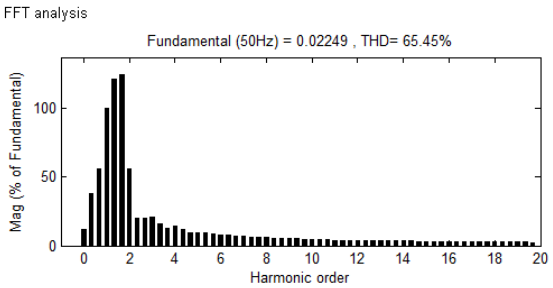


Fig 5: THD without Hybrid Filter

Voltage and Current Waveform With and Without Hybrid Filter

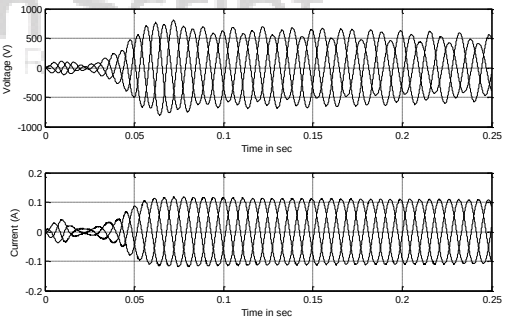
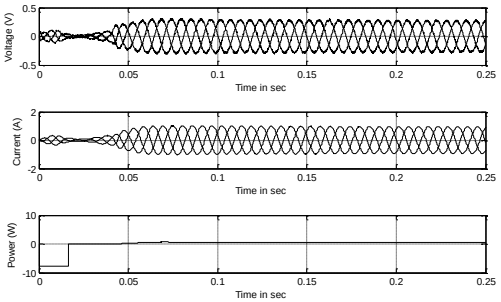


Fig 6: Input waveform without hybrid filter



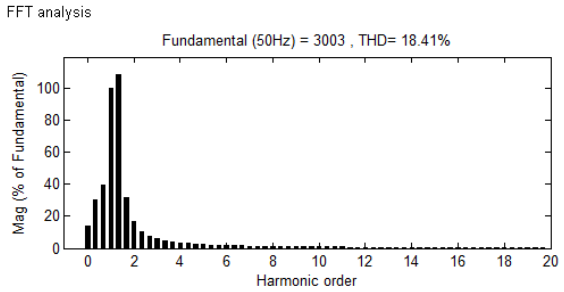


Fig 7: output wave form for Hybrid system and THD level

XI HARMONICS

The harmonic results because of the operation of power electronic converters. The harmonic voltage and current ought to be restricted to the suitable level at the purpose of alternative energy affiliation to the network. to confirm the harmonic voltage among limit, every supply of harmonic current will enable solely a restricted contribution shown in Fig eight, as per the IEC-61400-36 guideline. The speedy switch offers an outsized reduction in lower order harmonic current compared to the road commutated device, however the output current can have high frequency current and might be simply filter-out.

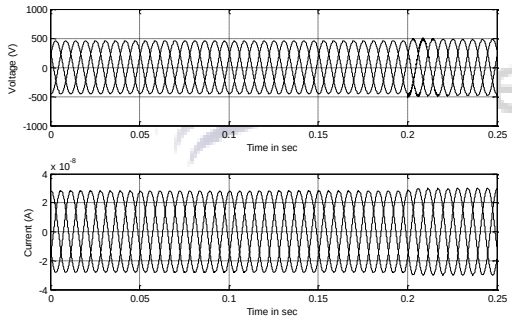


Fig 8: Load side Output wave form with hybrid filter

XII CONCLUSION

This paper has bestowed a unique management of Associate in Nursing existing grid interfacing electrical converter to enhance the standard of power at PCC for a 3-phase 4-wireDGsystem. it's been shown that the grid-interfacing electrical converter are often effectively used for power learning while not moving its traditional operation of real power transfer. The grid-interfacing electrical converter with the projected approach are often used to: i) inject real power generated from RES to the grid, and/or, ii) operate as a shunt Active Power Filter (APF), L,C Filter. Dynamic Voltage renovator to compensating the Voltage sags and swells. This approach therefore eliminates the requirement for extra power learning instrumentality to enhance the standard of power at PCC. intensive MATLAB/Simulink simulation further because the DSP based mostly experimental results have valid the projected approach and have shown that the grid-interfacing electrical converter are often used as a multi-function device. it's more incontestible that the PQ improvement are often achieved underneath 3 totally different scenarios: this unbalance, current harmonics and cargo reactive power, because of unbalanced and non-linear load connected to the PCC, Dynamic Voltage renovator to compensating the Voltage sags and swells area unit salaried effectively specified the grid aspect currents area unit perpetually maintained as balanced and curved at unity power issue. Moreover, the load neutral current is prevented from flowing into the grid aspect by compensating it domestically from the fourth leg of electrical converter. once the facility generated from RES is over the overall load power demand, the grid-interfacing electrical converter with the projected management approach not solely Peul fills the overall load active and reactive power demand (with harmonic compensation) however conjointly delivers the surplus generated curved active power to the grid at unity power issue.

REFERENCES

[1] J. M. Guerrero, L. G. de Vicuna, J. Matas, M. Castilla, and J. Miret, "A wireless controller to enhance dynamic performance of parallel inverters in distributed generation systems," IEEE Trans. Power Electron.,vol. 19, no. 5, pp. 1205–1213, Sep. 2004.

[2] J. H. R. Enslin and P. J. M. Heskes, "Harmonic interaction between a large number of distributed power inverters and the distribution network," IEEE Trans. Power Electron., vol. 19, no. 6, pp. 1586–1593, Nov. 2004.

[3] U. Borup, F. Blaabjerg, and P. N. Enjeti, "Sharing of nonlinear load in parallel-connected three-phase converters," IEEE Trans. Ind. Appl., vol. 37, no. 6, pp. 1817–1823, Nov./Dec. 2001.

[4] Hybrid Active Filter For Reactive And Harmonics Compensation In A Distribution Network Victor. Fabián Corasaniti, Member, IEEE, Maria Beatriz Barbieri, Senior Member, IEEE, Patricia Liliana Arnera, Senior Member, IEEE, And María Inés Valla, Senior Member, IEEE Transactions On Industrial Electronics, March 2009

[5] Design And Implementation Of A Current-ControlledParallel Hybrid Power Filter Vishal Verma, Member, And Bhim Singh, Senior Member, IEEE Transactions On Industry Applications, September/October 2009

[6] A Hybrid Passive Filter Configuration For VarControl And Harmonic Compensation Abdelhamid Hamadi, Student Member, Ieee, Salem Rahmani, Member, Ieee, And Kamal Al-Haddad, Fellow, IEEE Transactions On Industrial Electronics, July 2010

[7] Mehmet Ucar, Sule Ozdemir, "3-Phase 4-leg unified series–parallel active filter system with ultra capacitor energy storage for unbalanced voltage sag mitigation" Electrical Power and Energy Systems 2013.

[8] Mekri Fatiha, Machmoum Mohamed, Ait-Ahmed Nadia, "New hysteresis control band of an unified power quality conditioner" Electric Power Systems Research 2011.

[9] Morris Brenn, Roberto Faranda and Enrico Tironi, "A New Proposal for Power Quality and Custom Power Improvement: OPEN UPQC" IEEE Transactions on Power Delivery, Vol. 24, No. 4, October 2009.

[10] Power Quality Improvement In 3-Phase 3-Wire Distribution Systems Using Modular Active Power Filter R. El Shatshat, M. Kazerani, M.M.A. Salama

[11] Mukhtiar Singh, Student Member, IEEE, VinodKhadkikar, Member, IEEE, Ambrish Chandra, Senior Member, IEEE and Rajiv K. Varma, Senior Member, IEEE "Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features."IEEE Transactions on Power Delivery, Vol. 26, No. 1, January 2011.

[12] Y. Jaganmohan Reddy, K. Padma Raju, Y. VenkataPavan Kumar, "Use of DC Motor-Generator Set for Power Quality Improvement in a Renewable Energy Based Hybrid Power System." International Journal on Recent Trends in Engineering & Technology, Vol. 05, No. 02, Mar 2011.

[13] Hung-Cheng Chen, Jian-Cong Qiu, and Chia-Hao Liu "Dynamic Modeling and Simulation of Renewable Energy Based Hybrid Power Systems" DRPT 2008, pp. 2803-2809.

[14] D.M. Brod and D.W. Novotny, "Current Control of VSI PWM Inverters", IEEE Transactions Industrial Application, Vol. IA-21,no.4.pp.562-570,1985.

[15] M.takeda et al, "Harmonic Current Compensation With Active Filter", in IEEEIIAS Ann. Meeting,1987,pp,808.