International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 03 | Mar -2017 www.irjet.net p-ISSN: 2395-0072

POWER ANGLE CONTROL SCHEME FOR INTEGRATION OF UPQC IN GRID CONNECTED PV SYSTEM

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Abstract - *The quality of electric power is greatly affected by the proliferation of non-linear loads in electrical energy processing applications like switched mode power supplies, electric motor drives, battery chargers, etc., The custom power devices like UPQC has gained more importance in power quality arena as it gives the best solution for all power quality issues. UPQC is the combination of both shunt and series active power filters connected through a common DC link capacitor. The shunt active power filter is the most corrective measure to remove the current related problems, power factor improvement by supplying reactive power and regulates DC link voltage. The series APF acts as controlled voltage source and corrects voltage related problems, like sag or swell, flickering, harmonics, etc.,. As a combination of both of these, UPQC improves service reliability. In the present work, shunt inverter control is based on modified active- reactive (p-q) power theory, uses High selectivity filter (HSF) for reference current generation. The series APF uses Power Angle Control (PAC) scheme for compensating sag/swell, interruption and voltage related problems along with sharing a part of load reactive power demand with shunt APF and thus ease its loading and makes the utilization of UPQC to be optimal. The topology uses three phase three leg inverters for both shunt APF and series APF. The gating signals were generated using Hysteresis controller. The output of High step-Up DC-DC Converter is used to work as DC voltage source for both APFs. The input voltage for the converter is provided by Photo Voltaic array incorporated with P&O MPPT technique. The use of high step-up DC-DC converter is for high voltage gain with better efficiency. The present topology avoids the PLL in shunt active power filter.*

The simulation results are presented to show the effectiveness of the three phase, three-wire PV-UPQC and here obtained an acceptable THD for source current and kept load voltage at its nominal value.

Key Words*: *Unified Power Quality Conditioner (UPQC) High selectivity filter (HSF) Voltage Source Inverter(VSI)

INTRODUCTION:

The term power quality got significant importance in the electric power industry. The increasing application of electronic equipment and distributed generation has led to the degradation of power quality by injecting harmonics, flicker and voltage imbalance into the system. In addition, switching of capacitor banks, lightning strikes on transmission lines and various faults on the network also creates the power quality issues such as transients, voltage sag or swell, interruptions, etc.,.. The equipment which is increasingly susceptible to the variations in Power Quality is termed as Sensitive Equipment or Sensitive Load [4]. For proper load operation, it requires pure sinusoidal voltage. With fast growing digital technology, the devices that depending upon volatile memory chip for storages are increasing and these are potentially at risk from power quality events.

To achieve this pure sinusoidal voltage and to meet the power quality standards, it is necessary to use some compensation techniques. Previously passive filters using tuned LC components have been used to mitigate the harmonics, which are low in cost, simple in configuration. But this has drawbacks of fixed compensation, bulky in size and creates resonance problems. Hence a modern solution is found in the form of active power filtering. The shunt APF is suitable for suppressing source current harmonics and the series APF is suitable to compensate source voltage imperfections.

The power electronic controllers used in distribution system for the purpose of supplying a level of reliability or power quality, which is essentially required by sensitive load, is termed as custom power devices [4]. These devices have the ability to perform voltage regulation and current interruption functions within the distribution system and hence it can be treated as power conditioning device.

UPQC is one of those efficient custom power devices which is the combination of both shunt and series active power filters connected through a common DC link capacitor [1], [2], [6]. The shunt active power filter is the most corrective measure to remove the current related problems, power factor improvement by supplying reactive power and regulates DC link voltage [6]. The series APF acts as controlled voltage source [6] and corrects voltage related problems such as sag/swell, flickering, harmonics etc.,. As a combination of both of these, UPQC improves service reliability.

In the present work a modified p-q theory is used for reference current generation shunt APF. It uses two high selectivity filters (HSF) [15], [16], which are used to obtain the fundamental components from current and voltage signals in α-β reference frame. The fixed power angle control scheme [2], [5], is used to generate the reference voltage signals for series APF.

During voltage sag condition the amount of power in UPQC will be increased to a large extent. The normal UPQC can't compensate for the long duration power quality issues as the voltage across DC-Link falls steeply. But the proposed high step-up DC-DC converter operated PV-UPQC system overcomes this difficulty and able to compensate for long term voltage interruption, sag/swell, harmonics and reactive power. The additional energy will be supplied by the PV-array. While interconnecting the PV-UPQC to the grid, the voltage injected by series APF depends upon the measurement of power angle. As it creates the phase difference between the source voltage and load voltages, here both active and reactive power transitions getting involved. Usage of HSF in shunt APF reduces a considerable amount of THD in source current and avoiding the PLL improves its dynamic response. With the power angle control scheme, series APF shares a part of load reactive power demand along with the shunt APF. Thus reduces burden and rating of the shunt APF

PROPOSED SYSTEM DESCRIPTION

The PV-UPQC system consists of two voltage source inverters, a common DC-link capacitor which acts as source, PV array and a high step-up boost converter operating with MPPT algorithm. The block diagram of the proposed system is shown in below fig. 1.

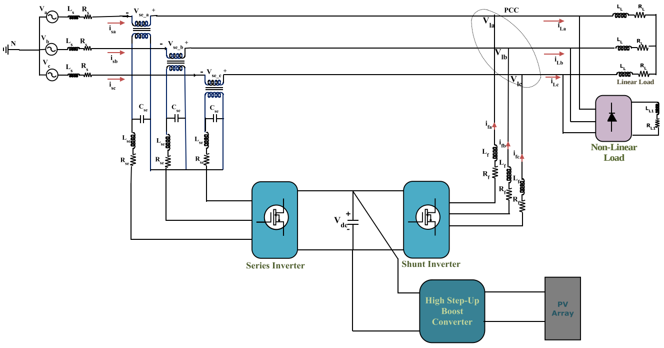


Fig. 1 System description block diagram

A three phase source of rated voltage 326 Volts (L-G_{peak}) is connected to the load through a feeder having an impedance of 1+**j** 0.314 *Ω*. The Load considered here is of combination of linear load and non-linear load. The linear load may be thought of a transformer or an induction motor or any other load which can be modeled as an R-L load in distribution system whose rating is 5KW +j5KVAR. The non-linear load is diode bridge rectifier with R-L load.

The series APF consists of a three phase injection transformer which is connected in series with the line which is used to inject the compensating voltage and provides isolation. This voltage is generated by the three phase three-leg series inverter connected across the DC-Link. The series inverter is connected to the series injection transformer through an LPF formed by R_{se}, L_{se} and C_{se}, whose purpose is to remove distortions resulted by switching of inverter. The shunt APF is used to inject the current at PCC through the inductor filter to mitigate the current harmonics and to maintain a constant voltage across the DC-Link.

The PV array is connected to the grid through the UPQC. It uses the high step-up DC-DC converter whose operating duty ratio is generated by Perturb and Observe MPPT algorithm. The output of this high step-up boost converter is connected across the dc-link, whose voltage remains constant.

GENERATION OF REFERENCE VOLTAGES FOR SERIES APF

The generation of reference voltages for series APF is based on the power angle control scheme. The brief explanation and advantages of the scheme is explained in the following section.

POWER ANGLE CONTROL SCHEME

The rating of series APF used in UPQC depends upon the maximum percentage of sag/swell that it should compensate. But these are of small duration issues. But the shunt APF operates as long as the non-linear currents are drawn from the source. It supplies the reactive power continuously, which leads to increased utilization of it compared to series APF. The power angle control scheme is mainly used to increase the utilization factor of series APF without causing any additional burden on it. Here the series APF is used to share a part of load reactive power demand along with compensating voltage sag/swell by creating a power angle difference between source voltage and load voltage.

The compensation of sag can be done by active power approach or reactive approach or by both of these in UPQC. Here this scheme uses both active and reactive power approach to compensate the sag/swell by maintaining a constant load voltage. The operation is better explained using the phasor diagram shown in below fig. 2

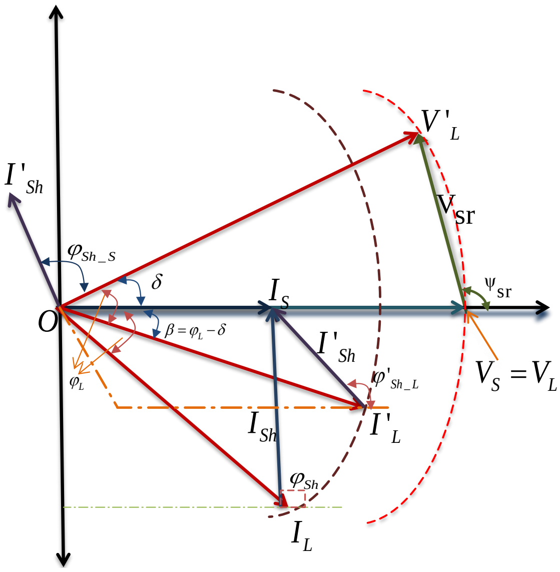


Fig. 2 Phasor representation of PAC scheme

Let $|V_{sr}| = |V_L| = |V_L^*| = k$ be the required voltage magnitude. And its assumed to have no sag/swell initially and the load current is I_L and phase angle is φ_L.

When we inject a series voyage of $V_{sr}\angle\psi_{sr}$ such that the resultant voltage across PCC is constant, then its load current varied to I_L' and creates a phase angle reduces to φ_L' due to the creation of a power angle, between the source and load voltages. This reduces the amount of reactive power supplied by the source i.e. that same amount of reactive power is supplied by the series APF. And the shunt APF needs to supply the remaining reactive power demanded by load. Hence it can be rated accordingly. Thus by controlling the power angle, we can reduce the burden on shunt APF and can improve the utilization factor of series APF.

Let the fluctuation in supply voltage (v_x) because of voltage sag/swell from reference load voltage is expressed as:

$$k_f = \frac{V_s - V_L^*}{V_L^*}$$, where K_f is the fluctuation factor

(1)

Then from the phasor diagram we can calculate the required series injected voltage V_{sr} and angle (ψ_{sr}) a

$$V_{sr} = \sqrt{2} * k * \sqrt{1-\cos\delta}$$

(2)

$$\psi_{sr} = 180^\circ - \angle\gamma = 180^\circ - \tan^{-1}\left(\frac{\sin\delta}{1-\cos\delta}\right)$$

(3)

$$\delta = \sin^{-1}\left[(1+k)\left(\frac{Q_L - Q_{sh,\max}}{P_L}\right)\right]$$

(4)

Where V_{sr} = series injected voltage

V_L = Load Voltage

V_L' = Resultant Load voltage

V_L^* = Reference Load voltage

ψsr = Series injected phase angle

δ = Power angle

P_L = Load active power

Q_L = Load reactive power

$Q_{sh,\max}$ = Maximum reactive power rating of shunt inverter

REFERENCE VOLTAGES CALCULATION FOR SERIES INVERTER

The reference voltages generation for series inverter using PAC approach can be done in two steps. The first step is to insert the required dc component to mitigate the sag voltage and the second step is to create power angle difference between the source and load voltages.

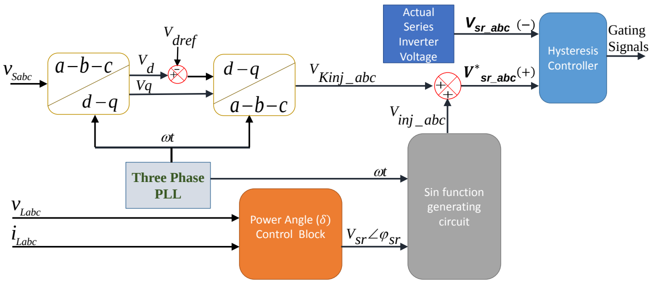


Fig. 3 Reference voltage signal generation block diagram for series inverter

The first step is carried out by transforming the source voltage into d-q frame using the parks transformation. Then the actual d-axis voltage (V_d) is compared with the reference voltage (V_{dref}). The difference signal will indicates the error component which represents sag/swell and supply voltage harmonics present in the supply.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix}_{ref} = \begin{bmatrix} V_d \\ V_q \end{bmatrix} - \begin{bmatrix} V_{dref} \\ 0 \end{bmatrix} \quad (5)$$

This error component will be transformed into a-b-c coordinates (V_{kinj_abc}) using inverse Park's transformation. During the second step, this error component is added to the $V_{sr}\angle\psi_{sr}$ measured from power angle control measurement block using equations (4.1) to (4.4) and the output voltage , $V^*_{sr\_abc}$, is compared with series APF output voltage for the PWM pulse generation of series APF inverters using Hysteresis controller. For tracking the supply frequency it uses PLL. The complete approach is summarized in the block diagram shown in fig. 3.

GENERATOIN OF REFERENCE CURRENTS FOR SHUNT INVERTER

The reference currents for shunt inverters are generated using modified p-q theory. Here we are using the two HSFs in place of classical extraction filters such as LPF and HPF, which are used to extract the fundamental components of both voltage and current directly from $\alpha - \beta$ frame.

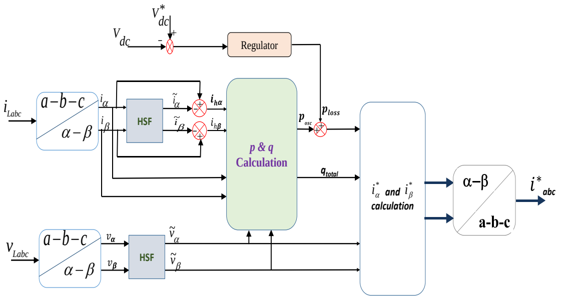


Fig. 4 Control block diagram for modified instantaneous *p-q* Theory

The line currents are transformed to α-β frame using the a-b-c to α-β coordinates using Clarke's transformation. Using HSF the fundamental current is being extracted and compared with actual current. The difference current will gives the required Harmonic currents $i_{h\alpha}$ and $i_{h\beta}$.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

(6)

$$\begin{bmatrix} i_{h\alpha} \\ i_{h\beta} \end{bmatrix} = \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} - \begin{bmatrix} \tilde{i}_\alpha \\ \tilde{i}_\beta \end{bmatrix}$$

(7)

Similarly using HSF, the fundamental components of Load voltages are extracted after transforming it into α-β frame. These will be used to calculate the instantaneous oscillating active and total reactive components of power.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{La} \\ v_{Lb} \\ v_{Lc} \end{bmatrix}$$

(8)

$$\begin{bmatrix} p_{osc} \\ \tilde{q} \end{bmatrix} = \begin{bmatrix} \tilde{v}_\alpha & \tilde{v}_\beta \\ -\tilde{v}_\beta & \tilde{v}_\alpha \end{bmatrix} \begin{bmatrix} i_{h\alpha} \\ i_{h\beta} \end{bmatrix}$$

(9)

But the total reactive power is given by $q = \tilde{q} + \hat{q}$ i.e.,

$$q = i_\beta \tilde{v}_\alpha - i_\alpha \tilde{v}_\beta$$

(10)

The loss component of power is added to the oscillating component of active power. The loss component of power is proportional to the difference between V_{dc}^* and V_{dc} .PI controller is used to regulate the voltage across dc-link and is used to measure the loss component of power directly. These are used to generate the reference currents in α-β frame using following equations.

$$p_{loss} = K_p (V_{dc}^* - V_{dc})^2 + K_i \int (v_{dc}^* - v_{dc})^2 \, dt$$

(4.11)

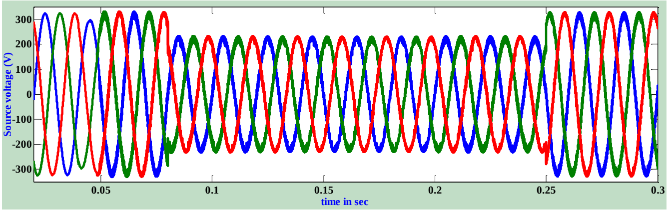
$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -p_{osc} + p_{loss} \\ -q \end{bmatrix}$$

(12)

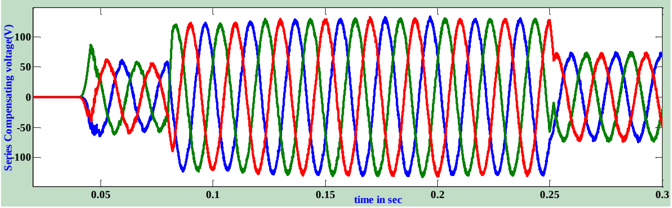
The measured currents are compared with actual shunt APF currents in order to generate the gating signals for shunt inverter using Hysteresis controller. The corresponding block diagram is shown in fig. 4.

SMULATON RESULTS FOR VOLTAGE SAG

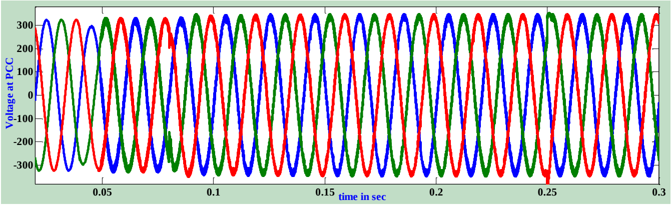
In this case, the results are carried out for 29.5% voltage sag, which is occurred between time t=0.08sec and t=0.25 sec.



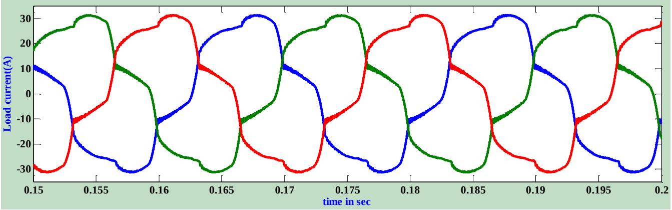
(a) Source Voltage



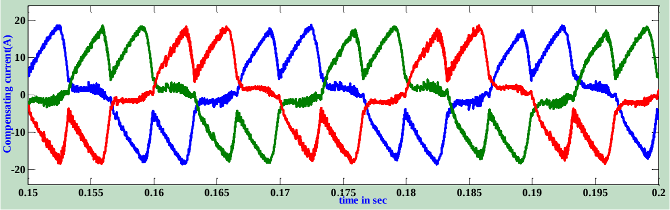
(b) Series Compensating Voltage



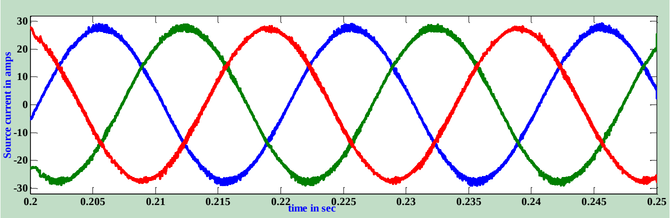
(c) Voltage across PCC



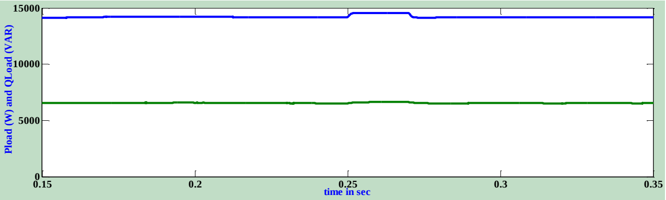
(d) Load Current



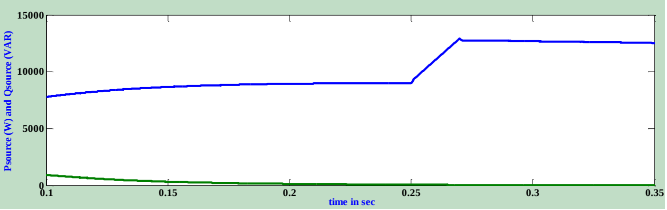
(e) Compensating current supplied by shunt APF



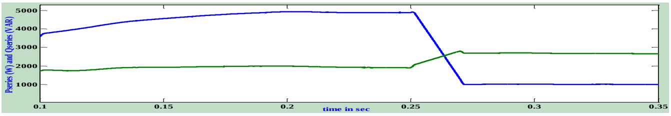
(f) Source current after compensation



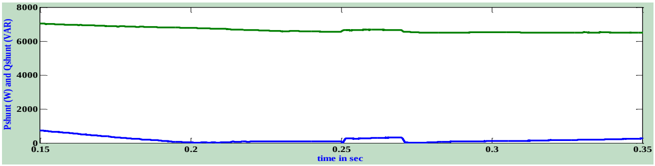
(g) Load demanded active and reactive power



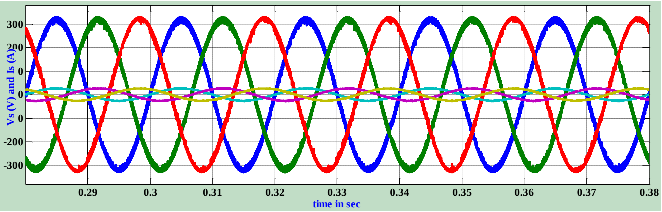
(h) Source supplied active and reactive power



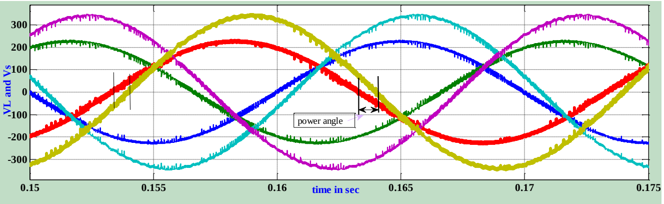
(i) Active and Reactive power supplied by Series APF



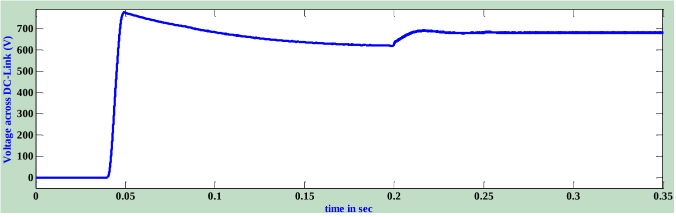
(j) Active and Reactive power supplied by Shunt APF



(k) Variation of V_S and I_S after compensation



(l) Variation of V_S and V_L (δ= 12.86°)

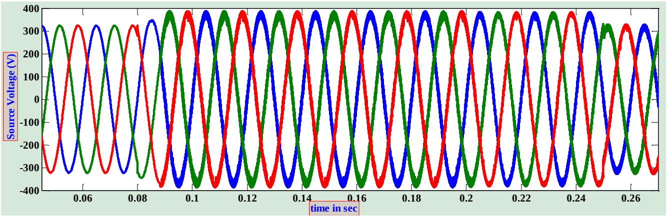


(m) Voltage across DC-Link

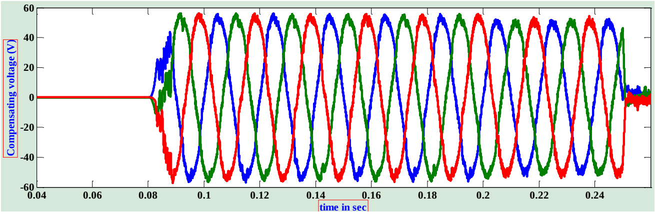
Fig. 5 Simulation results under voltage sag condition

RESULTS FOR VOLTAGE SWELL

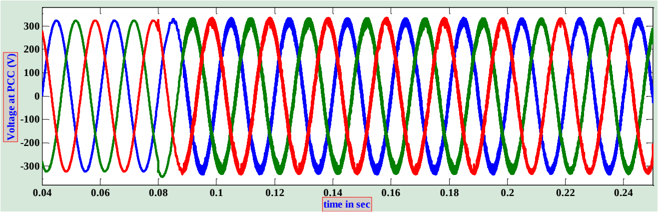
In this case, the results are carried out for 16.56% voltage Swell, which is occurred between time t=0.08sec and t=0.25 sec.



(a)) supply voltage

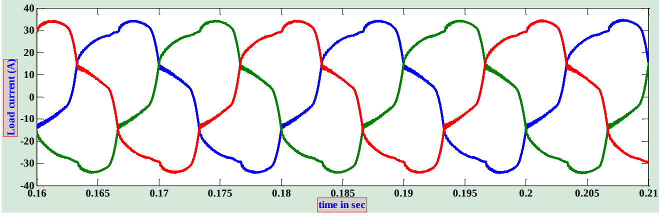


(b)series inverter injected voltage

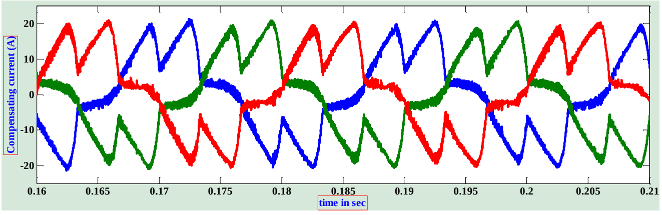


(

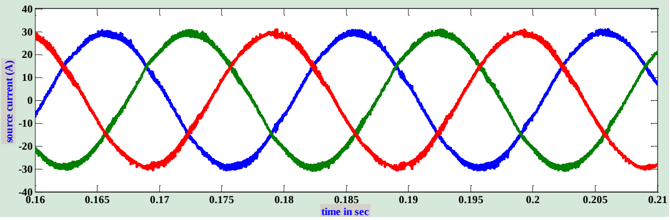
c) Voltage across PCC



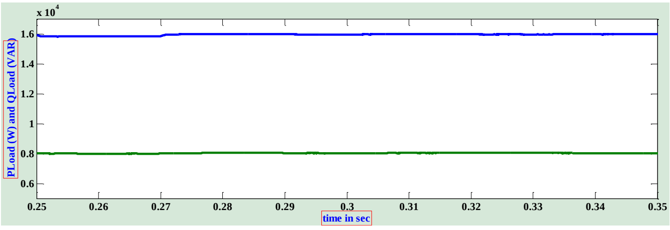
(d) Source current before compensation



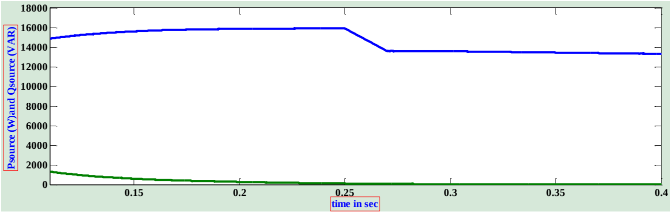
(e) Compensating current injected by shunt APF



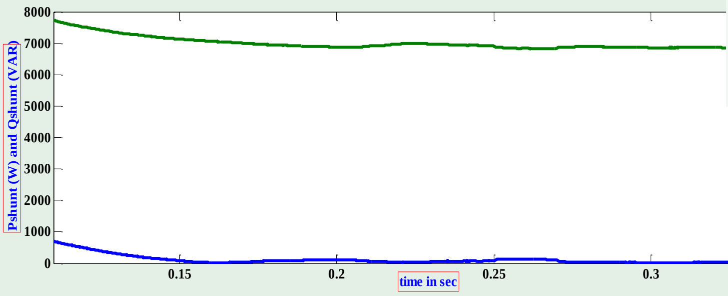
(f) Source current after compensation



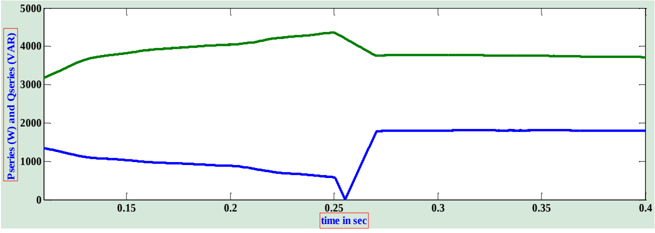
(g) Load demanded Active and Reactive Powers



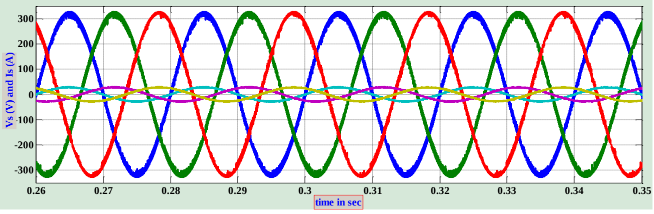
(h) Source supplied Active and Reactive Powers



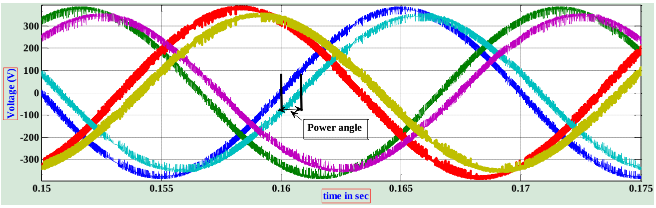
(i) Shunt APF supplied Active and Reactive Power



(j) Series APF supplied Active and Reactive Power



(k) Variation of V_S and I_S after compensation

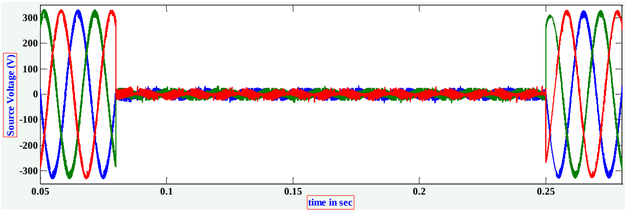


(l) Variation of V_S and V_L (δ= 14.85°)

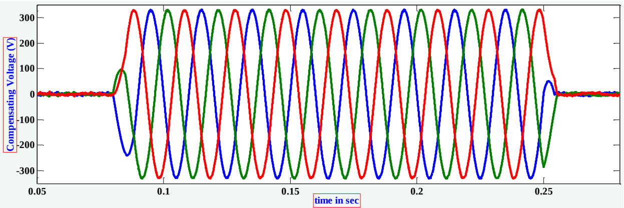
Fig. 6 Simulation results under voltage swell condition

RESULTS FOR VOLTAGE INTERRUPTION

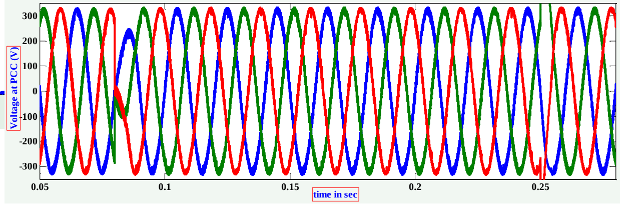
In this case, the results are carried out for voltage Interruption, which is occurred between time t=0.08sec and t=0.25 sec.



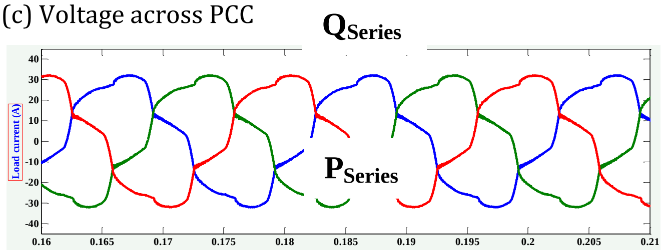
(a) Supply voltage



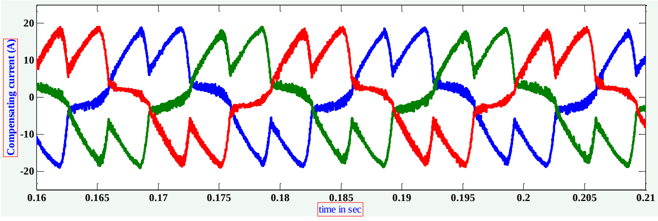
(b) Series inverter injected voltage



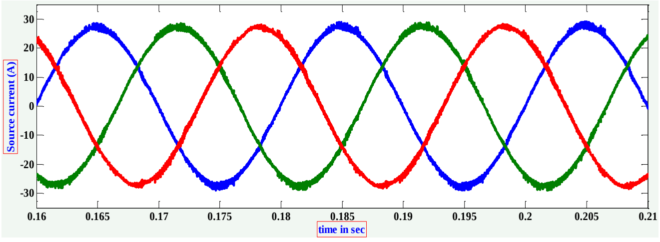
(c) Voltage across PCC



(d) Source current before compensation



(e) Compensating current injected by shunt APF



(f) Source current after compensation

From the results the following observations are concluded:

The voltage Sag, Swell and Interruptions are effectively compensated by series APF which is shown in Fig.5 (a), (b), (c), Fig. 2 (a), (b), (C) and Fig 3 (a), (b), (c) respectively.

The shunt APF effectively compensating the Load current Harmonics in all the three cases as shown in the Fig. 1 (d), (e), (f), Fig. 2 (d), (e), (f) and Fig. 6 (d), (e), (f) respectively. The THDs obtained are reduced to 0.7%, 0.89% and 1.41% from 16.41%, 15.09% and 15.53% respectively. The reason behind of obtaining such low THD is the usage of HSF, which extracted the fundamental component thoroughly.

From the waveforms we can observe that the rms value of Load current is greater than the rms value of source current and the values of Load currents are 23.72A, 23.08A and 24.22A and of source current are 19.78A, 20.41A and 19.62A respectively. As shown in fig. 1 (*l*) and fig. 2 (*l*) the power angle (δ), between the source voltage and load voltage is maintained at 12.86° and 14.85°.

As shown in the fig. 1 (j), 2 (j) and 3 (j) the Series inverter supplies both active power and reactive power in all the three cases, which means, the injected voltage is neither in series nor in quadrature with i_s. As it is supplying the reactive power demanded by load at steady state, the burden on the shunt APF is reduced.

The advantage of Photo Voltaic System is observed from fig. 3 (h), (j) and (*l*), in the Voltage interruption mode, which is switched at t=0.08sec. When it is on, the high step-up DC-DC converter is maintaining nearly a constant voltage of 650 volts across DC-Link from the position of rapidly drooping as shown in fig. 5.3 (*l*). During this period, the entire load demanded power is supplied by series APF only i.e., source supplied power is almost zero due to interruption. During the voltage sag and swell it is switched at t=0.2 sec, and then on the voltage across DC-Link is maintained constant as shown in fig. 1 (m) and fig. 2 (m) respectively.

CONCLUSION

In this Paper the PV-UPQC is simulated for Voltage Sag, Swell and Interruption modes using MATLAB SIMULINK and showed that the burden and on shunt APF is reduced, which also reduces the overall rating and cost of UPQC. The PV-UPQC is showed to be advantageous in order to supply power under voltage interruption mode and long duration power quality issues, which cannot be done by the conventional UPQC and thus improving the overall service reliability too. The usage of two high selectivity filters reduced THD below acceptable level. The simulation results had shown the effectiveness of mitigating voltage and current related problems.

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