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Smart Grid Power Quality Improvement Using Modified UPQC

DR A NALINI[1], G AZARIYA SAM DAVID[2], L M KIRUBAKARAN[3], N S SHAKTHIVEL[4]
[1] *Professor, Department of Electrical and Electronics Engineering, Dr. M. G. R Educational and Research Institute*
[2, 3, 4] *Department of Electrical and Electronics Engineering, Dr. M. G. R Educational and Research Institute*

Abstract- The Smart Grid (SG) system typically deals with different issues involving security and Power Quality (PQ) improvement. With frequent usage of power electronic devices and nonlinear load, harmonics are inserted into the system. The well-known Flexible AC Transmission System (FACTS) devices like Unified Power Quality Conditioners (UPQC) are usually employed to resolve the issues related to voltage sag, swell, flicker, PQ, and neutral current reduction of distribution systems. An UPQC itself inserts harmonics into the system that affects the system stability for sensitive loads. This paper describes biogeography-based optimization (BBO) with harmonics elimination techniques for modified UPQC connected with SG. Lower order harmonics are eliminated by proper selection of switching angles and at the same time the higher order harmonics are suppressed by injecting same order harmonics with equal magnitude but opposite in phase from the other converter. The excitation of Modified UPQC converters are obtained from PV (Photo-Voltaic) panel. The firing angles of series-shunt converter are obtained in real-time from the already stored angles in the microcontroller memory.

Indexed Terms- UPQC, PV panel, biogeography-based optimization; Quasi-sine (Q-S) wave switching, Power Quality.

I. INTRODUCTION

To overcome the problems of present grid technology, SG [1] with distributed generators (DGs) are introduced with smarter technologies. In last few decades for the massive use of power electronics devices and growth of non-linear loads injects non-sinusoidal component into the grid, thus generates the PQ degradation [2]. The voltage fluctuation [3] or system harmonics make a serious issue in power system. Numerous no of devices [4] such that Active Low Pass Filter [5], STATCOM [6], SVC [7], capacitor bank [8] etc are connected to the grid for the solution of different issues like reactive power, PQ management, voltage sag, swell, flicker, harmonics, and negative sequence current. With development of research methodology UPQC [9] is efficiently able to solve almost all the issues. For the sensitive load and manufacturing industry, maintaining PQ is the most important criteria for better process output otherwise manufacturing defects takes place. UPQC itself a power electronics switching devices with integration of series converter and shunt converter that injects harmonics or distortion in the grid which effect the system stability.

This current paper a mathematically modified switching technique for UPQC with harmonic optimization using BBO [10] algorithm is developed. Using this technique, an UPQC can effectively optimize any harmonic order and PQ issue of the SG.

II. PROPOSED TECHNIQUES

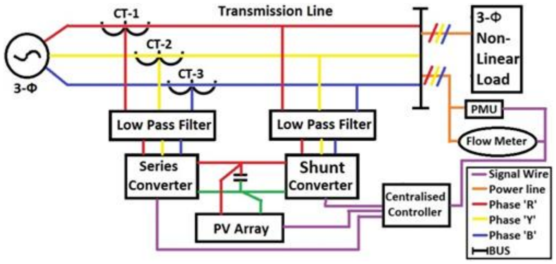

Fig.1. Schematic diagram of UPQC connected with SG

The UPQC is the grouping of a DVR and STATCOM which perform series, shunt compensating and phase shifting at the same time as in Fig.1. This is capable to control the PQ with leading and lagging reactive and real power flow through a particular route with enhance the system stability. The salient options of

UPQC device are its multiple management functions, like voltage management, transient stability improvement & damping oscillation. Voltage sag & swell compensation is important for secure system operation. This is a multivariable versatile AC transmission systems controller. In this work UPQC is excited by PV array with DC link Capacitor. In the SG using PMU and flow meter, measures the phase and related data, from this data of analysis centralized controller determine the harmonics amplitude and phase. At fault condition UPQC mitigate the fault with simultaneous or individual operation of series shunt converters. At the presence of harmonics these two converters work simultaneously and optimized the harmonics injected by the UPQC, the centralized controller calculates the switching angle for same magnitude with opposite phase harmonics and inject into the system. These two components eliminate each other and make the grid approximately harmonics free with mitigate the active and reactive power problem. The calculation for different harmonics is discussed below.

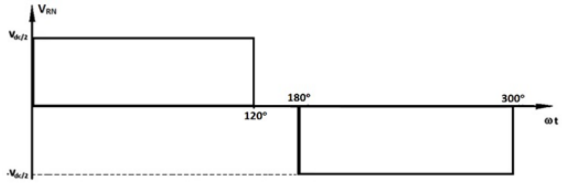

Fig.2. Quasi-sine waveforms for 120˚ switching

III. PROPOSED HARMONICS OPTIMIZATION TECHNIQUES

For Q-S wave switching with 120˚ mode of operation the phase voltage V_{Rn} is shown in Fig. 2. The Fourier series of V_{Rn} is expressed in (1),

$$\cos\left(n\frac{0}{2}\,t\omega\right) + b_n\sin(n\,t\omega) \qquad (1)$$

$$n=1$$

The waveform of Fig.2 is the odd quarter wave symmetry so even harmonics are eliminated from the system.

Here, DC part $A_0 = 0$, $a_n = 0\forall$ even n

From (4) and (5) the 3n harmonics are zero so only n=1, 5,7,11, 13, 17, 19, 23… i,e$n = \pm 6k$ 1 are present into the system.

The Proposed Switching:

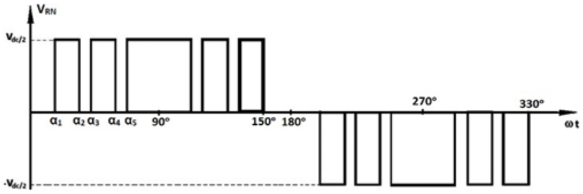

Fig.3. 3-Φ six step Q-S waveforms for 120˚ conduction with five different switching angles

3-Φ six-step Q-S waveforms of 120˚ conduction with five different switching angles is displayed in Fig. 3. In 3-Φ system first intersection point is at π/6. For phase 'A', $V_{Rn}$is the respective line voltage.

$A_0 = 0$, $a_n = 0\forall$ even n

$$1\ 2\pi\ b_n{}^{=}\ \_\_ V_{Rn}\sin(n\ t\ d\omega\ \omega)\ (\ t)\pi\ {}_0$$

$$b_n = -\ \_\_\_\_{}^{2Vdc\ m}\ (-1)^k \cos({}_n\gamma_k) \qquad (6)\ n\pi\ k=1$$

For 5 switching let m=5 and calculate upto n=13

$$\cos\gamma\ \gamma\ \gamma\gamma\ \gamma_1 - \cos{}_2 + \cos{}_3 - \cos{}_4 + \cos{}_5 = M$$
$$\cos 5\gamma_1 - \cos 5\gamma_2 + \cos 5\gamma_3 - \cos 5\gamma_4 + \cos 5\gamma\ \varepsilon_5 = {}_5\ (7)$$
$$\cos 7\gamma_1 - \cos 7\gamma_2 + \cos 7\gamma_3 - \cos 7\gamma_4 + \cos 7\gamma\ \varepsilon_5 = {}_7$$

$$\cos 11\gamma_1 - \cos 11\gamma_2 + \cos 11\gamma_3 - \cos 11\gamma_4 + \cos 11\gamma_5 = \varepsilon_{11}$$
$$\cos 13\gamma_1 - \cos 13\gamma_2 + \cos 13\gamma_3 - \cos 13\gamma_4 + \cos 13\gamma_5 = \varepsilon_{13}$$

The $n = \pm 6k$ 1 harmonics would be eliminated if that coefficient of b_ni,e $b_5=b_7=b_{11}=b_{13}=0$. These can be solved using iterative method. The soft computed switching angles of converters reduces the %THD of the SG.

Conventional the output voltage $V_R(t)$ expressed in (8)

$$\infty$$

$$V_R\,(\ )^{t}\ {}^{=}\square a_n \cos({}^{n}\gamma_n{}^{)} + b_n\sin({}^{n}\gamma_n) \qquad (8)$$

$$n=1$$

As a result of quarter wave symmetry, even magnitude of harmonics are eliminated and for odd magnitude of harmonics switching angle range is

$0 < \gamma\ \gamma\ \gamma_1 <_2 <_3 .... < \gamma_m < \pi/2$

Eq. 6 can be obtained any harmonics and Eq. 7 calculate the suitable switching angles. The THD percentage of output phase can figured using (9) where $n = \pm 6k\ 1$ and k=1,2,3,4…….

$1\ \infty \qquad {}_2\ 1/2$

$\%THD^{=} \underline{\quad}_2\ (\ )b_n \times 100$ (9)

${}^{b}{}_1\ n{=}5$

The impartial function $F(\ )\gamma$ optimized the harmonics by optimizing (10).

$F(\ )\gamma\ \gamma\gamma\gamma\ \gamma = F(\ {}_1, {}_2, {}_3, ..., {}_m)$ (10)

$0 < \gamma\ \gamma\ \gamma_1 <_2 <_3 .... < \gamma_m < \pi/2$ (11) b_1=M, $b_5 \le \varepsilon\ \varepsilon_5$, $b_7 \le {}_7$ and $b_n \le \varepsilon_n$ (12)

Where, b_1 is the fundamental amplitude, $\varepsilon\varepsilon\ \varepsilon_5, {}_7 .... {}_n$ are the individual harmonics permissible amplitude.

Switching angles remain arbitrarily generated to satisfy (11). Best solution within this from γ_1 to γ_m for a quarter wave are taken as the best angle. In each iteration, new search points are generated. This searching points and the best solutions is found by using BBO. Consider the Ps is the possibility that habitat contains S species. Ps changes with time t to T+ΔT as follows:

$P_s\,(T\ TP\ T{+}\Delta\ ) = {}_s\,(\ )(1 - \Delta - \Delta + \lambda\ \mu_s T\ {}_s\ T\ P)\ \ {}_{s-1}\lambda_{s-1}\Delta + T\ P_{s+1}\mu_{s+1}\Delta T$ (13)

Where λ_s is immigration and μ_s is emigration rates having S species in habitat. ΔT is the possibility of other immigration and emigration can ignored. Taking the ΔT tents to 0, of Eq. (13). Designed every habitat, bring up-to-date the possibility of species computation using Eq. (14) and compute every habitat suitability index (HSI). HSI also satisfying the constraints of suitability index variable (SIV).

$P.s = - +(\lambda\ \mu s \quad s\ )P\ Ps + s{+}1\mu s{+}1$, for $S = 0$ (14)

$Ps = -(\lambda\ \mu s + s\ )P\ Ps + s{-}1\lambda\ \mu s{-}1 + Ps{+}1\ s{+}1$, for $1 \le S$ $S \le \max -1$

$Ps = - +(\lambda\ \mu s \quad s\ )P\ Ps + s{-}1\lambda\ \mu s{-}1 + Ps{+}1\ s{+}1$, for $S\ S = \max$

The (14) can be written in single matrix (15)

$P{=}AP$ (15)

From [11]

$\underline{\qquad}\ \ \mu = \ EK\ \ \lambda = \ -$

□ $-\,k$ □

And $\quad {}^{I}$

${}_{k\ k}$□^{1} □ (16) n □ n □

Where, λ_k is emigration and μ_k is immigration rate with k no of species. The maximum rate of possible immigration rate is I and the emigration rate is E. Now, for special case E = I, we have,

$\lambda\ \mu k + {=}k\ E$ (17)

The steady state value of the number of each species is given by (18)

$$P(\ )\infty = \frac{V}{{}_{n+1}}$$

(18)

V_i

$i{=}1$ Where, V is the eigenvector. m is the mutation rate which inversely proportional with the solution Possibility and is given in (19)

$= \qquad 1\underline{-P_s}$

$m\ s(\ )\ {}^m{}_{\max}$ (19)

$P\max$

Where, $m_{\max}$ is user defined maximum mutation rate. This (19) makes HSI solutions.

Application of BBO based SHE-PWM problem will be précised using (20). This nonlinear equations can be represented as

$F_j(\gamma\gamma\gamma\ \gamma_1, {}_2, {}_3, ..., {}_m) = 0, where\ {}_j = 1,2,3,..,m$ (20)

The (20) is obtained by equating (6). HSI specifies the superiority of solution set. For the considered problem, HSI represents with THD by the solution set (20).

$F(\ )\gamma = 0$ (21)
T

$F^{=}[F\ FF\ F_{1,\ 2,\ 3,...,\ m}]$ (22)
T

$=$ $\gamma\ \gamma\gamma\gamma\ \gamma[\ ,\ ,\ \ ,...,$
$]$ (23)
$1\ \ _{2}\ \ _{3}\ \ _{m}$

Eq. (21) can solved using BBO technique, where the nonlinear equations give an approximate solution. The steps are as follows. The switching angle matrix,

T
$\gamma\ \gamma\gamma\gamma j = jj\ \ j\ \ j$
$1\ _{,\ 2\ 3\ ,...\ m}$ (24)

The nonlinear system matrix,

$\cos\gamma\ \gamma\ \gamma\ \gamma\ \gamma_1{}^{j} - \cos\ _2{}^{j} + \cos\ _3{}^{j} - \cos\ _4{}^{j} + \cos\ _5{}^{j}$
$j\ \ j\ \ j\ \ j\ \ j$
$\cos5\gamma_1 - \cos5\gamma_2 + \cos5\gamma_3 - \cos5\gamma_4 + \cos5\gamma_5$ (25) $F\ ^{j}$
$= \cos7\gamma_1{}^{j} - \cos7\gamma_2{}^{j} + \cos7\gamma_3{}^{j} - \cos7\gamma_4{}^{j} + \cos7\gamma_5{}^{j}$
$\cos11\gamma_1{}^{j}\ - \cos11\gamma_2{}^{j}\ + \cos11\gamma_3{}^{j}\ - \cos11\gamma_4{}^{j}$
$+\cos11\gamma_5{}^{j}$
$\cos13\gamma_1{}^{j} - \cos13\gamma_2{}^{j} + \cos13\gamma_3{}^{j} - \cos13\gamma_4{}^{j} + 13\cos\gamma_5{}^{j}$

$-\sin\gamma\ \gamma\ \gamma\gamma\ \gamma_1{}^{j} + \sin\ _2{}^{j} - \sin\ _3{}^{j} + \sin\ _4{}^{j} - \sin\ _5{}^{j}$

$j\ \ j\ \ j\ \ j\ \ j$
$-\sin5\gamma_1 + \sin5\gamma_2 - \sin5\gamma_3 + \sin5\gamma_4 - \sin5\gamma_5$ (26)
$\_\_\_dF\alpha j\ =\ -\sin7\gamma1j\ \ j + \sin7\gamma2j\ \ -j\ \ \sin7\gamma3j\ \ +j\sin7\gamma4j$
$-\sin7j\ \gamma5j\ \ \ \ j$

$d\ \ -\sin11\gamma1\ \ +\sin11\gamma2\ \ -\sin11\gamma3\ \ +\sin11\gamma4$
$-\sin11\gamma5$
$-\sin13\gamma_1{}^{j} + \sin13\gamma_2{}^{j} - \sin13\gamma_3{}^{j} + \sin13\gamma_4{}^{j}$
$-\sin13\gamma_5{}^{j}$

For example let a harmonics matrix of coefficient b_n(27)

(27) $b_n = 0$ *where* $n, = 5$

0

Step: 1

Find a set of value for switching anglesγ. BBO representation is in (28)

$\gamma0\ \ \ \gamma\gamma\gamma\gamma\ \gamma10,\ 20,\ 30,\ 40, ...,\ m0$

$\gamma1\ \ \ \ \gamma\gamma\gamma\gamma\ \gamma11\ \ 1\ \ \ \ 11$
$1,\ 2,\ 3,\ 4, ...,\ m$

$.\ \ \ =\ .$
(28)

$\gamma\ \gamma\gamma\gamma\gamma\ \gamma4\ 4\ \ 4\ \ \ 4\ \ \ \ \ 4$
4
$1\ ,\ 2\ ,\ 3\ ,\ 4, ...,\ m$

Step: 2

The values of (29)

$=$

$F(\gamma^4)^F4$

Step: 3

$$^{0} + \left[\frac{\partial F^{0}}{\ }\right]\ \gamma^{0} = 0 \qquad F$$
d (28)

$\partial\gamma$

Determine $d\gamma^{0} = \lceil\ \ \gamma^{0}\ \ \gamma^{0}\ \ \gamma^{0}\ \ \gamma^{0}\ \ \ \ \gamma^{0}_{m}d\ dd\ d1$, 2, 3 , $4, ..., d\ ^{T}$ at γ^0 then solve (28) for$_d\gamma^0$

Step: 4 Repeat
step 1 to step 3

$\gamma\ \gamma\ \gamma j + 1 = +j\ \ j$
d (29)

The above iterative method is repeated continual (21) and fulfilled the desired accuracy. If previous method converges, then it gives a solution of (21). Otherwise make a new initial guess. The best solution must satisfy (11). The total process is illustrated in Flow chart Fig.4.

5 0 23.0699

Fig.5 shows the simulation and Digital Storage Oscilloscope (DSO) output at sag condition with duration is 0.1 sec. to 0.3 sec. When the series converter set at M= 0.67, the calculated switching values are 28.0295, 33.2034, 44.5603, 51.9774, and 58.1643. For the calculated switching value upto 13th order harmonics are completely eliminated with the higher order harmonics are suppressed. Similarly, at M=0.73 and 0.87 the 120° optimised switching angles are shown in Table. 1.

In Fig. 6 illustrated the DSO output of the Low-High step up converter when the DC linkage voltage is not its desired value.

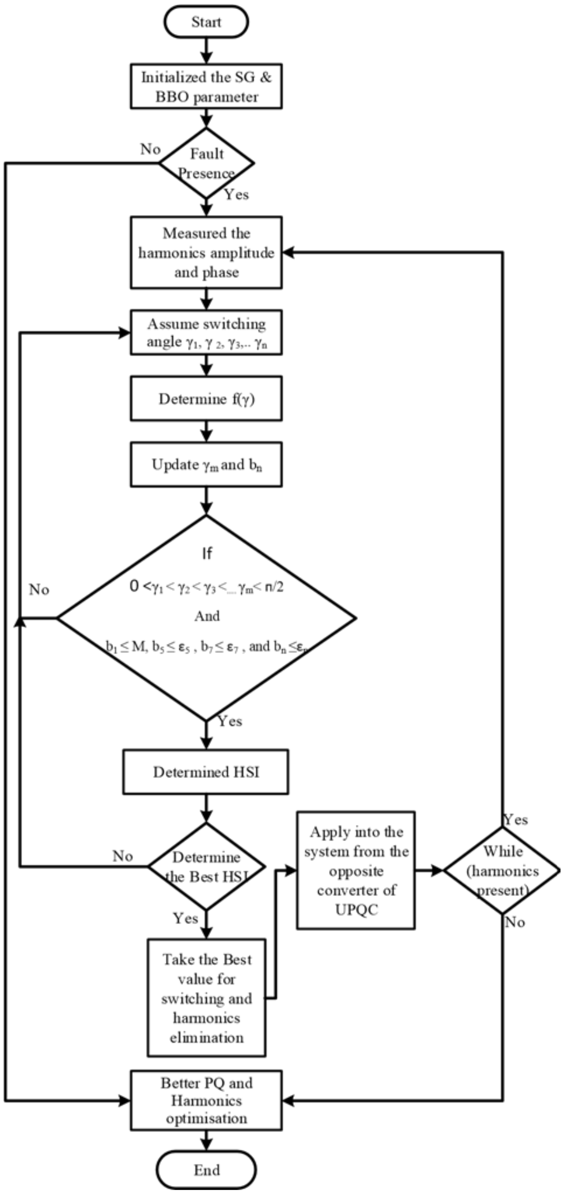

Fig.4. Flow chart of the total system operation connected with SG

IV. RESULTS AND DISCUSSION

Table 1. Switching angle at 120° mode with different M

Harmonic order	M	Switching angles (Deg.)
1	0.67	28.0295
5	0	33.2034
7	0	44.5603
11	0	51.9774
13	0	58.1643
1	0.73	22.6782
5	0	28.1435
7	0	37.9299
11	0	47.2386
13	0	54.6010

11 0 45.6847

13 0 48.6366

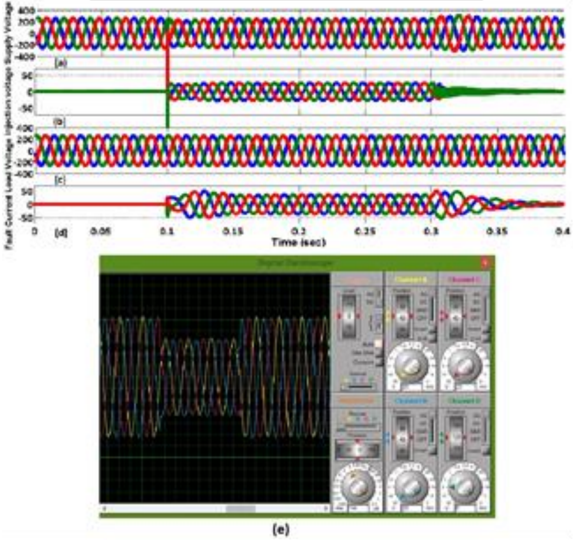

Fig.6. DSO output of Low-High step up converter

In Fig.7. demonstrated the overall hardware setup of the proposed system with gate pulses and FFT of SG. Fig.8 shows the matlab simulation output for reactive and active power flow for series and shunt converter applying modified UPQC technique under the condition of voltage sag and swell.

1 0.87 15.2133

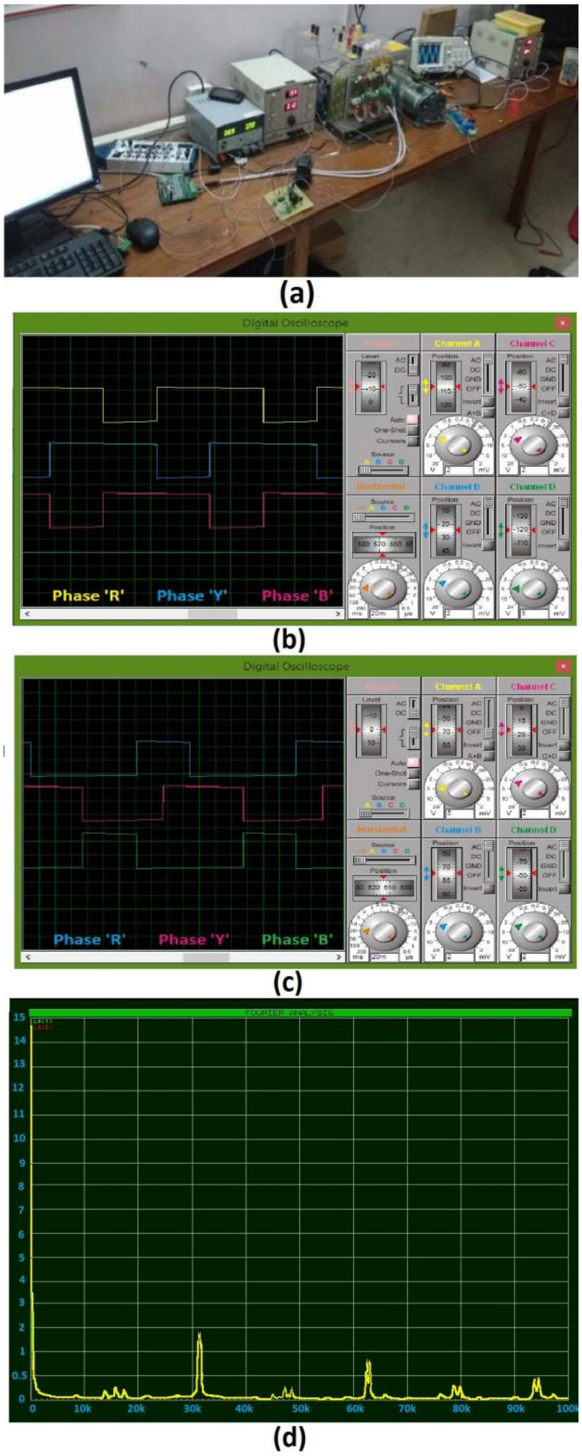

Fig.7. DSO output for (a) hardware setup of the proposed system (b) gate pulse for upper group of thyristor (c) gate pulse for lower group of thyristor (d) FFT output of SG upto 100KHz

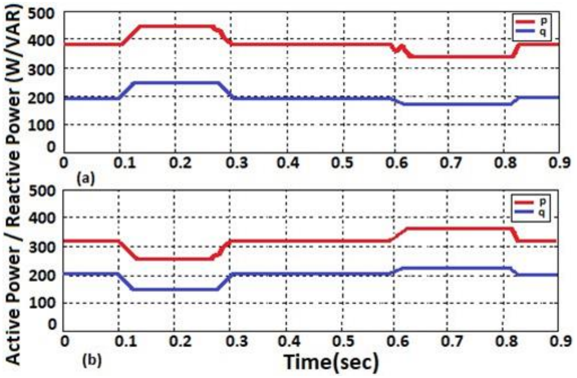

Fig.8. Matlab simulation output of Active and Reactive power at non linear R-L-C load (a) series converter (b) shunt converter.

V. CONCLUSION

The suggested technique efffectively eliminates the tergated lower order harmonics at different modulation indeices by proper selection of switching angles and same time the higher order harmonics are suppressed. Also this innovative technique solve the smart grid PQ issues like sag, swell, flicker, active, reactive power and increase the overall grid performance. The proposed technique can be efficiently implemented for online application through commercially available “Raspberry pi 3”, advanced microcontroller.

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