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Implementation of Fuzzy Logic Approach on TSC-TCR SVC Switching At Distribution Level for Minimal Injected Harmonics

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***Abstract*— Electrical distribution system suffers from various problems like reactive power burden, unbalanced loading, voltage regulation and harmonic distortion. Though DSTATCOMS are ideal solutions for such systems, they are not popular because of the cost and complexity of control involved.StaticVar Compensators (SVCs) remain ideal choice for such loads in practice due to low cost and simple control strategy. These SVCs, while correcting power factor, inject harmonics into the lines causing serious concerns about quality of the distribution line supplies at PCC. This paper proposes to minimize the harmonics injected into the distribution systems by the operation of TSC-TCR type SVC used in conjunction with fast changing loads at LV distribution level. PI controller, Fuzzy logic system is used to solve this nonlinear problem, giving optimum triggering delay angles used to trigger switches in TCR. Using PI controller it is very complex to solve this nonlinear problem. The scheme with o fuzzy logic system can be used at distribution level where load harmonics are within limit.**

***Index Terms*—SVC, fuzzy logic, TSC, TCR PI Controller.**

1. INTRODUCTION

The Indian power distribution systems are facing a variety of problems due to proliferation of nonlinear loads in the last decade. In addition to poor voltage profile, the power factor and harmonics of the system are the major concerns of the utility. A variety of power factor improvement & harmonic minimization techniques are available ranging from various power factor-correcting devices to passive & active harmonic filters. Thyristor controlled Static Var Compensators (SVCs)

are popularly used in modern power supply systems for compensating loads. A Static Var Compensator generally consists of a Thyristor Controlled Reactor (TCR) & a Thyristor Switched Capacitor (TSC) and compensates loads through generation or absorption of reactive power. The operation of Thyristor Controlled Reactors at appropriate conduction angles can be used advantageously to meet the phase-wise unbalanced and varying load reactive power demand in a system. However, such an operation pollutes the power supply in another form by introducing harmonic currents into the power supply system. In such cases, it becomes necessary either to minimize harmonic generation internally or provide external harmonics filters. It is obvious that the latter approach is associated with additional investment. This paper deals with minimizing harmonic generation internally by using optimized switching determined by using Fuzzy logic in MATLAB.

2. SVC OPERATION

A thyristor switched capacitor (TSC) is a type of equipment used for compensating reactive power in electrical power systems[1]. It consists of a power capacitor connected in series with a bidirectional thyristor valve and, usually, a current limiting inductor (reactor). The thyristor switched capacitor is an important component of a Static VAR Compensator (SVC) where it is often used in conjunction with a thyristor controlled reactor (TCR). Static VAR compensators are a member of the FACTS family. This compensator overcomes two major shortcomings of the earlier compensators by reducing losses under operating conditions and better performance under large system disturbances. In view of the smaller rating of each capacitor bank, the rating of the reactor bank will be 1/n times the maximum output of the svc, thus reducing the harmonics generated by the reactor. In those situations where harmonics have to be reduced further, a small amount of FCS tuned as filters may be connected in parallel with the TCR. When large disturbances occur in a power system due to load rejection, there is a possibility for large voltage transients because of oscillatory interaction between system and the svc capacitor bank or the parallel. The LC circuit of the svc in the fc-compensator. In the TSC-TCR scheme, due banks to the flexibility[2] of rapid switching of capacitor Without appreciable disturbance to the power system, oscillations can be avoided, and hence the transients in the system can also be avoided. The capital cost of this svc is higher than that of the earlier one due to the increased number of capacitor switches and increased control complexity.

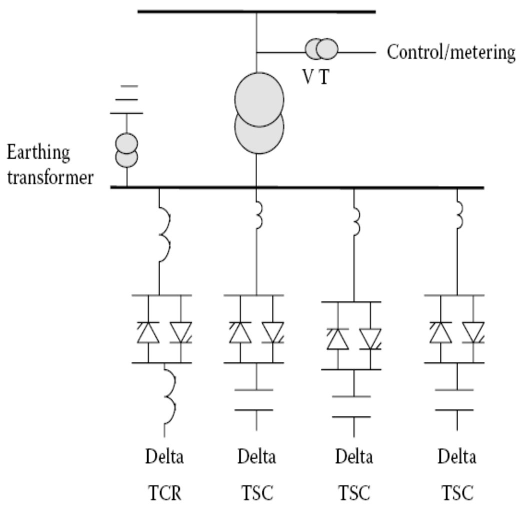

Fig.1: TCR-TSC SVC Diagram

2.1 SYSTEM MODELLING

The single line diagram of the distribution substation under consideration is shown in Fig.2. The compensator essentially functions[11] as a Thyristor Switched Capacitor &Thyristor Controlled Reactor (TSC-TCR). In the scheme, TSC is connected in star whereas TCR in delta .A series of steady state loads at discrete time instants are recorded which represent time varying loads. The compensator requirement is to generate/absorb unbalanced reactive power which when combined with the load demand, will represent balanced load to the supply system. The phase wise load demands are $P_{La}+jQ_{La}$, $P_{Lb}+jQ_{Lb}$, $P_{Lc}+jQ_{Lc}$ and the phase wise load seen by the source after compensation are

$P_{Sa}+jQ_{Sa}$, $P_{Sb}+jQ_{Sb}$, $P_{Sc}+jQ_{Sc}$

Phase wise complex voltages at the load bus are given by

$$[V_L] = [V_S]-I[Z_S] \qquad (1)$$

Where $[VL]=[VLa\ VLb\ VLc]^I$

The complex voltage vector at the load bus.

$[V_S]=[V_{Sa}\ \ V_{Sb}\ \ V_{Sc}]^I$ is the complex voltages vector at the source bus and Z = diagonally[Za Zb Zc] is the line impedance matrix. The vector of currents in the lines between the source bus and the load bus, $[I_S]=[I_{Sa}\ I_{Sb}\ I_{Sc}]^I$ is obtained from.

$$I_{Sa} = (P_{La}- jQ_{Sa}) / V_a$$
$$I_{Sb} = (P_{Lb}-jQ_{Sb}) V_b \qquad (2)$$
$$I_{Sa} = (P_{Lc}- jQ_{Sc}) / V_c$$

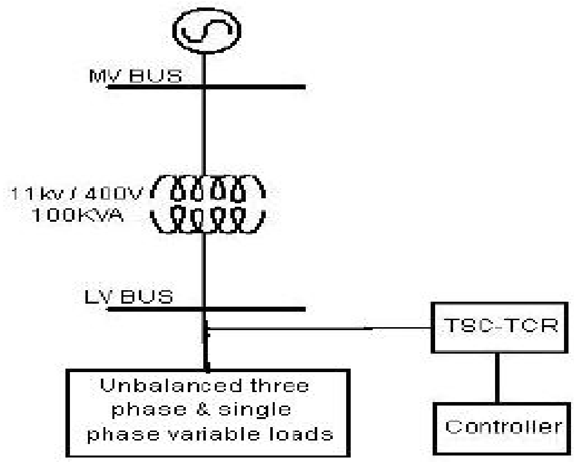

Fig.2: Single line diagram of the system

The non-linear complex set of equations given by equations (1) and (2) can be solved for load bus voltages[11]. The reactive power balance equations at the load bus are

$$[Q_S] + [Q_C] = [Q_R] + [Q_L] \qquad (3)$$

For a given reactive power demand $Q_L=[Q_{La}, Q_{Lb}, Q_{Lc}]^I$ setting balanced values for $Q_C=[Q_{Ca}, Q_{Cb}, Q_{Cc}]$ of the TSC and $Q_S=[Q_{Sa}\ Q_{Sb}\ Q_{Sc}]^I$ of the source, the unbalanced reactive power absorbed by the TCR, $Q_R=[Q_{Ra}\ Q_{Rb}\ Q_{Rc}]^I$can be obtained from (3). Once the voltage vector at the load bus is determined, the values of delta connected compensator reactance's, X_{ab} X_{bc} X_{ca}, required to absorb the computed reactive power can be determined. The variable reactances of the compensators are realized by delaying the closure of the appropriate thyistor switch by varying its firing delay angle α [0 - 2T/2]. The unsymmetrical firing of thyistor can be advantageously used to obtain the unsymmetrical delta connected reactance's [8]. Considering only the fundamental component, the unsymmetrical firing delay angle a, corresponding to the delta reactance x_{ab} can be obtained by solving the following equation.

$$X_{ab} = \frac{x°ab}{1-\frac{2\alpha1}{\pi}-\ sin2\alpha1/\pi} \qquad (4)$$

Wherex_{ab} is the reactance for full conduction of thyistor (corresponding to zero firing angles). Similar equations can be written for X_{bc}&X_{ca} to obtain the values of α2 & α3.

2.2 HARMONICS DUE TO SVC OPERATION

The power quality at the point of common coupling (PCC) is expressed in terms of various parameters. Total Harmonic Distortion (THD) at PCC is one of these parameters, which is commonly used in practice. The performance index THD is given by

$$THD = \frac{1}{If}\sqrt{\sum_{n=2}^{m} I\ h^2} \qquad (5)$$

Where $I_f$the fundamental is current, I_h is the harmonic line current for h^{th} harmonic and m is the maximum order of harmonics considered. Assuming balanced three-phase voltage at the load bus. The fundamental and harmonic components of the line currents can be obtained by using the following equations [5]

$$I_f = \frac{Vm}{2\pi\omega L}\sqrt{Gf^2 + Hf^2}\ \sin(\omega t - \phi - \theta_f) \qquad (6)$$

$$Ih = \frac{Vm}{2\pi\omega L}\sqrt{Gh^2 + Hf^2}\ \sinh((\omega t - \phi) - \theta_h)$$

Where I_fRMS value of fundamental line current

I_h= RMS value of harmonic line current ofh^{th} order

α =Fundamental frequency

L= Inductance of each delta connected inductance

G_f =(3Π-4γ-2sin2γ-2β-2sin2 β)

$H_f = \sqrt{3}$(Π-2β-2sin2β)

$$G_h = \left[\frac{\sin(h+1)\gamma}{(h+1)} - \frac{\sin(h-1)\gamma}{(h-1)} - \frac{2\sin\gamma\ \cosh\gamma}{h}\right] + \frac{1}{2}\left[\frac{\sin(h-1)\beta}{(h+1)} - \frac{\sin(h-1)\beta}{(h-1)} - \frac{2\sin\beta\ \cosh\beta}{h}\right] \qquad (7)$$

$$H_{h=\pm}\sqrt{3/2}\left[\frac{\sin(h+1)\,\beta}{h+1}\ \ \frac{\sin(h-1)\,\beta}{(h-1)}\ \frac{2\sin\beta\cosh\beta}{h}\right]$$

$$\&\ \theta_f = \tan^{-1}\left(\frac{Hf}{Gf}\right)\ \&\ \theta_h = \tan^{-1}\left(\frac{Hh}{Gh}\right) \qquad (8)$$

ϕ=0, γ= $\alpha1$,β= $\alpha3$; ϕ=2Π/3, γ= $\alpha2,\ \beta = \alpha1$

ϕ=4Π/3, γ= $\alpha3$, β= $\alpha2$

For line currents an, I_b& I_C respectively, H=harmonic order, (6k ± 1) , k=1, 2, 3 .... + Sign for harmonics of order (6k+1) - Sign for harmonics of order (6k-1). For tripled harmonics (3rd, 9th,),

$$G_h = \left[\frac{\sin(h+1)\gamma}{(h+1)} - \frac{\sin(h-1)\gamma}{(h-1)} - \frac{2\sin\gamma\ \cosh\gamma}{h}\right] + \left[\frac{\sin(h-1)\beta}{(h+1)} - \frac{\sin(h-1)\beta}{(h-1)} - \frac{2\sin\beta\ \cosh\beta}{h}\right]$$

$$H_h=0 \qquad (9)$$

A program in MATLAB is written to get the above values and is used in the fuzzy logic toolbox.

3.MINIMIZATION OF HARMONICS

3.1 SVC Control using PI Controller

PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled with a weighted sum of the error (difference between the output and desired set point) and the integral of that value. It is a special case of the common PID controller in which the derivative (D) of the error is not used.

Using PI controller it is more complex to control the SVC. For the non-linear problems it is not much suitable. This traditional controller requires more complex design to solve this type of problems.

3.2 SVC Control using Fuzzy control system

For a given load reactive power demand, QL, it is required to minimize the reactive power drawn from the source, Qs. By setting balanced values for Qc and Qs, the unbalanced reactive power absorptions of TCR, Q, can be obtained using the procedure described in [3]. Then the unsymmetrical reactance's required absorbing QR, and the corresponding unsymmetrical firing angles can be computed from (4). Knowing the voltages at the compensator node and the firing angles of the TCR, harmonic analysis can be carried out and the performance index, THD, can be evaluated. The different combinations of firing angles lead to various harmonic levels, as indicated by the value of performance index. In order to minimize the harmonics generated due to SVC operation, the TCR should be operated at a combination of firing angles which results in low harmonic level. It has been further shown that there are several combinations of firing angles which leads to lower level of harmonic generation. The combination of firing angles that corresponds to the minimum THD value usually conflicts with the objective of minimizing the reactive power drawn from the source. Therefore it is necessary to find a combination of firing angles, which can simultaneously keep both Qs and THD satisfactorily low. However, the task of selecting the particular combination firing angles from a set of all (or many) plausible combinations of firing angles to achieve optimum values of Qs and TDD is not straight forward. For a given load reactive power demand, QL, the best combination of firing angles are intuitively selected and the method can be adopted for controlling SVC used for compensating a constant or cyclic load with several known load steps. However if the load is continuously varying, the SVC controller needs to be capable of selecting the appropriate set of firing angles without human intervention.

In this paper fuzzy logic controller is used to get the triggering delay angles al, a2 and a3 for the TCR. These triggering delay angles correspond to minimum THD values and an acceptable compromised reactive power Qs. SVC control with Fuzzy Ranking System. A Mamdani type fuzzy logic system was designed for ranking the combinations of TSC step size and three firing angles.

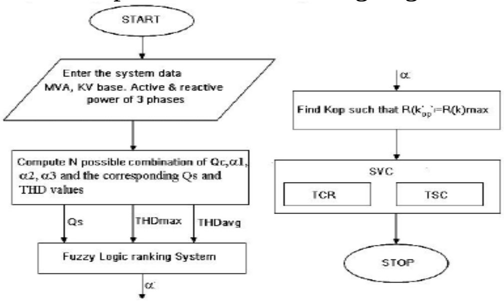

Fig.3. Flowchart of the fuzzy controller

The schematic diagram of the SVC control algorithm shown in Fig. 3, takes phase wise active and reactive power demands of the load as inputs and determine the step size of TSC and the unsymmetrical firing angles of the TCR as outputs. The first block computes a set of feasible combinations (say N different combinations), firing angles a1, a2, a3 and the corresponding Qs and THD values. The second block is the ranking of each feasible TSC step size-firing angles combination using the fuzzy logic ranking system. The fuzzy logic ranking system assigns a ranking score, R (k) for the kth combination depending on the corresponding Qs (k) and THD (k) values. In the case of three phase unbalanced loads, three different THD values 1resulting for the three phases exist. After various considerations, both the highest THD value amongst the three phases, THDmax (k) and the average THD of the three phases, THD avg (k), are used for ranking a particular firing angle combination. In the last step, the TCR step size firing angles combination that has the highest-ranking score is selected as the desired TSC and TCR operating points.

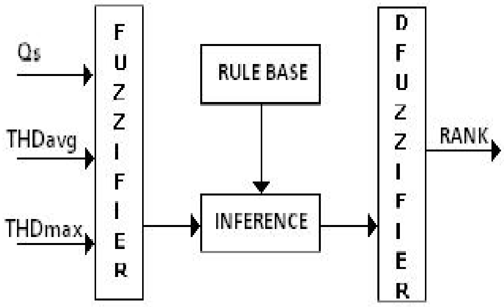

Fig.4:Block diagram of fuzzy controller

4 SIMULATION RESULTS

An 11 kV/400V, 100kVA distribution substation feeding a fluctuating load is taken for simulation as shown in Fig. 2. The load consists of single phase & three phase motors, laboratory equipments and SMPSs. The static VAR compensator was considered consisting of a TSC that can vary through four steps; 0, 10, 20 & 30 kVAR per phase and a Thyristor Controlled Reactor (TCR) of capacity of 30 kVAR per phase under full conduction. The parameters of the line between the source bus and load bus are taken as R=0.02 ohms per phase, X= 0.07 ohms per phase. The simulated results using Fuzzy logic in the MATLAB environment.

4.1 Matlab Design Of Svc Based On Fuzzy logic

The diagram shown below indicates a 11 kV/400V, 100kVA distribution substation feeding a fluctuating load. The load consists of single phase & three phase motors, laboratory equipments and SMPSs. The below Fig.6, Fig.7, Fig.8 shows the simulated results of Total harmonic distortion for three phases individually for reactive power not optimized condition. In this case we observed more distortions than the optimized case.

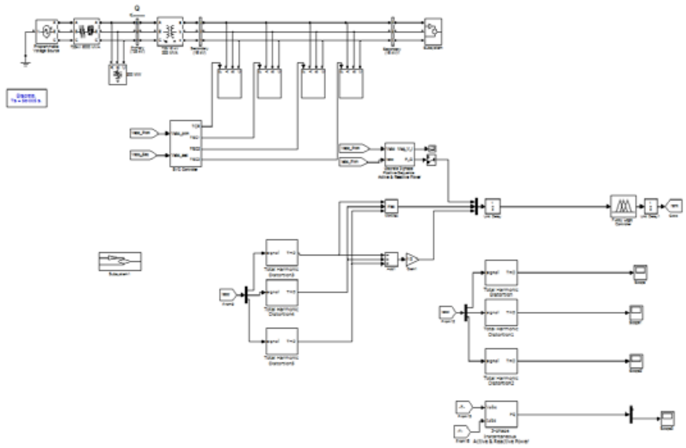

Fig.5: Matlab Simulink diagram for SVC Based Fuzzy Q Not Optimised

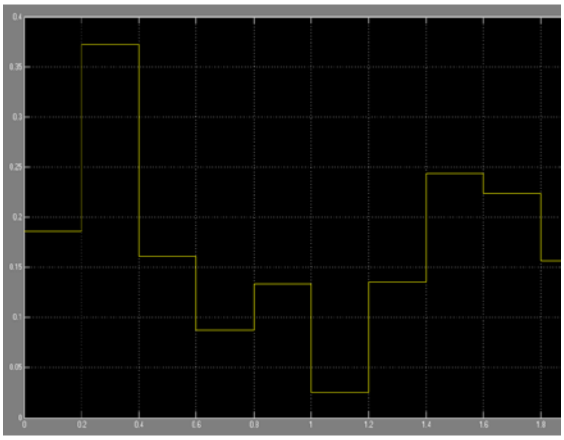

Fig.6: Total Harmonic Distortion In Phase A Of SVC Based Fuzzy Q Unoptimized ($Q \neq 0$)

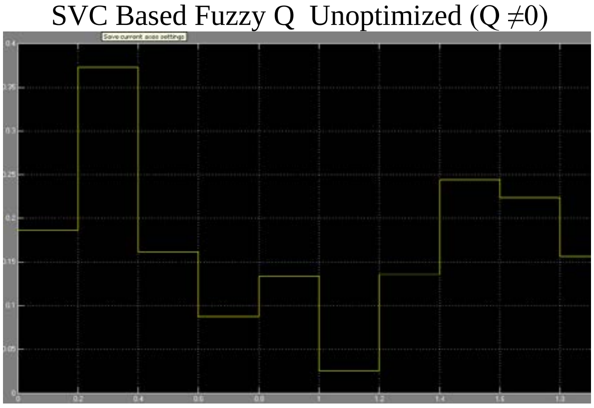

Fig.7: Total Harmonic Distortion In Phase B Of SVC Based Fuzzy Q Unoptimized

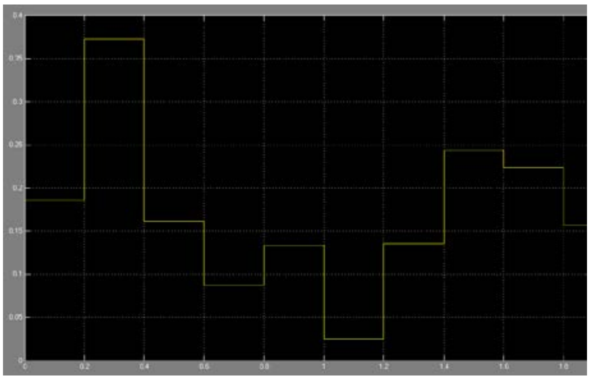

Fig.8: Total Harmonic Distortion In Phase C Of SVC Based Fuzzy Q Unoptimized

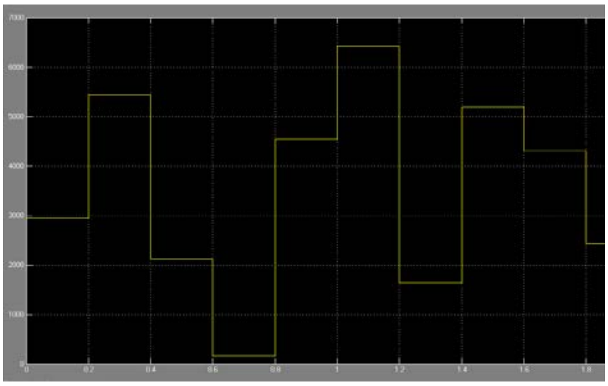

Fig.9: 3-phase instantaneous active and reactive power

4.2 SVC Based On Fuzzy Q Optimized

The diagram shown below indicates a 11 kV/400V, 100kVA distribution substation feeding a fluctuating load. The load consists of single phase & three phase motors, laboratory equipment and SMPSs. The simulation diagram is Q under optimized condition.

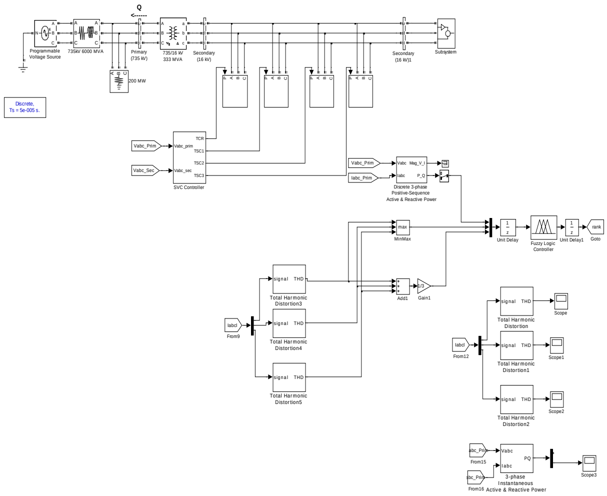

Fig.10:Matlab Simulink diagram for SVC Based Fuzzy Q Optimised

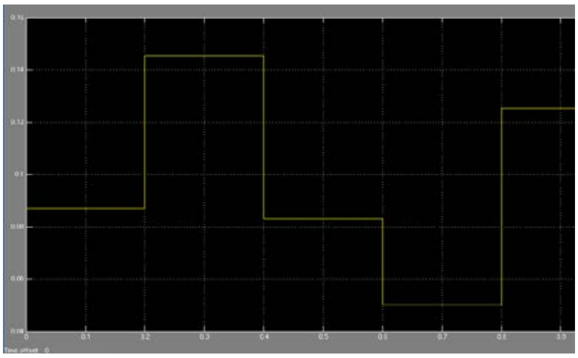

Fig.11: Total harmonic distortion in phase A of svc based on fuzzy Q Optimized

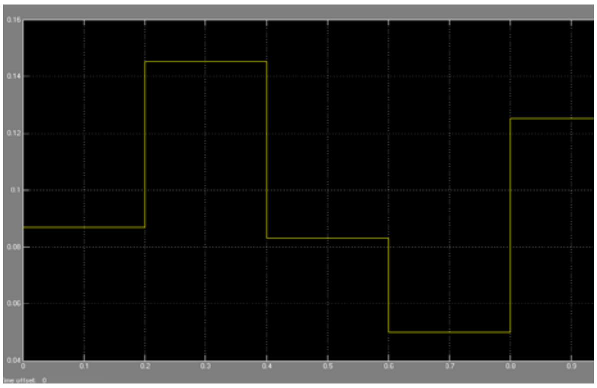

Fig.12: Total Harmonic Distortion In Phase B Of SVC Based Fuzzy Q Optimized

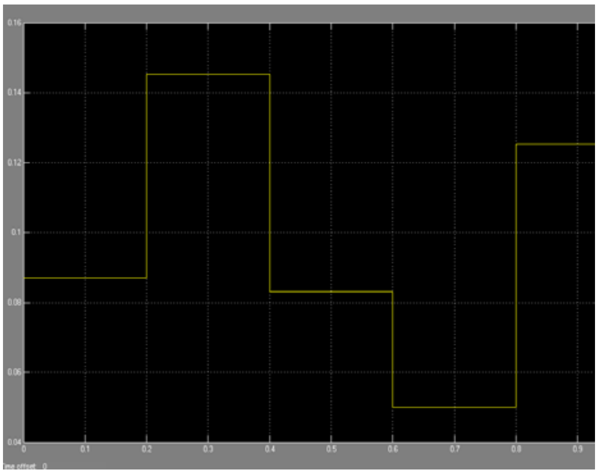

Fig.13: Total Harmonic Distortion In Phase C Of SVC Based Fuzzy Q Optimized

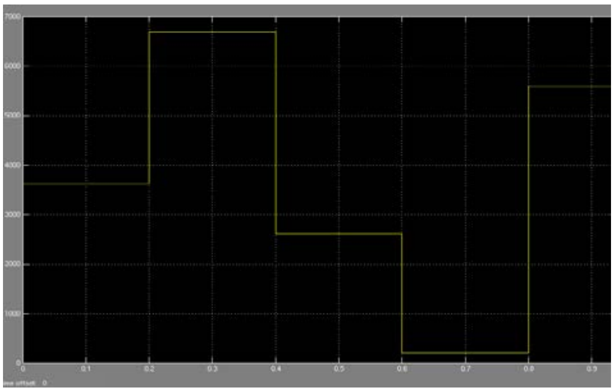

Fig.14: 3-phase instantaneous active and reactive power

In this case the distortions are reduced in all phases when compared to Unoptimized condition. The fuzzy logic approach minimizes the distortion created by the SVC. The proposed Fuzzy logic based approach can be effectively used to reduce and balance the reactive power drawn from the source under unbalanced loadings.

5 CONCLUSION

Static Var Compensators (SVCs) remain ideal choice for fast changing loads due to low cost and simple control strategy. DSTATCOM being ideal solution suffers from serious limitation of high cost and complex control strategy. The SVCs, while correcting power factor, inject harmonics in distribution lines. The operation of thyristor-controlled compensators at various conduction angles can be used advantageously to meet the unbalanced reactive power demands in a fluctuating load environment. The proposed Fuzzy logic based approach can be effectively used to reduce and balance the reactive power drawn from the source under unbalanced loadings while keeping the harmonic injection into the power system low. It proves that the THD under optimized condition is much less than the THD under unity power factor condition. The computational time required was found to be satisfactory for the system considered. The scheme can be effectively used at distribution level where the load harmonics is not a major problem. This approach effectively reduces the harmonics.

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