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Thyristor Controlled Reactor with Different Topologies Based on Fuzzy Logic Controller

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Abstract: This paper studies improving the power factor by using Thyristor Controlled Reactor (TCR) shunted with a fixed capacitor to get a controlled source of reactive power. This technique has three topologies of TCR connection like Star, Delta, and Hybrid. The fuzzy controller is used to control the thyristor firing angle according to the reactive power measured at the PCC to improve the power factor. Also, the paper discusses the using of the hybrid technique to solve the problem of Total Harmonic Distortion (THD) as one side effect of the using the TCR system.

Keywords: Power factor, THD, star, delta, hybrid, TCR, SVC, FLC

I. Introduction

The data from the statistics refer that the most plant loads are inductive loads like motors, transformers, and arc furnaces which require a magnetic field to operate. The magnetic field is necessary for these load types, the nature of these loads cannot be altered but the problems arising from these load types can be overcome. Increasing the reactive power will decrease the power factor and consequently will decrease the capacity of the electrical network. Improving power factor can be achieved by using conventional techniques or by using advanced techniques. This paper introduces the TCR system as advanced technique to compensate the reactive power smoothly.
Actually, the TCR system is not exist as a standalone compensator but combined with other configuration such as FC, TSC, MSC, and the filter. The TCR branch is responsible for a positive reactive power while the other integrated branches with the TCR system are used for producing the negative reactive power [1-4] as shown in the Fig 1.
As for controllers, they can be implemented by conventional controller like PI and PID or by using advanced controller like a fuzzy logic controller. The comparison between the two previous types is shown in many literatures. The question attends why the fuzzy logic controller?, the answer mainly comes from that the fuzzy controller is preferred upon the conventional controllers for the following reasons; there is no need for mathematical model, its rule are based on the human experience so it is easy to be understood, flexibility to be changeable, dealing with linear and nonlinear systems, and behaves like traditional controllers [5].

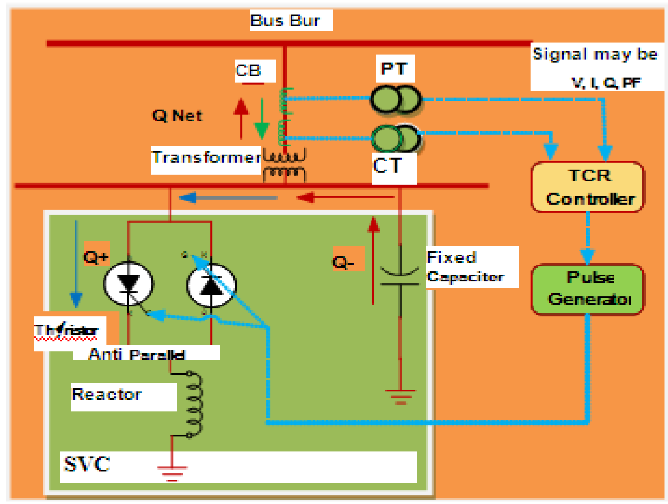
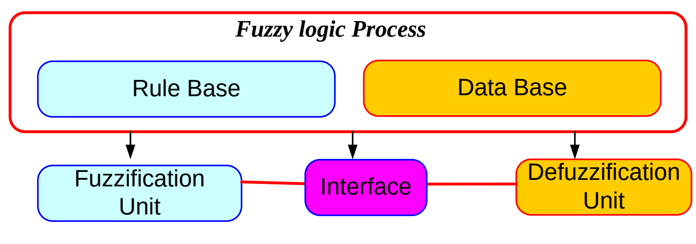


Fig. 1.Configuration for FC-TCR.

The fuzzy consists of the following modules as in the Fig.2.



Anti Parallel
Fig. 2.Fuzzy logic proce

Fuzzification has two processes: getting the membership functions for input and output variables and represent them with linguistic variables. The fuzzy rule is a process to relate the input with the output through a sequence of IF THEN rules. The interface block stage is used to obtain the fuzzy outcome which is based on the grades of each member function related to each rule. The defuzzification is a process to convert the fuzzy output to the crisp value based on one of the following; Mean of Maximum method, Centre of Gravity method and the Height method [6].
This paper studies the behaviour of the TCR system based on the fuzzy logic controller. The FLC gives a suitable firing angle based on the calculated reactive power from both current and voltage signals measured at the PCC. Also, the behaviour of the TCR system with different topologies based

on the fuzzy logic controller has been studied under load change form lagging to leading reactive power to achieve the desired power factor. Different TCR topologies are used for reducing the injected harmonics from the TCR system. Many techniques like TCR segmentation and delta connection are suggested as the solutions for the harmonics reduction. Also, in this paper the hybrid technique will be discussed to solve this problem [7]

II. The Proposed System Configuration

The proposed system is designed to achieve reactive power control from 3 kvar inductive to 3 kvar capacitive according to the load requirements. This band of reactive power compensation is achieved through three TCR system topologies like Star, Delta, and Hybrid connections. So there will be three different coil inductors for each system to achieve this band of the reactive power control as described in the following equations (1-3) [8].

$$L_{delta} = 3.L_{star} \quad (1)$$

$$L_{starH} = 2.L_{star} \quad (2)$$

$$L_{deltaH} = 6.L_{star} \quad (3)$$

Where:

L_{delta} , L_{star} is the inductance of the TCR in the delta and in the simple star configuration.

L_{starH} , L_{deltaH} are the inductance in the star branch and the delta branch of TCR- hybrid system to get the same band of reactive power control.

So, to achieve this band of reactive power the FC rating is equal to 3kvar, and the inductor rating of the TCR branch is equal to 6kvar.

Table-1 summarizes the proposed system parameters of each TCR system connection.

Table.1: Parameters of the proposed TCR system at different topologies

Item		R	Q inductive		Q capacitive		Connection type
Unit		ohm	k var	L Henry	k var	C farad	
Load		3000	3		3000		Star connection
TCR star		1	0 - 6	0.077			Star connection
TCR delta		1	0 - 6	0.229			Delta connection
TCR Hybrid	TCR Hstar	1	0 - 3	0.154			Star connection
	TCR Hdelta	1	0 - 3	0.459			Delta connection
FC star		1			0-3	6.60E-05	Star connection
FC delta		1			0-3	2.20E-05	Delta connection
Snubber circuit		10000				1.00E-08	
Thyristor		0.001	Voltage Forward = 0.8 V				
Source voltage line			380 V	Source frequency	50 Hz		Star connection

The stand alone Star or Delta TCR system is defined as 6 pulse system where there are only six thyrisors to control the three coil inductors. As for hybrid TCR system it is known as 12 pulse system. The main advantage of using 12 pulse or hybrid TCR system is the harmonic reduction in the network and the injected harmonics order will be 12n+/-1 for n= (1, 3, 5…)[9].

The Fig (3) represents three phase FC-TCR hybrid system shunted at the PCC.

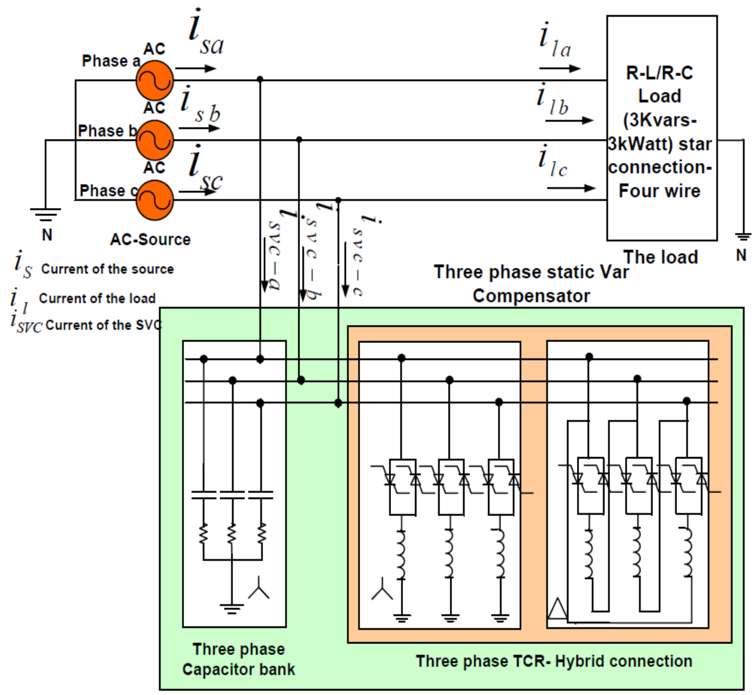


Fig. 3. Three phase FC-TCR Hybrid system at the PCC

III. Controller and Methodology

1. Fuzzy logic controller

There are many types of fuzzy logic control systems. First one is the simple fuzzy system which used for the simple systems. The hierarchical fuzzy system with multiple layers is used for complex system which needs many inputs.

The main objective of the fuzzy controller enforces the system to reach a desired set point, and prevent the system oscillations. This can be achieved by using fuzzy logic controller like PI, PID controller [9-10].

2. Fuzzy logic controller like PID

To design a fuzzy logic controller the system behaviour should be presented and divided into five zones as shown in Fig. 4.

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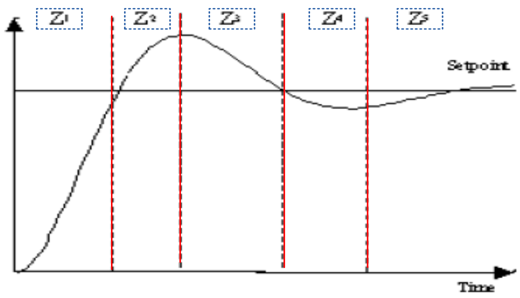

Fig. 4. Fuzzy like PID controller

According to the sign of the error and the change of the error the required response from the system should be considered, So the rules which constrain the controller response can be summarized as follows:

1- Concerning the error if the error moves to the set point the controller should give a small action, while if the error moves away from the set point the controller should give a big action to enforce the system near the set point.

2- The change of error determines the direction of the system response, so if the system moves in positive direction toward the set point, the contribution of the controller should be in small value, while if the direction of the change of error in negative side far the set point, the system should take a reverse action to restore the system to steady state

3- The last case when the system reaches around the steady state such that the error and the change of error are around the zero, so the output of the controller should be zero.

In the fuzzy logic controller like PID the integration of the output is important, so the output of previous cycle is summed to the current output multiplied with a suitable gain, this integration helps the system reaching the steady state and preventing the oscillation system[5][11].

Fig. 5 shows the block diagram of the proposed system based on fuzzy logic controller.

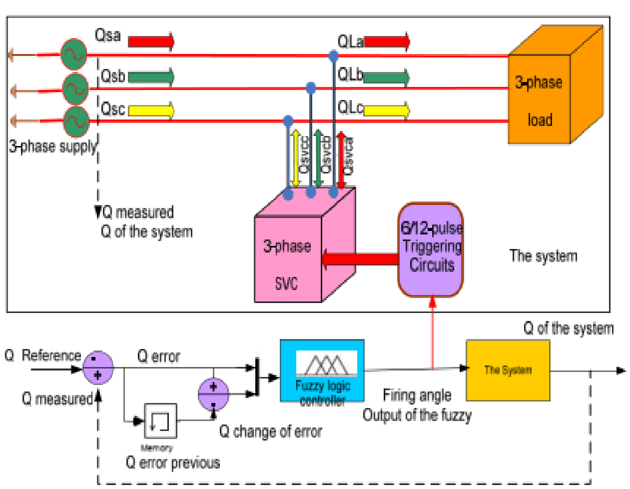

Fig. 5. Block diagram for fuzzy controller based on using Q reactive power as a variable input

3- Methodology for the used controller

The fuzzy like PID is based on two inputs and five membership functions to compute the error and the change of error of the measured reactive power, the fuzzy rules will be 25 rules. As for fuzzy output, it is based on nine membership functions to compute the firing angle as shown in the figures (6-9).It is important to declear that the firing angle of the TCR system is in the range from nearly 90 degree to 180 degree. Since the FLC output is based on this range to achieve fast and smooth reactive power control.

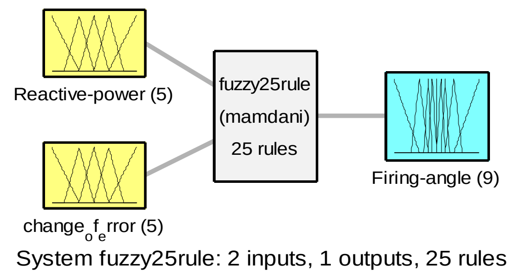

Fig. 6. Simple fuzzy system structure with two inputs, one output

The labels of each membership function is assigned to match with their values, the membership functions may take the symmetric shapes or asymmetric based on the response of the system

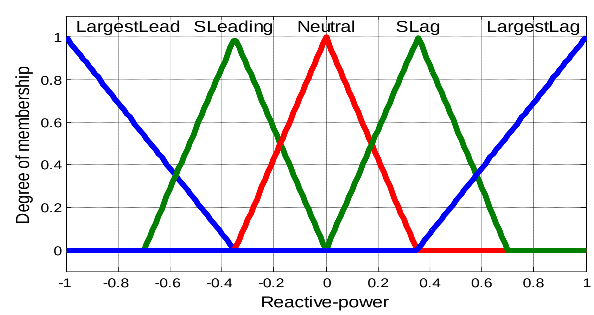

Fig. 7. Five membership functions for the input–reactive power.

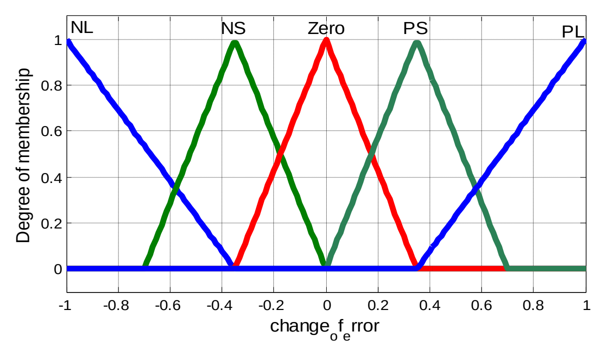

Fig. 8. Five membership functions for the input– change of error for the reactive power.

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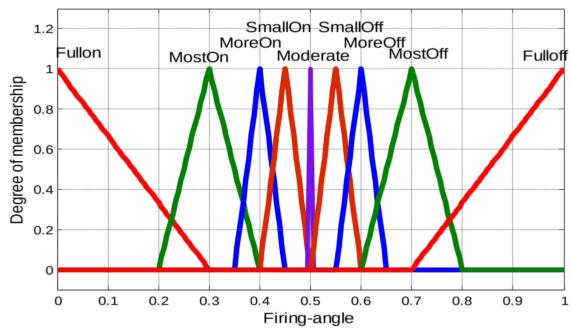

Fig. 9. Nine membership functions for the Output–Firing angle

The membership function output of the firing angle is not symmetric due to the reactive power output from the TCR is not linear with firing angle as shown in the Fig (10).

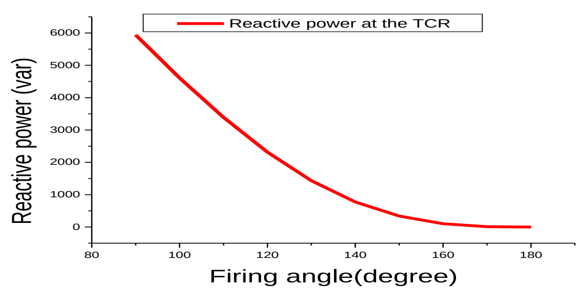

Fig. 10. The relation of the reactive power and the firing angle

IV. Simulation Results

The following section shows the many results for various TCR connections such as (Star, Delta, and Hybrid).

The load is changed from fully inductive rating for the R-L load (3kwatt, 3Kvar) to fully capacitive rating for R-C load (3kwatt, 3Kvar). This case study is to test the ability of the system to reach for the desired power factor reference under a sudden change conditions.

The reactive power at the PCC will be calculated; hence the fuzzy controller will generate a suitable firing angle to help the system to reach its steady value.

1.1 Simulation of star connected TCR System

Fig (10) shows the system response when the reactive power of the load is changed from (+ve Q = 3000 var) as inductive load to (-ve Q = -3000 var) as a capacitive load.

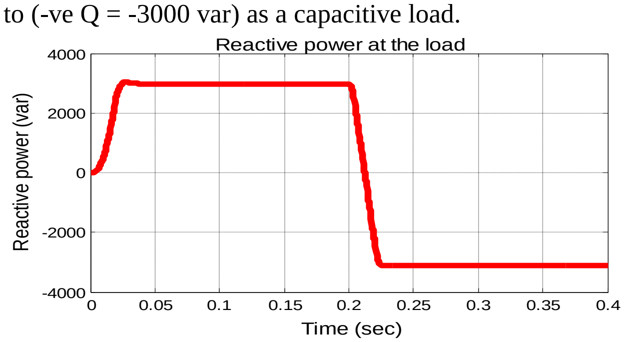

Fig. 11. Reactive power at the load

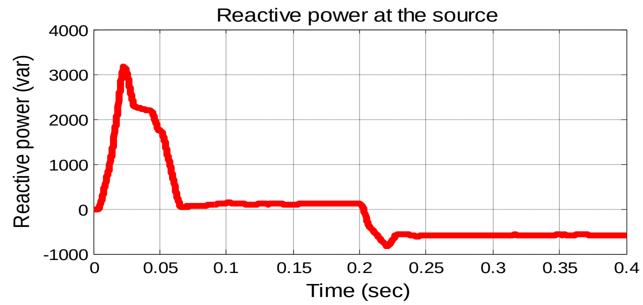

Fig. 12. Reactive power at the PCC – TCR star

Fig. 12 shows reactive power at source side. Initially, the FLC controller starts with 115° to ensure zero reactive power from the SVC system (FC-TCR). This starting angle will generate (+Q =3000 var) to cancel the capacitor effect till get an information about the reactive power of the load during the first cycle.

After one complete cycle the FLC has the information about the reactive power of the load. Then the FLC starts to compensate the error between the desired and actual reactive power at the source. It is clear that the FLC is succeeded to control the TCR system to force the reactive power at the source side near to its desired value.

After the 0.2 sec the load changes to fully capacitive(-Q =3000 var); hence the fuzzy controller regenerates a new firing angle nearly to 90 degree, the fuzzy controller succeeded to reduce the reactive power in the two cases near to zero at (PCC). The FLC requires only about 0.025 sec to satisfy changes of the system

Fig (13) shows the firing angle variation according to the requirements of the system.

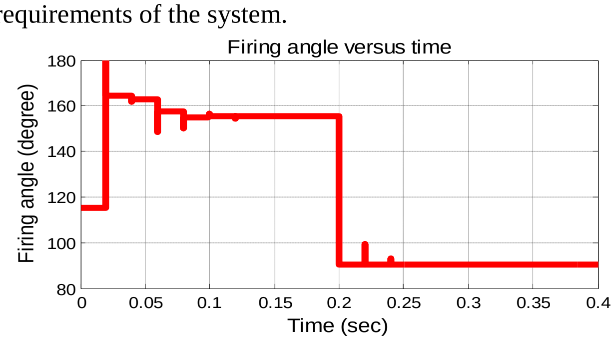

Fig. 13. Firing angle versus time – TCR star.

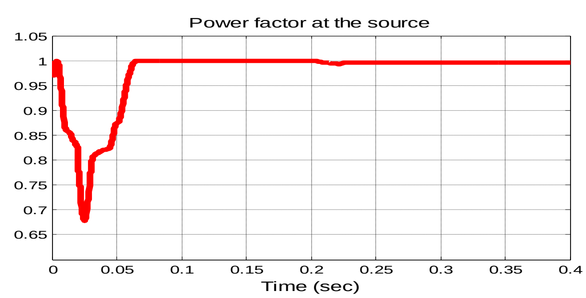

Fig. 14. Power factor at the PCC– TCR star**.**

In Fig (14) shows that the power factor after the 0.08 sec is nearly unity, the controller is present with its actual response

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suitable to the reactive power appeared at the PCC, after 0.2 sec, there is a small ripple due to changing in the load consequently at the PCC, in the two cases the fuzzy controller is able to take the system near to the unity power factor.

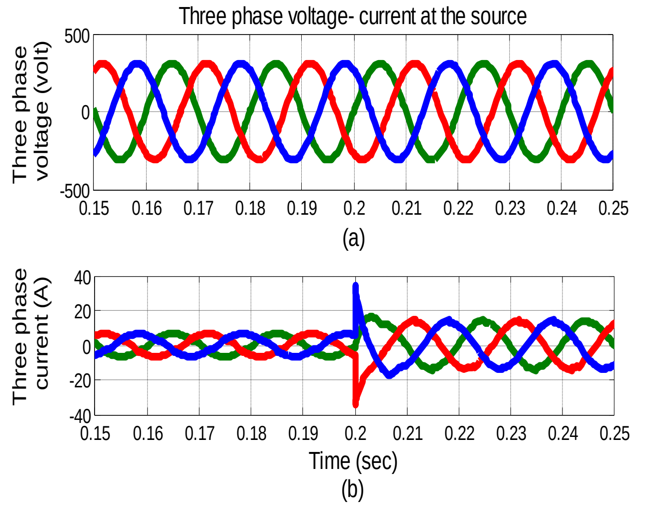

Fig. 15. (a): Three phase voltage,(b):Three phase current at PCC – TCR star.

The change of the load change the value of the inputs of the controller represented in the reactive power; hence the output of the fuzzy which represented in the firing angle will change also, the current magnitude change before and after 0.2 sec as in Fig (15). The three phases of current at the PCC change from small value to big values after changing of the load, due to there is over compensation appeared on the PCC, The apparent, average power, reactive power at the PCC change for the two loads, but their values are still lower than the absent of the SVC as in Fig (16).

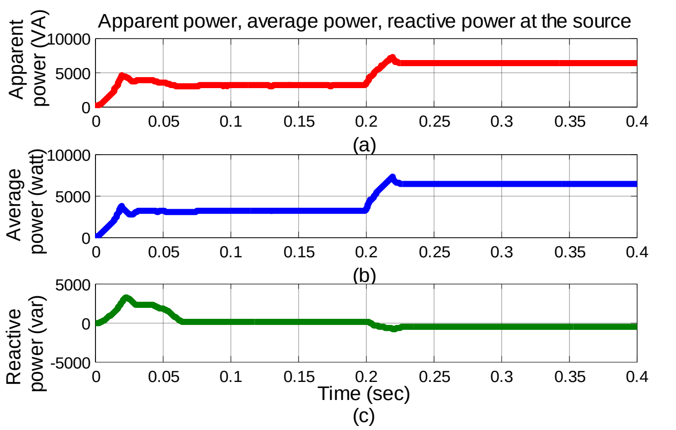

Fig. 16. (a): Apparent power (b): Active Power (c): Reactive power for phase a versus time at PCC – TCR star.

In Fig (17), the relation between the voltage and the current through the antiparallel thristors is shown, the current across the TCR through the two antiparallel thristor is near zero due to preventing the TCR from conducting when the load is fully inductive (+Q =3000 var), while for the capacitive load (-Q =3000 var), the TCR current is nearly equal to the rated current due to the firing angle is equal to 90 degree, consequently the conduction angle is nearly 90 degree.

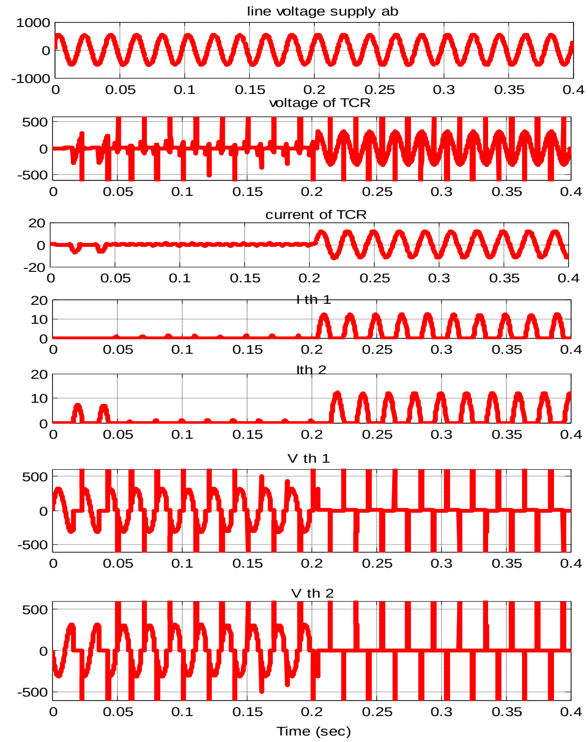

Fig. 17. Line voltage ab, Line voltage TCR, line current for TCR, current for thyristor1, 2, voltage for thyristor1, 2 by fuzzy for– TCR star.

The results show how the FLC can track the system about the desired power factor correction; also the results confirmed about the flexibility of the controller to face the changes on the system

1.2 Simulation of Delta connected TCR System

the circuit with delta connection of the TCR is used, the reactive power appears at the PCC with higher magnitude at the begin of operation due to the firing angle initialization with 115 degree, The system during the first cycle is able to discover the nature of load and the value of the reactive power through getting an information about the system after one cycle the FLC take the system around zero at the PCC, although the load changes, the controller is still able to restore the system near to zero of reactive power ; hence the unity of power factor as illustrated in Figs (18-20).

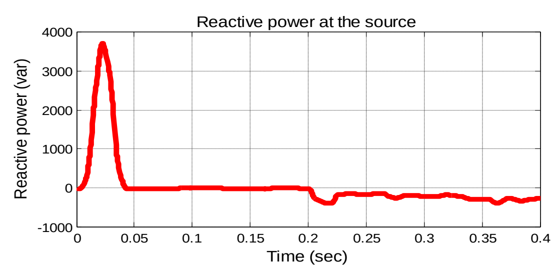

Fig. 18. Reactive power at the PCC – TCR delta.

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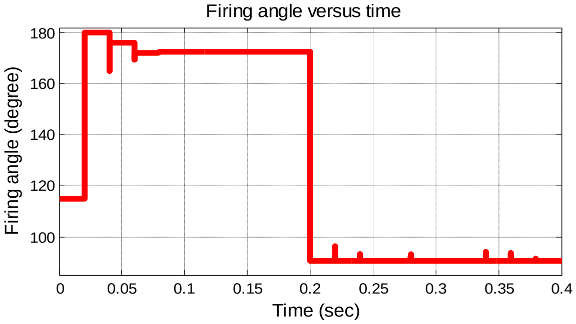

Fig. 19. Firing angle versus time – TCR delta.

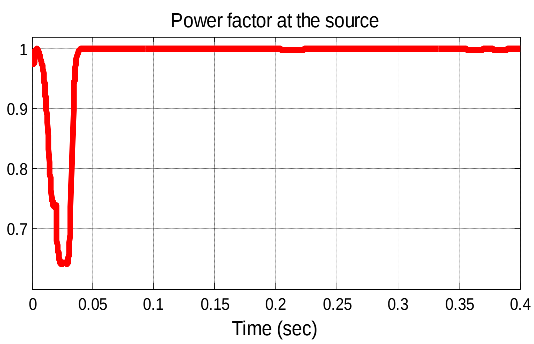

Fig. 20. Power factor at the PCC – TCR delta

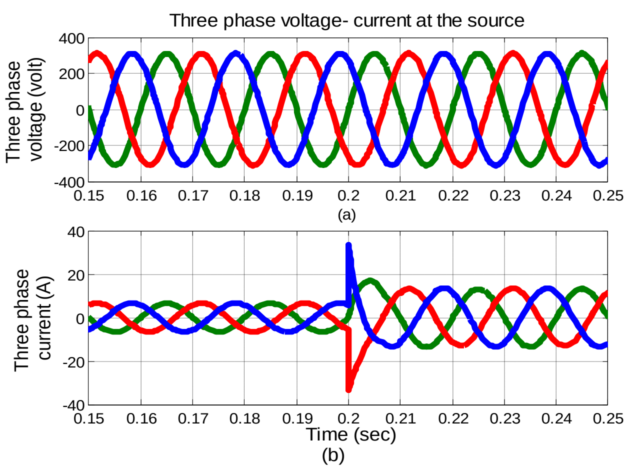

Fig. 21. (a) Three phase voltage, (b): Three phases current at PCC – TCR delta.

Although the power factor is enhanced for the two loads, but it is noticed that the current at the source is larger in magnitude in case of RC load than RL load as in Fig (21),, it is eaiser to control the TCR in closed mode (180 degree) rather than in opening mode (variable angle), so the current in the TCR branch appears for the RC load, while the current should be near to zero for the inductive load, although the reactive power is near to zero, there is no complete compensation for the reactive at PCC, the apparent, active power, and reactive power have a transitional period due to the changing of the load as in Fig (22), their values are still lower comparison with the absent of the SVC.

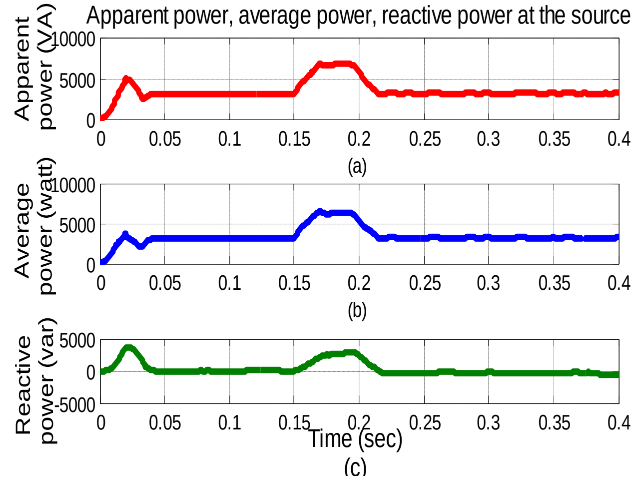

Fig. 22. (a) Apparent power (b): Power (c): Reactive power for phase a versus time at PCC - TCR delta.

The results show that the firing angle at the starting is 115 degree to neutralize the output of SVC from sharing with its reactive power, the reactive power of the load appears at the PCC only, then the controller generates the firing angle between 170 and 180 degree, which effects on the power factor to reach near the unity, after the capacitive load (-Q =3000 var) is connected to the system, the firing angle jumps to be around 90 degree, so the power factor is still near to the unity.

1-3 Simulation of Hybrid connected TCR System

The fuzzy control is applied for the hybrid technique, the load will change at 0.2 sec from fully inductive(+Q =3000 var) to fully capacitive(-Q =3000 var), the firing angle changes from 115 degree to 175 degree which is suitable to the inductive load continuing for 2 cycles, after 0.2 sec the controller triggers the thyristors with a firing angle near to 90 degree, the firing angle is sent to the two branches such that there is 30 degree between the star branch and the delta branch, each branch contributes with apart of the reactive power to get a suitable compensation for the all system, this difference shift between the two branches is desired to cancel the harmonics as shown in the Figs (23-25)

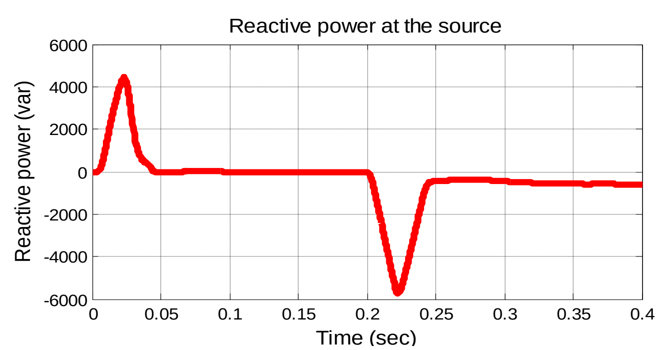

Fig. 23. Reactive power at the PCC –TCR hybrid

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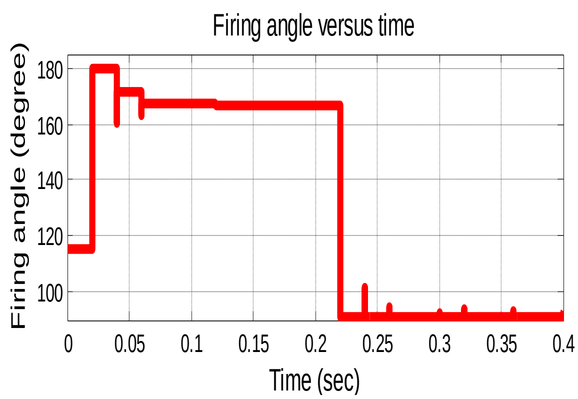

Fig. 24. Firing angle versus time – TCR hybrid.

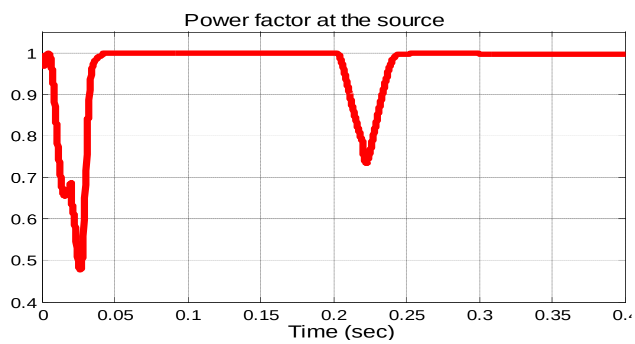

Fig. 25. Power factor at the PCC– TCR hybrid.

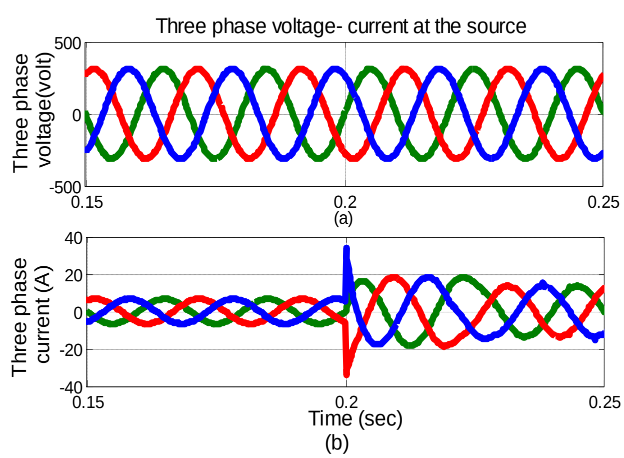

Fig. 26. (a):Three phases voltage, (b):Three phases current at PCC for change – TCR hybrid by fuzzy control.

The three phases current are changed for the two cases of the load as described in the star and delta connection, the three phases are symmetrical due to the nature of the loads as in Fig (26), in case of the load is not symmetric, the controller is able to compensate each phase individually through a specific firing angle for each phase.the design of the compensator will vary to match the values of each phase.

The apparent power, the average power, and the reactive power with their lower values are shown in the Fig (27).

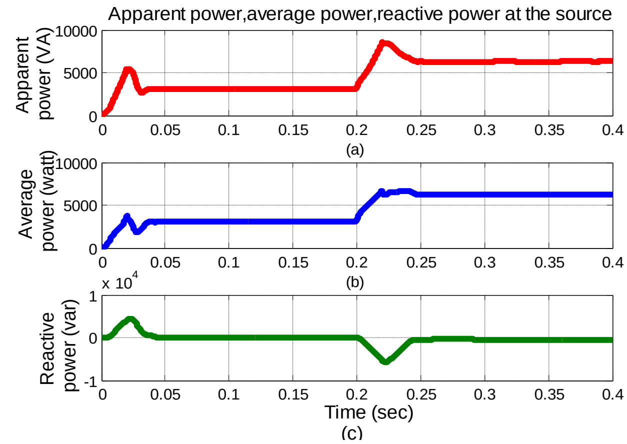

Fig. 27. (a): Apparent power (b): ActivePower (c): Reactive power for phase-a versus time at source – TCR hybrid.

The results show that the power factor is enhanced for the two loads except the two transition periods, after the controller get the need information from the system the FLC is able to restore the system for required reference, the hybrid topology is tested by the fuzzy controller, although the hybrid topology requires two inductors for the two branches but the merit of reduction the harmonics order is obtained as in the following section.

1.4 Total Harmonic Distortion

Although the harmonics produced from the TCR branch is one disadvantage feature from using TCR, the result shows that it can be minimized by using a suitable technique as the hybrid.

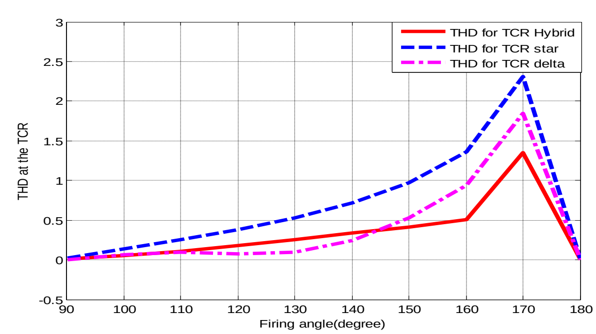

Fig. 28. THD versus firing angle at TCR for TCR hybrid / TCR star /TCR delta

The comparison between the three topologies of connection TCR (star- delta- hybrid) at the TCR is presented, the result show that the THD at the TCR for the hybrid connection is the best for the ranges 145-180 degree and from 90-112 degree which is suitable for the fully inductive and fully capacitive loads as in the Fig (28), the delta connection also has intermediate values due to the trap of the third and their multiples from circulations outside the delta connections, the star connections has a higher values for the THD, the value of the THD at the TCR is reflected directly at the THD at the source.

V. Conclusion

The results of simulation confirm that the hybrid connection is effective when used for RL load and RC load, where the power factor is improved and the reduction of the harmonics is achieved with the hybrid, also the using fuzzy control is very important due to the nature of the fuzzy for no required for the model. The 12 pulse technique (Hybrid) used in the industrial applications for their merits, it can be extended to higher pulses as 24-48 pulse to overcome the harmonics which produced from the TCR in higher order.

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