Power Quality Improvement using a Combination of
Shunt Hybrid Power Filter and Thyristor-Controlled Reactor

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Abstract: This project proposes a combined system of FACTS controller i.e., thyristor
controlled reactor (TCR) and a shunt hybrid power filter (SHPF) for harmonic and reactive
power compensation. The issue of reactive power is resolved using SHPF and TCR with
combination in the power system. Installing a SHPF for nonlinear loads connected in power
system helps in reducing the harmonic effect. The main emphasis of this combination is on
compactness of configurations, simplicity in control, reduction in rating of components, thus
finally leading to saving in overall cost. The necessary modeling and simulations are carried
out in MATLAB environment using SIMULINK and power system block set toolboxes. The
simulation results of combination of SHPF with TCR are found to be quite satisfactory to
mitigate harmonic distortions and reactive power compensation, thereby improving the
power quality at ac mains.

Keywords: Power Quality, Harmonics, Shunt hybrid power filter, Thyristor controlled
reactor, Reactive power.

1. INTRODUCTION
The quality of electrical power is one of the major growing concerns for utility as well as
consumers. Power quality is becoming important due to proliferation of nonlinear loads,
such as rectifier equipment, adjustable speed drives, domestic appliances and arc furnaces.
These nonlinear loads draw non-sinusoidal currents from ac mains and cause a type of
current and voltage distortion called as „harmonics“ . These harmonics causes various
problems in power systems and in consumer products such as equipment overheating,
capacitor blowing, motor vibration, transformer over heating excessive neutral currents and
low power factor. Power quality problems are common in most of commercial, industrial and
utility networks. Natural phenomena, such as lightning are the most frequent cause of
power quality problems. Switching phenomena resulting in oscillatory transients in the
electrical supply.
Traditionally, passive filters have been used to eliminate current harmonics of the supply
network. However, these devices suffer from resonance. Recently, thyristor-switched filters
(TSFs), which contain several groups of passive filters, have been used to compensate
reactive power [1]. The compensation amount of TSFs can be adjusted with the variation of
load power [2]. However, the parallel and the series resonance could occur between TSF
and grid impedance. Active filters were developed to mitigate problems of passive filters
[3]–[5]. They are more effective in harmonic compensation and have good performance
[6]–[8]. However, the costs of active filters are relatively high for large scale system and
require high power converter ratings [9], [10]. Hybrid filters effectively soften the problems
of the passive filter and an active filter solution and provide cost-effective harmonic
compensation, particularly for high-power nonlinear loads [11]–[14].

In this paper, a new combination of a shunt hybrid power filter (SHPF) and a TCR (SHPF-
TCR compensator) is proposed to suppress current harmonics and compensate the reactive
Power generated from the load. The hybrid filter consists of a series connection of a small-rated active filter and a fifth-tuned LC passive filter. In the proposed topology, the major part of the compensation is supported by the passive filter and the TCR while the APF is meant to improve the filtering characteristics and damps the resonance, which can occur between the passive filter, the TCR, and the source impedance. The shunt APF when used alone suffers from the high kilovoltampere rating of the inverter, which requires a lot of energy stored at high dc-link voltage. On the other hand, as published by some authors [15], the standard hybrid power filter is unable to compensate the reactive power because of the behavior of the passive filter. Hence, the proposed combination of SHPF and TCR compensates for unwanted reactive power and harmonic currents. In addition, it reduces significantly the voltampere rating of the APF part. The control method of the combined compensator is presented. A control technique is proposed to improve the dynamic response and decrease the steady-state error of the TCR. It consists of a PI controller and a lookup table to extract the required firing angle to compensate a reactive power consumed by the load. A nonlinear control of SHPF is developed for current tracking and voltage regulation purposes. It is based on a decoupled control strategy, which considers that the controlled system may be divided into an inner fast loop and an outer slow one. The currents injected by the SHPF are controlled in the synchronous orthogonal dq frame using a decoupled feedback linearization control method. The dc bus voltage is regulated using an output feedback linearization control. The SHPF can maintain the low level of dc bus voltage at a stable value below 50 V. The proposed nonlinear control scheme has been simulated and validated experimentally to compute the performance of the proposed SHPF-TCR compensator with harmonic and reactive power compensation and analysis through the total harmonic distortion (THD) of the source and the load current. The proposed methodology is tested for a wide range of loads as discussed further. Simulation results show that the proposed topology is suitable for harmonic suppression and reactive compensation.

2. SYSTEM CONFIGURATION

Fig. 1 shows the topology of the proposed combined SHPF and TCR. The SHPF consists of a small-rating APF connected in series with a fifth-tuned LC passive filter. The APF consists of a three-phase full-bridge voltage-source pulse width modulation (PWM) inverter with an input boost inductor ($L_{pf},R_{pf}$) and a dc bus capacitor ($C_{dc}$). Shunt active power filter compensate current harmonics by injecting equal-but-opposite harmonic compensating current.

In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180 degrees. This principle is applicable to any type of load considered a harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. Because of these merits, The presented combined topology is very appropriate in compensating reactive power and eliminating harmonic currents in power system. The tuned passive filter in parallel with TCR forms a shunt passive filter (SPF). This is the most commonly used configuration of passive filters. This passive filter scheme helps in sinking the more dominant 5th and 7th and other higher order harmonics and thus prevents them from flowing into ac mains and PF correction.

The small-rating APF is used to filter harmonics generated by the load and the TCR by enhancing the compensation characteristics of the SPF aside from eliminating the risk of resonance between the grid and the SPF. The TCR goal is to obtain a regulation of reactive power.
3. PI CONTROLLER

PI control with a view to have a self-regulated dc bus, the voltage across the capacitor is sensed at regular intervals and controlled by employing a suitable closed loop control. The dc link voltage, \( v_{dc} \) is sensed at a regular interval and is compared with its reference counterpart \( v_{dc}^{*} \). The error signal is processed in a PI controller. The output of the PI controller is denoted as \( i_{sp}(n) \). A limit is put on the output of controller this ensures that the source supplies active power of the load and dc bus of the SHPF-TCR Later part of active power supplied by source is used to provide a self-supported dc link of the SHPF-TCR Thus, the dc bus voltage of the SHPF-TCR is maintained to have a proper current control.

![FIGURE 1: Basic circuit of the proposed SHPF-TCR compensator](image)

By using this PI Controller in the control scheme of the proposed SHPF-TCR compensator it has been shown that the system has a fast dynamic response, has good performance in both steady-state and transient operations, and is able to reduce the THD of supply currents well below the limit of 5% of the IEEE-519 standard. According to Haines, control is the preferred method to improve the power quality because of the improvements in accuracy and energy consumption when compared to proportional control. A PI controller is a kind of
Fuzzy logic control is deduced from fuzzy set theory; which was introduced by Zadeh in 1965. In the fuzzy set theory concept, the transition is between membership and non-membership function. Therefore, limits or boundaries of fuzzy sets are undefined and ambiguous but useful in approximating systems design. In order to implement the fuzzy logic control algorithm of an active power line conditioner in a closed loop, the dc-link capacitor voltage is sensed and compared with the desired reference value.

The error signal \( e(t) \) passes through a Butterworth low pass filter that allows only the fundamental component. The voltage error signal \( e(n) \) and change of error signal \( ce(n) \) are used as inputs for fuzzy processing as shown in Fig.3. The output of the fuzzy logic controller estimates the magnitude of peak reference current \( I_{max} \).

![Schematic diagram of the fuzzy logic controller](image)

**Figure 3:** Schematic diagram of the fuzzy logic controller

The fuzzy logic controller is characterized as follows:

1. Seven fuzzy sets (NB, NM, NS, ZE, PS, PM, PB) for each input and output variables.
2. Triangular membership function is used for the simplicity.
3. Implication using Mamdani-type min-operator.
4. Defuzzification using the centroid method.

**KNOWLEDGE BASE**

The Knowledge Base (KB) stores the available knowledge about the problem in the form of fuzzy "IF THEN" rules. It composed of two main components, Data Base (DB) and Rule Base (RB). Data Base (DB) stores the membership functions of fuzzy sets and scaling functions for context adaptation purpose. Rule Base (RB) stores the FUZZY IF THEN rules for the purpose inference and decision making. Multiple rules can be fired simultaneously for the same input.
FUZZIFICATION
Fuzzy logic uses linguistic variables instead of numerical variables. In a closed loop control system, the error signal $e(n)$, change of error signal $ce(n)$ and output of peak reference current $Imax$ are considered as membership functions. It can be labeled as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB) as shown in Fig.4. Converting numerical variable (real number) into a linguistic variable (fuzzy number) is the process of fuzzification.

![Membership functions](image)

**Figure 4**: Membership functions (a) the input variables $e(n)$, $ce(n)$ and (b) output variable $Imax$

FUZZIFICATION INTERFACE
It transforms the crisp input data into fuzzy values that acts as input to fuzzy reasoning process.

DEFUZZIFICATION
The rules of fuzzy logic produce the set of modified control output in a linguistic variable. The defuzzification module converts these linguistic variables into a crisp value (real number) according to real time applications. The different methods of defuzzification available are Bisector, Centroid, Middle of Maximum (MOM), Smallest of Maximum (SOM) and Largest of Maximum (LOM), etc., however, the selection of method is a compromise between accuracy and computational intensity (that influences hardware requirement for real time application). The centroid (or center of gravity) method is used for simplicity and accuracy. The linguistic output variable from the rule evaluator and definition of output membership are used to calculate the hidden area. Finally, crisp output is obtained by using output $Ai xi / Ai$.

DEFUZZIFICATION INTERFACE
It converts the fuzzy sets obtained from the inference process into a crisp action that constitutes the global output of the FRBS. Mamdani based fuzzy logic interfacing rule is adopted for correction of power factor. Complex power is taken from power measuring block, in which power angle is taken as input of fuzzy controller. According to power angle control output (firing angle) is provided by fuzzy controller. When power angle is large firing
angle is also large. Controlled output is supplied to variable delay circuit and it is supplied to thyristor. According to the output of variable time delay circuit firing angle of thyristor is changed. When power angle is very small then firing angle is also very small. When power angle is medium then firing angle is also medium. When power angle is large then firing angle is also large.

5. SIMULATION RESULTS
To demonstrate the performance of SHPF-TCR compensator, modeling is carried out in MATLAB environment along with SIMULINK and power system block set toolboxes. Fig.5, shows the matlab model of proposed system with both non-linear and reactive loads.

![Figure 5: Matlab model of proposed system with both non-linear and reactive loads](image)

The controller’s performance has been evaluated by achieving a number of tests on the proposed SHPF-TCR compensator:
1) Steady-state response of the SHPF-TCR compensator to load-generating harmonics;
2) Dynamic response of the SHPF-TCR compensator to harmonic-produced load variations; and
3) Response of the SHPF-TCR compensator to the harmonic and reactive power type of load variation.

The steady-state waveform of the SHPF-TCR compensator for harmonic elimination with a three-phase harmonic-produced load is shown in Fig.6. The supply voltage ($v_s1$), the supply current ($i_s1$), the load current ($i_L1$), the SHPF-TCR current ($i_c1$) in phase 1, and the dc bus voltage ($v_{dc}$) are depicted in this figure.

The harmonic spectrum of the supply current before and after compensation are shown in Fig.7 (a) and (b). The THD of the supply current is brought down from 27.76% to 2.91%. It is found that the SHPF-TCR compensator offers a very good level of performance such that the supply current is close to sinusoidal and locked in phase with the supply voltage.
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Figure 6: Steady-state response of the SHPF-TCR compensator with harmonic generated load

Figure 7: Harmonic spectrum of source current in phase 1. (a) Before compensation. (b) After compensation
In order to observe the SHPF-TCR compensator behavior under both harmonic and reactive power type of load variation, the load-generating reactive power current was subjected from zero to a full load step increase and the other way around. The corresponding phase-1 dynamic responses of the SHPF-TCR compensator for reactive power compensation and harmonic elimination are shown in Fig.9.

It is observed from Fig.10 that the supply current before compensation was quite distorted and has a THD of 15.10%; however, its THD is reduced to 1.26% after compensation. The compensated source current shown in this figure suggests that the proposed SHPF-TCR
compensator can effectively compensate the load-generated harmonics and reactive power exchanged by both loads.

![Harmonic spectrum of source current in phase 1](image1)

(a)

![Harmonic spectrum of source current in phase 1](image2)

(b)

**Figure 10**: Harmonic spectrum of source current in phase 1. (a) Before compensation. (b) After compensation

The matlab modeling using fuzzy logic design is as shown in Fig.11.

![Matlab modeling of SHPF-TCR compensator using fuzzy logic design](image3)

**Figure 11**: Matlab modeling of SHPF-TCR compensator using fuzzy logic design
FFT Analysis of Source Current of the SHPF-TCR Compensator on harmonic generation load during steady state attains THD as 0.81%, operated under fuzzy Controller is shown in Fig.12.

![FFT Analysis of source current during steady state](image12)

**Figure 12:** FFT Analysis of source current during steady state

FFT Analysis of Source Current of the SHPF-TCR Compensator during dynamic state attains THD as 0.81%, operated under fuzzy Controller is shown in Fig.13.

![FFT Analysis of source current during dynamic state](image13)

**Figure 23:** FFT Analysis of source current during dynamic state

6. **CONCLUSION**

The power quality problems in distribution systems are not new but customer awareness of these problems increased recently. Maintaining the electric power quality at acceptable limits is very difficult. One modern and very promising solution to achieve harmonic elimination and reactive power compensation is by using SHPF-TCR Compensator. The shunt active filter and SPF have a complementary function to improve the performance of filtering and to reduce the power rating requirements of an active filter. The scheme has the advantage of simplicity and is able to provide self-supported dc bus of the active filter through power transfer from ac line at fundamental frequency. The proposed nonlinear control scheme of the SHPF-TCR compensator has been established, simulated, and implemented by using the Matlab/Simulink platform. The compensator has been tested in both steady state and dynamic state conditions.

A fuzzy logic controller has been designed for stabilization of power systems. The response of the power system with the fuzzy controller over a non-linear control system is observed. Overall, the fuzzy controller gives the best performance in comparison. It has been shown that the system has a fast dynamic response, has good performance in both steady-state and transient operations.
7. REFERENCES


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