International Journal of Power Electronics Controllers and Converters
eISSN: 2456-1614
Vol. 3: Issue 2
www.journalspub.com

Multifunctional Shunt Hybrid Power Filter and Thyristor Controlled Reactor for Distributed Generation Integration and Power Quality Improvement

*Sandeepthi Nandhyala[1], A.N.V.J. Rajagopal[1], *R.C. Garimella[2]*
1Department of EEE, BVC Institute of Technology and Science, Batlapalem, Amalapuram, AP, India
2Department of EEE, Madanapalle Institute of Technology and Science, Angallu, Chittoor District, India

ABSTRACT

This project presents a multifunctional PV fed SHPF-TCR compensator for achieving maximum benefits from these grid-interfacing inverters. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. An inverter can be used as power converter to insert the power created from RES to the grid, and shunt APF to reimburse load current harmonics. A SHPF-TCR compensator of a TCR and a SHPF has been proposed to achieve harmonic elimination. A proposed nonlinear control scheme of a SHPF-TCR compensator has been established and simulated. The shunt active filter and SPF have a complementary function to advance the performance of filtering and to diminish the power rating supplies of an active filter. It has been found that the SHPF-TCR compensator can effectively eliminate current harmonic and reactive power compensation during steady and transient operating conditions for a variety of loads. 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.

Keywords: *Dynamic response, harmonics, power, thyristor*

Corresponding Author
E-mail: *raghuchandhra@gmail.com*

INTRODUCTION

Electrical energy is the most efficient and popular form of energy and the modern society is heavily dependent on the electric supply. The life cannot be imagined without the supply of electricity. At the same time the quality of the electric power supplied is also very important for the efficient functioning of the end user equipment.

The term power quality became most noticeable in the power sector and both the electric power supply company and the end users are fretful about it. The quality of power delivered to the consumers depends on the voltage and frequency ranges of the power. If there is any deviance in the frequency and voltage of the electric power delivered from that of the standard values then the quality of power delivered is affected [1].

Now-a-days with the advancement in technology there is a drastic improvement in the semi-conductor devices. With this development and advantages, the semi-conductor devices got a permanent place in the power sector helping to ease the control of overall system. Moreover, most of the loads are also semi-conductor based equipment. But the semi-conductor devices are non-linear in nature and draws non-linear current from the source. And also, the semiconductor devices are involved in power conversion, which is either AC to DC or from DC to AC [2]. This power conversion contains lot of switching operations which may introduce discontinuity in the current. Due to this non-linearity and discontinuity, harmonics exists which affect the quality of power delivered to the end user. In order to maintain the quality of power delivered, the harmonics should be filtered out. Thus, a device named filter is used which serves this purpose.

There are several filter topologies in the literature like- passive, active and hybrid. In this project the use of shunt hybrid power filters and thyristor controlled reactor for the improvement of electric power quality is studied and analyzed [3–5].

Non-linear loads cause significant harmonic currents with poor input power factor, which creates serious problems at the power supply system.

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. The compensation amount of TSFs can be adjusted with the variation of load power. However, the parallel and the series resonance could occur between TSF and grid impedance. Active filters were developed to mitigate problems of passive filters. They are more effective in harmonic compensation and have good performance [6, 7].

However, the costs of active filters are relatively high for large-scale system and require high power converter ratings. Hybrid filters efficiently soften the problems of the passive filter and an active filter solution and provide profitable harmonic compensation, mainly for high-power nonlinear [8]. Many control techniques such as instantaneous reactive power theory, synchronous rotating reference frame, sliding-mode controllers, neural network techniques, nonlinear control feed forward control lyapunov function-based control, etc. have been used to improve the performance of the active and hybrid filters [9]. Several filter topologies for compensating harmonics and reactive power have been reported in the literature in a multi-converter conditioner topology formed by an active conditioner operating in parallel with a hybrid conditioner has been proposed. The hybrid conditioner consists of one or more passive filters in series with a low-rated active power filter (APF). The conditioner compensates harmonic distortion, imbalance, and reactive power in three-phase four-wire systems [10]. This topology constitutes an effective solution at high-power levels, which is cost-effective because of the kilovolt-ampere rating reduction of the inverters [11].

A hybrid configuration based on the combination of a three-phase three-level neutral point clamped (NPC) inverter and a series connection of a three-level H-bridge inverter with a novel control scheme to control the floating voltage source of the H-bridge stage has been presented [12]. In this topology, the NPC inverter is used to supply the total active power while the H-bridges operate as series active filters for the harmonic compensation of the NPC output voltage. The rating of the series active filter is reduced because the latter provides only the reactive power for the operation of the floating capacitor. In a combination of a resonant impedance-type hybrid APF and a thyristor-controlled reactor (TCR) for harmonic cancellation, reactive power compensation, and load balancing has been proposed. The control strategy of the system is based on the voltage vector transformation for compensating the negative-sequence current caused by the unbalance load without using phase-locked loops [13, 14]. A predictive current controller based on Smith predictor is suggested to compensate the widespread current delay. A combined system of a static var compensator (SVC) and a small-rated APF for harmonic suppression and reactive power compensation have been reported in ref. [15]. The SVC consists of a Y-connected passive power filter and a delta-connected TCR.

The APF is used to eliminate harmonic currents and to avoid resonance between the passive power filters and the grid impedance.

System Description

In this project, 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 kilovolt-ampere 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, 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 [16].

In addition, SHPF-TCR reduces significantly the volt-ampere 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 [17]. The proposed methodology is tested for a wide range of loads as discussed further.

Simulation and experimental results show that the proposed topology is suitable for harmonic suppression and reactive compensation of a three-phase full-bridge voltage-source pulse width modulation (PWM) inverter with an input boost inductor (Lpf, Rpf) and a dc bus capacitor (Cdc). The APF sustains very low fundamental voltages and currents of the power grid, and thus, its rated capacity is greatly reduced. Because of these merits, the presented combined topology is very appropriate in compensating reactive power and eliminating harmonic currents in power system. The modified passive filter in parallel with TCR forms a shunt passive filter (SPF). This latter is generally for fifth harmonic compensation 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 reactor power [18]. The set of the load is a combination of a three-phase diode rectifier and a three-phase star connected resistive inductive linear load.

PROPOSED SYSTEM

Here in this project, we developed a new combination of a TCR (SHPF-TCR compensator) and a shunt hybrid power filter (SHPF) is projected to suppress the current harmonics and to compensate the generated reactive power 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 kilovolt ampere 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 (Figure 1). In addition, it reduces significantly the volt ampere 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 (Figure 2). 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 and experimental results show that the proposed topology is suitable for harmonic suppression and reactive compensation.

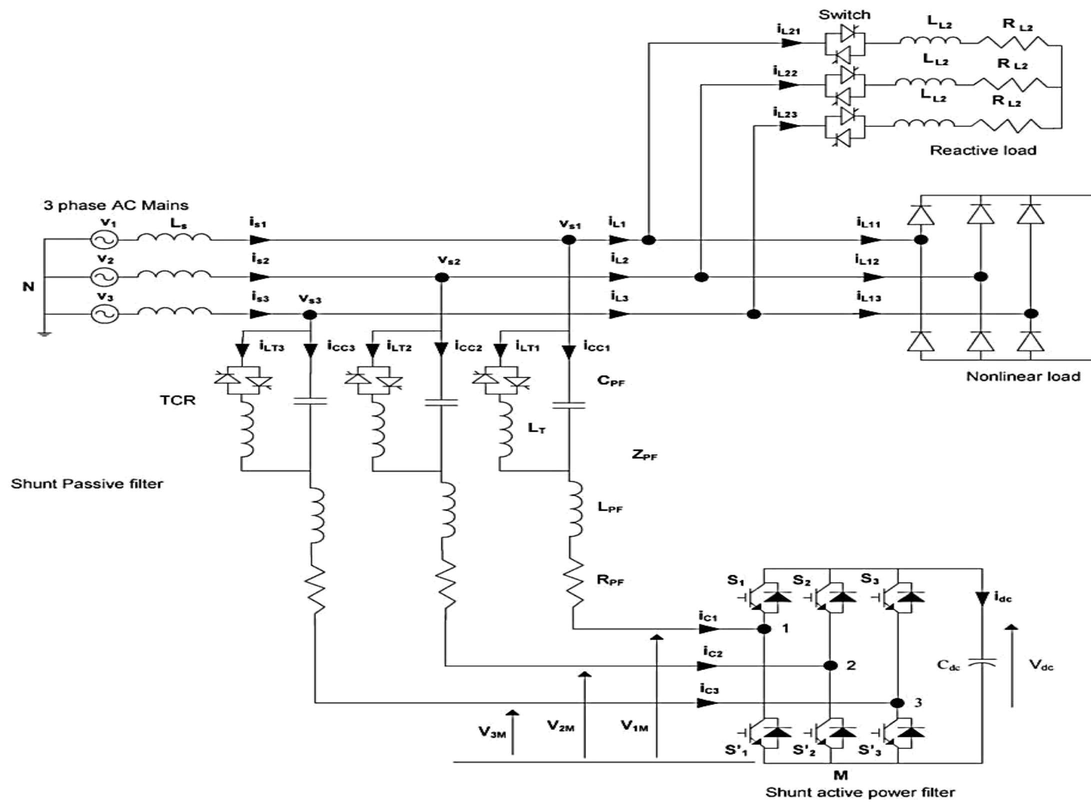

Fig. 1. *Basic circuit of the proposed SHPF-TCR compensator.*

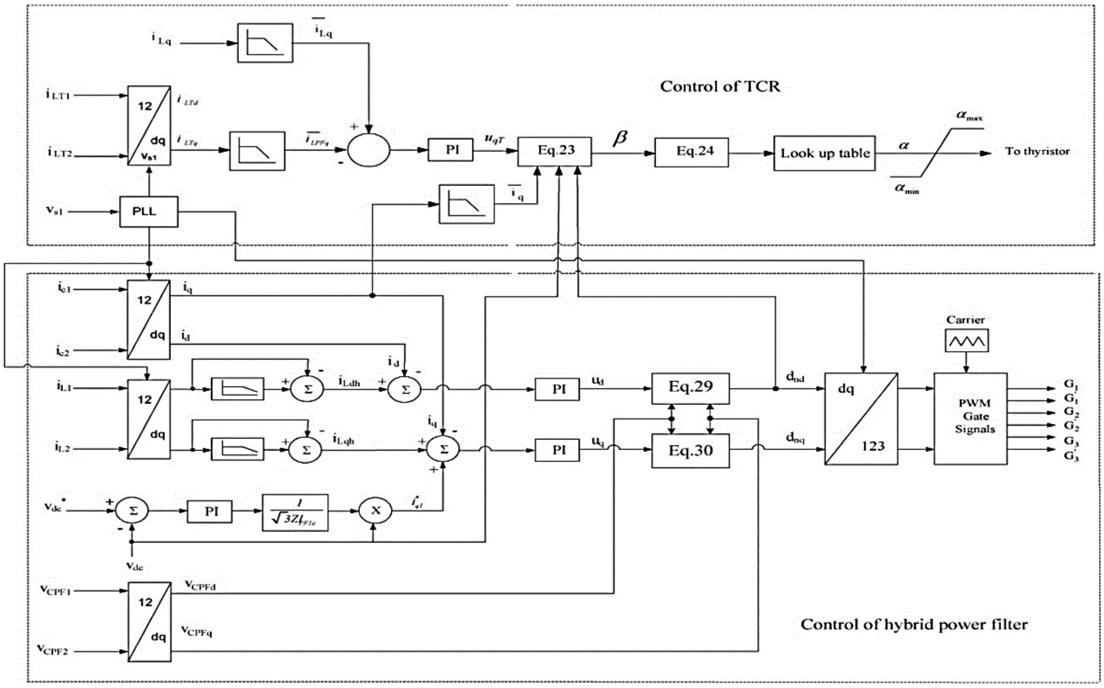

Fig. 2. *Control scheme of the proposed SHPF-TCR compensator.*

SIMULATION RESULTS

The total circuit configuration is simulated using MATLAB 2012a and it is analyzed in power graphical user interfacing environment and the total harmonic distortion is calculated by the use of the fast Fourier transformation technique. In POWERGUI, the following result represents the combined system of a thyristor-controlled reactor (TCR) and a shunt hybrid power filter (SHPF) for harmonic and reactive power compensation. The proposed device is tested under different case scenarios using MATLAB/Simulink to evaluate its capability to improve the PQ and reliability of the distribution network. A proportional–integral controller was used, and a triggering alpha was extracted using a lookup table to control the TCR. A nonlinear control of APF was developed for current tracking and voltage regulation. The following tabular form represents the different electrical parameters of the source, transmission and load end (Table 1).

Table 1. *Parameters used in simulation.*

Line to Line source voltage, and frequency	$V_{S\text{-}L\text{-}L}=208\ V,\ f_s=60\ Hz$
Line impedance	$L_s=0.5\ mH,\ R_s=0.1\ \Omega$
Non linear load	$L_{L1}=10\ mH,\ R_{L1}=27\ \Omega$
Linear load	$L_{L2}=20\ mH,\ R_{L2}=27\ \Omega$
Passive filter parameters	$L_{pf}=1.2\ mH,\ C_{pf}=240\ \mu F$
Active filter parameters	$C_{dc}=3000\ \mu F\ ,\ R_{dc}=1k\ \Omega$
DC bus voltage of APF of SHAF	$V_{dc}=50\ V$
Switching frequency	1920 Hz
Inner controller parameters	$K_{p1}=K_{p2}=43.38$; $K_{i1}=K_{i2}=37408$
Outer controller parameters	$K_1=0.26$; $K_2=42$
Cut off frequency of the low pass filters	$F_c=70\ Hz$
TCR inductance	$L_T=25\ mH$

Figure 3 represents the circuit configuration of the general circuit without shunt hybrid power filter and thyristor-controlled reactor in steady state condition and (Figures 4 and 5) represents the complete MATLAB-based results in POWERGUI environment.

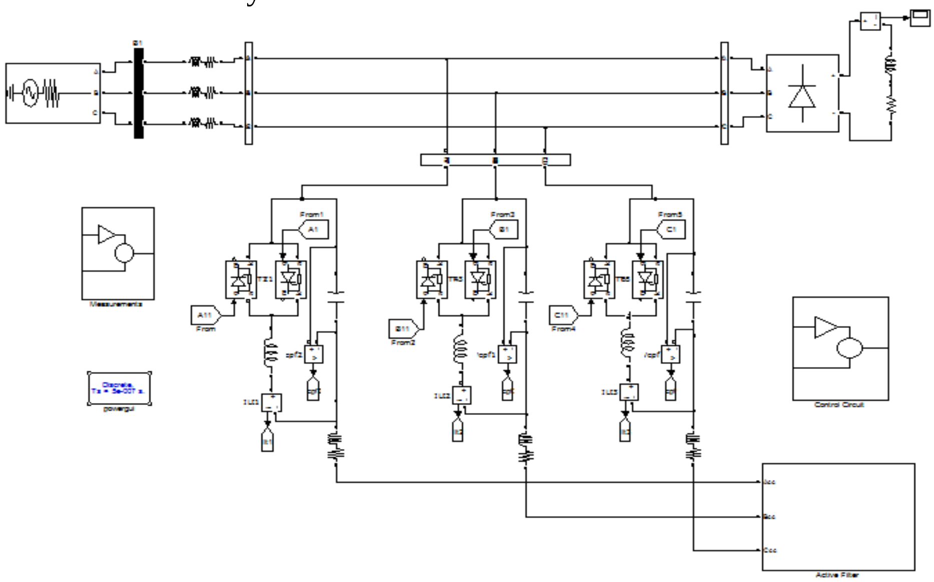

Fig. 3. *A combination of shunt hybrid power filter and thyristor-controlled reactor under normal load*.

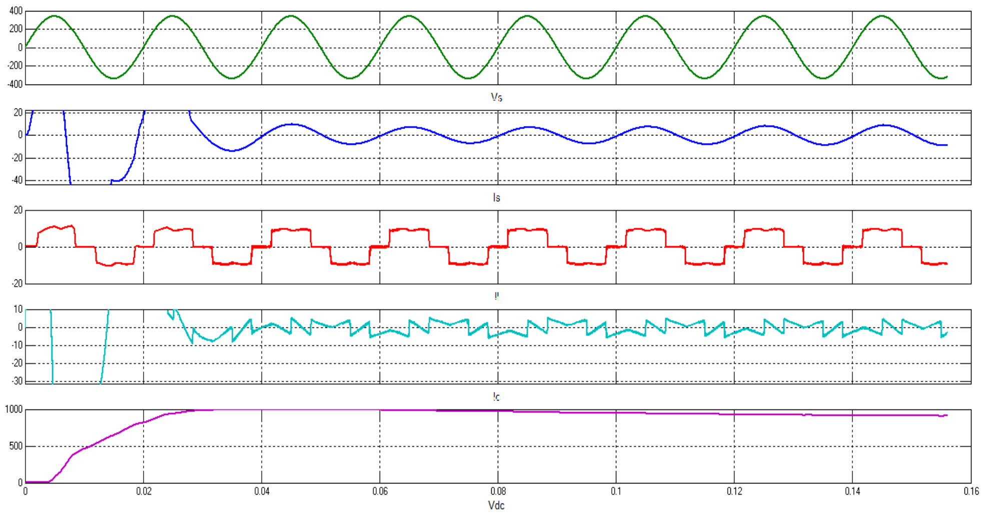

Fig. 4. *Wave form representation of a combination of shunt hybrid power filter and thyristor-controlled reactor under normal load*.

V(S)V the above waveform represent voltage at source side with represent time in Matlab software it shows no change in voltage at source because we are applied constant load so constant power required to drain load so that constant voltage will be applied from the source side.

I(S)A the waveform represents current source side and it all constant because constant load applied and steady-state configuration so the constant current from source.

I(L)A the above waveform represents load current with represent time and fast wave from constant of load of harmonic it all constant because load is not in change under steady state constant.

I(C)A the above waveform represents capacitor charge with represent time and load current from steady state constant so that APF state charging and discharging that represent.

Vdc(V) Vdc voltage with represent time and steady-state constant from the perform load constant.

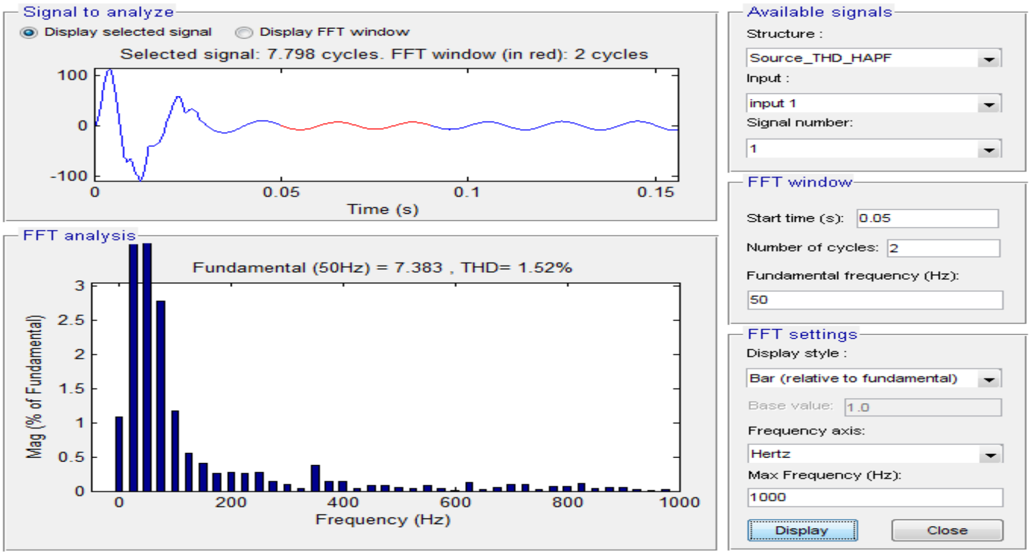

Fig. 5. *Harmonic order a combination of shunt hybrid power filter and thyristor-controlled reactor under normal load.*

Figure 6 represents the circuit configuration of the combination of shunt hybrid power filter and thyristor-controlled reactor in dynamic state condition and Figures 7 and 8 represent the complete MATLAB based results in POWERGUI environment.

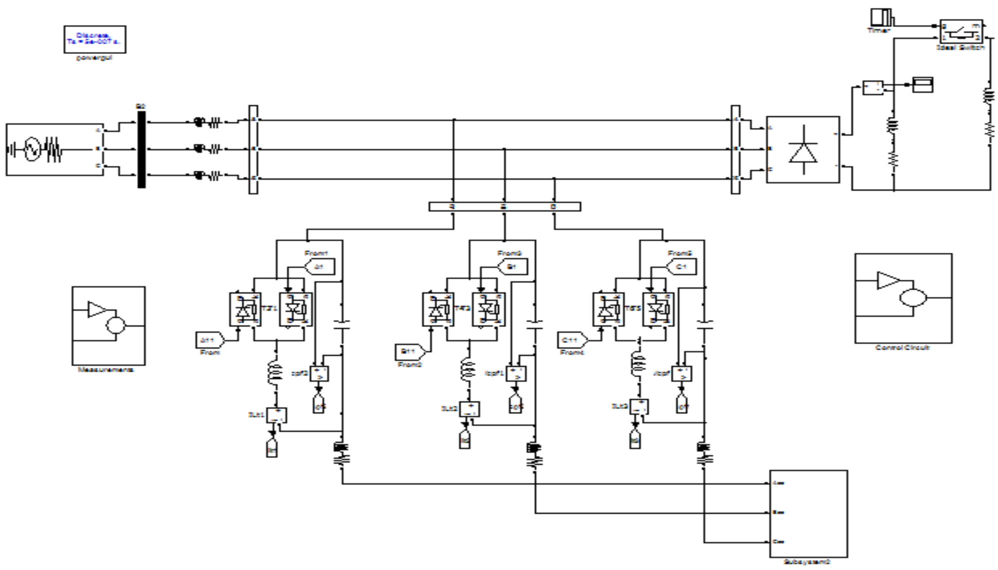

Fig. 6. *Circuit configuration of a combination of shunt hybrid power filter and thyristor-controlled reactor under sudden load (variation at DC load).*

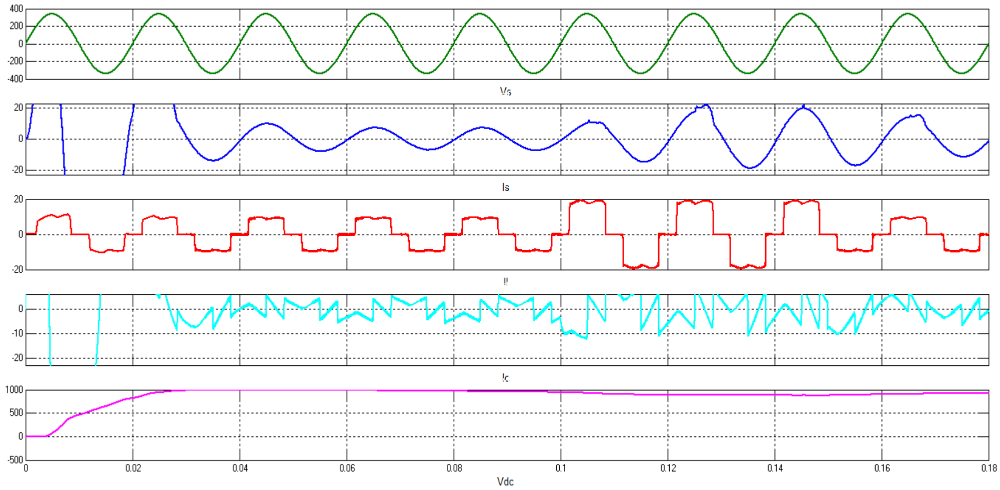

Fig. 7. *MATLAB-based waveforms of a combination of shunt hybrid power filter and thyristor-controlled reactor under sudden load (variation at DC load).*

V(S)V the above waveform represents voltage at source side with represent time in MATLAB software it shows no change in voltage at source because we are applied constant load so constant power required to drain load so that constant voltage will be applied from the source side.

I(S)A the waveform represents current source side and it all constant because constant load applied and Dynamic response configuration so the constant current from source.

I(L)A the above waveform represents load current with represent time and fast wave from constant of load of harmonic it all constant because load is not in change under Dynamic response constant.

I(C)A the above waveform represents capacitor charge with represent time and load current from dynamic response constant so that APF state charging and discharging that represent.

Vdc (V) voltage with represent time and Dynamic response constant from the perform load constant.

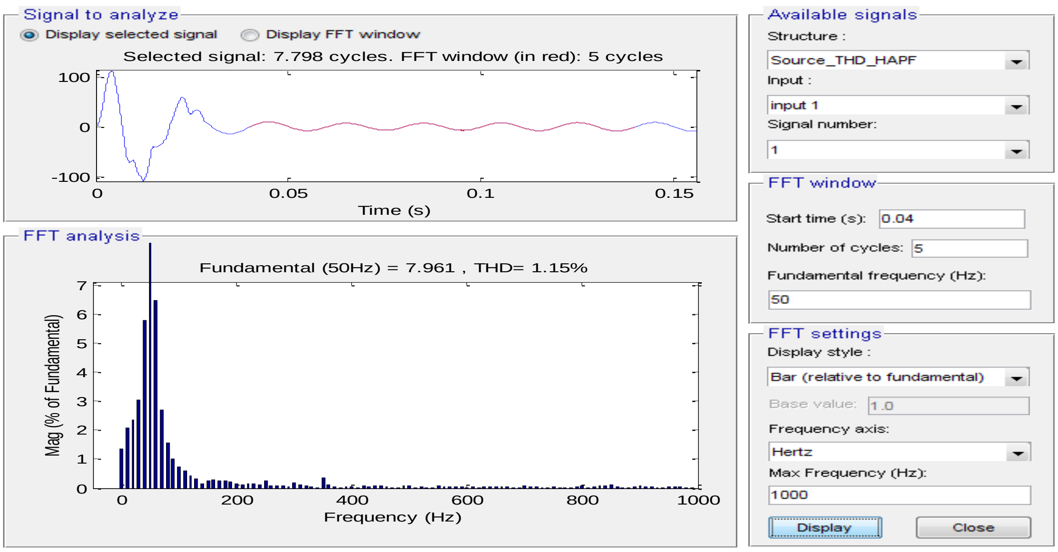

Fig. 8. *Harmonic order a combination of shunt hybrid power filter and thyristor-controlled reactor under sudden load (variation at DC load).*

 © JournalsPub 2017. All Rights Reserved

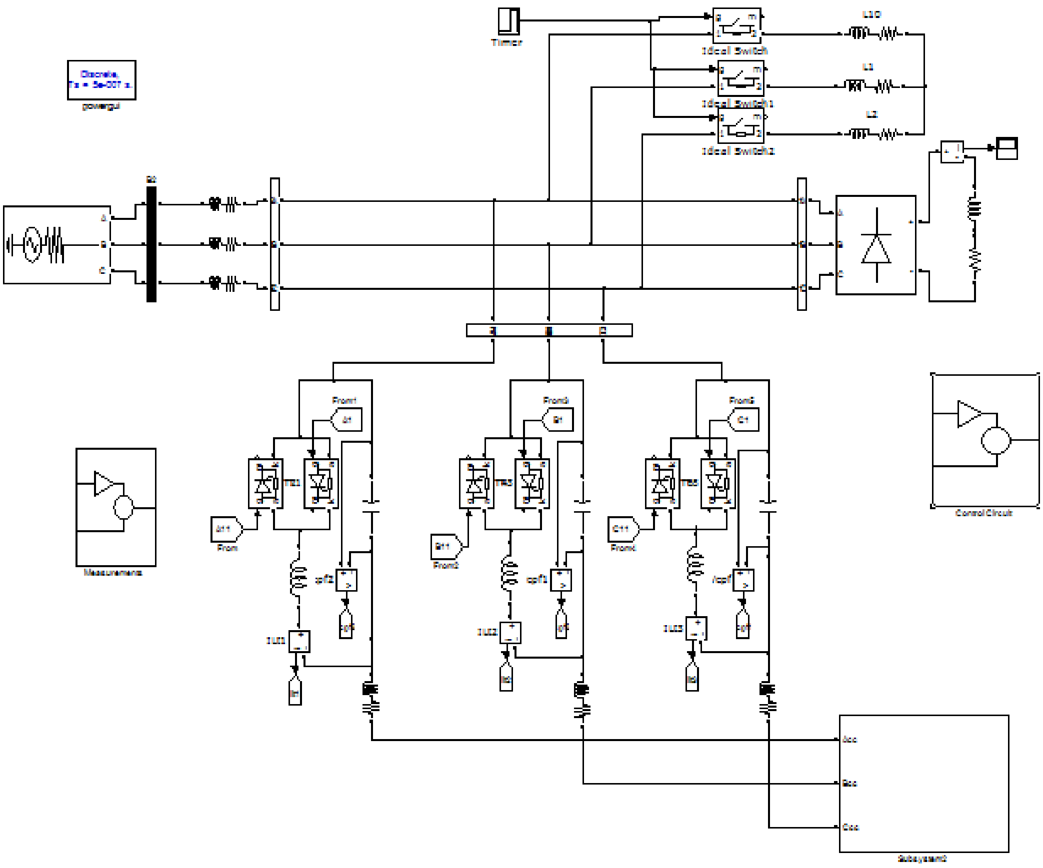

Fig. 9 *Circuit configuration of a combination of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor with reactive load*

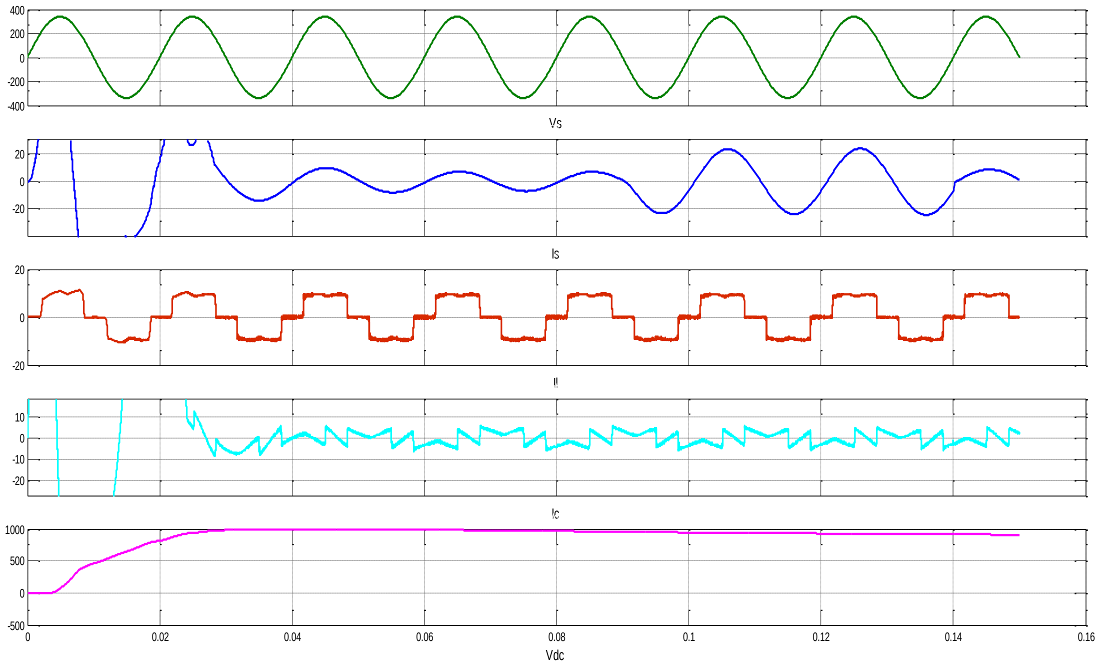

Fig. 10 *MATLAB based waveforms of A Combination of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor with reactive load*

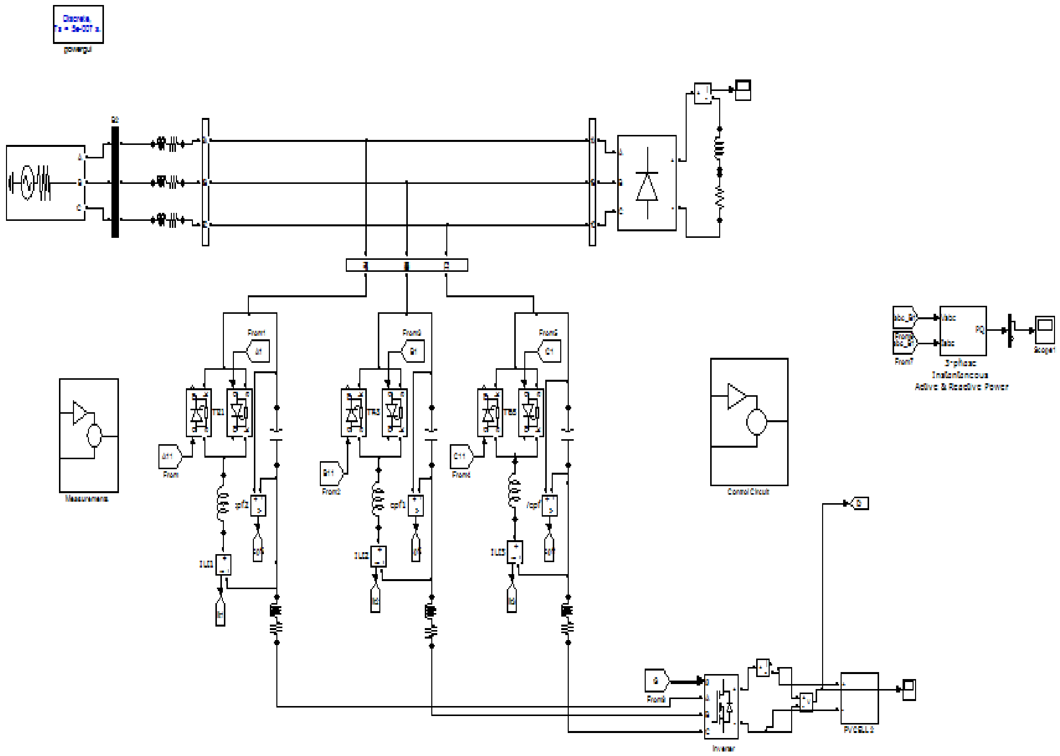

Fig. 11 *Circuit Configuration of PV fed Combined Shunt Hybrid Power Filter and Thyristor-Controlled Reactor with reactive load*

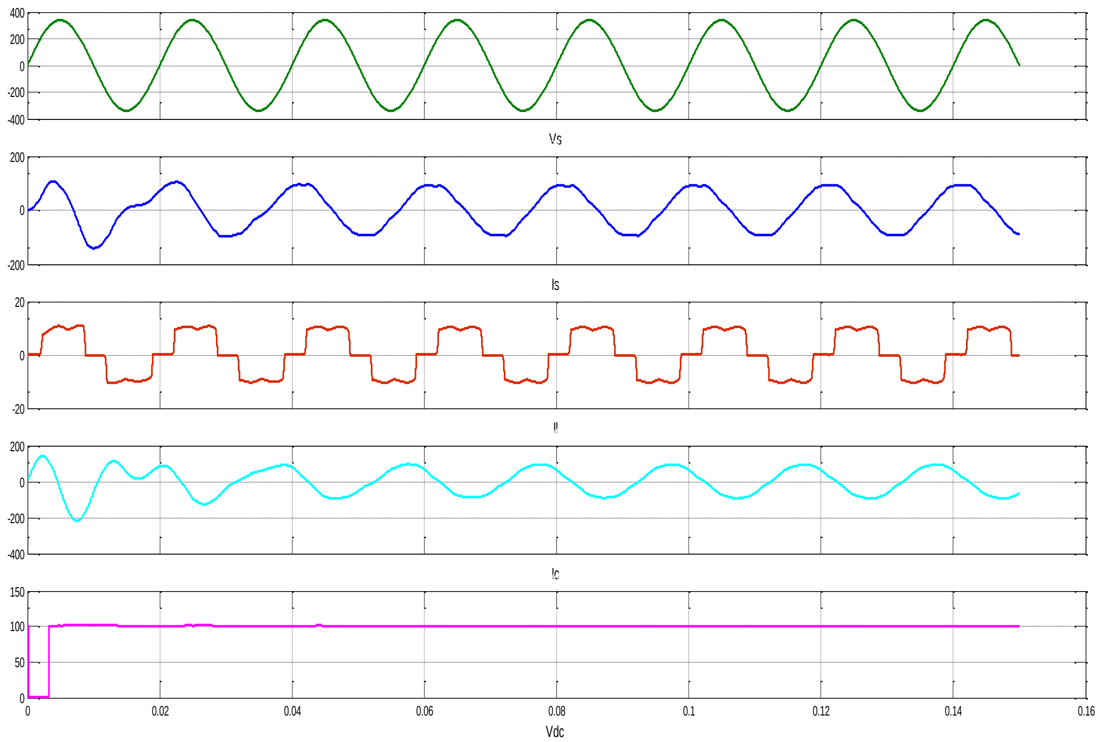

Fig. 12 *MATLAB based waveforms of PV fed Combined Shunt Hybrid Power Filter and Thyristor-Controlled Reactor with reactive load*

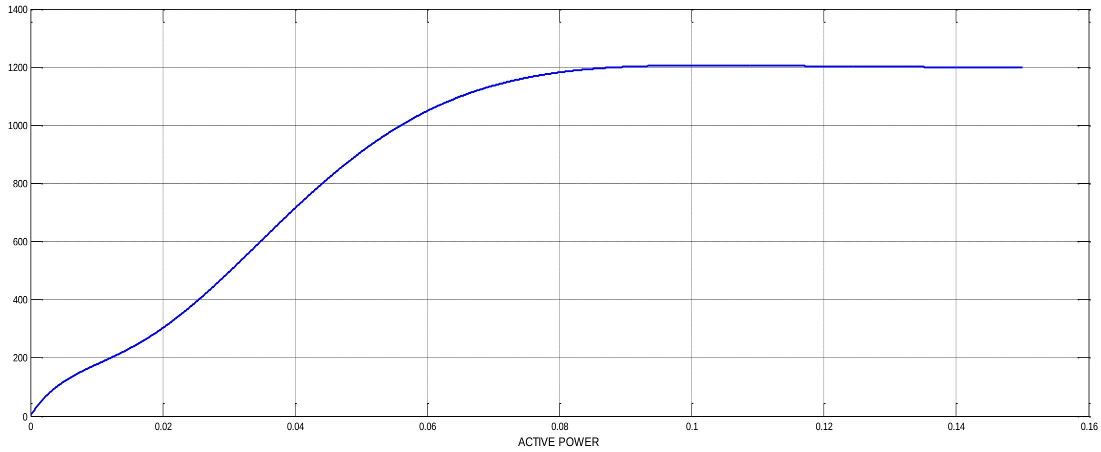

***Fig. 13** Instantaneous power injected from PV to grid*

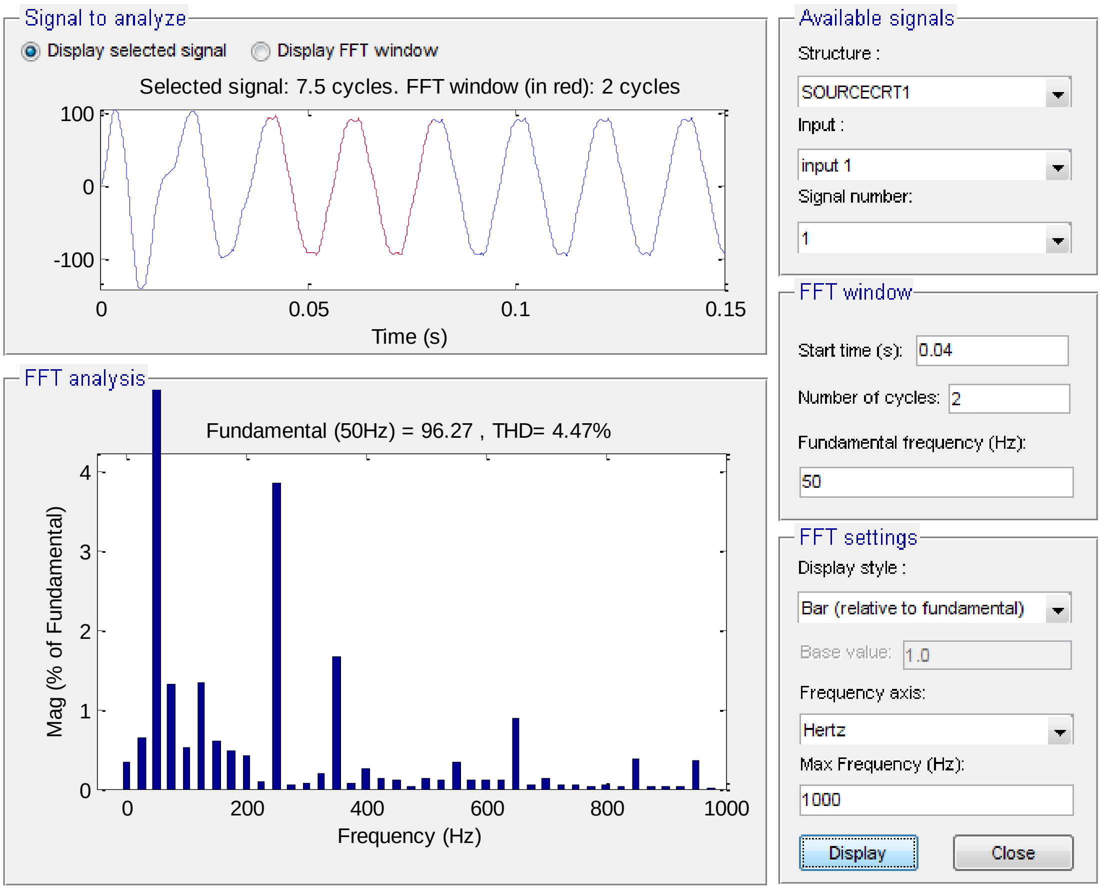

***Fig. 14** Harmonic order PV Fed Combined of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor*

CONCLUSION

In this paper, an SHPF-TCR compensator of a TCR and an SHPF has been proposed to achieve harmonic elimination and PV Fed SHPF-TCR compensator is also proposed. It has been shown that the grid-interfacing inverter can be efficiently consumed for power conditioning without affecting its normal operation of real power transfer. A proposed nonlinear control scheme of an SHPF-TCR compensator has been established and simulated. It has been found that the SHPF-TCR compensator can effectually eliminate current harmonic and reactive power compensation during both the steady as well as in the transient operating conditions for a variety of loads. It has been shown that the system has a fast-dynamic response, has good performance in both steady-state and dynamic operations. The simulation results obtained in this work and the current analysis serve as a fundamental step towards the design of control circuits for hardware implementation of the device in the future. In this paper, an SHPF-TCR compensator of a TCR and an SHPF has been proposed to achieve harmonic elimination and PV Fed SHPF-TCR compensator is also proposed. It has been shown that the grid-interfacing inverter can be efficiently consumed for power conditioning without affecting its normal operation of real power transfer. A proposed nonlinear control scheme of an SHPF-TCR compensator has been established and simulated. It has been found that the SHPF-TCR compensator can effectually eliminate current harmonic and reactive power compensation during both the steady as well as in the transient operating conditions for a variety of loads. It has been shown that the system has a fast-dynamic response, has good performance in both steady-state and dynamic operations. The simulation results obtained in this work and the current analysis serve as a fundamental step towards the design of control circuits for hardware implementation of the device in the future.

REFERENCES

[1] A. Hamadi, S. Rahmani, K. Al-Haddad. A hybrid passive filter configuration for VAR control and harmonic compensation, *IEEE Trans Ind Electron*. 2010; 57(7): 2419–34p.

[2] P. Flores, J. Dixon, M. Ortuzar, R. Carmi, P. Barriuso, L. Moran. Static Var compensator and active power filter with power injection capability, using 27-level inverters and photovoltaic cells, *IEEE Trans Ind Electron*. 2009; 56(1): 130–8p.

[3] H. Hu, W. Shi, Y. Lu, Y. Xing. Design considerations for DSP controlled 400 Hz shunt active power filter in an aircraft power system, *IEEE Trans Ind Electron*. 2012; 59(9): 3624–34p.

[4] X. Du, L. Zhou, H. Lu, H.-M. Tai. DC link active power filter for three-phase diode rectifier, *IEEE Trans Ind Electron*. 2012; 59(3): 1430–42p.

[5] M. Angulo, D.A. Ruiz-Caballero, J. Lago, M.L. Heldwein, S.A. Mussa. Active power filter control strategy with implicit closed loop current control and resonant controller, *IEEE Trans Ind Electron*. 2013; 60(7): 2721–30p.

[6] X. Wang, F. Zhuo, J. Li, L. Wang, S. Ni. Modeling and control of dual-stage high-power multifunctional PV system in d-q-0 coordinate, *IEEE Trans Ind Electron*. 2013; 60(4): 1556–70p.

[7] J.A. Munoz, J.R. Espinoza, C.R. Baier, L.A. Moran, E.E. Espinosa, P.E. Melin, D.G. Sbarbaro. Design of a discrete-time linear control strategy for a multicell UPQC, *IEEE Trans Ind Electron*. 2012; 59(10): 3797–807p.

[8] L. Junyi, P. Zanchetta, M. Degano, E. Lavopa. Control design and implementation for high performance shunt active filters in aircraft power grids, *IEEE Trans Ind Electron*. 2012; 59(9): 3604–13p.

[9] Y. Tang, P.C. Loh, P. Wang, F.H. Choo, F. Gao, F. Blaabjerg. Generalized design of high performance shunt active power filter with output LCL filter, *IEEE Trans Ind Electron*. 2012; 59(3): 1443–52p.

[10] Z. Chen, Y. Luo, M. Chen. Control and performance of a cascaded shunt active power filter for aircraft electric power system, *IEEE Trans Ind Electron*. 2012; 59(9): 3614–23p.
[11] S. Rahmani, A. Hamadi, K. Al-Haddad, A.I. Alolah. A DSP-based implementation of an instantaneous current control for a three-phase shunt hybrid power filter, *J Math Comput Simul Model Simul Elect Mach Convert Syst*. 2013; 91: 229–48p.
[12] C.S. Lam, W.H. Choi, M.C. Wong, Y.D. Han. Adaptive dc-link voltage-controlled hybrid active power filters for reactive power compensation, *IEEE Trans Power Electron*. 2012; 27(4): 1758–72p.
[13] A. Hamadi, S. Rahmani, K. Al-Haddad. Digital control of hybrid power filter adopting nonlinear control approach, *IEEE Trans Ind Informat*. to be published.
[14] A. Bhattacharya, C. Chakraborty, S. Bhattacharya. Parallel connected shunt hybrid active power filters operating at different switching frequencies for improved performance, *IEEE Trans Ind Electron*. 2012; 59(11): 4007–19p.
[15] S. Rahmani, A. Hamadi, N. Mendalek, K. Al-Haddad. A new control technique for three-phase shunt hybrid power filter, *IEEE Trans Ind Electron*. 2009; 56(8): 2904–15p.
[16] A. Luo, X. Xu, L. Fang, H. Fang, J. Wu, C. Wu. Feedback feedforward PI-type iterative learning control strategy for hybrid active power filter with injection circuit, *IEEE Trans Ind Electron*. 2010; 57(11): 3767–79p.
[17] S. Rahmani, A. Hamadi, K. Al-Haddad. A Lyapunov-function-based control for a three-phase shunt hybrid active filter, *IEEE Trans Ind Electron*. 2012; 59(3): 1418–29p.
[18] M.I. Milanés-Montero, E. Romero-Cadaval, F. Barrero-González. Hybrid multiconverter conditioner topology for high-power applications, *IEEE Trans Ind Electron*. 2011; 58(6): 2283–92p.