International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 13
October 2017

Simulation Modeling and Analysis of Reactive Power Compensation using Thyristor controlled LC Compensator in smart grid

G.Shahina[1], V.Nirmala Devi[2]
[1]M Tech student of Dr KVSRIT, KURNOOL, INDIA.
[2]HOD & Associate Professor, Department of EEE, Dr KVSRIT, KURNOOL,INDIA.

ABSTRACT

The Smart grid, regarded as the next-generation power grid, is considered as a promising solution for energy crisis. However, the development of smart grid brings many new challenges for power quality. Compared with traditional grid, the smart grid requires substantial renewable resources like the wind energy and the high demand of reactive power is one of the major power quality issues of wind farms.

In this thesis, a thyristor controlled LC (TCLC) compensator is proposed for dynamic reactive power compensation in smart grid. The simulations will be compared with traditional compensation methods. The effectiveness of TCLC performance can be implemented using Matlab Simulink.

Keywords— Harmonic currents rejection, reactive power Compensation, smart grid, thyristor controlled *LC* (TCLC) compensator and wind energy.

I. INTRODUCTION

A large number of nonlinear loads are used in applications at various power levels. Examples of nonlinear loads include variable speed drives, lighting systems, switch mode power supplies and many more types besides. These devices can cause distortion to the mains supply by drawing harmonic currents and voltages. Traditionally tuned passive filters have been used to attenuate the harmonic distortion. The use of passive filters is not desirable as they are bulky, de-tune with age and can resonate with the supply impedance. In order to overcome the limitations of passive filtering techniques, there has been much research activity in the use of active power filters (APF) to mitigate the harmonic distortion produced by semiconductor switched loads.

The APF has many advantages over using passive filters. The APF can be smaller, cheaper, more versatile, better damped, more selective and less prone to failure through component drift than its passive counterpart. It can also be used to compensate reactive power.

Wind energy is one of the fastest growing renewable energies in the world. The generation of wind power is clean and non-polluting; it does not produce any byproducts harmful to the environment. Nowadays, modeling is the basic tool for analysis, such as optimization, project, design and control. Wind energy conversion systems are very different in nature from conventional generators, and therefore dynamic studies must be addressed in order to integrate wind power into the power system. According to [Lubosny, 2003], in the case of power systems with classical sources of energy analysis, the modeling is relatively simple because the models of objects and controllers are well known and even standardized; the data are available. But in the case of wind turbine modeling, researchers meet problems related to the lack of data and lack of control-system structures due to strong competition between wind turbine manufacturers. This leads to the situation in which many researchers model the wind energy conversion systems in relatively simple form, almost neglecting the control systems, which significantly influence the reliability of the analytical results.

A. Objective of the thesis

The objective of this thesis is to design a thyristor controlled *LC* (TCLC) compensator for dynamic reactive power compensation in a smart grid system. Compared with the traditional static var compensators like a fixed capacitor-thyristor controlled reactor (FC-TCR) which generates low order harmonic currents, the proposed TCLC can significantly mitigate the injection of harmonic currents. In this thesis, the design of the TCLC parameters is investigated with the considerations of its reactive power compensation range and harmonic currents rejection. And a control method based on the generalized instantaneous reactive power theory is proposed. Moreover, representative simulation results of the proposed three-phase three-wire TCLC are presented to show its effectiveness in dynamic reactive power compensation in comparison with the traditional FC-TCR and parallel combination of FC-TCR and passive power filter. The simulations were performed in the environment of MATLAB/SIMULINK.

.

II. PROBLEM FORMULATION

The phenomenon of harmonic currents injection by the SVCs was firstly presented in 1985 [8]. However, there was no solution provided at that time. Years later, the authors in [15] and [16] suggested using parallel combination of SVC and passive power filter (SVC+PPF) to reduce the harmonic currents injection by the SVC. However, the oscillating time and cost of these combined systems can be significantly increased. Afterwards, the authors in [17]–[20] proposed the combined systems of the SVC and STATCOM, which can eliminate the harmonic currents injection by the SVC and compensate both the reactive power and harmonic currents of the nonlinear loads. By doing so, the initial cost of the combined systems can be very high. To reduce the initial cost, Kulkarni and Udupi [21] proposed an artificial neural network (ANN) approach to find the optimum trigger angles for the thyristor controlled reactor and thyristor switched capacitor (TCR-TSC) to reduce its harmonic currents injection. However, as the firing angles are probably not matching with the required compensating reactive power, the TCR-TSC may sacrifice its good reactive power compensation capability.

A thyristor controlled *LC* (TCLC) compensator is proposed in this thesis for dynamic reactive power compensation in smart grid. The contributions of this thesis are summarized as follows.

1. A low cost TCLC compensator is proposed for dynamic reactive power compensation with less harmonic injection.
2. Its parameter design method is proposed not only based on the consideration of the reactive power compensation range but also harmonic currents rejection analysis, which is different from the traditional SVCs.
3. Its corresponding control method is proposed based on the generalized instantaneous reactive power theory [10] instead of the traditional definition of reactive power [5]–[8].

III. CIRCUIT CONFIGURATION AND DESIGN PARAMETERS

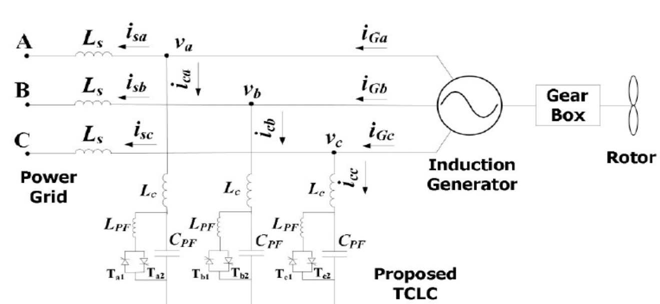


Fig.3.1. Circuit configuration of three-phase three-wire TCLC

The three-phase three-wire wind farm system with a shunt Connected TCLC compensator is shown in Fig.3.1. The subscript "*x*" denotes phase *a*, *b* and *c*. *Vx* is the grid voltage; *Isx*, *IGx* and *Icx* are the power grid system, wind farm generation and the TCLC compensating currents for each phase, Fig. 3.1. *Ls* is the system inductance; *Lc* is the coupling inductor of TCLC compensator; *LPF* and *CPF* are the parallel inductor and capacitor of the TCLC compensator. In Fig. 3.1, the detailed modeling and design procedures of wind turbine (WT) and generator are similar to those proposed in [22] and [23]. Due to page-length limit, the design of wind farm will not be included in this paper. Fig.3.1 shows that the TCLC compensator is composed of a coupling inductor *Lc* connected in series with the combination of a fixed capacitor *CPF* in parallel with a thyristor controlled reactor *TCR(α)*, *α* is the firing angle. Therefore, the equivalent fundamental impedance of the TCLC compensator can be expressed as:

$$X_{TCLC}(\alpha) = \frac{X_{TCR}(\alpha)\cdot X_{C_{PF}}}{X_{C_{PF}} - X_{TCR}(\alpha)} + X_{L_c} = \frac{\pi X_{L_{PF}} X_{C_{PF}}}{X_{C_{PF}}(2\pi - 2\alpha + sin2\alpha) - \pi X_{L_{PF}}} + X_{L_c}$$

Where, *XLc*, *XLPF* and *XCPF* are the fundamental impedances of the coupling inductor *Lc*, parallel inductor *LPF* and capacitor *CPF*, respectively. The equivalent fundamental impendence of the thyristor controlled reactor *TCR(α)* can be given as:

$$X_{TCR}(\alpha) = \frac{\pi}{2\pi - 2\alpha + sin2\alpha}\cdot X_{L_{PF}}$$

In addition, the proposed TCLC compensator can be connected in either star or delta connection, and the following analysis and discussion are valid for both cases.

In this section, the design parameters of TCLC compensator are proposed with the considerations of its reactive power compensation range and harmonic currents rejection. Based on the required reactive power compensation range, the parallel TCLC inductor (*LPF*) and capacitor (*CPF*) can be calculated accordingly. Through the harmonic currents rejection analysis, the design criteria of the coupling *Lc* can then be set. With the proposed design of *Lc*, the problem of harmonic currents injection by the thyristor controlled part can be significantly alleviated.

The purpose of the TCLC compensator is to provide the same amount of compensating reactive power *Qcx* as the wind farm generated reactive power Q_{GX}. The compensating reactive power *Qcx* is related to the controllable fundamental impedance of the TCLC compensator *XTCLC(α)* (1), which can be expressed as:

$$Q_{cx} = \frac{V_x^2}{X_{TCLC}(\alpha)} = \frac{V_x^2}{\frac{\pi X_{L_{PF}} X_{C_{PF}}}{X_{C_{PF}}(2\pi - 2\alpha + sin2\alpha) - \pi X_{L_{PF}}} + X_{L_c}}$$

where *Vx* is the root mean square (rms) phase grid voltage. In (3), the phase compensating reactive power *Qcx* depends on *XLc*, *XLPF*, *XCPF* and *α*. Hence, the required reactive power compensating range can be used to design the TCLC compensator parameters.

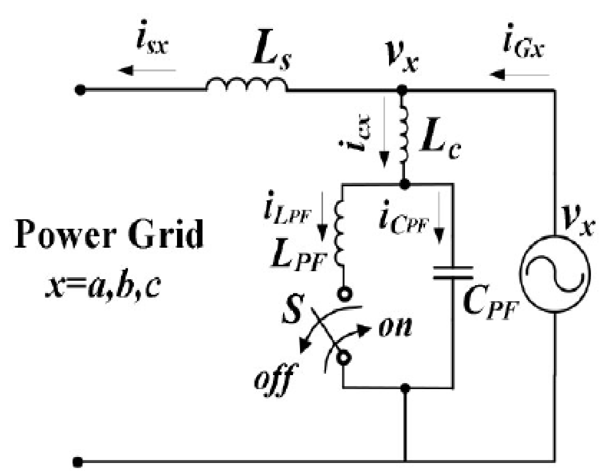


Fig.3.2. Equivalent single phase TCLC compensator model for harmonic currents rejection analysis

Then the corresponding harmonic ordersgenerated can be given as:

$$n_1 = \frac{\omega_1}{2\pi f} = \frac{1}{2\pi f\sqrt{L_c C_{PF}}}$$

$$n_2 = \frac{\omega_2}{2\pi f} = \frac{1}{2\pi f}\sqrt{\frac{L_c + L_{PF}}{L_c L_{PF} C_{PF}}}$$

where the harmonic orders $n1$ and $n2$ mainly depend on the Lc, LPF and CPF values.

IV. SIMULATION RESULTS

In this Chapter, the proposed model of simulation results is presented for both inductive and capacitive load. In order to validate the proposed topology, simulation is carried out using the Matlab/Simulink.

In this section, the compensating performances of the proposed TCLC compensator will be verified by simulations in comparison with the traditional FC-TCR and FC-TCR+PPF [15], [16].

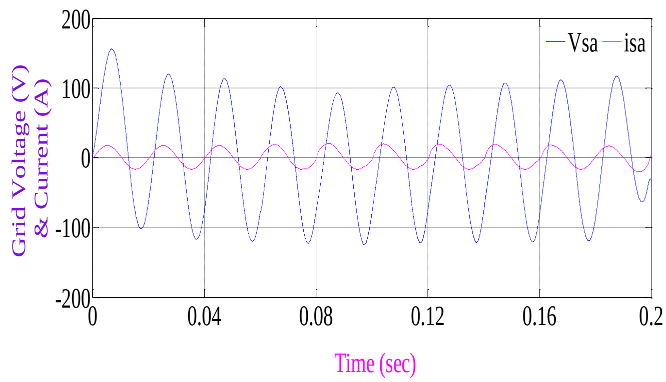
	Parameters	Physical values
Power Grid	v_x, f, L_s	110V, 50Hz, 1mH
FC-TCR	L_{PF}, C_{PF}	30mH,160μF
PPF of FC-TCR+PPF	L_P, C_P	8mH, 50μF
TCLC Compensator	L_c, L_{PF}, C_{PF}	5mH, 30mH,160μF

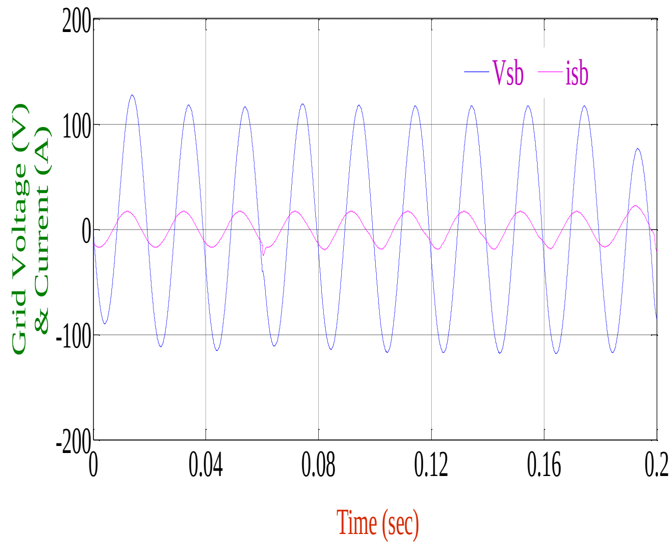
Table 4.1: System parameters of Power Grid and Compensators

When FC-TCR is applied, Fig. 4.1 and Fig.4.4, Table 4.2 show that the simulated power factors (PFs) of the worst phase have been compensated from the original 0.72 (inductive PF) and 0.66 (capacitive PF) to 0.98 for both cases. As shown in Fig. 4.1 and Fig.4.4, Fig. 4.7(a) and (d), the system current total harmonic distortions (*THDisx*) are increased after FC-TCR compensation.

When the TCLC compensator is applied, Figs. 4.3 and 4.6 and Table 4.1 show that the simulated PFs of the worst phase are compensated to close to unity for inductive and capacitive reactive power compensations. As shown in Figs. 4.3 and 4.6, and Figs.4.7(c) and (f), the simulated system current *THDisx* of the worst phase are compensated to 7.5% for inductive case and 8.1% for capacitive case, in which the simulated *THDisx* satisfies the IEEE, 519-2014 standards [25]. Moreover, Figs. 4.7(c) and (f) clearly show that much smaller 5th and 7th order harmonic currents are injected into the power grid system after TCLC compensation. In addition, Fig. 4.6 shows that the proposed TCLC compensator can dynamically compensate the inductive and capacitive reactive power.

Based on simulation results, both FC-TCR+PPF and the proposed TCLC compensator can achieve better performance than FC-TCR. Comparing FC-TCR+PPF with TCLC, they obtain similar compensation performances but TCLC requires fewer components, thus resulting in lower cost.





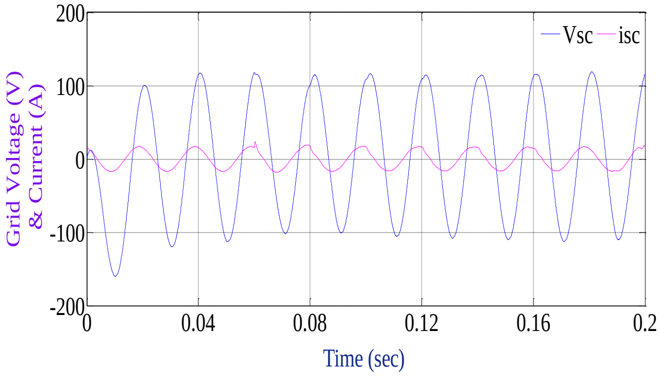


Fig.4.1: Inductive reactive power compensation using FC-TCR

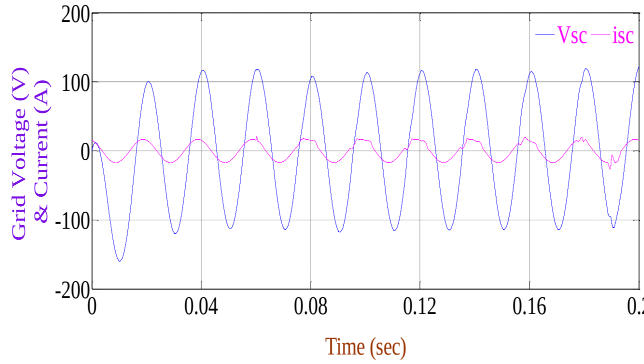
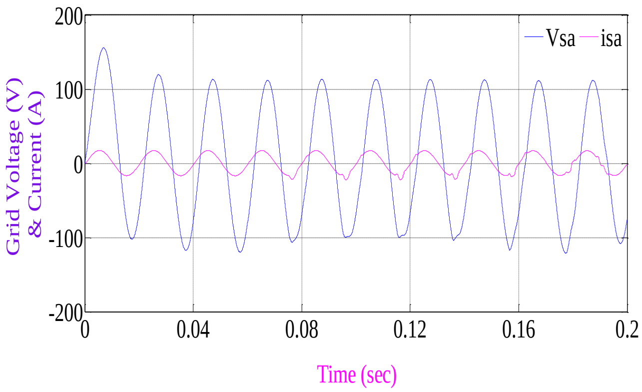
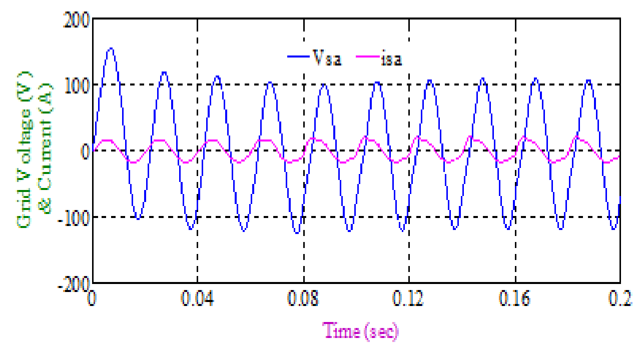
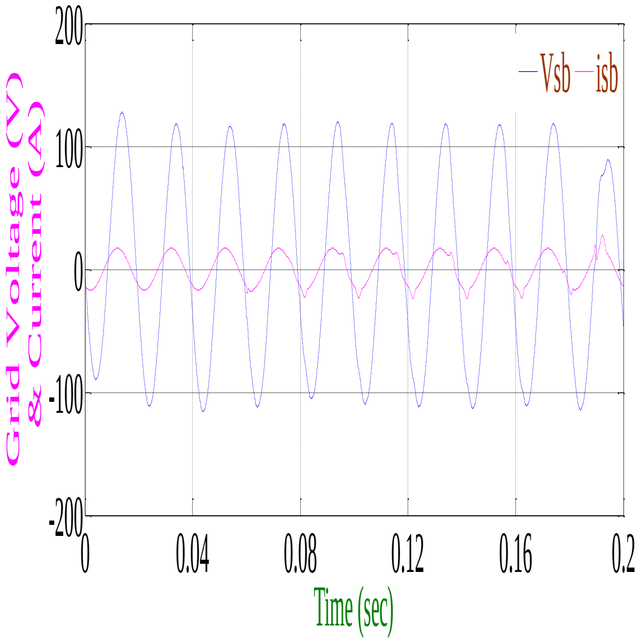
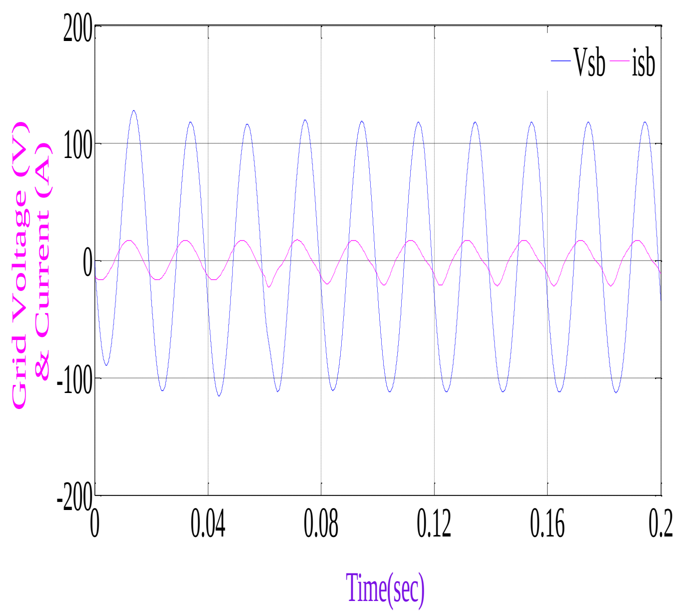


Fig.4.2: Inductive reactive power compensation using PPF









e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 13
October 2017

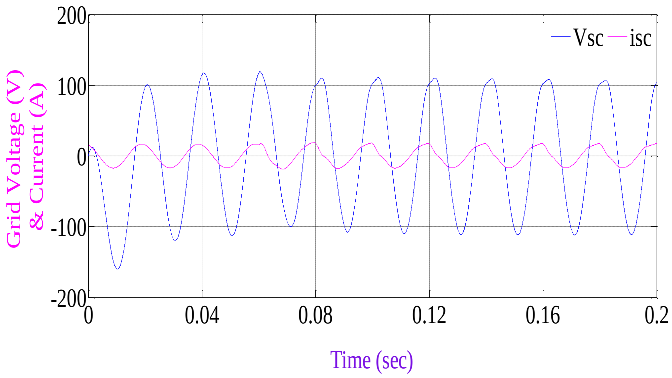
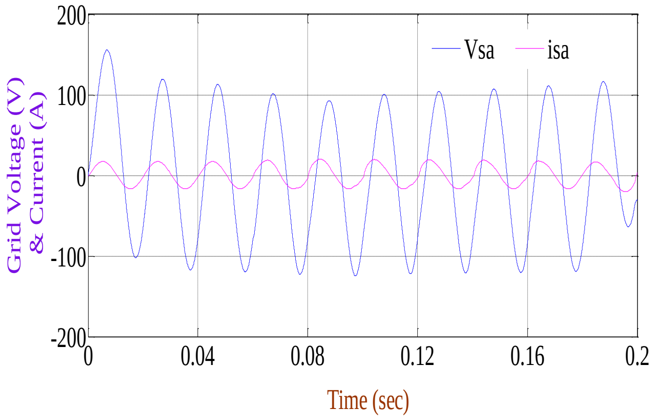
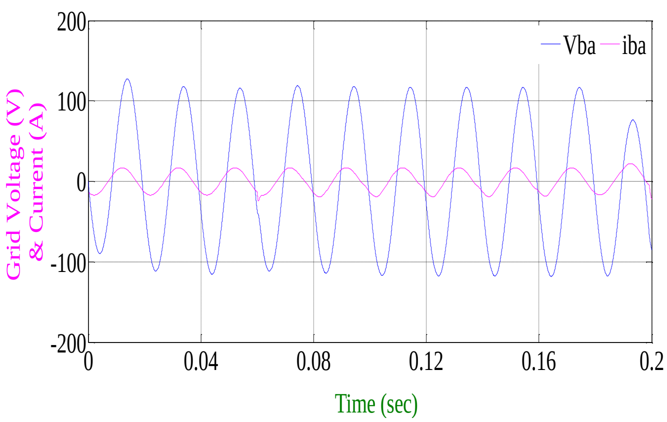


Fig.4.3: Inductive reactive power compensation using TCLC





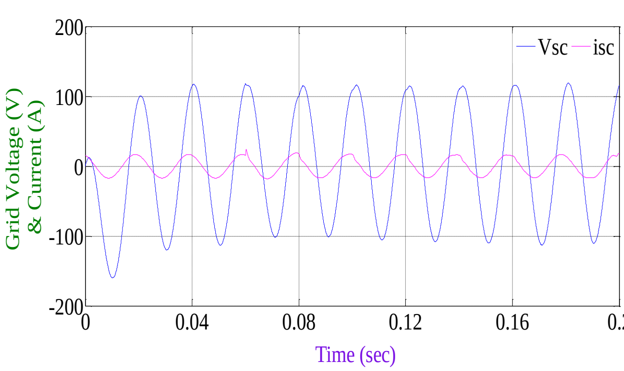
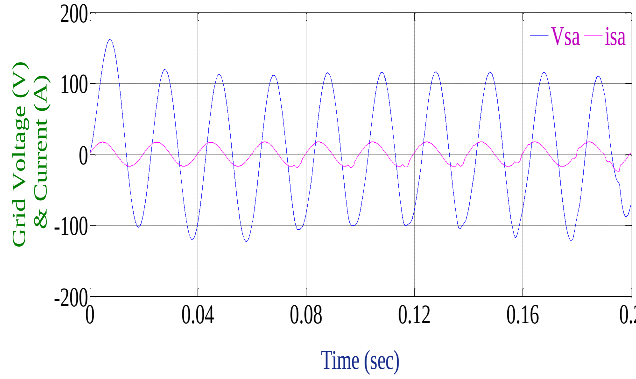
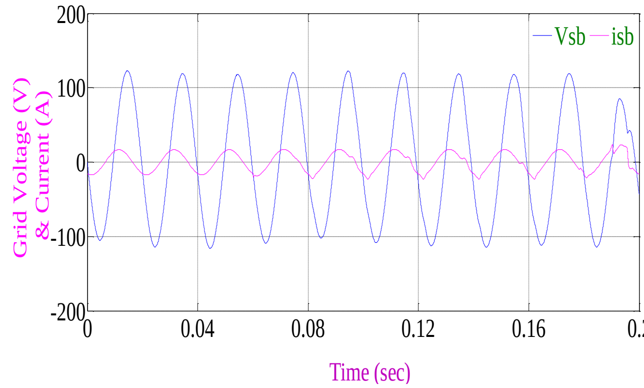


Fig.4.4: Capacitive reactive power compensation using FCTCR





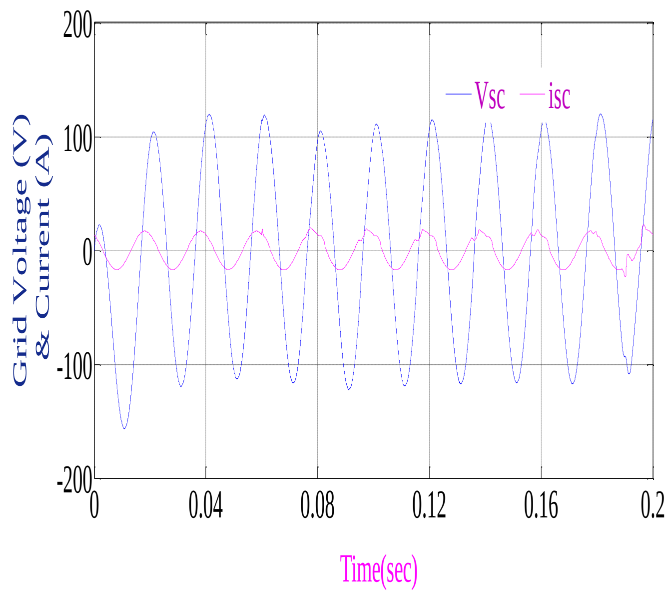


Fig.4.5: Capacitive reactive power compensation using PPF

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 13
October 2017

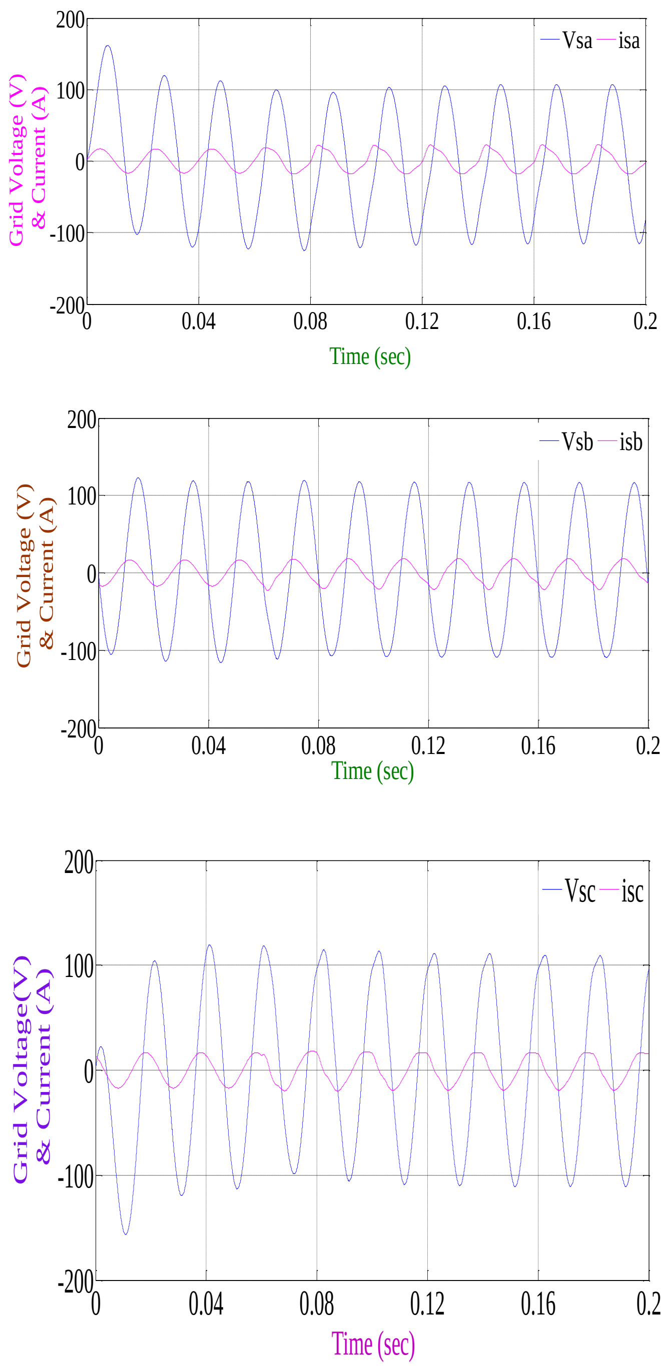


Fig.4.6: Capacitive reactive power compensation using TCLC

The simulations are carried out by using Matlab/Simulink. Table 5.1 shows the system parameters of the power grid, traditional FC-TCR, FC-TCR+PPF and the proposed TCLC compensator.

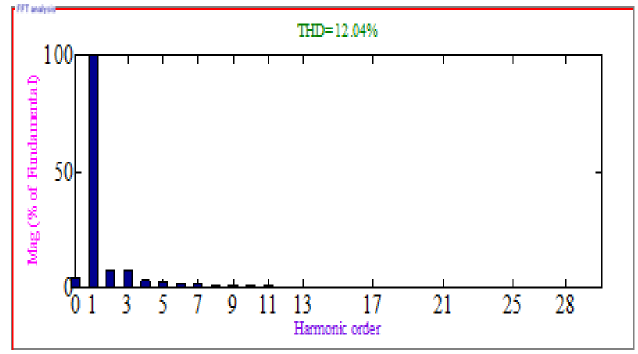


Fig.5.9a

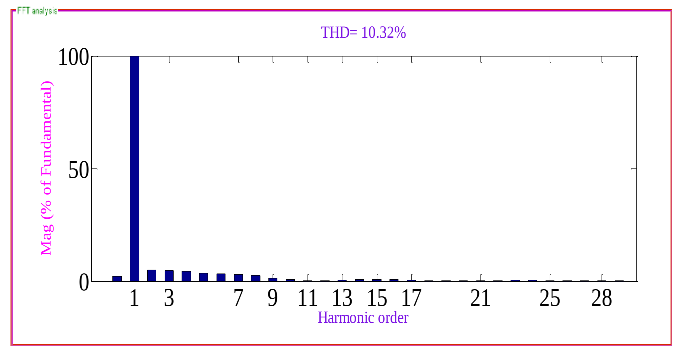


Fig.4.7b

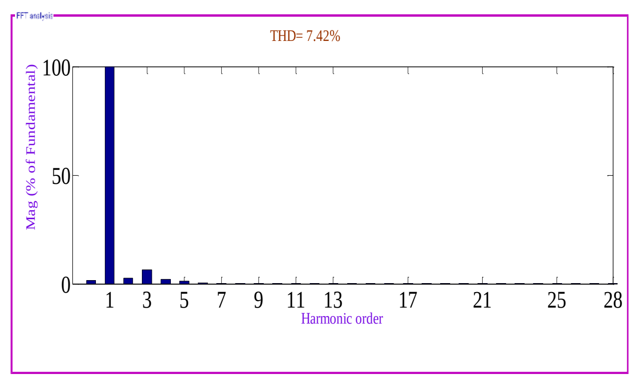


Fig.4.7c

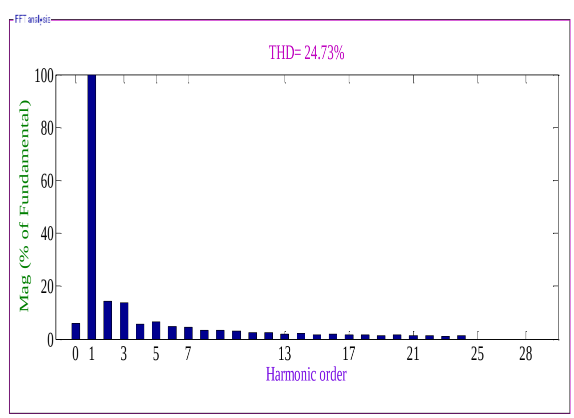


Fig.4.7d

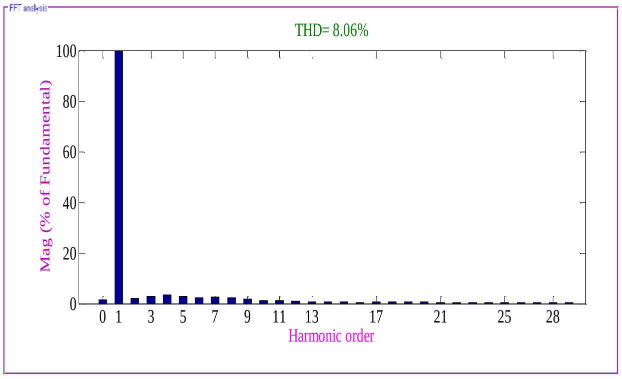


Fig.4.7e

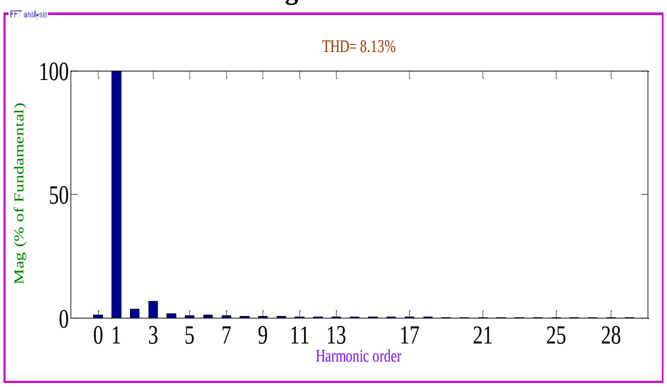
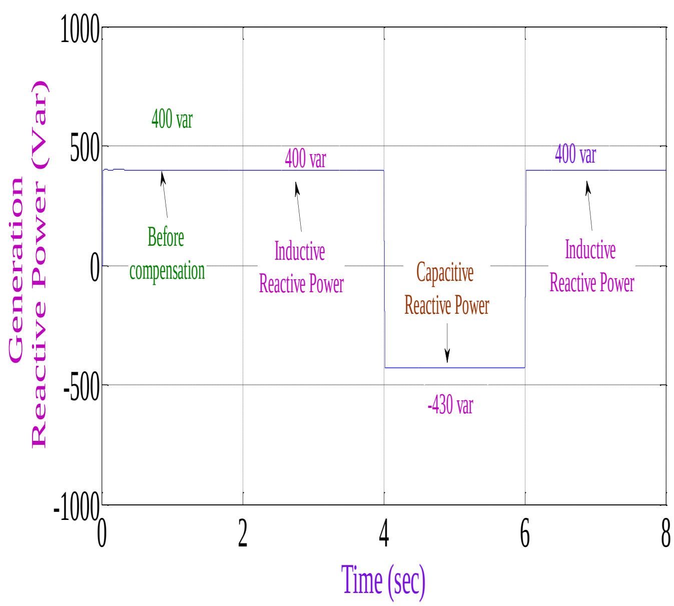


Fig.5.9f

Fig.4.7: Simulated grid systems current spectrums for inductive and capacitive reactive power compensation



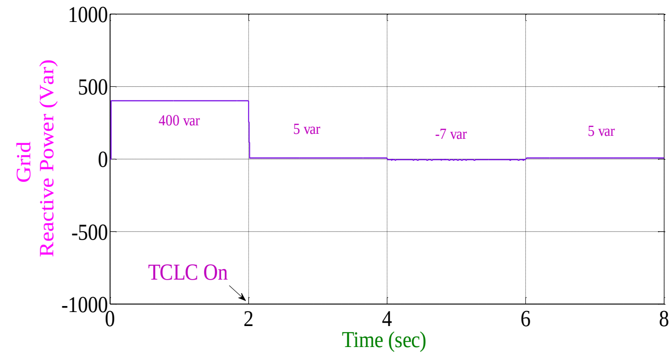


Fig.4.8: Simulation results of TCLC compensator dynamic reactive power compensation

	Inductive reactive power				Capacitive reactive power			
	Before Comp.,	FC-TCR	PPF	TCLC	Before Comp.,	FC-TCR	PPF	TCLC
i_{sx} (A)	6.102	3.9	3.9	3.899	5.07	3.6	3.501	3.501
Q_{sx} (var)	400	8.996	6.036	5.1	-430	-8.952	-7.149	-6.979
PF	0.731	0.98	0.99	0.99	0.66	0.98	0.99	0.99
THD_{vx} (%)	0.3	1.2	0.6	0.5	0.1	1.747	0.3	0.348
THD_{isx} (%)	0.1	12.04	10.33	7.501	0.17	24.72	8.08	8.104

Table 4.2: Simulation results for Inductive and Capacitive reactive power compensations

V. CONCLUSION

In this thesis, a three-phase three-wire TCLC compensator for dynamic reactive power compensation in a smart grid system is proposed, simulated and tested in the laboratory. The design of the TCLC parameters is proposed and discussed with the considerations of its reactive power compensation range and the harmonic currents rejection analysis and the control method is proposed based on the generalized instantaneous reactive power theory. From the simulation and experimental results, it is proved that the proposed TCLC compensator could provide dynamic reactive power compensation with acceptable grid voltage and system current *THD* levels, while the traditional FC-TCR may not satisfy the *THD* standard due to its self-harmonics injection characteristic of its thyristor controlled part. Even though this problem of FC-TCR can be reduced by adding PPF, the total cost of FC-TCR+PPF are significantly increased. Therefore, the proposed TCLC can be considered as a cost-effective solution for reactive power compensation with less harmonic injection in smart grid system.

VI. REFERENCES

[1]. X. Yuan, F. Wang, D. Boroyevich, Y. Li, and R. Burgos, "DC-link voltage control of a full power converter for wind generator operating in weak-grid systems," *IEEE Trans. Power Electron.*, vol. 24, no. 9, pp. 2178–2192, Sep. 2009.

[2]. H. Mahmood and J. Jiang, "Modeling and control system design of a grid connected VSC considering the effect of the interface transformer type," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 122–134, Mar. 2012.

[3]. R. G. Wandhare and V. Agarwal, "Reactive power capacity enhancement of a PV-grid system to increase PV penetration level in smart grid scenario," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1845–1854, Jul. 2014.

[4]. M. Glinkowski, J. Hou, and G. Rackliffe, "Advances in wind energy technologies in the context of smart grid," *Proc. IEEE*, vol. 99, no. 6, pp. 1083–1097, Jun. 2011.

[5]. R. A. Otto, T. H. Putman, and L. Gyugyi, "Principles and applications of static, thyristor-controlled shunt compensators," *IEEE Trans. Power App. Syst.*, vol. PAS-97, no. 5, pp. 1935–1945, Sep. 1978.

[6]. K.-J. Sun, "Thyristor control LC capacitance compensation circuit," Chinese Patent 201966624U, Sep. 7, 2011.

[7]. T. J. Dionise, "Assessing the performance of a static VAR compensation for an electric arc furnace," *IEEE Trans. Ind. Appl.*, vol. 50, no. 3, pp. 1619–1629, May/Jun. 2014.

[8]. S. E. Haque, N. H. Malik, and W. Shepherd, "Operation of a fixed capacitor-thyristor controlled reactor (FC-TCR) power factor compensator," *IEEE Trans. Power App. Syst.*, vol. PAS-104, no. 6, pp. 1385–1390, Jul. 1985.

[9]. B. Singh, R. Saha, A. Chandra, and K. Al-Haddad, "Static synchronous compensators (STATCOM): A review," *IET Power Electron.*, vol. 2, no. 4, pp. 297–324, Jul. 2009.

[10]. F. Z. Peng and J.-S. Lai, "Generalized instantaneous reactive power theory for three-phase power systems," *IEEE Trans. Instrum. Meas.*,vol. 45, no. 1, pp. 293–297, Feb. 1996.

[11]. X. Lu, K. L. V. Iyer, K. Mukherjee, and N. C. Kar, "A wavelet/PSO based voltage regulation scheme and suitability analysis of copper and aluminum-rotor induction machines for distributed wind power generation," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1923–1934, Dec. 2012.

[12]. X. Luo *et al.*, "Distributed voltage control with electric springs: Comparison with STATCOM," *IEEE Trans. Smart Grid*, vol. 6, no. 1, pp. 209–219, Jan. 2015.

[13]. K. Habur and D. O'Leary, *Facts for Cost Effective and Reliable Transmission of Electrical Energy*, Siemens, Berlin, Germany, 2004.

[14]. L. M. Tolbert *et al.*, "Power electronics for distributed energy systems and transmission and distribution applications: Assessing the technical needs for utility applications," Oak Ridge Nat. Lab., Oak Ridge, TN, USA, Tech. Rep. ORNL/TM-2005/230, Dec. 2005.

[15]. J. S. Benton, "Virtual instrument measures harmonic filter duty," *IEEE Comput. Appl. Power*, vol. 8, no. 4, pp. 43–46, Oct. 1995.

[16]. L. Zanotto *et al.*, "Filter design for harmonic reduction in high-voltage booster for railway applications," *IEEE Trans. Power Del.*, vol. 20, no. 1, pp. 258–263, Jan. 2005.

[17]. A. Luo, Z. Shuai, W. Zhu, and Z. J. Shen, "Combined system for harmonic suppression and reactive power compensation," *IEEE Trans. Ind. Electron.*, vol. 56, no. 2, pp. 418–428, Feb. 2009.

[18]. L. Wang, C.-S. Lam, and M. C. Wong, "An unbalanced control strategy for a thyristor controlled LC-coupling hybrid active power filter (TCLC-HAPF) in three-phase three-wire systems," *IEEE Trans. Power Electron.*, to be published, doi: 10.1109/TPEL.2016.2555330.

[19]. L. Wang, C.-S. Lam, and M.-C. Wong, "A hybrid-STATCOM with wide compensation range and low DC-link voltage," *IEEE Trans. Ind. Electron.*, vol. 63, no. 6, pp. 3333–3343, Jun. 2016.

[20]. S. Rahmani, A. Hamadi, K. Al-Haddad, and L. A. Dessaint, "A combination of shunt hybrid power filter and thyristor-controlled reactor for power quality," *IEEE Trans. Ind. Electron.*, vol. 61, no. 5, pp. 2152–2164, May 2014.

[21]. D. B. Kulkarni and G. R. Udupi, "ANN-based SVC switching at distribution level for minimal-injected harmonics," *IEEE Trans. Power Del.*, vol. 25, no. 3, pp. 1978–1985, Jul. 2010.

[22]. W. Qiao, G. K. Venayagamoorthy, and R. G. Harley, "Real-time implementation of a STATCOM on a wind farm equipped with doubly fed induction generators," *IEEE Trans. Ind. Appl.*, vol. 45, no. 1, pp. 98–107, Jan./Feb. 2009.

[23]. L. Wang and K.-H. Wang, "Dynamic stability analysis of a DFIG-based offshore wind farm connected to a power grid through an HVDC link," *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 1501–1510, Aug. 2011.

[24]. L. Wang, C.-S. Lam, and M.-C. Wong, "Hardware and software design of a low DC-link voltage and wide compensation range thyristor controlled LC-coupling hybrid active power filter," in *Proc. Region Conf. (TENCON)*, Nov. 2015, pp. 1–4.

[25]. *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, IEEE Standard 519-2014, 2014.

[26]. L. Wang *et al.*, "Non-linear adaptive hysteresis band pulse-width modulation control for hybrid active power filters to reduce switching loss," *IET Power Electron.*, vol. 8, no. 11, pp. 2156–2167, Nov. 2015.

[27]. M.-C. Wong *et al.*, "Self-reconfiguration property of a mixed signal controller for improving power quality compensation during light loading," *IEEE Trans. Power Electron.*, vol. 30, no. 10, pp. 5938–5951, Oct. 2015.