www.rericjournal.ait.ac.th

Performance Analysis of DSTATCOM for Three Phase Three Wire Distribution System

Aseem K.*[,1], V. Vanitha*, and Selva Kumar S.*

Abstract – *During the last few decades, many research works have been reported in the area of harmonics and reactive power compensation, focusing on both control techniques and power electronic circuit topologies. Nowadays, nonlinear type of residential loads and industrial loads are used increasingly, which cause a large amount of harmonics in the power system. This paper presents an analysis of the performance of distribution static compensator (DSTATCOM) for different types of non-linear loads like diode rectifier, semi converter and controlled rectifier with RL and RLE loads. Different control methods such as instantaneous reactive power theory (IRP), synchronous reference frame theory (SRF) and synchronous detection method (SDM) are used for generating reference currents for DSTATCOM and the results are presented and compared.*

Keywords – *DSTATCOM, instantaneous reactive power theory, power quality, synchronous reference frame, synchronous detection method.*

1. INTRODUCTION

Single phase and three phase nonlinear loads in power system result in production of harmonics and the reactive power consumption leads to distorted and out of phase voltage and current waveforms. These power quality problems cause the deterioration of power factor and hence the derating and heating of equipment. Custom power devices such as DSTATCOM, DVR etc. come up with a solution to these problems faced by the utilities. Just like flexible AC transmission system (FACTS) in transmission side, custom power devices are used in the distribution system to supply value-added power to the customers. DSTATCOM is a shunt type power electronic controller used in the custom power solution which compensates load by correcting its power factor and improve the quality of supply voltage and current. Figure 1 shows the ideal DSTATCOM connected in a network. The ideal behavior of DSTATCOM is represented by the current source I_f. The load 2 is assumed to be reactive, unbalanced and nonlinear type. In the absence of I_f, source has to supply harmonic and reactive components of load current, which will have an impact on load 1. If DSTATCOM is connected at the point of common coupling (PCC), it supplies I_f such that it makes the source current free from any reactive, and harmonic components. DSTATCOM can also be used for supplying unbalanced currents of load and also it can perform voltage regulation.

Figure 2 shows the three phase three wire system with DSTATCOM, which consists of a voltage source inverter (VSI), supplied by a DC link capacitor.

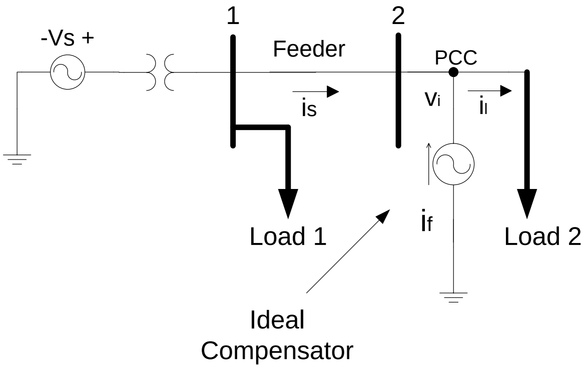

Fig. 1. Ideal load compensator.

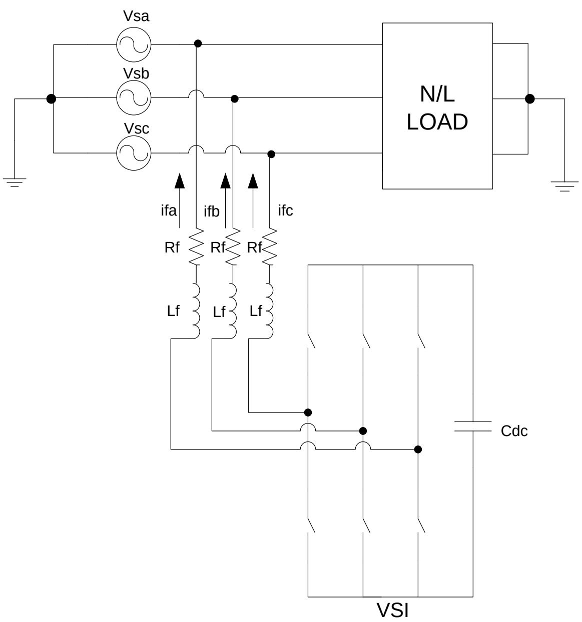

Fig. 2. Three phase three wire system with DSTATCOM.

*Department of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.

[1] Corresponding author;
Tel: + 91 9496463548
E-mail: azieee@gmail.com.

The DC bus voltage should be greater than double the maximum value of the per phase voltage of the system. DC capacitor value depends on the energy required during transients. The inverter consists of IGBT/GTO switches, which are controlled in such a way that the injected current completely follows the reference current generated by control methods. Each leg of VSI is connected to PCC through interfacing reactors.

2. SYSTEM UNDER STUDY AND CONTROL ALGORITHMS

Table 1 shows the specifications of the three phase system under study. Table 2 shows the parameters of DSTATCOM.

Table 1. Specifications of the system under study.

3 Phase Supply	Source Impedance	$R_s = 0.02\Omega$	$L_s = 1.9mH$
	Line-Line Voltage	$415V$	
	Frequency	$50Hz$	
Non Linear Load	Types	Three phase diode bridge rectifier, Semi converter and Controlled rectifier with RL and RLE loads	
		$P = 2.5KW$	$Q = 1.45KVAR$
		$0.866\, pf\ lag$	

Table 2. STATCOM parameters.

DC link Voltage	$V_{dc} = 680V$	
DC link Capacitance	$C_{dc} = 2000\mu F$	
Coupling Inductance	$L = 6.5mH$	
PI Controller	$K_p = 0.4$	$K_i = 20$
VSI Switching frequency	$f_s = 10KHz$	

The compensator must inject current such that source current becomes harmonic free and has unity power factor with respect to source voltage. Reference current generation for DSTATCOM is carried out by three methods such as Synchronous detection method, Synchronous reference frame theory and Instantaneous reactive power theory. In synchronous detection method, load currents, source currents, terminal voltages and DC bus voltage are sensed as feedback signals. These are used for average power calculation to generate the reference source currents. In synchronous reference frame strategy, the three phase voltages and load currents are transformed into α-β plane. Then, d-q load current components are derived from a synchronous reference frame based on the Park's transformation, from which the compensating currents are generated. In instantaneous reactive power theory, instantaneous real power and reactive power are split into DC and AC components by transforming source voltage and load current from abc to α-β plane. The reference currents are generated from the reactive power to be compensated by the DSTATCOM.

3. SIMULATION RESULTS AND COMPARITIVE STUDY

3.1 Without Compensation

The three phase system is simulated in MATLAB/SIMULINK with different types of non-linear loads and different algorithms. Various nonlinear loads are used for analysis such as diode rectifier with RL and RLE load, controlled and semi controlled converter with different firing angels.

The system is analysed with these loads without any compensation. Table 3 shows current THD, phase angle and power factor for an uncompensated system. From the results, it is seen that the current THD is high and power factor is reduced for all types of loads. As the firing angle of controlled rectifier increases, more harmonics are injected into the grid. The power factor deteriorates and THD of the source current increases accordingly.

For the controlled rectifier with RL load, even though THD is 25.17% with zero firing angle, the power factor is maintained at 0.95. But as the firing angle increases to 60 degree, the power factor drastically reduced to 0.49. The decrease in the power factor is an indication of the requirement of reactive power. Figures 3, 4 and 5 show the respective source voltage and source current waveforms for diode rectifier, controlled rectifier and semi converter with RLE load.

3.2 With DSTATCOM

Three phase system with DSTATCOM is simulated for different loads and the results are tabulated for different algorithms in Table 4. From the analysis of these results, it is seen that the reactive power compensation is done by DSTATCOM and the power factor improvement is satisfactorily achieved with all three methods under all load conditions. But, the harmonic reduction is much unsatisfactory for higher firing angles. FFT analysis of source current and its THD for controlled rectifier of

2020 Published by RERIC in International Energy Journal (IEJ). Selection and/or peer-reviewed under the responsibility of the Organizers of the **"Artificial Intelligence, Smart Grid and Smart City Applications (AISGSC-2019)"** and the Guest Editors: Dr. L. Ashok Kumar and Dr. R. Latha (PSG College of TechnologyCoimbatore-641 004, Tamilnadu, India.
www.rericjournal.ait.ac.th

firing angle 30° with RLE load are shown in Figure 6. The current THD with SRF is 5.79%. Figure 7 shows the waveform of DC link voltage of DSTATCOM. DC voltage is maintained at 800V by the PI controller. Figures 8, 9 and 10 show the waveforms of source voltage, source current and compensating current for the diode rectifier with RLE load using SDM, SRF and IRP methods respectively. From the results, it is clear that the source voltage and current are in phase and hence the reactive power compensation function performed by DSTATCOM. The current waveform is sinusoidal which shows the DSTATCOM harmonic compensation.

Figures 11, 12 and 13 show the source voltage, source current and compensating current with controlled rectifier and RLE load using SDM, SRF and IRP control methods respectively. Figures 14, 15 and 16 show the source voltage, source current and compensating current with semi converter and RLE load using SDM, SRF and IRP control methods, respectively. Figures 17 to 22 shows the bar chart for the comparison of performances of DSTATCOM in terms of THD and power factor under various load conditions with three different control strategies.

Table 3. Current THD, phase angle and power factor without compensation.

Diode Rectifier with RL			Diode Rectifier with RLE			Controlled Rectifier with RL				Controlled Rectifier with RLE				Semi converter with RL				Semi converter with RLE			
THD	Phase angle	Power factor	THD	Phase angle	Power factor	Firing angle	THD	Phase angle	Power factor	Firing angle	THD	Phase angle	Power factor	Firing angle	THD	Phase angle	Power factor	Firing angle	THD	Phase angle	Power factor
						0°	25.2	17.4	0.95	0°	25.82	17.1	0.96	0°	33.9	27.6	0.88	0°	34.9	27.2	0.88
28.9	16.5	0.96	29.2	16.7	0.96	30^0	30.2	34.8	0.82	30^0	30.79	34.4	0.83	30^0	58.9	43.4	0.73	30^0	61.1	43.2	0.73
						60^0	33.7	60.6	0.49	60^0	36.94	59.7	0.5	60^0	75.9	58.7	0.52	60^0	80.6	59.2	0.51

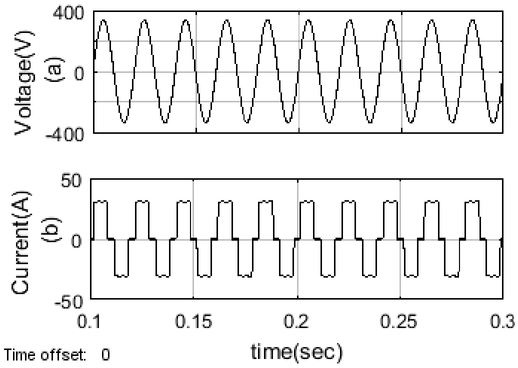

Fig. 3. Source voltage and source current for diode rectifier with RLE load without compensation.

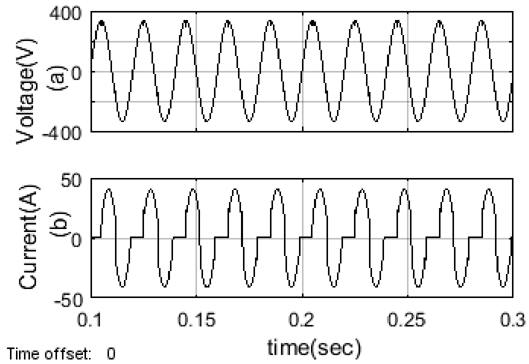

Fig. 4. Source voltage and source current for controlled rectifier with RLE load without compensation.

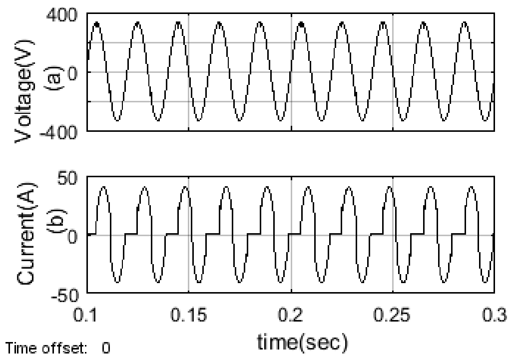

Fig. 5. Source voltage and source current for semi converter with RLE load without compensation.

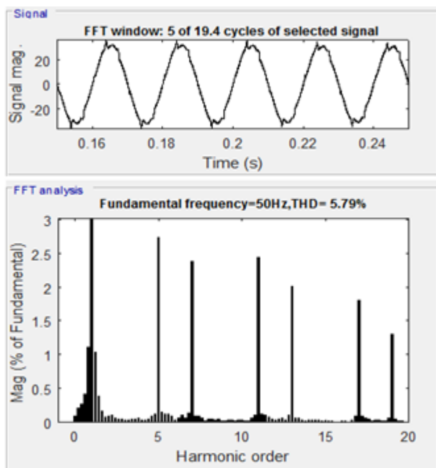

Fig. 6. FFT window and THD plot (controlled rectifier with RLE load and SRF method).

Table 4. Current THD, phase angle and power factor with DSTATCOM.

Diode Rectifier with RL				Diode Rectifier with RLE				Controlled Rectifier with RL					Controlled Rectifier with RLE					Semiconverter with RL					Semiconverter with RLE				
Method	THD	Phase angle	Power factor	Method	THD	Phase angle	Power factor	Method	Firing angle	THD	Phase angle	Power factor	Method	Firing angle	THD	Phase angle	Power factor	Method	Firing angle	THD	Phase angle	Power factor	Method	Firing angle	THD	Phase angle	Power factor
SRF	1.9	1.1	1	SRF	2	1.2	1		0°	2.1	1.2	1		0°	1.9	1.1	1		0°	9.4	5.4	1		0°	9.2	5.4	1
SDM	5.4	5.02	0.99	SDM	5.1	4.94	0.99	SRF	30°	3.56	2.05	0.99	SRF	30°	5.4	3.33	0.99	SRF	30°	19	11	0.98	SRF	30°	24.2	13.7	0.97
IRP	6.5	4.56	0.99	IRP	5.76	5.03	0.99		60°	26.6	15.2	0.96		60°	22.2	12.6	0.97		60°	44.3	23.9	0.91		60°	53.2	28	0.88
									0°	2	4	1		0°	2	4	1		0°	8	5	1		0°	7	5	1
								SDM	30°	6.8	5.37	0.99	SDM	30°	7.2	5.25	0.99	SDM	30°	14.2	8.7	0.98	SDM	30°	14	8.6	0.98
									60°	23.3	15.4	0.96		60°	23	13.4	0.97		60°	20.5	12	0.97		60°	14	13.5	0.97
									0°	7.1	5.2	0.99		0°	7.1	5.2	0.99		0°	14.7	8.94	0.98		0°	14	9.4	0.98
								IRP	30°	16.7	9.98	0.98	IRP	30°	17.3	10.4	0.98	IRP	30°	42.4	23.1	0.91	IRP	30°	14	24.1	0.91
									60°	50.4	26.9	0.89		60°	50.8	27.1	0.89		60°	75.4	37.3	0.79		60°	14	38.6	0.78

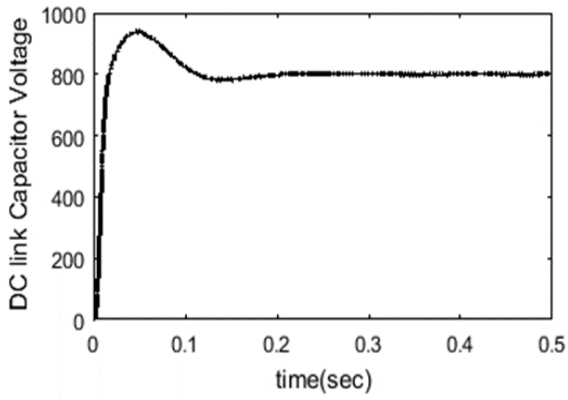

Fig. 7. DC link capacitor voltage.

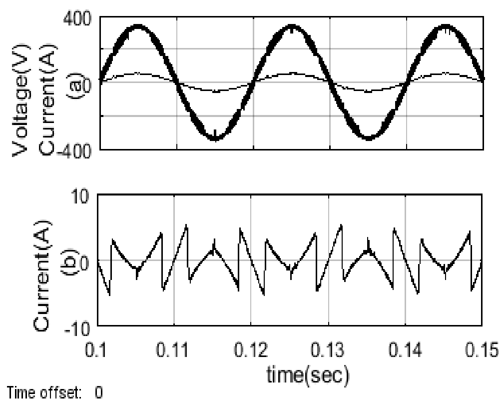

Fig. 8. Diode rectifier with RLE load with compensation (SDM) (a) source voltage and current (b) compensating current.

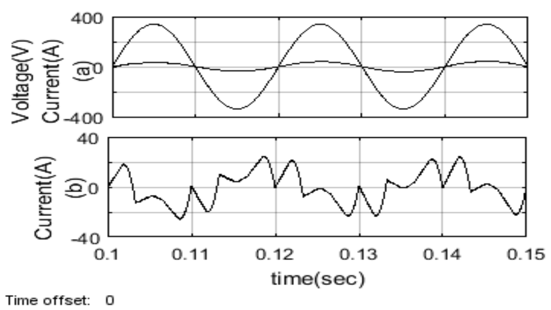

Fig. 9. Diode rectifier with RLE load with compensation (SRF) (a) source voltage and current (b) compensating current.

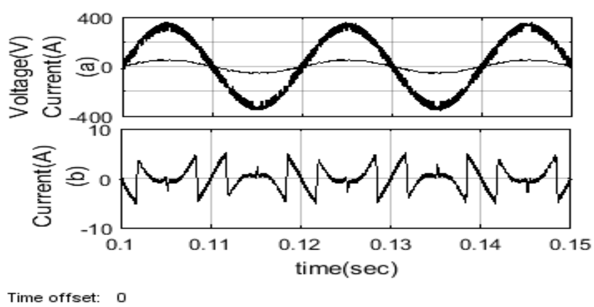

Fig. 10. Diode rectifier with RLE load with compensation (IRP) (a) source voltage and current (b) compensating current.

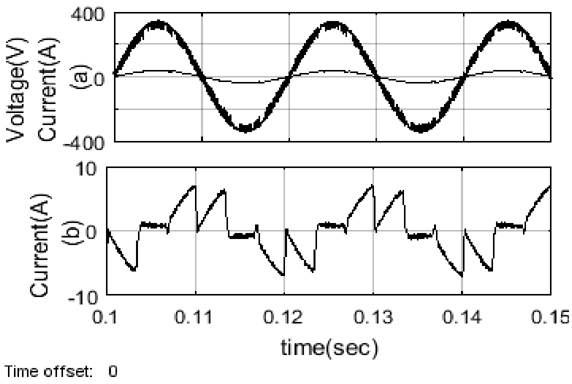

Fig. 11. Controlled rectifier with RLE load with compensation (SDM) (a) source voltage and current (b) compensating current.

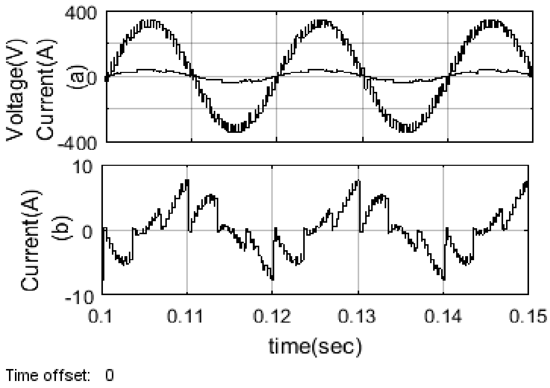

Fig. 12. Controlled rectifier with RLE load with compensation (SRF) (a) source voltage and current (b) compensating current.

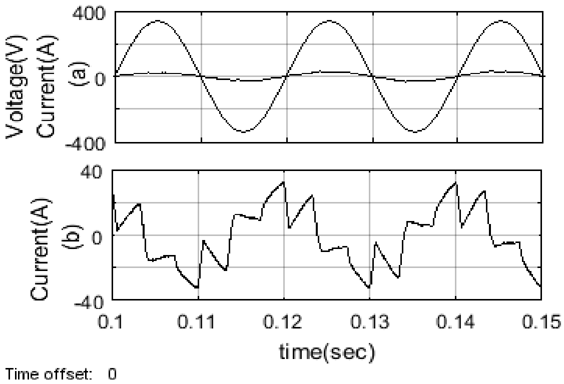

Fig. 13. Controlled rectifier with RLE load with compensation (IRP) (a) source voltage and current (b) compensating current.

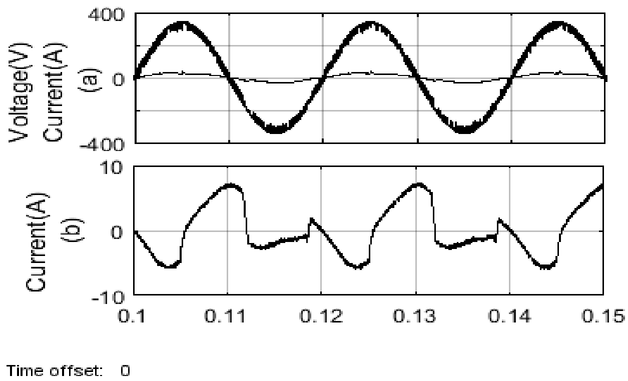

Fig. 14. Semi converter with RLE load with compensation (SDM) (a) source voltage and current (b) compensating current.

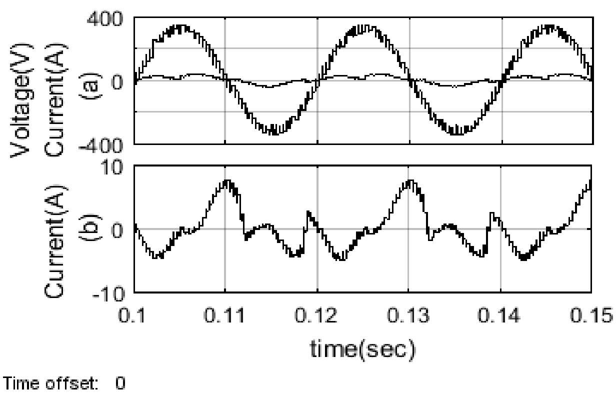

Fig. 15. Semi converter with RLE load with compensation (SRF) (a) source voltage and current (b) compensating current.

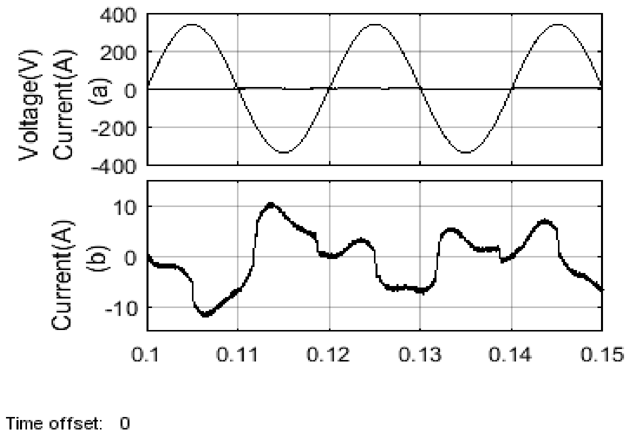

Fig. 16. Semi converter with RLE load with compensation (IRP) (a) source voltage and current (b) compensating current.

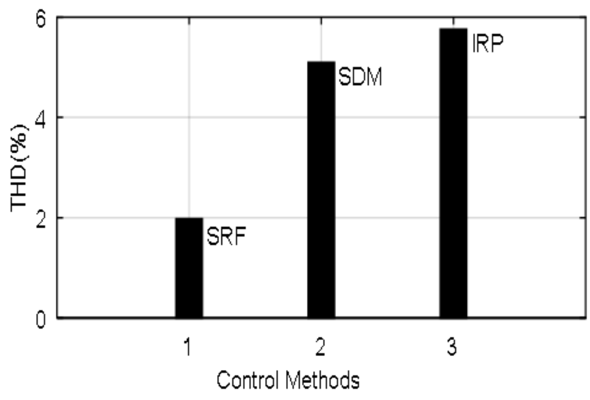

Fig. 17. Diode rectifier with RLE load THD comparison with different control strategies.

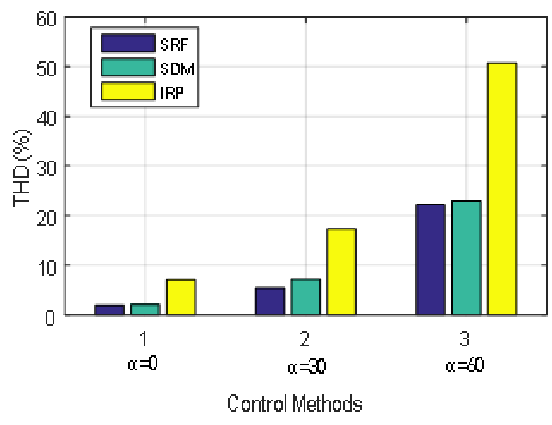

Fig. 18. Controlled rectifier with RLE load THD comparison with different control strategies with different firing delay.

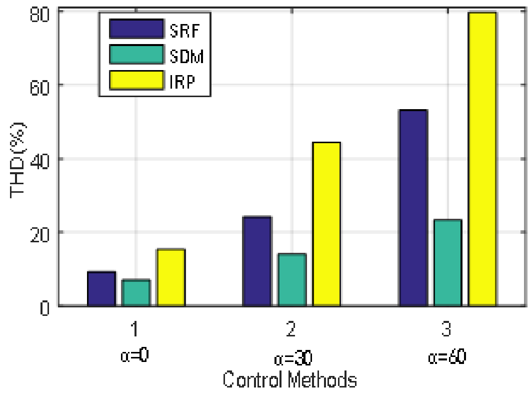

Fig. 19. Semi converter with RLE load THD comparison with different control strategies with different firing delay.

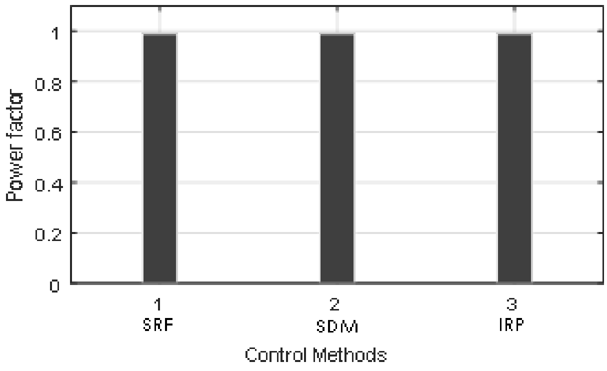

Fig. 20. Diode rectifier with RLE load power factor comparison with different control strategies.

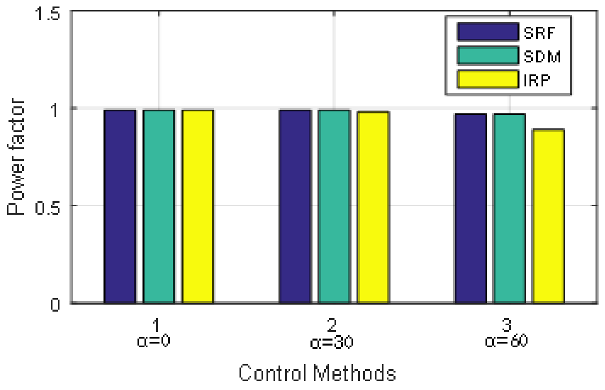

Fig. 21. Controlled rectifier with RLE load power factor comparison with different control strategies with different firing delay.

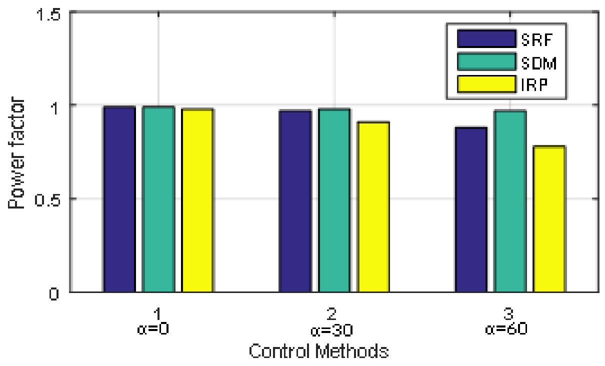

Fig. 22. Semi converter with RLE load power factor comparison with different control strategies with different firing delay.

4. CONCLUSION

In this paper, a comparative analysis of DSTATCOM for control methods SDM, SRF and IRP is presented with different types of nonlinear loads such as diode rectifier, controlled rectifier and semi converter. Power factors and current THDs under various load conditions are measured and tabulated. All three methods are per-

2020 Published by RERIC in International Energy Journal (IEJ). Selection and/or peer-reviewed under the responsibility of the Organizers of the **"Artificial Intelligence, Smart Grid and Smart City Applications (AISGSC-2019)"** and the Guest Editors: Dr. L. Ashok Kumar and Dr. R. Latha (PSG College of TechnologyCoimbatore-641 004, Tamilnadu, India.
www.rericjournal.ait.ac.th

forming satisfactorily for compensating reactive power and hence improving the power factor. The compensation of harmonics becomes poor with increased nonlinearity for all three methods especially with IRP method. Current research is focusing on the DSTATCOM with new control methods to mitigate multiple power quality issues, which will be important in future grid guaranteeing high quality, reliable supply.

REFERENCES

[1] Akagi H., Kanazawa Y., and Nabae A., 1984. Instantaneous reactive power compensation comprising switching devices without energy storage components. *IEEE Transactions on Industrial Applications* 20: 625–631.

[2] Akagi H., 1992. Trends in active power line conditioner. In *IEEE Industrial Electronic Conference*. pp.19–24.

[3] Mishra M., Ghosh A., and Joshi A., 2003. Operation of a DSTATCOM in voltage control mode. *IEEE Transactions on Power Delivery* 18(1): 258–264.

[4] Singh B., Jayaprakash P., Somayajulu T.R., and Kothari D.P., 2009. Reduced rating VSC with a zig-zag transformer for current compensation in a three-phase, four-wire distribution system. *IEEE Transactions on Power Delivery* 24(1): 249–259.

[5] Singh B., Jayaprakash P., Kothari D., Chandra A., and Al Had-dad K., 2014. Comprehensive study of DSTATCOM configurations. *IEEE Transactions on Industrial Informatics* 10(2): 854–870.

[6] Kumar C. and M. Mishra. 2014. A voltage-controlled DSTATCOM for power-quality improvement. *IEEE Transactions on Power Delivery* 29(3): 1499–1507.

[7] Sindhu S., Sindhu M.R., and Nambiar T.N.P., 2015. An exponential composition algorithm based UPQC for power quality enhancement. *Elsevier Procedia Technology* 21: 415–422.

[8] Dugan R.C., McGranaghan M.F., and Beaty H.W., 2006. *Electric Power Systems Quality.* New York: McGraw-Hill.

[9] Sindhu M.R., Nair G., and Nambiar T.N.P., 2014. Dynamic power quality compensator with an adaptive shunt hybrid filter. *International Journal of Power Electronics and Drive System (IJPEDS)* 4(4): 508–516.

[10] Mohan N., Undeland T., and Robbins. 1991. Power Electronics Converters, Applications and Design. New York: John Wiley & Sons.

[11] Ghosh A. and G. Ledwich. 2002. *Power Quality Enhancement Using Custom Power Devices.* Netherlands: Kluwer Academic Publishers.

2020 Published by RERIC in International Energy Journal (IEJ). Selection and/or peer-reviewed under the responsibility of the Organizers of the **"Artificial Intelligence, Smart Grid and Smart City Applications (AISGSC-2019)"** and the Guest Editors: Dr. L. Ashok Kumar and Dr. R. Latha (PSG College of TechnologyCoimbatore-641 004, Tamilnadu, India.
www.rericjournal.ait.ac.th