ISSN 2347 - 3983
Volume 8. No. 9, September 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter106892020.pdf
https://doi.org/10.30534/ijeter/2020/106892020

A New Active Power Injection Scheme Using CHB-MLI DSTATCOM for PQ Improvement

J. Ganesh Prasad Reddy[1], Dr. K. Ramesh Reddy[2]
[1]Research Scholar, Department of EEE, JNTU Hyderabad, Hyderabad, Telangana, India
[2]Principal, G. Narayanamma Institute of Technology and Science for Women, Shaikpet, Hyderabad, Telangana, India [1]jgpreddy@gmail.com

ABSTRACT
Power quality is the term that which appears often in electrical terminology. With good quality in power, power system performance increases. Maintaining the power system parameters close to ideal values is power quality. FACTS devices, using power electronic technology, are extremely fine devices to keep the power system well composed. A FACTS device without active energy source is confined in its operation and the addition of energy storage device can make FACTS device to exchange real and reactive power to PCC and can significantly improve the grid performance. The paper illustrates to improve quality in power system with a battery unified DSTATCOM and active power injection to PCC. DSTATCOM is a multi-level device giving out five-level output reducing the stress across the power switches of DSTATCOM. A multi-carrier level shifted carrier PWM technique is used to trigger five-level DSTATCOM. The model is designed as well as simulation results are evaluated by using Computer Simulation platform.

Key words: Active Power Control, Battery Energy, DSTATCOM, Multilevel Inverter, Instantaneous Power Controller, Power-Quality Improvement.

1. INTRODUCTION

Power Quality (PQ) is very important aspect in a power system which contributes to the progress of a country. Power quality is related to economy and with continuous power quality monitoring, net-worth can be increased. Developments in power electronic technology and usage of non-linear loads create a challenging environment. Power system parameters of a waveform like frequency, symmetry and magnitude are not always steady in nature due to faults, load disturbances [1]. Varying power system parameters can cause to inject harmonics, voltage disturbances and reactive power issues. Power quality annoyance can generate loss to the industries with end user equipment damage as well.

Use of passive filters to compensate the power system annoyance is affective for some extent but not completely. Passive filters are tuned for fixed frequency and can able to eliminate fixed harmonics. To filter lower order harmonics, the size of the interfacing inductor gets larger. Based on pertained disadvantages, a novel FACTS device has been developed for PQ improvement [2-3]. The recommended FACTS devices are Static Compensator (STATCOM), Distributed Static Compensator (DSTATCOM), Dynamic-Voltage Restorer (DVR), Unified Power-Flow Controller (UPFC) and Unified Power-Quality Compensator (UPQC), etc. The above-specified FACTS devices have specific compensation principle to enhance PQ features in both transmission and distribution system.

Generally, every FACTS device is equipped with small (DC-Link) capacitor to meet the losses in converter. DC-Link supplies the required real power and stabilizes the power balance. DC-Link capacitor based FACTS devices are restraining in degree of freedom. Equipping the FACTS device with battery energy storage system (BESS) expands its operation by inducing active power to PCC (point of common coupling). During power system transients, FACTS controllers with battery energy storage systems (BESS) [4-5] can stabilize the system with real and reactive power exchange and also can increase the power transfer capability.

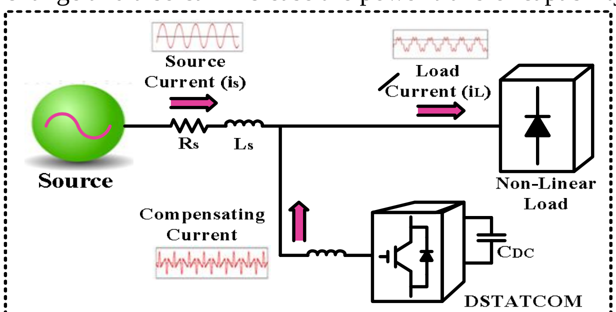

Figure 1: DSTATCOM in the distribution power system

Conventional power electronic converters with two level output makes much higher voltage stress across the power switches which increase the losses and can even damage the power switches. Inventing multi-level structures of power converters which gives out higher (more than two) voltage levels reduces the stress across the switch. Multi-level power converters also reduce the losses and increase the reliability.

The paper illustrates to improve quality in power system with a battery unified DSTATCOM and active power injection to PCC. DSTATCOM is a multi-level device [6-7] giving out five-level output reducing the stress across the power switches of DSTATCOM. IRP theory [8-10] with level-shifted-PWM technique has been used to drive the five-level DSTATCOM. The proposed battery integrated DSTATCOM for improvement in power quality and injection of active power in system is validated with fixed power injection and variable power injection from battery source (BESS).

2. PROPOSED MULTILEVEL DSTATCOM

2.1 5-Level DSTATCOM

Recent developments in power electronic technology has led path to take up research in upgrading the existing power system in replacing conventional passive filters with FACTS devices for PQ improvement is the utmost development. DSTATCOM is a FACTS controller that eliminates harmonics inducing compensating currents to PCC. DSTATCOM is a shunt power filter and induces compensating currents to PCC. Two-level converter generates harmonics in the output voltage and voltage stress across the switching device increases. As the number of output levels is increased, the harmonics in the output waveform has been reduced eventually this decreases the voltage stress across the switching device.

Obtaining the higher number of leveled output from a converter is termed as multi-level converter. Multi-level DSTATCOM gives out five-level output and the output is smoothened using interfacing inductors which is fed to PCC. The cascaded H-Bridge structure is considered for multi-level operation in this paper. Five-level DSTATCOM is represented in the Figure.1 and only one phase of the complete five-level CHB structure is represented in the Figure.2. Controlled pulses from the controller triggers five-level DSTATCOM to induce compensating currents to PCC to maintain harmonic limit in the source current.

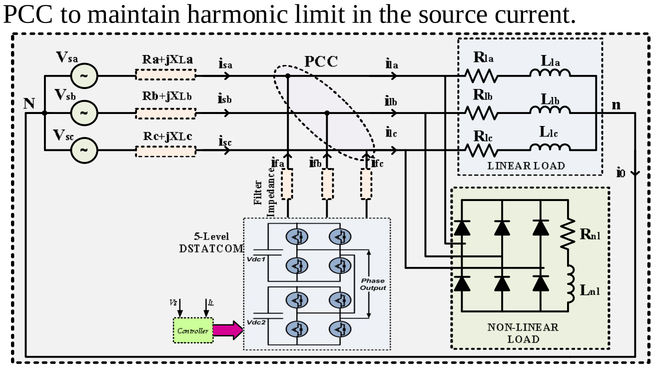

Figure 2: Power system with Five-Level DSTATCOM

2.2 IRP theory for Multi-Level DSTATCOM

Current harmonics in source currents generated from non-linear load are compensated using five-level DSTATCOM controlled by IRP algorithm. A transformation from three-coordinates to two-coordinate terminology of voltage and load current is the base step.

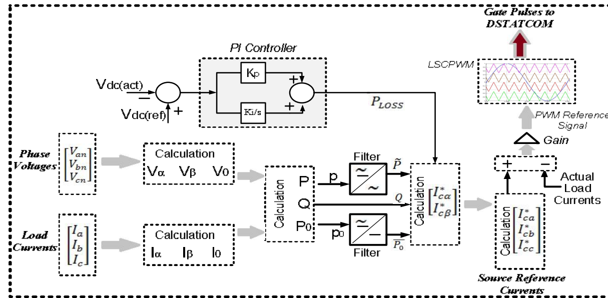

Figure 3: Control of Five-Level DSTATCOM

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

Instantaneous active component of power is

$$P_{3\emptyset} = V_0 I_0 + V_\alpha I_\alpha + V_\beta I_\beta \quad (3)$$

Meanwhile, the power loss of DC-link is measured based on differential value of set and actual DC-Link voltages. The power terms are operated to give equation (4)

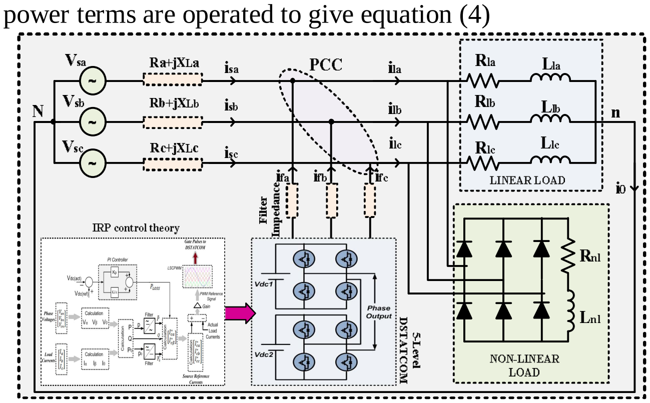

Figure 4: Complete schematic layout of five-level DSTATCOM with IRP algorithm

$$\begin{bmatrix} I_{c\alpha}^* \\ I_{c\beta}^* \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2 + V_\beta^2}}\begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \quad (4)$$

Inverse transformation process of above equation gives out reference components as in equation (5).

$$\begin{bmatrix} I_{ca}^* \\ I_{cb}^* \\ I_{cc}^* \end{bmatrix} = \frac{\sqrt{2}}{3}\begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} I_{c0}^* \\ I_{c\alpha}^* \\ I_{c\beta}^* \end{bmatrix} \quad (5)$$

The reference current wave shapes are compared with load currents and a PWM (voltage) reference signals are generated by adding a gain. The reference component generated is processed to LSCPWM pattern to generate control pulses to all the switches of five-level DSTATCOM. The multi-carriers are differentiating with reference current signals for generation of switching pulses to five-Level DSTATCOM. The complete schematic algorithm of controlling five-level DSTATCOM is shown in Figure.3. The complete schematic layout of five-level DSTATCOM using IRP control theory is shown in Figure.4.

3. PROPOSED ACTIVE POWER INJECTION METHOD

3.1 Five-Level DSTATCOM with BESS for active power injection

Generally, every FACTS device is equipped with small (DC-Link) capacitor to meet the losses in converter. Equipping the FACTS device with BESS expands its operation by inducing active power to PCC (point of common coupling).

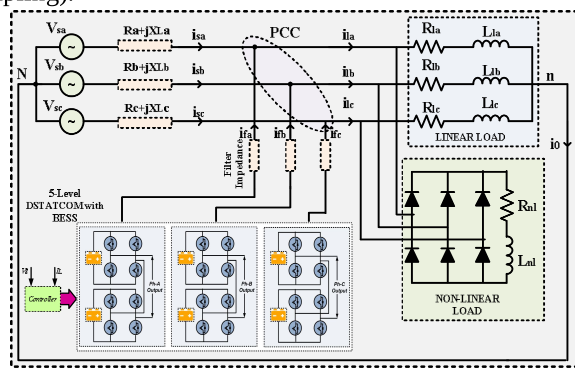

Figure 5: Five-Level DSTATCOM with BESS for active power injection

During power system transients, FACTS controllers with BESS can stabilize the system with real and reactive power exchange and also can increase the power transfer capability. Five-level DSTATCOM using BESS is represented in Figure.5. Controlled pulses from the controller triggers five-level DSTATCOM to induce compensating currents to PCC to maintain harmonic limit in the source current.

3.2 Control theory for Multi-Level DSTATCOM with Battery storage system

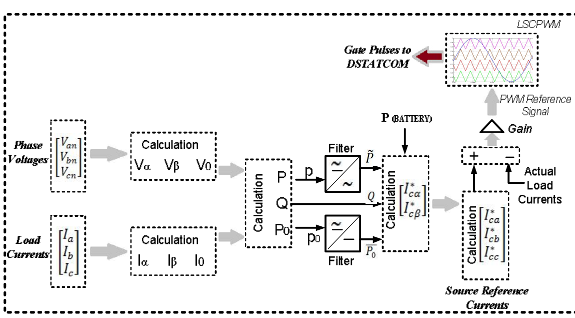

Figure 6: Control circuit of Five-Level DSTATCOM with battery storage system

Current harmonics in source currents generated from non-linear load are compensated using five-level DSTATCOM controlled by algorithm as explained in section 2.2. The battery power is sensed and active power after filter along with the battery power is processed to Inverse Clarke's and Park's transformation block for generation of reference currents. The reference currents in a-b-c coordinates are compared with the load currents and a PWM (voltage) reference signals are generated by adding a gain. The reference component generated is processed to LSCPWM pattern to generate switching states to proposed 5-level CHB–MLI DSTATCOM. The overall control algorithm of BESS based 5-level CHB-MLI DSTATCOM is depicted in Figure.6. The complete schematic layout of five-level BESS based DSTATCOM with control theory is shown in Figure.7.

Current harmonics in source currents generated from non-linear load are compensated using five-level DSTATCOM controlled by IRP algorithm. A transformation from three-coordinates to two-coordinate terminology of voltage and load current is the base step. Meanwhile, the DC-link power loss is measured by differential value of set and actual DC-Link voltages using PI / Fuzzy controllers. Fuzzy controller transforms the input data to fuzzier data and relates to rule base set (as in Table.1). Error signal is de-fuzzier and generates reference signal. Inverse transformation of reference signals generates gate pulses to inverter circuit.

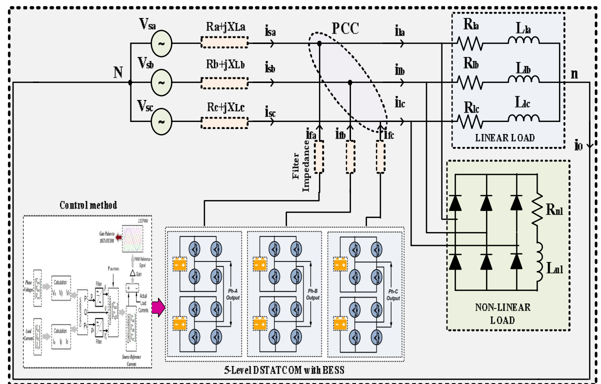

Figure 7: Complete circuit layout of BESS based DSTATCOM

4. MATLAB/SIMULINK RESULTS

The performance of proposed Battery integrated Five-Level DSTATCOM topology is verified under both fixed and variable battery source by utilizing Matlab/Simulink tool. The system parameters of proposed model are clearly illustrated in Table.1.

Table 1: System Specifications

Parameter	Value
Supply Voltage	11 KV, 50 Hz
Line Impedance	0.1 Ohms, 0.9 mH
DC Link Capacitance	1550 µF
Filter Impedance	0.001 Ohms, 0.9 mH
Carrier signal frequency	3960Hz

4.1 Multi-level DSTATCOM without Battery

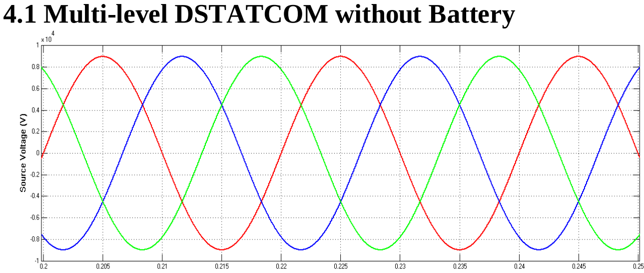

Figure 8: 3-phase voltage source

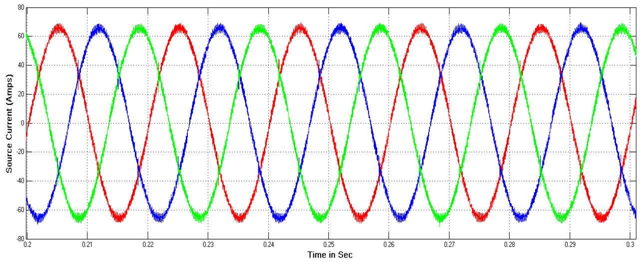

Figure 9: Three-phase current source

The source voltage and currents are illustrated in Figure.8 and Figure.9 with NO battery storage system in the DSTATCOM, the source power meets the load demand.

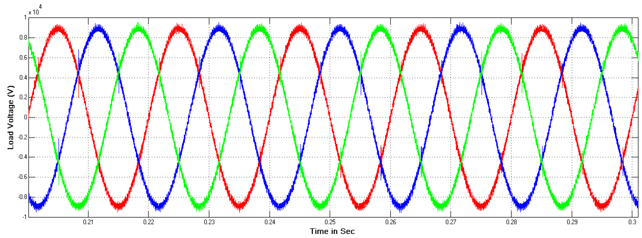

Figure 10: Voltage at 3 - phase load

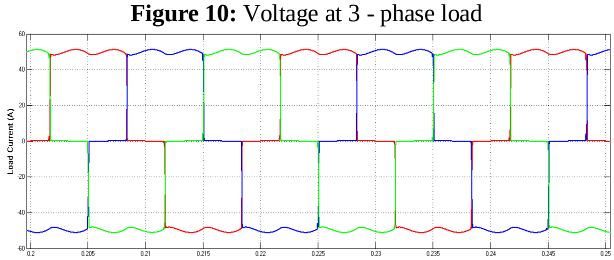

Figure 11: Current at 3 - phase load

Figure.10 and Figure.11 show the three-phase voltage and currents across the load respectively. With NO connection of BESS in the DSTATCOM, the load power requirement is met by the source.

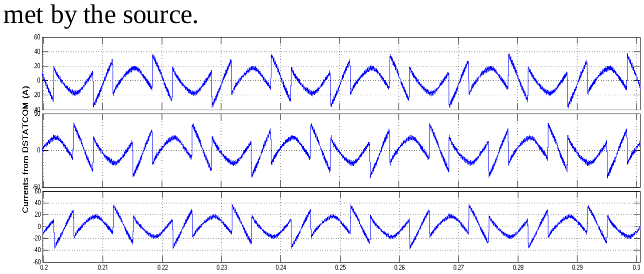

Figure 12: DSTATCOM induced currents

Figure.12 illustrates the DSTATCOM induced currents for compensation of harmonics to make source current more close to ideal sinusoidal shape. Figure.13 illustrates the five-level output from DSTATCOM to PCC.

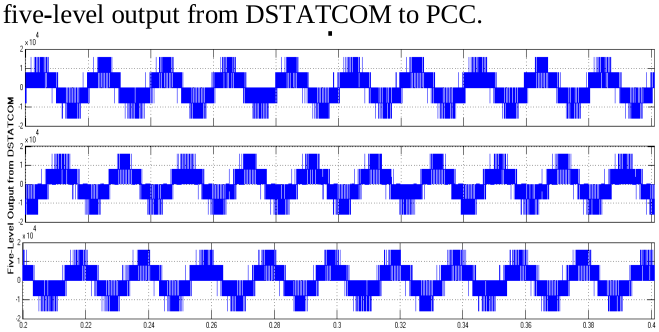

Figure 13: Five-level output from DSTATCOM

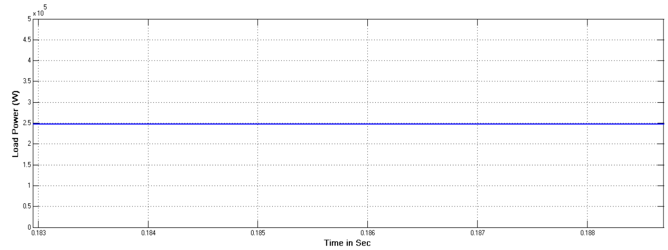

Figure.14 Active power to load

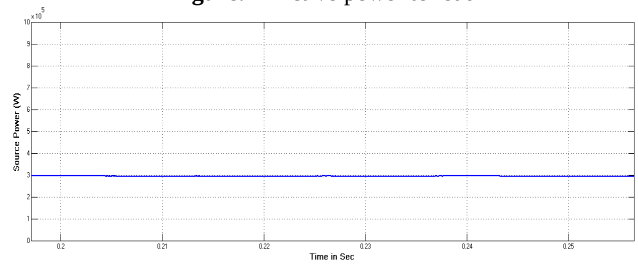

Figure 15: Active power from source

Figure.14 and Figure.15 shows the active power absorbed by load and fed from source respectively. Source feds 3KW power and the load draw 2.5KW of power from the source. The total power consumed by load is met from the source in this case where DSTATCOM is without battery storage system.

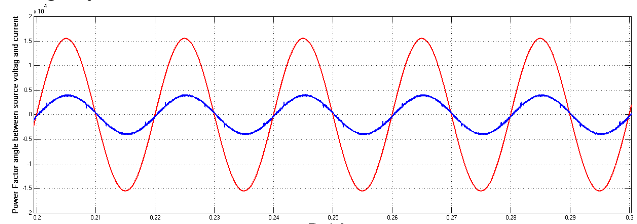

Figure 16: The in-phase condition between source current and voltage (Unity Power-Factor)

Figure.16 and Figure.17 illustrate the in-phase condition between source current and voltage represents the unity power-factor, but the load side values doesn't maintain the in-phase condition represents the non-unity power factor.

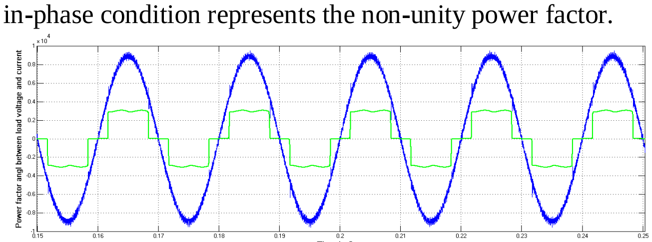

Figure 17: The in-phase condition between load current and voltage (Non-Unity Power-Factor)

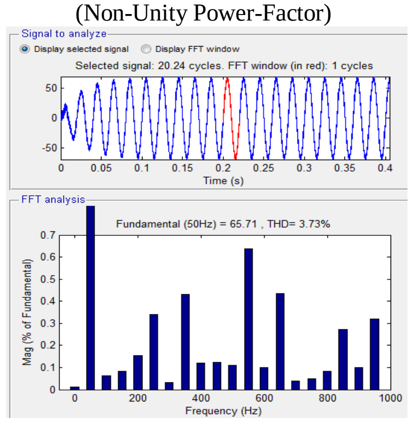

Figure 18: THD in source current

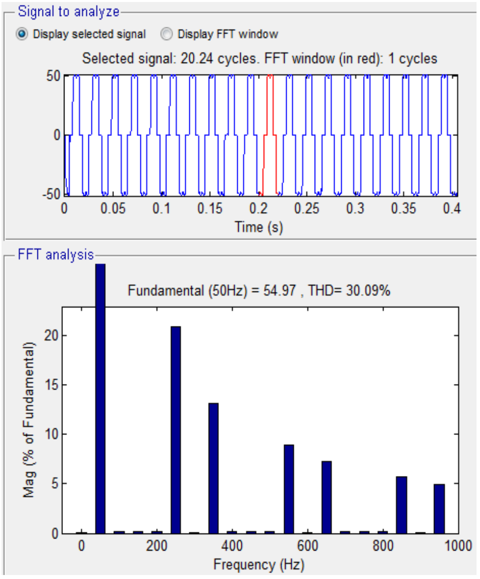

Figure 19: THD in load current

Figure.18 shows the harmonic components in source current and Figure.19 shows the harmonic components in load current. Five-level DSTATCOM makes up for harmonics in source current and hence THD is 3.73% with respect to fundamental. Load being non-linear in nature, THD is 30.09%. DSTATCOM maintains current source distortion within rated limits.

4.2 Battery Integrated Multilevel DSTATCOM with Fixed Battery Power

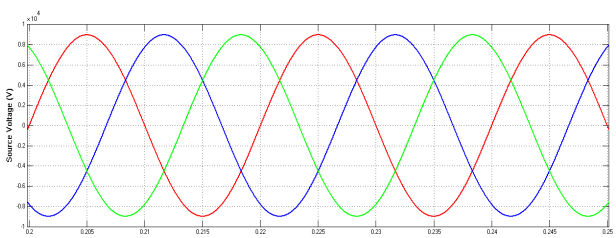

Figure 20: Three-phase source voltage

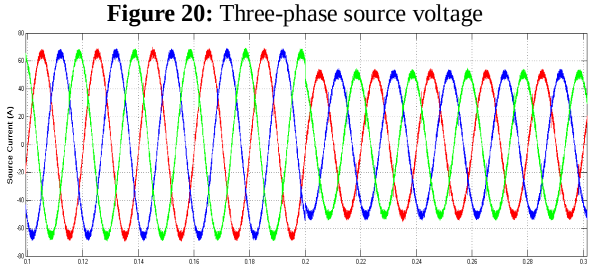

Figure 21: Three-phase source current

Figure.20 and Figure.21 shows the three-phase source voltages and currents maintained as balanced, sinusoidal and fundamental nature. The source side active power provides the required load demand through BESS energy which is used to feed the active power demand at a time instant at 0.2 sec by using proposed control objective. The proposed BESS-DSTATCOM reduces the usage of source side active power which is furnished by battery energy source.

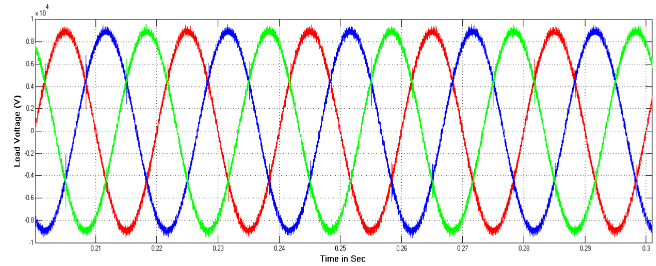

Figure 22: 3- phase load voltage

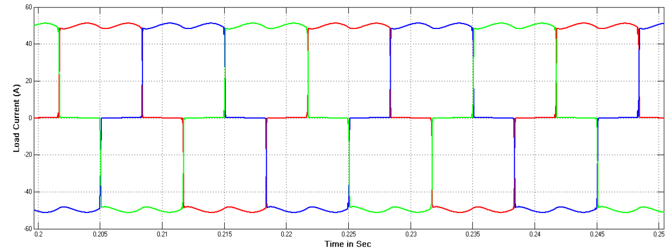

Figure 23: 3 - phase load current

Figure.22 and Figure.23 shows the three-phase load voltage and load currents respectively. With the battery storage system in the DSTATCOM feeding the required power, the load power requirement is met by the source and battery system.

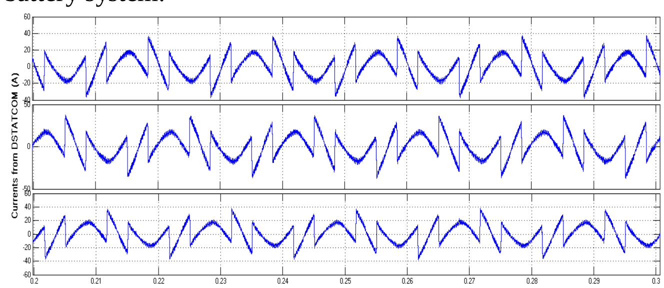

Figure 24: DSTATCOM induced currents

Figure.24 illustrates the DSTATCOM induced currents for the compensation of harmonics to make source current more close to ideal sinusoidal shape.

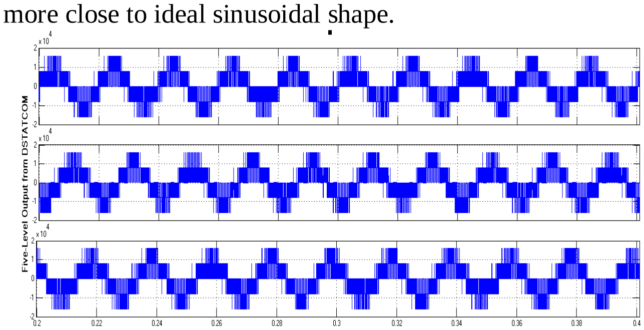

Figure 25: Five-level output from DSTATCOM

Figure.25 illustrates the five-level output from DSTATCOM to PCC. Each phase of three-phase output of DSTATCOM is shown in Figureure.

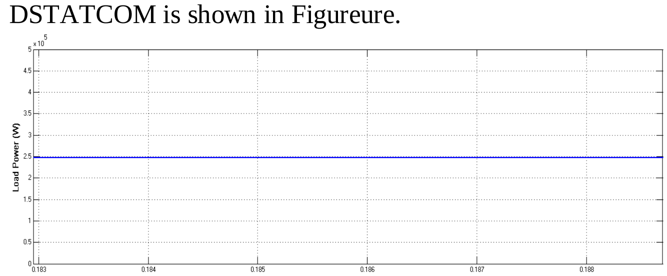

Figure 26: Active power to load

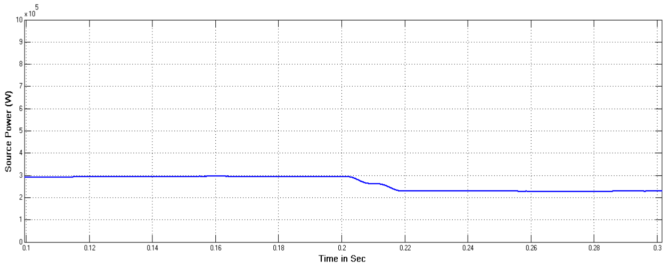

Figure 27: Active power from source

The demanded load side active power and forwarded source side active power is represented in Figure.26 and Figure.27. The active power of utility supply system provides 3KW and the load consumes 2.5KW from the source. At the time 0.2 sec, the consumption of active power from source is reduced, the required active power is furnished by BESS system which reduces the utilization of source active power. The required demanded load power is supported by both BESS and utility systems.

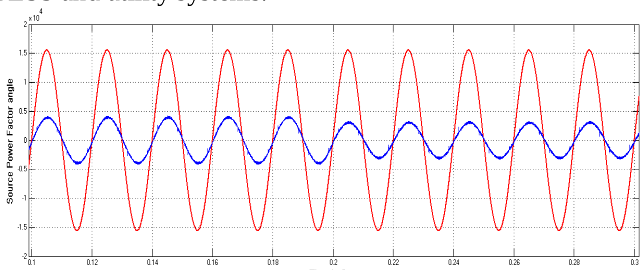

Figure 28: The in-phase condition between source current and voltage (Unity Power-Factor)

Figure.28 and Figure.29 illustrate the in-phase condition between source current and voltage represents the unity power-factor, but the load side values doesn't maintain the in-phase condition represents the non-unity power factor.

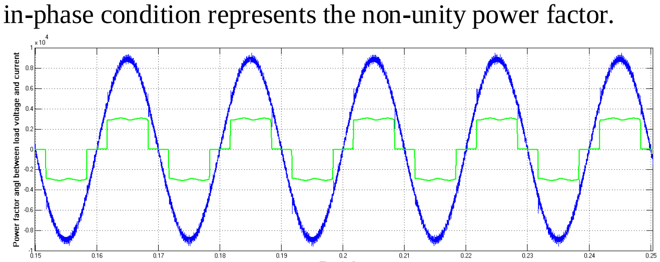

Figure 29: The in-phase condition between load current and voltage (Non-Unity Power-Factor)

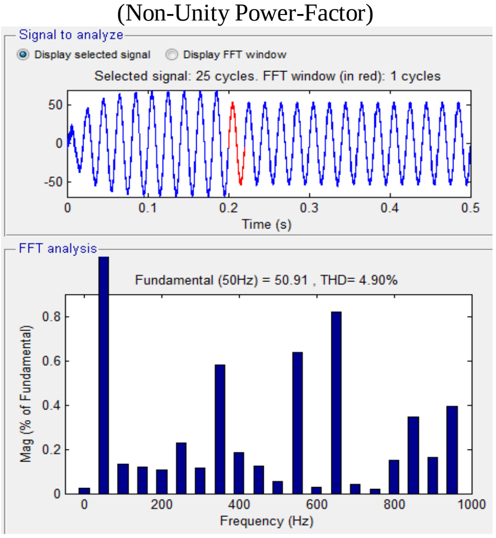

Figure 30: THD in source current

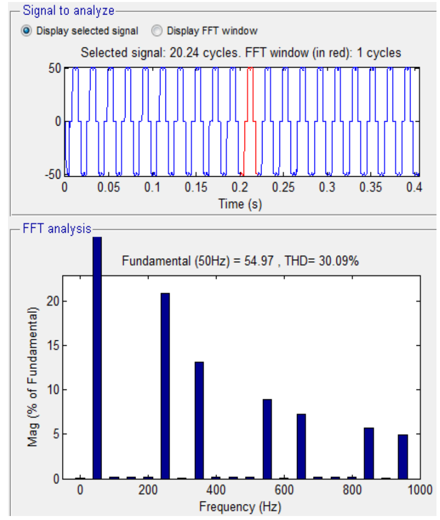

Figure 31: THD in load current

Figure.30shows the harmonic components in source current and Figure.31shows the harmonic components in load current. Five-level DSTATCOM makes up for harmonics in source current and hence THD is 4.90% with respect to fundamental. Load being non-linear in nature, THD is 30.09%. DSTATCOM maintains current source distortion within rated limits.

4.3 Battery Integrated Multilevel DSTATCOM with variable battery power

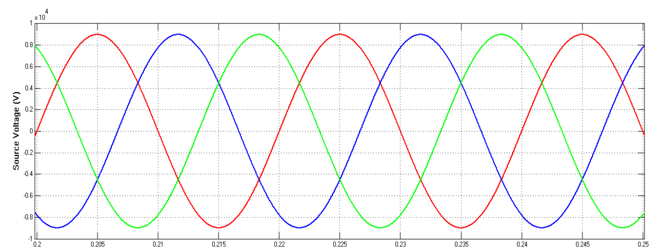

Figure 32: Three-phase source voltage

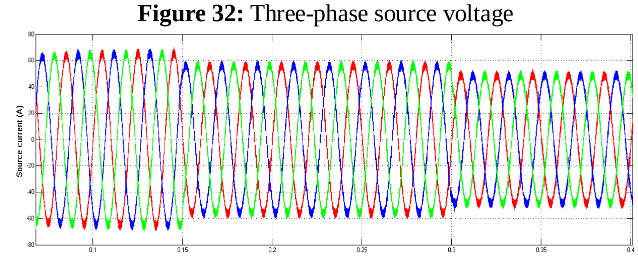

Figure 33: Three-phase source current

Figure.32 and Figure.33 shows the three-phase source voltages and currents maintained as balanced, sinusoidal and fundamental nature. The source side active power provides the required load demand through BESS energy which is used to feed the active power demand at a time instant at 0.2 sec by using proposed control objective. The proposed BESS-DSTATCOM reduces the usage of source side active power which is furnished by battery energy source.

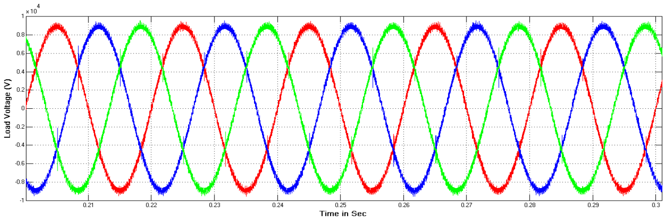

Figure 34: Three-phase load voltage

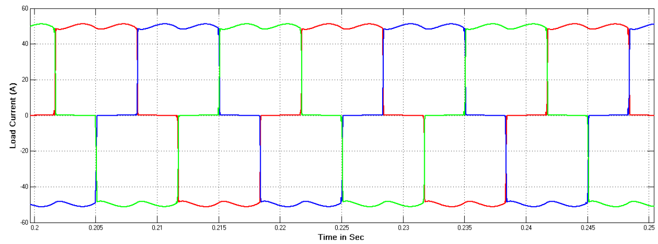

Figure 35: Three-phase load current

Figure.34 and Figure.35 represents the three-phase load voltage and currents respectively. With the battery storage system in the DSTATCOM, the load power requirement is met by the source and battery storage system.

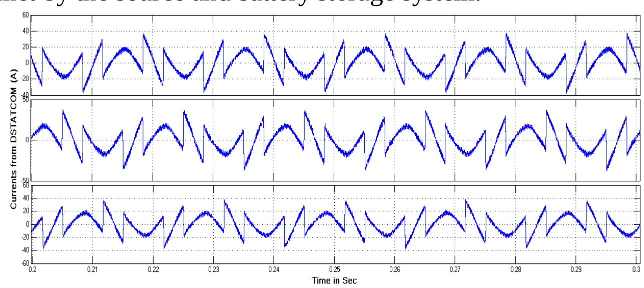

Figure 36: DSTATCOM induced currents

Figure.36 illustrates the DSTATCOM induced currents for the compensation of harmonics to make source current more close to ideal sinusoidal shape.

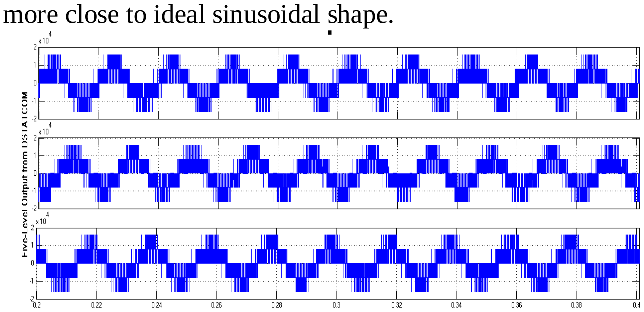

Figure 37: Five-level output from DSTATCOM

Figure.37 illustrates the five-level output from DSTATCOM to PCC. Each phase of three-phase output of DSTATCOM is shown in Figureure.

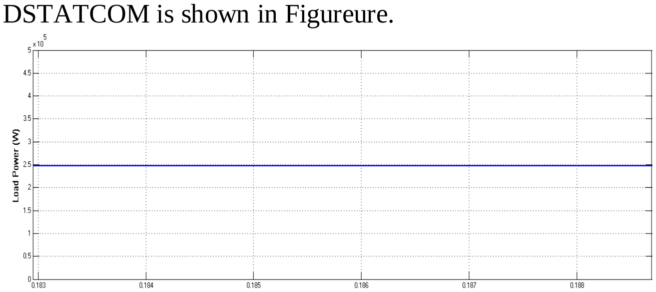

Figure 38: Active power to load

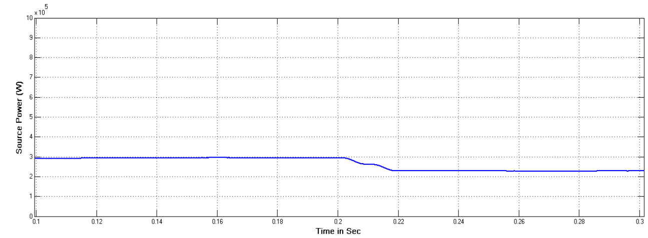

Figure 39: Active power from source

The demanded load side active power and forwarded source side active power is represented in Figure.38 and Figure.39. The active power of utility supply system provides 3KW and the load consumes 2.5KW from the source. At the time 0.2 sec, the consumption of active power from source is reduced, the required active power is furnished by BESS system which reduces the utilization of source active power. Similarly, at a time instant of 0.3 sec, the consumption of active power from source is merely reduced; the required active power is furnished by BESS system which reduces the utilization of source active power. The required demanded load power is supported by both BESS and utility systems.

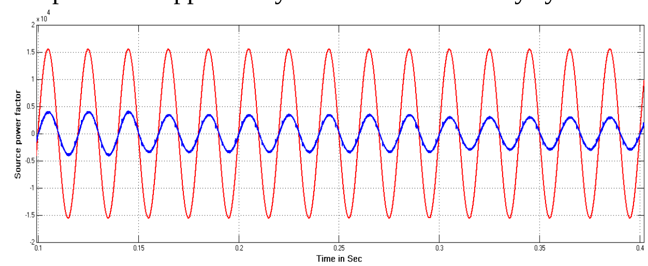

Figure 40: The in-phase condition between source current and voltage (Unity Power-Factor)

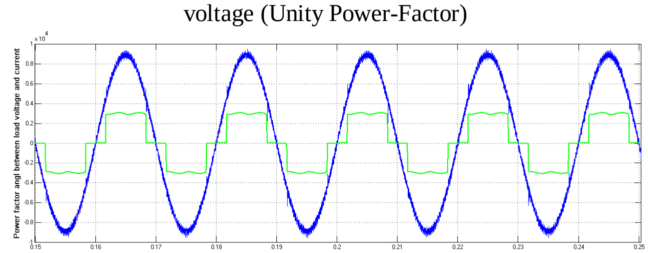

Figure 41: The in-phase condition between load current and voltage (Non-Unity Power-Factor)

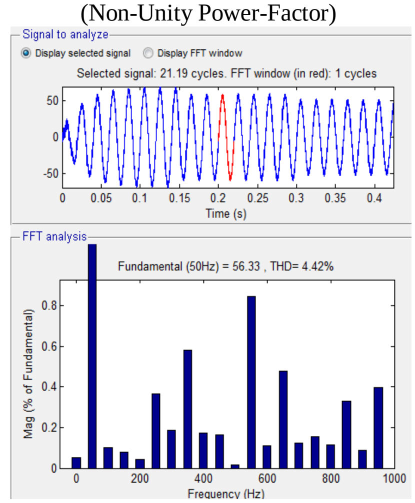

Figure 42: THD in source current

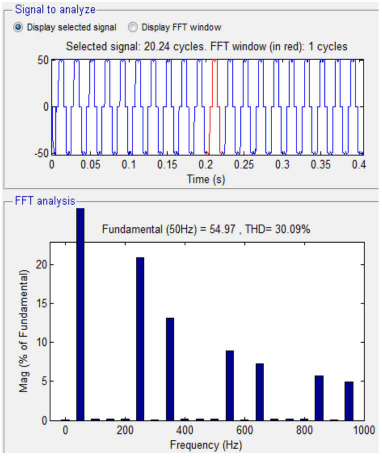

Figure 43: THD in load current

Figure.40 and Figure.41 illustrate the in-phase condition between source current and voltage represents the unity power-factor, but the load side values doesn't maintain the in-phase condition represents the non-unity power factor.Figure.42shows the harmonic components in source current and Figure.43shows the harmonic components in load current. Five-level DSTATCOM makes up for harmonics in source current and hence THD is 4.42% with respect to fundamental. Load being non-linear in nature, THD is 30.09%. DSTATCOM maintains current source distortion within rated limits. The THD comparative analysis of various cases is clearly illustrated in Table.2.

Table 2: Comparative Analysis Distortion for Various Cases in Power Network

THD (%)	Source Current	Load Current
DSTATCOM without battery source	3.73 %	30.09 %
DSTATCOM with battery source and feeding fixed active power	4.90 %	30.09 %
DSTATCOM with battery source and feeding fixed active power	4.42 %	30.09 %

5. CONCLUSION

Power quality is one area which concerns the electrical engineers the more. DSTATCOM is proved to be one of the FACTS controllers to compensate harmonics in source current. It's a challenging task to reduce the conventional power generation and to meet the load demand. This paper presents a battery energy storage based DSTATCOM for active power injection to the system along with performing harmonic compensation task. Tabular comparison is presented which shows the source current is maintained within nominal harmonic distortion of 5% in all the test cases. The required active power injecting to power distribution system through BESSfed DSTATCOM operated under both fixed and variable power flow conditions. While battery storage based DSTATCOM feeds the power system, the reducing source current indicates the reduction in source power and the total load requirement is met from both source and battery storage based DSTATCOM. The waveforms of active power in test cases proves the depletion of source power in order to meet therequired load demand and compensating load power is met from battery storage based DSTATCOM. This concept is very much useful to relieve the reliability and burden on conventional power generating stations and also will be helpful in emergency situations of power system.

REFERENCES

1. A. Luo H. Xiao F. Ma et al. "Distribution static compensator based on an improved direct power control strategy" IET Power Electron. vol. 7 no. 4 pp. 957-964 2014.
2. C. Kumar M.K. Mishra "An improved hybrid DSTATCOM topology to compensate reactive and nonlinear loads" IEEE Trans. Ind. Electron. vol. 61 no. 12 pp. 6517-6527 2014.
3. A. A. Patel and A. A. Patel, "Application of DSTATCOM for harmonics elimination and power quality improvement," *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, Chennai, India, 2017, pp. 3007-3011.
4. O. P. Mahela, P. Gupta, S. Ali and N. Gupta, "Power Quality Improvement in Renewable Energy Sources Based Power System Using DSTATCOM Supported by Battery Energy Storage System," *2019 Fifth International Conference on Electrical Energy Systems (ICEES)*, Chennai, India, 2019, pp. 1-6.
5. O. P. Mahela and A. G. Shaik, "Power quality improvement in distribution network using DSTATCOM with battery energy storage system", *Int. J. Electr. Power Energy Syst.*, vol. 83, pp. 229-240, 2016
6. T. S. Saggu, L. Singh and B. Gill, "Harmonics Mitigation in a Steel Industry Using 11-Level Cascaded Multilevel Inverter-Based DSTATCOM," in *Canadian Journal of Electrical and Computer Engineering*, vol. 40, no. 2, pp. 110-115, Spring 2017.
7. Y. R. Ashtekar, A. A. Mude and S. A. Khubalkar, "Power quality improvement by using modular multilevel cascade converter based STATCOM," *2018 2nd International Conference on Inventive Systems and Control (ICISC)*, Coimbatore, India, 2018, pp. 169-173.
8. M. Pradhan and M. K. Mishra, "Dual P-Q Theory based Energy Optimized Dynamic Voltage Restorer for Power Quality Improvement in Distribution System," in *IEEE Transactions on Industrial Electronics, 2018 (early access).*
9. G. Varshney, D. S. Chauhan and M. P. Dave, "Performance analysis of photovoltaic based DSTATCOM using SRF and IRP control theory1," *2015 1st International Conference on Next Generation Computing Technologies (NGCT)*, Dehradun, 2015, pp. 779-783.
10. M. Bajaj and M. Pushkarna, "An IRP based control algorithm for load compensation by DSTATCOM under polluted supply system, *ICCC Conference*, Trivandrum, 2015, pp. 303-308.