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Modelling and Simulation of Current Source Converter based Dynamic Voltage Restorer for Voltage Regulation cum Harmonics Mitigation

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***Abstract*— The modern electric power distribution system faces lots of power quality (PQ) problems such as short and long duration voltage variations, voltage imbalance, waveform distortions, impulsive and oscillatory transients and voltage flicker etc. The custom power devices (CPD) have been designed and developed with the aim of mitigating these problems. The major CPDs introduced so far include distribution-static synchronous compensator (D-STATCOM), dynamic voltage restorer (DVR), unified power quality conditioners (UPQC), active power filters (APF) etc. However, most of these CPDs are designed and implemented using voltage source converter (VSC) topology. Although lots of research works have been carried out for realizing DVR system based on VSC topology, not much research work has been reported on the application of CSC topology in DVR system over the last one decade. Through this paper, it has been attempted to develop a model of DVR system based on CSC topology capable of performing dual power quality enhancement tasks viz. voltage regulation and harmonics mitigation at a power distribution system catering power to a variety of loads. The DVR system has been modeled and simulated in the MATLAB / Simulink platform and the simulation results reveal the effectiveness and validity of the proposed model for use in power distribution system.**

***Keywords*— power quality; dynamic voltage restorer; current source converter; voltage regulation; harmonics mitigation.**

I. Introduction

Nowadays, electric power customers are quite anxious about the quality of power supplied to them by the electric power distribution utilities. The majority of customers' loads are quite sensitive to voltage variations and presence of harmonics emanating mostly from non-linear loads. Some large industrial customers are critically dependent on the uninterrupted electrical power supply and suffer from large financial losses as a result of even minor losses in the quality of power [1]. For instance, an electric power customer sharing the same load distribution bus with another customer having a large motor load shall have to encounter a voltage variation which is known as voltage sag in his supply voltage every time the motor load is turned on. In some extreme cases, the customer has to bear with blackouts [1]. Such situations are not desirable to happen especially to those electric power customers operating voltage sensitive loads. Some examples of customer who are having very sensitive loads to the voltage variations include life support systems, operation theater, and patient database systems in hospitals, semiconductor device, food, rayon and fabrics processing industries, power supply to air traffic control systems, financial institutions and telecommunication facilities [1]. In recent years, there has been a tremendous increase in the use of power electronics based devices and equipment such as uninterruptible power supply (UPS), rectifier and many other types of the power converter in large scale at industries, offices, and homes. Such nonlinear loads are not only sensitive to the input voltage variations but also pollute the power distribution systems. This scenario has led to the emergence of unwanted PQ problems such as harmonics, noise, spikes, voltage flicker etc. at the power distribution system. In order to eliminate the bad effects of using power electronics based systems and to extract only the best possible benefits from this technology, the attention of power electronics industry has been attracted towards the development of dynamic compensation schemes adaptable to the dynamics of power distribution networks and load fluctuations. In the recent years, power system engineers and researchers have proposed and developed various types of VSC based CPDs for providing an integrated solution to PQ problems. These CPDs are meant for harmonic reduction, voltage regulation, power factor improvement and mitigation of voltage sag and swell etc. The classification of CPD is generally done based on the converter topology, control scheme and compensation characteristics and so on. The most popular CPDs include D-STATCOM or shunt active power filter (SAPF), DVR or series active filter, hybrid filter (i.e. a combination of passive and active filters) and UPQC. The type of CPD suitable for enhancing the PQ depends on the nature of the problem. The choice of design and selection of control strategy for CPDs are based on the characteristics of PQ disturbances and their causes. The recent advancement in the field of power semiconductor devices and control strategies has propelled the researchers and engineers that there are considerable scopes for further research in PQ assessment and its improvement methodologies using CPDs. This approach will enable the power distribution utilities to provide good quality power with increased reliability to their customers. The CPDs will help the customers, manufacturers, and utilities to assess and solve most of the PQ problems.

The control of voltage magnitude (i.e. voltage regulation) in the electric power distribution system is very important for the proper operation of most the electrical machinery or equipment. The main objectives of the voltage regulation include prevention of that equipment from damage due to overheating, reduction of power losses, to maintain the ability of the distribution system to withstand and prevent from voltage collapse. A voltage collapse occurs when the system tries to serve much more load than the voltage that can support. When the voltage magnitude decreases, current increases to maintain the required power supply causing the system to consume more reactive power and the voltage drops further. Hence, voltage magnitude is one of the major factors that determine the power quality. Amongst the various types of PQ problems, load voltage waveform distortions caused by harmonics emanating from the non-linear loads connected to the power distribution system are also treated as one of the serious PQ problems. The passive filter, active filter and hybrid filter with shunt and series configurations are being used to deal with such problems. In most of the literature, active power filters (shunt, series, and hybrid) based on VSC topology are discussed and not much research work has been reported on the CSC based active filters. Although the custom power concept gives more emphasis on the PQ and reliability, other benefits such as voltage regulation, voltage balancing, and harmonic mitigation etc. can also be achieved from this technology [1]-[4]. For the purpose of improving PQ at distribution voltage levels, CPDs are usually designed and implemented by using VSC topology instead of CSC [5]-[7].

In this work, it has been attempted to develop a model of DVR system based on CSC topology which is capable of performing dual PQ improvement tasks viz. voltage regulation and harmonics mitigation at the point of common coupling (PCC). The proposed model is interfaced with a distribution system catering power supply to a variety of loads comprising of the 3-phase induction motor, rectifier, resistive and capacitive loads that resemble the environment of a modern power distribution utility. The DVR system has been modeled and simulated in the MATLAB / Simulink platform and simulation results reveal the effectiveness and validity of the model for use in power distribution system.

II. MATERIAL AND METHOD

A. *Technical Comparison Between the VSC and CSC Topologies*

The present research work has been carried out due to the inspirations received after studying the literature available at [5]-[10]. The technical comparisons between the VSC and CSC topologies have been formulated briefly and these are presented hereunder.

1) In terms of power and control schemes, the CSC topology is more complex than that of the VSC. The overall cost of the converter circuit is increased due to the use of filter capacitors at the AC output terminals of CSC for producing good sinusoidal current and voltage waveforms. There is also the possibility of causing high harmonic distortion on the AC side current as the filter capacitors may resonate with the AC side inductances.

2) The power switching devices used in the CSC should possess high reverse voltage blocking capability. If IGBTs are used in the CSC instead of Gate-Turn-Off Thyristors (GTOs), a diode needs to be connected in series with each of the IGBT switches. Hence, the conduction losses are increased nearly two times as compared to that of the VSC.

3) The energy storage element on the dc side of VSC is a capacitor whereas it is a choke or an inductor in the case of CSC. The power loss in the choke or inductor is higher than that of the capacitor as the energy is stored by circulating current through the inductor which is lossier than capacitive energy storage element. The power loss in the choke or inductor is generally in the range of 2% to 4% whereas it is approximately 0.5% in the case of the capacitor when used in the converters as energy storage element. Therefore, the efficiency of CSC is likely to be less than that of the VSC.

However, the drawbacks of the CSC cited above will be overcome in the near future from the viewpoint of the recent advancement in the field of power electronics technology and advent of new control schemes. And the research work on the CSC based DVR being presented through this paper has been motivated due to the following reasons:

1) Since the output voltage and current waveforms of the CSC are good sinusoidal, it is quite suitable and advantageous for use in the DVR system where the voltage is to be injected in series and synchronism with the distribution feeder or bus voltage through the coupling transformers. Through careful design of the filter circuit and adding of sufficient damping by using proper control methods, the problem of the resonance between the output filter capacitors and inductances on the ac-side can be solved effectively [5].

2) The requirement of power semiconductor switches capable of withstanding large reverse voltage can be fulfilled by using GTOs and Integrated Gate Commutated Thyristor (IGCTs). The IGCT is a promising switching device for use in CSC based high power applications. This device has excellent features such as high voltage and current ratings, high reverse voltage blocking capability, low snubber requirements, lower gate drive power requirement and higher switching speed than GTO [9]. Hence, the problem of higher conduction losses in the switching elements due to the series connection of diodes with IGBTs in the CSC based

DVR can be eliminated by using either GTO or IGCT switches.

3) By using superconducting materials in making the dc link inductor or choke, the power losses on the dc side can be minimized [5]. Also, the reliability of the energy storage inductor or reactor used in the CSC is much higher than that of the capacitor used in the VSC. The reliability of the energy storage capacitor rises if the newly improved film capacitors are used. But the film capacitors are still relatively costlier and have less capacitance per unit volume as compared to that of the electrolytic capacitors [8]. Hence, the CSC based DVR is expected to be operated with optimum reliability.

4) Due to the presence of large series inductor which limits the rate of rising of current in the event of a fault, the CSC topology is more reliable and fault tolerant than a VSC [1]. The CSC also offers additional short circuit protection as compared to the VSC because of the directly controlled dc current [8]. Therefore, these characteristics provide the basis for the reliable operation of the CSC based DVR.

5) The VSC is a buck type inverter circuit as the dc bus voltage must be twice the maximum AC phase voltage for preventing overmodulation whereas the CSC is a boost type inverter circuit [8new]. Hence, the CSC based DVR is likely to be more suitable and flexible for incorporating in the power distribution system.

6) The AC side filter circuit in VSC is made of inductors and as a result, it causes a voltage drop and phase shift in the voltage injected thereby affecting the control scheme of the DVR. But this problem will not occur in the case of CSC based DVR as the AC side filter is made of capacitors only.

Thus, the realization of the DVR based on CSC topology is expected to offer favorable characteristics such as good quality sinusoidal injection voltage, more fault tolerant capability, more reliable and efficient converter operation, simpler AC side filter configuration etc.

B. Dynamic Voltage Restorer and its Configuration

The DVR is a versatile series connected power electronic converter based CPD which is capable of protecting sensitive loads from all supply-side disturbances except outages [1]. In other words, it can be used for solving a variety of PQ problems such as voltage sag, swell, unbalance, harmonics and poor power factor etc. and reliability issues [2]. This type of CPD generally employs IGBT switches driven by a PWM (pulse-width modulation) based VSC. It has the capability of either generating or absorbing controllable active and reactive power at its AC output terminals [1]. The schematic diagram of a VSC based DVR system is shown in Fig. 1. Through the series coupling transformer, the DVR can inject AC output voltages of the VSC in synchronism with the feeder voltages of the distribution system. The control of the active and reactive power exchange between the DVR and the power distribution system are made possible and flexible due to the fact that the amplitude and phase angle of the injected voltages can be changed very easily. The dc link voltage of the DVR system can be obtained either from an external energy source (ac-dc converter) or from an energy storage element. The DVR system does not utilize passive elements such as capacitors or inductors to absorb or generate reactive power for exchanging with the distribution system [1].

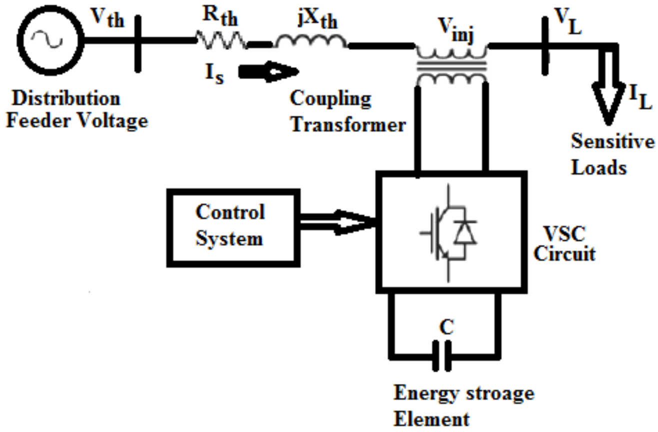

Fig. 1 Schematic diagram of a VSC based DVR system

For enabling the DVR to exchange active power with the distribution system, the dc link power of the DVR should be supplied from a stiff dc source [2]. At distribution voltage level and CPD applications, IGBT switches with PWM control scheme can be chosen if VSC topology is employed. Since the proposed model is based on the CSC topology, power electronic switches having large reverse voltage blocking capability (GTOs) have been selected [6], [7], [11].

C. Model Development of the CSC based DVR

The VSC based DVR is a popular type of CPD and it has been widely used to address most of the PQ problem issues due to the drawbacks of CSC topology discussed at Subsection-A. The schematic structure of the proposed CSC based DVR is shown is Fig. 2. In the CSC based DVR, a dc link choke or inductor ‘L’ or ‘L_{dc}’ is used instead of a pre-charged capacitor. In comparison with that of a VSC based DVR, the proposed CSC based DVR is expected perform the desired PQ improvement tasks with greater converter reliability, injection of cleaner sinusoidal voltage, reduced conduction losses and hence efficiently. The control system of Fig. 2 is presented in the form of block diagram as well as simulink model at Fig. 3 and Fig. 4 respectively. And the values of various parameters, components and subsystems of the proposed DVR are listed at Table 1.

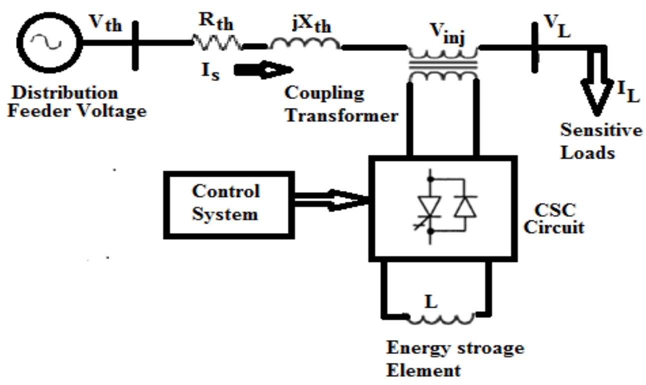

Fig. 2 Schematic diagram of the proposed CSC based DVR system

The objective of the proposed CSC based DVR is to investigate the performance and validity of the model in regulating the voltage on the distribution feeder bus which is supplying power to a variety of loads comprising of the 3-phase induction motor, rectifier, resistive and capacitive loads with the least harmonic content. This variety of loads has been chosen in the model to simulate the loading environment of modern power distribution systems. The induction motor draws heavy current at the time of starting, as a result, the voltage magnitude falls and then the motor continues to operate under lagging power factor thereby absorbing reactive power. Thus, the DVR system should able to generate and supply the required reactive power for maintaining the desired voltage profile on the bus. The rectifier load generates current harmonics and feeds it to distribution bus causing unwanted voltage waveform distortion. The capacitive load also resonates with the distribution system inductance and contributes to the waveform distortion. So, the proposed DVR system has to be designed in such a way that it acts as a series active power filter capable of mitigating such harmonics. The passive capacitor filter circuit incorporated on the output AC side of the CSC is to restrict the flow of the higher order harmonic currents towards the coupling transformer. In the case of VSC, the inductor is used as filter component, as a result, it causes a voltage drop and phase shift in the voltage injected thereby affecting the control scheme of the DVR. However, this problem does not arise in the case of CSC as the output filter is constructed by using a capacitor as filter components and provides good sinusoidal output waveform [6], [7], [10]. The design details of the low pass filter (LPF) are discussed at [6], [11]. Referring to the schematic diagram of the CSC based DVR shown in Fig. 2; the circuit on the left-hand side of the DVR represents the Thevenin's equivalent circuit of the distribution system. The system impedance, $Z_{th} = R_{th} + jX_{th}$ depends on the voltage characteristics the load bus. When the system voltage, V_{th} falls, the DVR injects a series voltage V_{inj} through the coupling transformer for maintaining the desired load voltage magnitude, V_L, The series injected voltage of the CSC based DVR can be expressed as:

$$V_{inj} = V_L + Z_{th}I_L - V_{th} \quad (1)$$

Where I_L is the load current and this can be obtained from the relation:

$$I_L = \left(\frac{P_L + jQ_L}{V_L}\right) \quad (2)$$

where P_L and Q_L represent the active and reactive power components of loads on the feeder bus. The complex power of the DVR can be expressed as:

$$S_{inj} = V_{inj} \times I_L \quad (3)$$

When the injected voltage V_{inj} is kept in quadrature with the load current, I_L no active power injection by the DVR is required to compensate the voltage [12]. The DVR system injects only reactive power as it is capable of generating the reactive power from itself. It must be noted that V_{inj} can be kept in quadrature with I_L only up to a certain value of voltage sag or fall and beyond which the quadrature relationship cannot be maintained to correct the under voltage variation. Under such situations, active power injection into the system is required and the injected active power can be obtained from the energy storage system of the DVR viz. lead acid batteries, flywheel, SMES or from an auxiliary ac-dc converter etc. When the injected voltage magnitude of the DVR is minimized, the desired voltage correction can be achieved with minimum reactive power injection into the system. This aspect of voltage correction is also very important because it minimizes the size of the coupling transformer [12]. Since the DVR is connected in series with the distribution system through a coupling transformer, it can also isolate the harmonics in between the nonlinear load and the source. This isolation can be done by injecting harmonic voltage through the coupling transformer. The injected voltages are added or subtracted to or from the source voltage for maintaining a pure sinusoidal voltage waveform across the nonlinear load. It is controlled in such a way that it offers zero impedance for the fundamental frequency component but appears as a resistor with high impedance for harmonic frequency components. Hence, no current harmonics can flow from nonlinear load to source and vice versa [13]. Since CSC topology is chosen, the dc link circuit has an inductor with its internal resistance, the time constant of the dc link circuit can be expressed as:

$$\tau_{dc} = \frac{L_{dc}}{R_{dc}} \quad (4)$$

The time constant of this circuit must be made as small as possible in order to allow rapid rise or fall of mean dc-link current [6], [11], [14]. From equation (4), it is learned that the value of L_{dc} should be chosen carefully and as low as possible. As this type of DVR provides the load with a good sinusoidal voltage waveform, it is quite suitable for enhancing the power quality in the power distribution system connected with nonlinear loads.

D. Control system development considerations

In order to achieve the desired voltage magnitude with clean sinusoidal waveform across the variety of loads including nonlinear one connected at the distribution feeder bus, the generation of proper gating signals for the power switching devices incorporated in the CSC circuit is indispensable. Hence, a proportional-integral (PI) controller-based control scheme has been developed for the purpose. The sinusoidal pulse width modulation (SPWM) switching scheme has constant switching frequency capability. This scheme can effectively minimize the level of switching stress on the converter switching devices [15]. This control strategy is capable of maintaining constant voltage magnitude sinusoidal AC voltage waveform at the point of common coupling (PCC) where the multiple loads are connected. This approach provides more flexibility than that of the fundamental frequency switching method [6]. Therefore, the CSC based on SPWM which also offers simplicity and the good response has been selected for the proposed model. In most of the custom power controllers, the reference source currents are generated by using the control schemes such as instantaneous reactive power theory (IRPT), synchronous reference frame theory (SRFT), unity power factor (UPF) based, instantaneous symmetrical components based, etc. [6, 15]. The reference signal to be processed by the controller is the key component which ensures the correct operation of the DVR system. The reference signal estimation is initiated through the detection of essential voltage or current signals for collecting accurate system variable information [13]. The SRFT belongs to the time domain reference signal estimation technique. It has the advantage of providing fast response to changes in the power system operation and also easy to implement and has little computational burden [16]. Hence, this control scheme has been adopted for the proposed model. The schematic block diagram of the control system for the proposed DVR system is shown in Fig. 3.

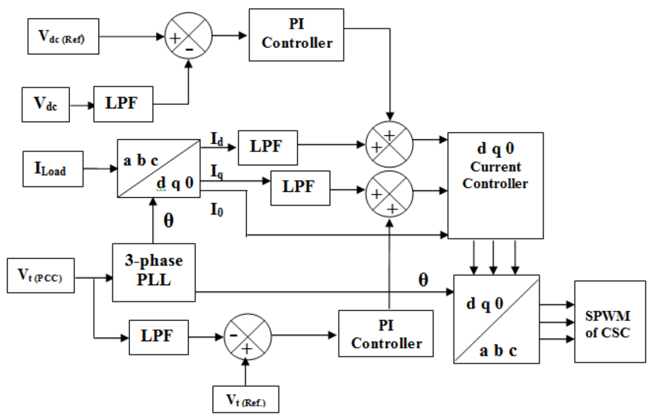

Fig. 3 Schematic block diagram of the control system for the proposed model

The SRFT is based on the Park's transformation for converting the 3-phase system voltage and current variables into a synchronous rotating frame. The active and reactive components of the three-phase system are represented by the direct and quadrature components respectively and the fundamental components are transformed into dc quantities which can be separated by using LPF [13].

E. Control strategies of the CSC based DVR system

The control strategies applied in the proposed model are as follows. The r.m.s voltages at the PCC are measured but there is no measurement of reactive power. The value of load currents, I_{Load}, the voltage at PCC, $Vt_{\,(PCC)}$ and the dc link voltage, V_{dc} of the DVR are monitored and these are utilized as feedback signals as illustrated in the Simulink model of the control sub-system shown in Fig. 4.

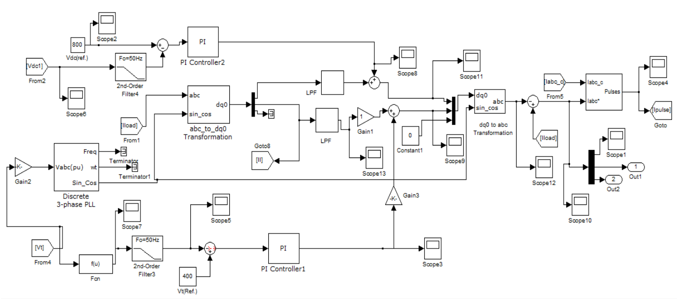

Fig. 4 Simulink model of the control sub-system

Firstly, the I_{Load} from a–b–c frame have been converted into the α–β–0 frames and then, it is converted into the d-q-0 frame by using the Park's transformation relation as:

$$i_d = \frac{2}{3}[i_a \sin\theta + i_b \sin(\theta - 2\pi/3) + i_c \sin(\theta + 2\pi/3)] \quad (5)$$

$$i_q = \frac{2}{3}[i_a \cos\theta + i_b \cos(\theta - 2\pi/3) + i_c \cos(\theta + 2\pi/3)] \quad (6)$$

$$i_0 = \frac{1}{3}[i_a + i_b + i_c] \quad (7)$$

Here, the three-phase phase-locked loop (PLL) sub-block incorporated in the Simulink model provides the cos θ and sin θ. In order to generate fundamental unit vectors for converting the monitored, I_{Load} into the d–q–0 reference frame, $V_{t(PCC)}$ is used as the required signal by the PLL. By using an LPF, the SRF controller segregates the dc quantities and eliminates the harmonics present in the reference signal [6], [7]. A PI controller is used to regulate the $V_{t(PCC)}$ after comparing $V_{t(PCC)}$ with a reference terminal voltage $V_{t(Ref.)}$. This action results to produce a quadrature current signal, i_q and adds with i_q available in equation (6) which acts as an input signal for the dq0 current controller as depicted in Figure 4. The error signal output after comparing with The V_{dc} is compared with a $V_{dc(Ref.)}$ to produce a dc error signal and this signal is processed by a PI controller for regulating the dc link voltage and generates direct current signal i_d. This i_d is added with the i_d developed in equation (5). The reference source current can be obtained by using reverse Park's transformation process as discussed at [17]. The SPWM now can provide necessary gate drive signals for the GTO switches used in the model.

III. Results and Discussion

In order to investigate the performance and effectiveness of the proposed CSC based DVR to regulate load voltage profile and mitigate harmonics, a Simulink model of the same has been developed as depicted in Fig. 5.

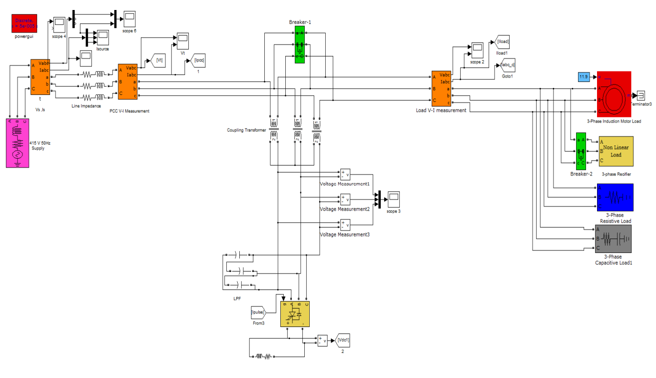

Fig. 5. Simulink model of the proposed CSC based DVR

Four different types of loads comprising of the 3-phase induction motor, 3-phase full wave bridge rectifier, resistive and capacitive loads are connected to the distribution system load bus after the DVR in order to simulate the impact of such loads to the power distribution utility. The circuit breaker-1 is used to connect or isolate the DVR with the distribution system for analyzing the performance of the model. The various parameter settings and constraints of the model are listed in Table 1 and results of the simulation are presented below.

TABLE I
PARAMETER SETTINGS OF THE PROPOSED MODEL

Sl. No.	Parameters	Values
1	Distribution feeder voltage and frequency	415 V (RMS), 50 Hz
2	Feeder system impedance	R_f= 0.01Ω, L_f= 2mH
3	Feeder system reference voltage and frequency	$V_{t\,(Ref.)}$= 400 V(RMS), 50Hz
4	Nominal power and frequency rating of the coupling transformer	5kVA, 50 Hz
5	AC side LPF capacitor of CSC circuit	C=2.85mF
6	DC reference voltage	$V_{dc(Ref.)}$ = 800 V
7	DC link inductor of CSC circuit	L_{dc} = 8000mH, R_{dc} = 0.01 Ω
8	PI controller gains for DC link voltage	$K_{P(dc)}$ = 0.03 $K_{i(dc)}$ = 0.04
9	PI controller gains for AC system voltage	$K_{P(q)}$ = 0.8 $K_{i(q)}$ = 0.02
10	Switching frequency of CSC circuit	f_s = 20 kHz
11	3-phase induction motor load rating	5.4 HP, 400V, 50Hz, 1430 RPM
12	Nonlinear load	3-phase bridge rectifier with 22.24% THD

A. *Simulation results under steady state condition without CSC based DVR*

The model has been simulated under steady state condition by closing the circuit breaker-1 in order to bypass or isolate the action of the DVR on the distribution system. The voltage and current waveforms observed at the PCC are shown in Fig. 6.

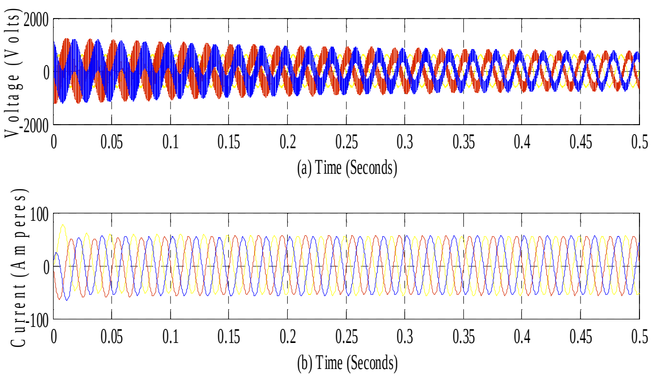

Fig. 6.Voltage and current waveforms at PCC without operating CSC based DVR

From the voltage waveform shown in Fig. 6 (a), it is observed that the voltage goes beyond 1000V with lots of distortions especially during the period from 0 to 0.2 seconds. The current waveform at Fig. 6 (b) is also found to be unbalanced at the beginning. The voltage and current waveforms monitored at the load bus are shown in Fig. 7.

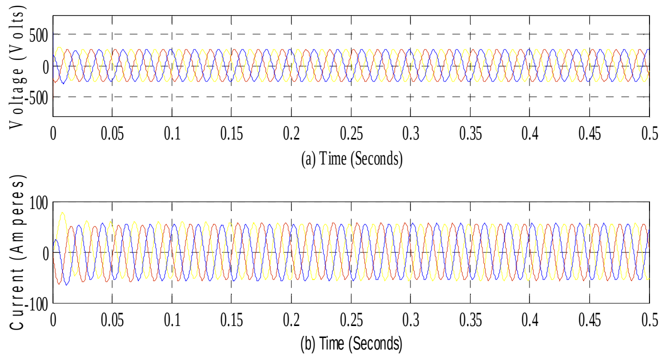

Fig. 7.Voltage and current waveforms at loads bus without CSC based DVR

Under this condition, the voltage magnitude falls well below the desired voltage of the 415 V (RMS) or 586 V (pp) as depicted in Fig. 7 (a). The current is also found to be unbalanced initially as shown in Fig. 7 (b). The total harmonic distortion (THD) under this condition has been investigated by using the Fast Fourier Transform (FFT) analysis facility available in the Simulink's power graphic user interface (GUI) system. The harmonic spectrum as observed during FFT analysis for the load bus voltage is depicted in Figure 8. The THD value under this condition is found to be 3.80 %.

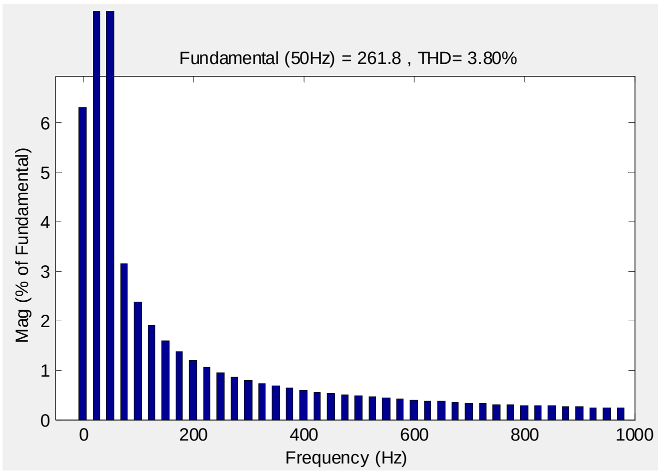

Fig. 8 Harmonic frequency spectrum at load bus without CSC based DVR

B. *Simulation results under steady state condition with CSC based DVR*

The performance of the CSC based DVR has been investigated by opening the circuit breaker-1 and bringing the DVR into action for compensating the load bus voltage and also to mitigate the presence of harmonics at the voltage waveform. The Voltage and current waveforms with the operation of the DVR monitored at the load bus are shown in Fig. 9 (a) and (b) respectively.

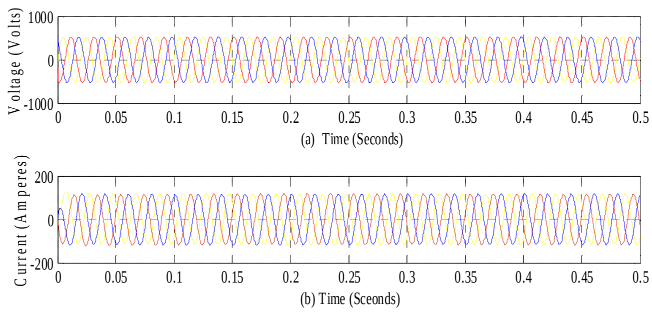

Fig. 9.Voltage and current waveforms at load bus with CSC based DVR

From the voltage waveform, it is observed that the DVR has successfully compensated the load voltage to 415 V (RMS) or 586 V (pp) which is required for proper operation of the loads connected to the power distribution system. The THD value of the load voltage obtained from the FFT analysis under this investigation is found to be 0.69 % as shown in Fig. 10 which is well within the prescribed limit of 3% for (special applications such as hospitals and airports), 5% (general systems) and 10% (dedicated systems viz. exclusively for converter loads) available at Table 10.2 of IEEE Standard 519-1992 [18].

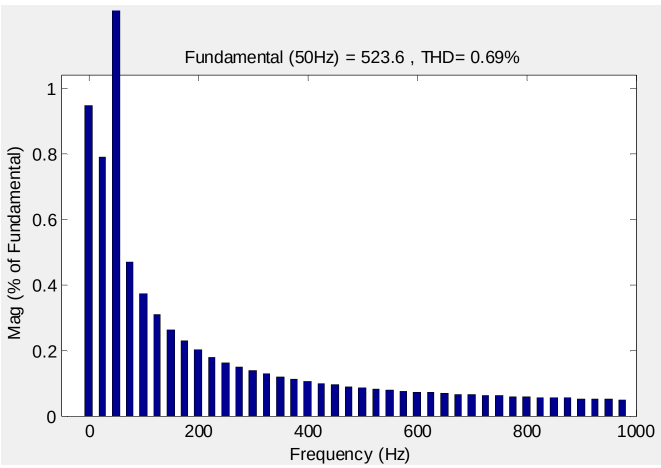

Fig. 10.Harmonic frequency spectrum at load bus with CSC based DVR

This THD value is less than that of the harmonics content in load voltage waveform without the operation of the DVR shown in Fig. 8. The above observations from the simulation study reveal that CSC based DVR is fairly capable of performing the dual tasks of PQ enhancement in terms of voltage compensation as well as harmonics mitigation at power distribution system simultaneously.

IV. CONCLUSIONS

Keeping in mind the various merits of CSC topology in comparison with that of the VSC one as discussed in the paper, the CSC based DVR can be considered as a viable solution for improving power quality. Through this research work, an attempt has been made to investigate the feasibility of implementing CSC topology in the CPD application by developing a CSC based DVR system capable of performing dual PQ improvement tasks. The various design considerations and steps to be followed with this approach while modeling the proposed system are also discussed. The simulation results of the model show that CSC based DVR can provide effective voltage regulation on the load bus under the dynamic behavior of a variety of loads connected to the distribution system. The problem of voltage waveform distortion due to the presence of harmonics emanating from the nonlinear load is also resolved. This work will also encourage the researchers to explore the feasibility of using such a topology in other types of CPDs for improving PQ at the distribution system.

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REFERENCES

[1] Ghosh, A., Ledwich, G., "Power Quality Enhancement using Custom Power Devices," *Springer International Edn.*, 1st Indian reprint, 2009, New Delhi, India

[2] Acha E, Agelidis, V. G, Anaya-Lara O, Miller T. J. E, "Power Electronic Control in Electrical Systems," *ELSEVIER–Newnes Power Engineering Series*, 1st Indian reprint, 2006, Delhi, India

[3] Hingorani, N. G., Gyugyi, L, "Understanding FACTS: Concepts & Technology of Flexible AC Transmission Systems," *John Wiley & Sons Inc.*, 2013, United Kingdom

[4] Hingorani, N..G, "Introducing Custom Power," *IEEE Spec.*, 1995, 32, (6), pp. 41- 48

[5] Yang, Y., Mehrdad, K., Victor, H. Q, "Current-Source Converter Based STATCOM: Modeling and Control," in *Proc. IEEE Trans on Power Delivery*, 2005, pp. 795-800

[6] Singh, M. D., Mehta, R. K., Singh, A. K, "Current source converter based D-STATCOM for voltage sag mitigation," *Int. J Simul Multisci Des Optim.*, 2015, 6, pp. 1 – 10

[7] Deben, S. M., Mehta, R. K., Singh, A. K, "Integrated fuzzy-PI controlled current source converter based D-STATCOM," *Cogent Engineering.*, 2016, 3, pp.1-15

[8] Radwan, A. A. A., Mohamed. Y. A. I, "Improved Vector Control Strategy for Current-Source Converters Connected to Very Weak Grids," in *Proc. IEEE Trans on Power Syst*., 2016, 31, pp. 3238-3248

[9] Steimer, P. K., Gruning, H. E., Werninger, J., Carroll, E., Klaka, S., Linder, S, "IGCT-A new emerging technology for high-power, low-cost inverters," *IEEE Inds. Appl. Mag*., 1999, 5, pp. 12–18.

[10] Padiyar, K. R, "FACTS Controllers in Power Transmission and Distribution," *New Age International (P) Ltd.*, 2007, New Delhi, India

[11] Bilgin, H.F., Ermis, M, "Current source converter based STATCOM: Operating principles, design, and field performance," *ELSEVIER J. on Elec. Power Syst. Res.*, 2011, 81, pp. 478- 487

[12] Haque, M. H, "Compensation of distribution system voltage sag by DVR and D-STATCOM," in *Proc. IEEE Porto Power Tech Conf.*, Porto, Portugal, September 2001, p.p 1-5

[13] Salam, Z., Cheng, T. P., Jusoh, A, "Harmonics mitigation using active power filter: a technical review," *Elektrika*, 2006, 8 pp. 17-26

[14] Bilgin, H. F., Ermis, M, "Design and Implementation of a Current Source Converter for Use in Industry Applications of D-STATCOM," in *Proc. IEEE Trans. on Power Elect.*, 2010, 25, (8), pp. 1943 – 1957

[15] Nagesh, G., Srinivas, B. K., Mahesh, K. M, "Synchronous Reference Frame Based Current Controller with SPWM Switching Strategy for DSTATCOM Applications," in *Proc. IEEE Int. Conf. on Power Elect. Drives and Eny. Syst. (PEDES)*, 2012, Dec 16-19, Bengaluru, India

[16] Grady, W. M., Samotyj, M. J., Noyola, A. H, "Survey of active power line conditioning methodologies," in *Proc. IEEE Trans. on Power Dely.*, 1990, 5, pp.1536 – 1542

[17] Singh, B., Jayaprakash, P., Kothari, D. P, " A T-Connected Transformer and Three-leg VSC Based D-STATCOM for Power Quality Improvement," in *Proc. IEEE Trans. on Power Elect.*, 2008, 23, (6), pp. 2710-2718

[18] IEEE Standard 519-1992: 'Recommended practices and requirements for harmonic control in electrical power systems', 1993