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Mitigation of Overall THD for the D-STATCOM Fed Low Voltage Grid

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Abstract- *As the need for electricity grows, the use of non-linear loads will rise day by day. These charges produce harmonics in the power grid. This is dangerous to the other load connected to the grid. There are some custom power machines, such as SVR, SSSC, UPFC, which are employees of the power transmission system. However, only D-STATCOM is used in the delivery system. D-STATCOM has an LC style filter that generates a high ripple at the PCC. This problem is removed by a high-level LCL filter. This paper addresses the modelling of the LCL filter with D-STATCOM. The proposed model is developed for the purpose of seeking findings in the MATLAB. The findings demonstrate the low harmonics of the power grid.*

Keywords**:**- Custom Power Device, D-STATCOM, STATCOM, LCL filter.

Introduction

Power quality problems are a significant problem due to the rise in the number of critical loads. The widespread use of electronic equipment such as information technology systems, adjustable speed drives (ASDs), arc furnaces, electronic fluorescent lamp ballasts and programmable logic controllers (PLCs) has often completely altered the essence of electrical loads. These loads are the key sufferers of problems of quality of power. The nonlinearity of these loads induces disruptions in the waveform voltage. The utility is likely to provide a low distortion balanced voltage to its customers, especially those with sensitive loads. In order to increase the efficiency of power and the stability of the system, FACTS devices and custom power modules are integrated into the power system. DSTATCOM/STATCOM, DVR, SSSC, UPFC, UPQC, etc. are some of the main instruments used to boost voltage sag and swelling. With the aid of these FACT devices, we are able to reduce energy efficiency issues.

STATCOM is known as D-STATCOM when attached to the distribution network. It consists of a two-level Voltage Source Converter (VSC), a dc energy storage unit, a coupling transformer connected to the distribution network by a coupling transformer. When attached to a single load, D-STATCOM injects offsetting current so that the overall demand follows the requirements for utility connections. Capacitive and inductive reactive power is created internally by D-STATCOM. Its control is very rapid and provides the device with adequate reactive compensation. D-STATCOM is used effectively to monitor the voltage of a set of small induction motor loads, which draw significant starting currents (5-6 times) of maximum rated current and can affect the operation of other responsive loads attached to the device.

The fundamental challenge posed by D-STATCOM is the present PCC ripple. This ripple allows the device to be harmonic in the power grid. In other words, the switching frequency voltage at the VSI regulated current leg is properly formed by a low-pass L filter to inject the desired filter current at the PCC. As a consequence, the filter currents pumped consist of a switching frequency current ripple. These ripples are transmitted to the source currents and also to the PCC voltages in the presence of the impedance of the feeder. The amplitude of this current ripple is inversely proportional to the value of the L filter.

Thus, a high value of L is needed to provide adequate ripple attenuation, which raises costs, deteriorates the rate of compensation and, therefore, the complex output of the system. In this article here discussed first the recent application of the D-STATCOM which is in part of modern power grid now a day. Then here discussed the proposed LCL based D-STATCOM model for improving the THD of the low voltage grid. The whole system is designed in the MATLAB software to find the validation of the proposed system with implementation of the proposed model.

II. Recent Application of D-STATCOM

Power quality management is one of the most active area for grid development today. Modern load consists of electronic controllers that lead to poor network voltage efficiency. Most academic papers have focused on improving current and voltage performance through the use of customizable control systems. A detailed review of the literature on power quality management on DSTATCOM mistreatment is presented here.

A D-STATCOM, based on a voltage source converter that injects reactive power into the distribution line, is built in [1]. [2] The optimal location and scale of D-STATCOM for radial transmission networks under the reconfigured network shall be determined in order to reduce the power loss which, in turn, saves energy and the environment. The operation of the Distribution Static Compensator (D-STATCOM) to control the power flow in the distribution line is presented in [3]. Various control methods for the operation of the D-STATCOM, where reference currents are measured in such a way that not only do none of the phase currents reach the limits, but even the fluctuations in the DC voltage remain within safe operating limits, are addressed in[4]. An up-to-date analysis of the literature on the optimum distribution of D-STATCOM to transmission networks is presented in [5]. The power quality control functionality of the DSTATCOM distribution system based on the d-q-0 reference framework is presented in [6]. A significant approach to finding the optimum location of the Combined Power Quality Conditioner (UPQC) and the Distributed Static Compensator (D-STATCOM) in the radial distribution grid is described in [7]. A comparative change of the voltage profile of the distributed power grid using the Dynamic Voltage Restorer (DVR) and the Distributed Static Synchronous Compensator (D-STATCOM) [8] is presented. Flexible in [9] DSTATCOM operation is specified here, where DSTATCOM changes its mode of operation, from current control mode (CCM) to voltage control mode (VCM) and vice versa. The Static Synchronous Distribution Compensator (D-STATCOM) is designed to effectively increase the voltage mismatch of the distribution channel connected to the microgrid device [10]. The effect of the various load models on the optimal allocation of D-STATCOM is shown by DNO for the radial distribution system with the goal of reducing the power loss by raising the voltage profile and saving total energy in [11].

A novel adaptive passivity-based control (PBC) of the cascaded multi-level D-STATCOM converter coupled with the medium voltage reactive power supply transformer is proposed in [12]. Optimized dynamic PI-Controller based on Fuzzy logic and Searcher Optimization Methodology (SOA) for Microgrid comprised of hybrid micro-sources to ensure the best end-user energy cost efficiency and reliability of energy supply is presented in [13]. A D-STATCOM for reactive power compensation in a distribution device that uses an inductive energy storage element connected to the grid via a matrix converter (MC) is discussed in [14]. A design protocol for a high-power D-STATCOM using an isolated, dual-converter topology is suggested in[15]. A Analysis of unbalanced radial distribution systems (UBRDS) using the D-STATCOM (Static Distribution Compensator) current in [16]. In [17] Suggested Matrix Converter Topology based Distribution Static Synchronous Compensators (D-STATCOM) which are used in the low voltage distribution network to compensate for the time-varying reactive demand of the load, thereby obtaining a unit power factor operation independent of the variance of the load power.

A Metaheuristic Optimization Technique, the Gravitational Search Algorithm (GSA) is proposed for the DS analysis with the proper positioning and dimensioning of the Distributed Static Synchronous Compensator (D-STATCOM) for power loss reduction, the minimum voltage profile table, the enhanced voltage profile and the annual energy savings for the distribution network operator [18]. A grid-connected solar PV system with a DSTATCOM bi-directional energy meter and improved power efficiency is being built in[19]. The configuration procedure for a high-powered D-STATCOM that uses an isolated, dual-converter topology is discussed in [20]. The use of the capacitor-less distribution static synchronous compensator (D-STATCOM) for power quality compensation in the existing distribution systems is discussed in [21]. The main results of the DG grid connection and the role of STATCOM in alleviating adverse effects, making the DG fully operational, are described in [22].

III. System Modelling

Figure 1 shows a three-phase VSC connected to the grid with an LCL-filter. In order to correctly model the grid action at the point of common coupling (PCC), the grid resistance (R_{grid}) and the grid inductance (L_{grid}) are taken into account. Any connections to the grid are made via PCC. It is also easier to assume that the LCL-filter is fixed between the VSC and the PCC.

PWM is very widely used in grid-connected VSC applications in combination with cascaded closed-loop control structure with external dc-link voltage control and internal current control loop. Unlike simple L-filters, LCL-filters have two currently available input state variables that offer versatility in calculating the trade-off between resonance damping and dynamic efficiency. Inner current loop uses either the converter-side current (i_c) or the grid (line) side current (i_g) as the input vector seen in Figure1. However, settling on the sort of input currently given is not a simple job. On the one hand, if the industrial unit contains current sensors embedded in the converter (i.e. for protection purposes), the return of the converter-side current is rational. However, the compensation of the power factor (PF) becomes mandatory due to the existence of the filter phase shift in this process. In the other hand, if the primary goal is to monitor PF at the PCC, the use of current grid-side input is rational. The current step angle of the line can then be directly controlled. However, the need for line current calculation contributes to the expense of current sensors and limits reliability. Overall, the priority of the design objectives is generally determined by the current feedback variable.

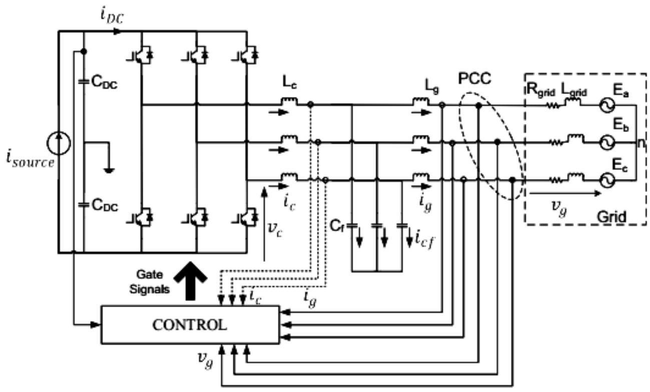

Fig. 1: Proposed Grid Interface LCL based D-STATCOM.

IV. Controller Design

The ideal LCL-filter consumes only reactive power; nevertheless, the components in real life have resistive components. However, the core and copper losses of the grid-side filter inductors (L_g) and the converter-side filter inductors (L_c) and the equivalent series resistances (ESRs) of the filter capacitors (C_f) are neglected in the controller design phase to model the worst case unmodified scenario.

Figure 2 displays the cascaded control system of the 3-phase VSC. The external control loop manages the VDC relation voltage dc to the constant reference value V_{DC}* by creating the reference value for the current controllers. The inner control loop controls the active and reactive components of the current feedback variable based on the reference value generated by the outer loop. This nested control loop configuration can also be referred to as a "voltage-oriented current control technique." Both the outer and the inner loop accomplish control in the synchronous reference frame which is locked directly to the grid voltage vector as seen in Figure 2. Either the current feedback grid or the current feedback converter can be set as the current feedback variable seen in Figure 2 noting that the LCL-filter transition function varies in each case.

In order to gain current control with rapid dynamic response, a spinning frame is often favoured in current controller designs. However, there are also other existing controllers, such as resonant controllers, which use a stationary frame. In this work, the control loop is modeled as a two-phase d-q-reference frame rotating at the grid frequency ω_g. As a result, the control of three-phase ac signals transforms into the control of two-phase d-q-reference frame dc signals. It is more desirable to control dc values because, as a well-known linear control strategy, i.e. the PI controller performs zero error relation monitoring in steady state using dc values. As a consequence, stability (zero steady state error) and simplicity (two PI current controllers instead of three) are guaranteed by integrating the current control configuration in the d-q-frame..

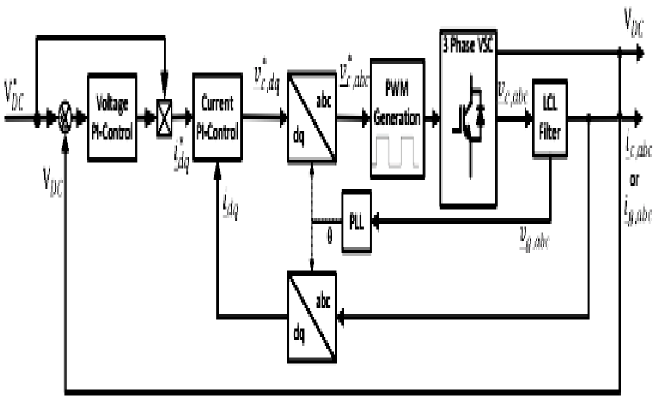

Fig. 2: Basic Control Strategy for proposed work.

In Figure 2, the outer dc-link voltage control loop produces the d-q current reference vector ($i^*_{\_dq}$) for the inner current control loop. Then, $i^*_{\_dq}$ is compared with the actual value of the current feedback variable $i^*_{\_dq}$ transformed into the d-q-frame and the output of the inner current control loop then determines the reference value for the d-q-frame VSC output voltage vector $v^*_{\_dq}$. Subsequently, this reference voltage value is returned to the stationary a-b-c-reference frame and then this three-phase voltage vector is used to produce PWM signals for VSC switching. The transition of balanced three-phase signals with respect to the spinning d-q-frame will be elaborated in the following paragraph prior to the descent of the system design details set out in Figure 2.

V. Design of LCL Filter for Controller

In order to model the LCL-line filter in the synchronous rotating d-q-reference frame, the park transformation is used. The LCL-filter model is given in the d-q-frame as the current control is carried out in the same reference frame with the d-axis matched to the grid space vector. On the basis of these transformations, LCL-filter equations can be derived as seen in (1)

$$\left.\begin{aligned} L_g\frac{di_{g\_dq}}{dt} &= v_{cf\_dq} - v_{g\_dq} - \left(R_g + j\omega L_g\right)i_{g\_dq} \\ C_f\frac{dv_{cf\_dq}}{dt} &= i_{c\_dq} - i_{g\_dq} - j\omega C_f v_{cf\_dq} \\ L_c\frac{di_{c\_dq}}{dt} &= v_{c\_dq} - v_{cf\_dq} - \left(R_c + j\omega L_c\right)i_{c\_dq} \end{aligned}\right\}[1]$$

Where v_{g_dq} and i_{g_dq} is grid side space voltage and current vector, v_{c_dq} and i_{c_dq} is converter side voltage and current space vector, v_{cf_dq} and i_{cf_dq} is capacitor side voltage and current space vector.

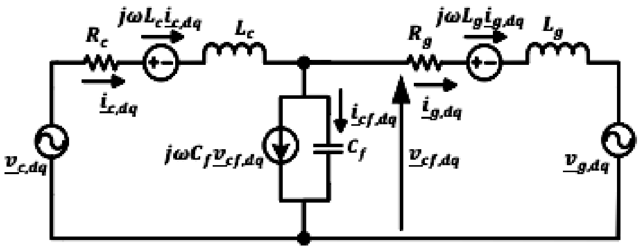

Fig. 3: Equivalent Circuit model of LCL network in d-q frame.

Cantered on LCL-filter equations in (1), the LCL-filter equivalent circuit in the revolving dq-reference frame can be modelled as shown in Figure 3. The LCL control filter model based on space vector notation in Figure 3 neglects the key loss of the grid-side filter inductors (L_g) and the converter-side filter inductors (L_c) and the filter capacitor ESRs (C_f) to model the worst case unmodified situation. Only the copper loss (winding resistance) of the converter-side inductor (R_c) and the grid-side inductor (R_g) are taken into account and modelled as sequence resistances.

VI. Simulation Results

The implementation of D-STATCOM is very useful for the harmonic reduction of the propagation end. This thesis explores the use of the LCL filter for D-STATCOM. To find the result, use the MATLAB program to simulate the proposed scheme. Figure 4 demonstrates the SIMULINK model for the proposed work. The whole model is based on a low voltage side grid. Table I displays the parameter used for the simulation used in the simulation process.

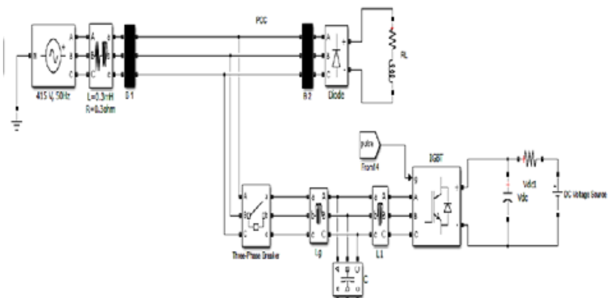

Fig. 4: SIMULINK model of proposed work.

Table 1: Parameter used in simulation of proposed work.

Parameter	Value
Grid Voltage	415 V, 50Hz
Converter	IGBT based 3 phase VSC
LCL Filter Parameter	L_g=1 mH, L_c= 0.5mH, C_f=30µF
DC Link Voltage	100 V
DC Link Capacitor	4700µF
Switching Frequency	10kHz
DC Load	R=20Ω, L=50mH

Figure 5 indicates the side current of the load. Here it is evident that the present ripple after 0.1 decreases, due to the relation of the LCL filters.

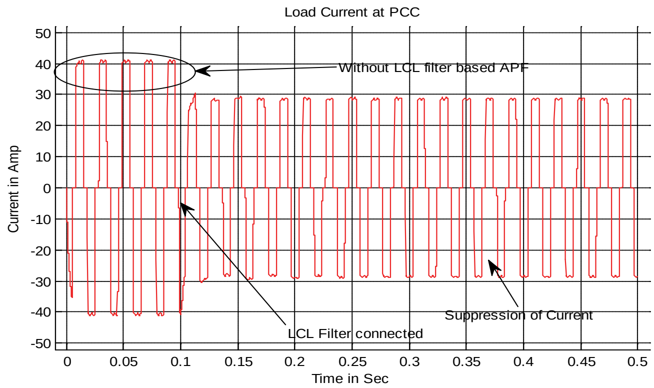

Fig. 5: Load Current at PCC.

Figure 6 indicates the existing source at the PCC. Here it is clear that with the implementation of the proposed method, the harmonics produced due to non-linear loading are cancelled. After 0.1 sec, when the proposed LCL based D-STATCOM is added to the PCC, the current harmonics are removed and the current rise is sudden. Here the current ripple is balanced due to the high order of the LCL filter.

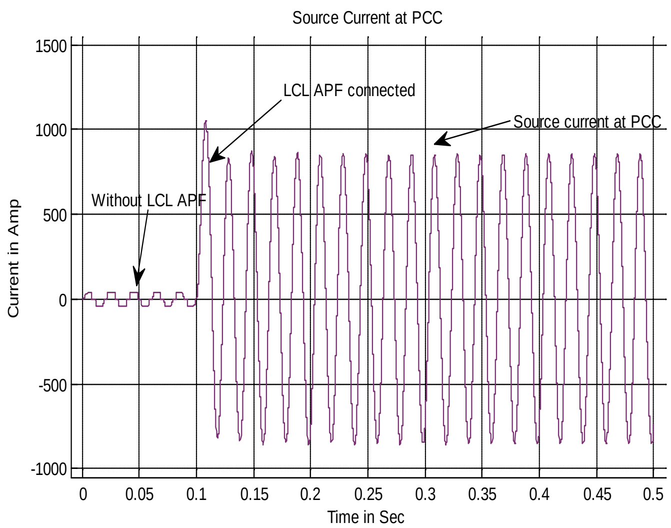

Fig. 6: Source current at PCC.

Figure 7 & 8 shows the FFT analysis of the current source before and after the LCL filter. The total harmonic distortion without the proposed system is 27.88%, as shown in Figure 7. It is clear from Figure 8 that when the proposed system is connected, the total harmonic distortion is 1.49 %.

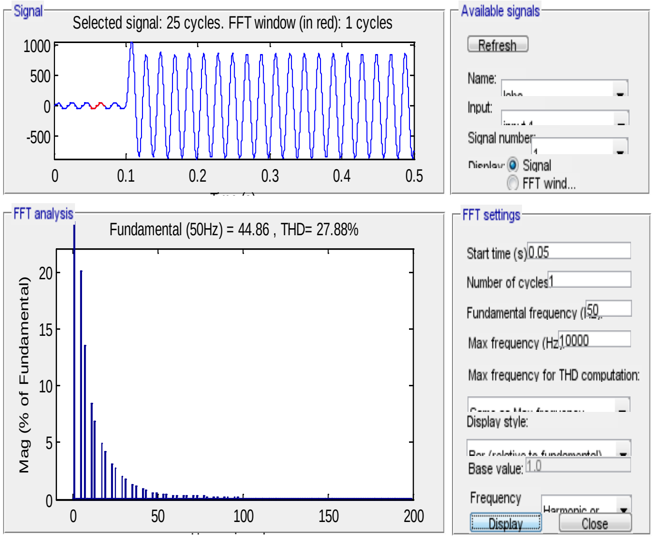

Fig. 7: FFT Analysis of Source current without proposed system.

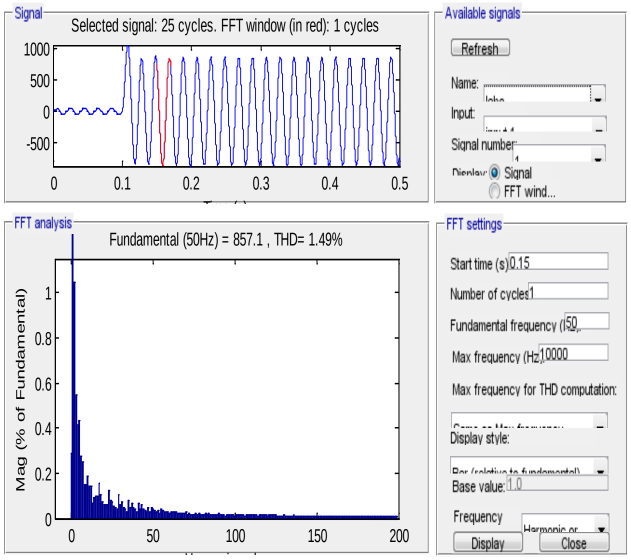

Fig. 8: FFT Analysis of source current with proposed system.

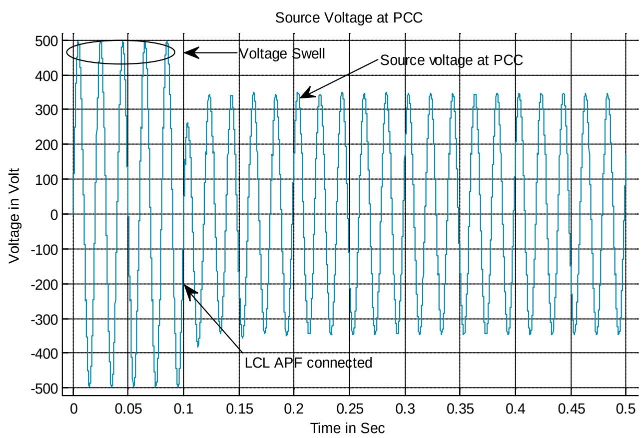

Fig. 9: Source side Voltage at PCC.

Figure 9 displays the PCC source voltage. Here it is obvious that the D-STATCOM compensates for the voltage swell caused on the supply side.

VII. Conclusion

D-STATCOM is a very useful method for reducing harmonics in the delivery chain. With the use of L or LC filters, however, they cannot manage high current ripples created by PCC. This paper explores the work of numerous researchers in the field of D-STATCOM. A new form of high order LCL filter is defined. The implementation of the LCL filter in D STATCOM is built and simulated in the MATLAB program. Here the results indicate the best outcome of the proposed framework.

References

[1]. Vinay M. Awasth; V. A. Huchche, 2016, "Reactive power compensation using D-STATCOM", International Conference on Energy Efficient Technologies for Sustainability (ICEETS),IEEE Publication.

[2]. Atma Ram Gupta, AshwaniKumar, 2015,"Energy Saving Using D-STATCOM Placement in Radial Distribution System under Reconfigured Network", Energy Procedia Volume 90, December 2016, Pages 124-136.

[3]. Piyushkumar M. Saradva; Ketan T. Kadivar; Mahesh H. Pandya; Abhayrajsinh J. Rana, 2016,"Application of D-STATCOM to control power flow in distribution line",International Conference on Energy Efficient Technologies for Sustainability (ICEETS), IEEE Publication.

[4]. Arash Khoshooei; Javad S. Moghani; Ignacio Candela; Pedro Rodriguez, 2017,"Control of D-STATCOM During Unbalanced Grid Faults Based on DC Voltage Oscillations and Peak Current Limitations", IEEE Transactions on Industry Applications, Volume: 54, Issue: 2.

[5]. Reza Sirjani, Ahmad Rezaee Jordehi, 2017, "Optimal placement and sizing of distribution static compensator (D-STATCOM) in electric distribution networks: A review", Renewable and Sustainable Energy Reviews Volume 77, Pages 688-694.

[6]. Prabir Ranjan Kasari; Manish Paul; Bikram Das; Abanishwar Chakraborti, 2017, "Analysis of D-STATCOM for power quality enhancement in distribution network", TENCON 2017 - 2017 IEEE Region 10 Conference, IEEE Publication.

[7]. Atma Ram Gupta & Ashwani Kumar, 2017, "Performance Analysis of Radial Distribution Systems with UPQC and D-STATCOM", Journal of The Institution of Engineers (India): Series B.

[8]. Nguyen Van Minh; Bach Quoc Khanh; Pham Viet Phuong, 2017, "Comparative simulation results of DVR and D-STATCOM to improve voltage quality in distributed power system", International Conference on System Science and Engineering (ICSSE), IEEE Publication.

[9]. Sachin Karare; Vijay M. Harne, 2017, "Modelling and simulation of improved operation of D-STATCOM in distribution system for power quality improvement using MATLAB Simulink tool", International conference of Electronics, Communication and Aerospace Technology (ICECA), IEEE Publication.

[10]. Li Wang; Wei-Sheng Liu; Chuan-Chieh Yeh; Chien-Hsiang Yu; Xiu-Yu Lu; Bing-Lin Kuan; Hong-Yi Wu; Anton Victorovich P, 2017, "Reduction of Three-Phase Voltage Unbalance Subject to Special Winding Connections of Two Single-Phase Distribution Transformers of a Microgrid System Using a Designed D-STATCOM Controller", IEEE Transactions on Industry Applications, Volume: 54, Issue: 3.

[11]. Atma Ram Gupta, Ashwani Kumar, 2018, "Impact of various load models on D-STATCOM allocation in DNO operated distribution network", Procedia Computer Science, Volume 125,Pages 862-870.

[12]. Yu Chen, Minghao Wen, Ertao Lei, Xianggen, Yin, Jinmu Lai, Zhen Wang, 2018, "Passivity-based control of cascaded multilevel converter based D-STATCOM integrated with distribution transformer", Electric Power Systems Research Volume 154, Pages 1-12.

[13]. Subhashree Choudhury, Pritam Bhowmik, Pravat Kumar Rout, 2018, "Economic load sharing in a D-STATCOM Integrated Islanded Microgrid based on Fuzzy Logic and Seeker Optimization Approach", Sustainable Cities and Society Volume 37, February 2018, Pages 57-69.

[14]. Wesam Rohouma; Robert S. Balog; Aaqib Ahmad Peerzada; Miroslav M. Begovic, 2018, "Capacitor-less D-STATCOM for reactive power compensation", IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018), IEEE Publication.

[15]. Ines Mehouachi, Mohamed Abbes, Souad Chebbi, 2019,"Design of a high power D-STATCOM based on the isolated dual-converter topology", International Journal of Electrical Power & Energy Systems, Volume 106,Pages 401-410.

[16]. Gupta, A.R., Kumar, A. Reactive power deployment and cost benefit analysis in DNO operated distribution electricity markets with D-STATCOM. Front. Energy 13, 86–98 (2019). https://doi.org/10.1007/s11708-017-0456-8.

[17]. Wesam Rohouma; Robert S. Balog; Aaqib Ahmad Peerzada; Miroslav M. Begovic, 2019,"Reactive Power Compensation of Time-Varying Load Using Capacitor-less D-STATCOM",10th International Conference on Power Electronics and ECCE Asia (ICPE 2019 - ECCE Asia), IEEE Publication.

[18]. Arya, A.K., Kumar, A. & Chanana, S. Analysis of Distribution System with D-STATCOM by Gravitational Search Algorithm (GSA). J. Inst. Eng. India Ser. B 100, 207–215 (2019). https://doi.org/10.1007/s40031-019-00383-2Power Electronics and Power Engineering (CPE-POWERENG), IEEE Publication.

[19]. Aishwarya A. Patil; Yogini Bhosale, 2019, "Development of Bi-directional energy meter for a grid-connected PV system with power quality improvement using D-STATCOM", International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC), IEEE Publication.

[20]. Ines Mehouachi, Mohamed Abbes, Souad Chebbi, 2019,"Design of a high power D-STATCOM based on the isolated dual-converter topology", Electrical Power and Energy Systems Vol.-106, pp 401–410.

[21]. Wesam Rohouma, Robert S. Balog, Aaqib Ahmad Peerzada, Miroslav M. Begovic, 2020,"D-STATCOM for harmonic mitigation in low voltage distribution network with high penetration of nonlinear loads", Renewable Energy, Vol. 145,pp 1449-1464.

[22]. Kamel Sayahia, Ameni Kadria, Faouzi Bachab, Hajer Marzouguia, 2020, "Implementation of a D-STATCOM control strategy based on direct power control method for grid connected wind turbine", Electrical Power and Energy Systems , Vol. 121, pp 106-105.