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Enhancement of Quality of Power by Multilevel D-STATCOM in Distribution Network

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Abstract—Utility distribution networks, crucial commercial operations, and critical industrial loads can suffer considerable financial losses as a result of a variety of service interruptions and outages. In developing countries like India, where alterations in power frequency and numerous other factors affecting power quality are a worry, it is crucial to take appropriate action. To control and reduce voltage disturbances, a variety of techniques are available. For their benefits, including suitable output waveforms, inverters with multilevel outputs, such as multilevel D-STATCOMs, are frequently utilized in the power system and industry (voltage and current). Multilevel D-STATCOM control can be accomplished with several controllers. A closed loop controller is one of the controllers that uses a feedback system to automatically control a system that ensures a desirable state or accepted value. Among the improvements are voltage sags and swells. A comparison is also made between the multilevel D-STATCOM and conventional PWM controls to demonstrate the performance of the proposed controller. In addition to its simplicity, robustness, and flexibility, the proposed method allows for all defects to be compensated.

Keywords—Multilevel D-STATCOM, Power Quality, Power Quality Enhancement, D-STATCOM, Voltage sag, Voltage swell

I. INTRODUCTION

Any nation's progress requires power as a necessary prerequisite. The contemporary power system is characterized by special characteristics. It is both the most complicated and the biggest system that has ever been created by humans. Every ten years, the demand for electricity more than doubles. The use of renewable energy sources (RES) and a reduction in the consumption of fossil fuels are required to meet future energy demands and address environmental issues. RES have expanded significantly during the past several years. Numerous technological obstacles, including issues with voltage stability and power quality (PQ), must be overcome in order to integrate RES into the current power system. Take the example of power-generating wind turbines. Fixed speed wind turbines create extreme voltage swings because all wind speed variations are converted into mechanical torque variations that are then converted into electrical power. In order to lessen the impact on the grid, curtailment is therefore frequently required [2].

The prevalence of sensitive loads necessitates paying attention to PQ issues. Huge financial losses will result from failing to pay attention to these issues. One of the key components of the PQ of networks is voltage stability, which is crucial for enhancing the security and dependability of power systems [3], [4]. A good way to maintain the network's voltage is by reactive power compensation. Switching capacitors and/or compensation inductors have historically been used to apply reactive power compensation to provide voltage regulation to the electric grid, which reduces changes in transmission line voltage. Due to their sluggish response times and potential for either over- or under-compensation, switched capacitors and inductors, which are passive compensators, are ineffective for voltage support. Because of their discrete nature, there is less VAR accessible at low voltages. To solve these issues, the static synchronous compensator (STATCOM) has been proven to be a practical dynamic shunt compensator in transmission and distribution systems. Because of its high degree of flexibility and controllability, STATCOM with a voltage source inverter has long been a contender among reactive power compensators. Due to the support of power systems and dynamic voltage supply, this compensator has become increasingly common during the past ten years [5-7]. The STATCOMs, which are based on solid-state converter topologies, have quick response times, a smaller footprint, greater operational flexibility, and outstanding dynamic properties under diverse operating situations.

Due to D-STATCOMs using commonly found switching devices, such as insulated gate bipolar transistors (IGBT) and integrated gate commutated thyristors (IGCT), high rating-Multilevel configurations for medium voltage applications are appealing. Since D-STATCOMs based on multilevel converter offer lower harmonic production and larger voltage ability, multilevel STATCOM design is crucial for direct power grid connection. Sinusoidal output waveforms are produced when STATCOM voltage levels are maximized, whereas the STATCOM is made easier for stable power stages and simple control applications when they are minimized. Three-level D-STATCOMs based on DCMC have been used extensively in HV power systems.

The subsequent sections of this paper are structured as follows. Section II examines D-Design STATCOM's and Development. Testing and Results are presented in Section III with the built control for D-STATCOM, and Chapter IV brings the paper to a conclusion.

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II. Design And Development Of D-STATCOM

A. Introduction

By delivering or absorbing reactive current, the fast-acting static synchronous compensator (STATCOM) regulates the voltage at the point of connection to the power grid. FACTS (Flexible AC Transmission System) devices are what it belongs to. The technology is founded on multi-level, modular VSC topologies using semiconductor valves. Voltage Source Converter (VSC) topologies, which employ GTO or IGBT devices, are the foundation of D-STATCOMs. One of the unique power supply equipment utilized to supply reactive harmonic currents of load demand is the D-STATCOM. In essence, this coupling transformer-based derivative switch device serves as a connection between the electrical power system (EPS) and the power grid. A voltage synchronised controller (VSC) that creates a voltage waveform by comparing it to the voltage waveform of the electrical system in order to achieve reactive power exchange Similar to an electronic synchronous capacitor, a D- STATCOM. By transferring active power back and forth between the other phases, a three-phase D-STATCOM provides reactive power to each phase.

B. Design of Multilevel D-STATCOM

A conventional D-STATCOM connected to a distribution system is shown in the block diagram. According to Figure 1, D-STATCOM is coupled in shunt with the system by a coupling transformer. The D-STATCOM comprises of a Voltage Source Converter (VSC) and a DC link Capacitor connected to the converter. The converter is output is controlled using Closed Loop Control.

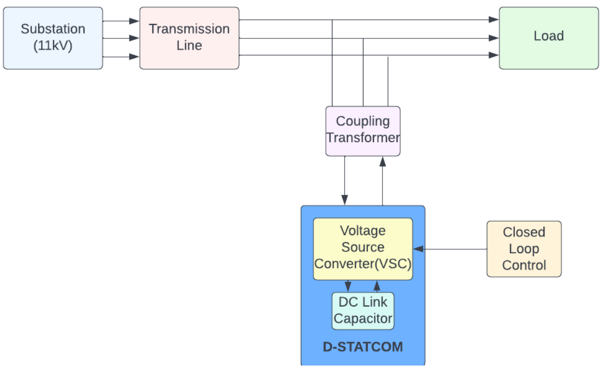

Fig 1. D-STATCOM connected to the Distribution System in a Block Diagram

The network voltage is altered by the current injected by the D-STATCOM in accordance with the voltage; when the voltage is low, it is raised, and when the voltage is high, it is reduced. The current injected by D-STATCOM should be set to a near-sinusoidal voltage with range of one per unit in order to remove flicker and harmonics and as well as other grid voltage abnormalities. A three-level clamp diode inverter is used as VSC by the D-STATCOM of Fig. 1 which can exchange reactive power with the system to regulate the power factor or voltage at the load terminal. To control the reactive and active power components of D-STATCOM, the voltage's magnitude and angle at the terminals must be regulated. In this proposed solution, the D-STATCOM voltage's magnitude and angle are modified using the closed loop control method.

C. Development of the Multilevel DSTATCOM

The fundamental parts of a multilevel D-STATCOM are a Voltage Source Converter (VSC), a DC link capacitor, a harmonic filter, and inductive reactance. A VSC, which consists of semiconductor valves which are self-commutating along with a capacitor on the DC bus, is the main component of a DSTATCOM The key benefits of D-STATCOM over a conventional static VAR compensator(SVC) include the ability to generate the desired current at almost any system voltage, better dynamic response, and the incorporation of a comparatively small capacitor on the DC bus. The size and expense of the compensator as a whole are greatly reduced because the steady-state generation of reactive power is mostly independent of capacitor capacity.

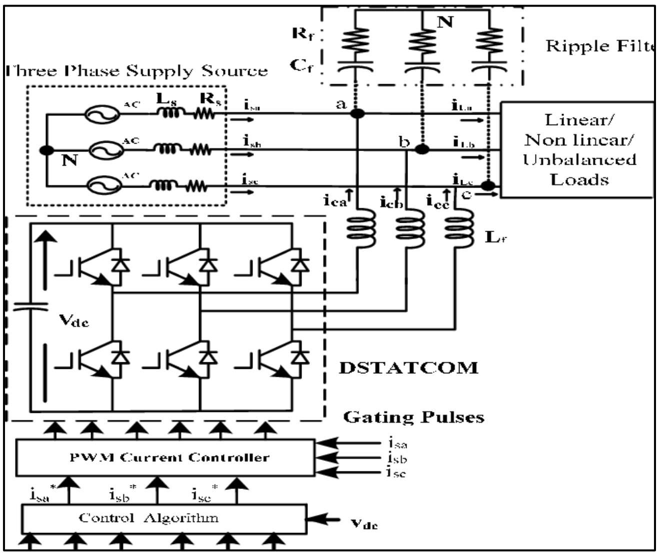

Fig 2. Schematic diagram of a DSTATCOM

TABLE 1 SYSTEM PARAMETERS

Parameters		***Value***
Source	Amplitude	1p.u(20kV)
	Frequency	50Hz
Load	Resistance	70Ω
	Inductance	6.5mH
Filter	Resistance	10Ω
	Capacitance	180μF

The configuration of a D-STATCOM coupled to a three-phase power source that is operating a three-phase load is shown in Fig. 2. The three-phase load may be balanced or linear. Inductors are employed in series with the VSC to reduce the ripples in compensatory currents. An RC filter coupled in shunt with the loads and VSC filters the high frequency switching noise in the voltage. Harmonic-free source currents and load reactive power correction arise from the DSTATCOM injecting the harmonic/reactive currents to cancel the harmonic/reactive power component of the load currents.

System parameters are displayed in Table 1. A three-phase load of amplitude 20kV feeds a three-phase series RL load with resistance and inductance values as shown in the table. The resistance and capacitance values are selected as 10 Ω and 180 µF respectively. The DC bus voltage and DC capacitance is computed using the formulas given below.

For the proper PWM regulation of the VSC of the DSTATCOM, the value of the DC bus voltage (Vdc) depends on the voltage at the Point of Common Coupling (PCC) and must be higher than the amplitude of the AC mains voltage. The DC bus voltage for a three-phase VSC is given by,

$$V_{dc}=2\sqrt{2}V_{LL}/(\sqrt{3}m) \quad (1)$$

Here VLL denotes the AC line to line output voltage of DSTATCOM. The modulation index, m, is regarded as 1. By substituting the above values, the Vdc is obtained as 32,659 V.

The DC bus voltage's depression when loads are applied and its increase when they are removed determines how the DC bus capacitor should be designed. The equation regulating C using the energy conservation principle is as follows:

$$0.5\ C_{dc}\ \{(V_{dc}^{2})-(V_{dc}1^{2}\ )\}=k\{3V_{ph}(a\ I)t\} \quad (2)$$

Here V_{dc} is the reference DC voltage, which is selected to be 32,700V, Vdc1 denoted the DC bus's minimum voltage level, I denotes the phase current of the VSC, V_{ph} denotes the phase voltage and t is the amount of time required to recover the Vdc. The k factor's value ranges from 0.05 to 0.15. Using Eq. (2) Cdc is calculated as 99280 µF and it is approximated to 10000 µF.

D. The Control Algorithm for DSTATCOM

The Closed Loop Controller's block diagram is depicted in Fig. 3 below. The Park and Clark Transformations convert the three-phase source voltage and current into DQ0 components. In terms of voltage and current, these transformations give rise to (Vsd, Vsq) and (Id, Iq), respectively. There are three parts to the controller. the inner current control loop, the outer DC voltage control loop, and the outer reactive power control loop.

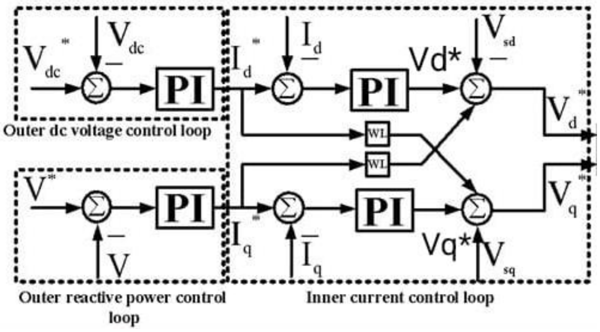

Fig 3. Block Diagram for a Closed Loop Controller

The D-STATCOM's voltage is compared to a reference voltage in the outer DC voltage control loop, and the error value is supplied to a PI controller. An output Id* is generated by this PI controller. In order to create an output Vd*, this output is compared to the source Id current and the error is given to the PI controller. The source Vsd voltage is increased through thisVd* and Iqwl. This produces our output Vd* signal which is later transformed into three phase abc signal using Inverse Park and Clark transformations.

The outer reactive control loop calculates the error in the source voltage and it is fed to a PI controller. This gives an output of Iq* which is then compared to the source Iq current. The error is then fed to a PI controller and it gives an output signal Vq*. It is further processed by removing the error and gives Vq* as output. The outputs Vd* and Vq* are converted into three phase abc components using Inverse Park and Clark Transformations. This output signal is given as an input to PWM pulse generator to generate pulses for the three-level Diode Clamped Inverter. As the inverter is connected in parallel to the network it absorbs or provides reactive power.

III. Testing and Results with the Developed Control For D-STATCOM

A. Introduction

This section presents the outcomes of the simulation of the proposed system. Voltage sag and voltage swell are two power quality issues that have been considered. The load current and voltage have been observed after these have been applied to the source. On the accessible structures, simulations have been run to evaluate the effectiveness of the suggested control algorithm. The source-load system is connected in parallel to a STATCOM, and the transmission line connecting the load to the source. The system parameters are displayed in Table 1. The suggested method is examined, and the simulation outcomes are shown. The results are further confirmed by contrasting the suggested controller's performance with that of traditional PWM control.

B. Simulation Results

A Source-Load system is considered with the parameters as mentioned in Table 1. A three-phase AC Source is considered and is connected to a Series RL Load through a Transmission line. The D-STATCOM is connected in parallel with the above system. The gate pulses for the IGBTs of inverter are given by two methods. By Discrete PWM Method and by Closed Loop Control (CLC) Method. Later the output waveforms of both the methods are compared.

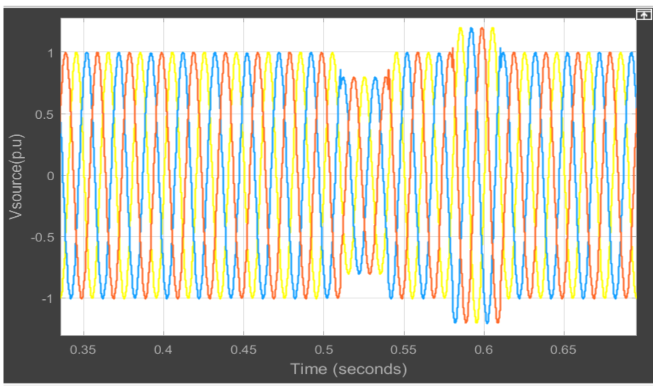

Fig 4. Source voltage waveform with the proposed CLC Control Method

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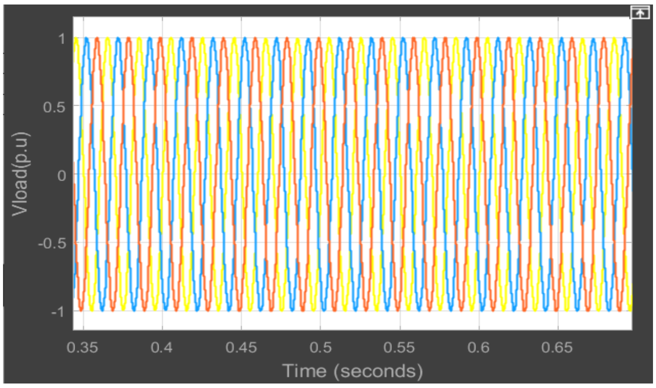

Fig 5. Load voltage waveform with the proposed CLC Method

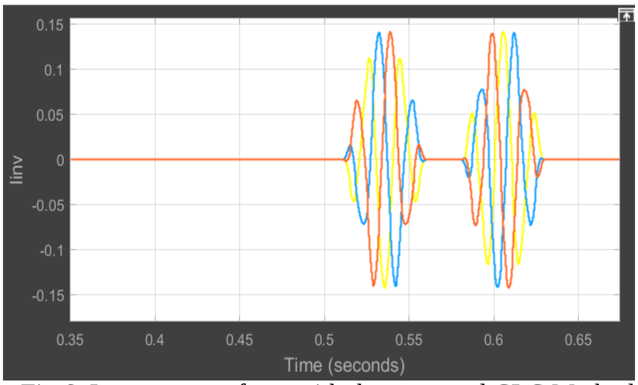

Fig 6. Inverter waveform with the proposed CLC Method

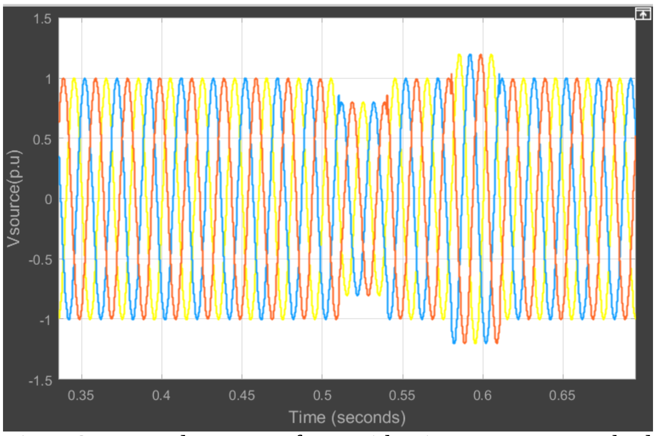

Fig 7. Source voltage waveform with Discrete PWM Method

The Figures from 4-9 shows the source and load voltage waveforms using Closed loop control and Discrete PWM control method. The voltage sag is applied from 0.51-0.54sec which is for 1.5 cycles. Voltage swell is applied from 0.58-0.61sec which is again 1.5 cycles. The load voltage is observed as shown in Fig 5 and Fig 8. Even though the source voltage has issues like sag and swell the output voltages are free from any disturbances. The current injected by the inverter is as shown in the Fig 6 and Fig 9. It is observed that while using closed loop control method the STATCOM injects/absorbs approximately zero current into the network when there is no sag or swell in Source voltage. But while using discrete PWM method there is some injection/absorbtion even though no voltage sag or swell is observed.

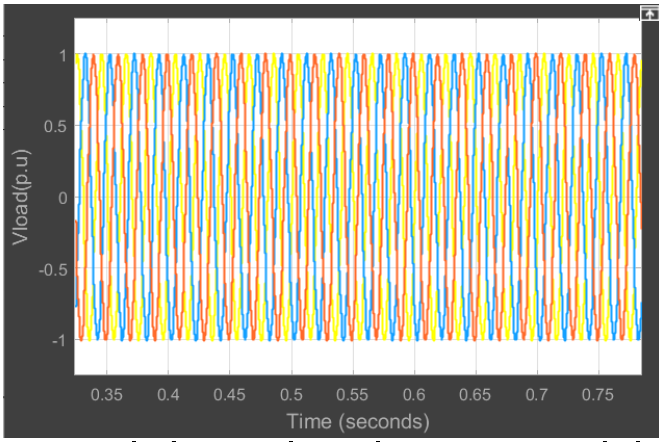

Fig 8. Load voltage waveform with Discrete PWM Method

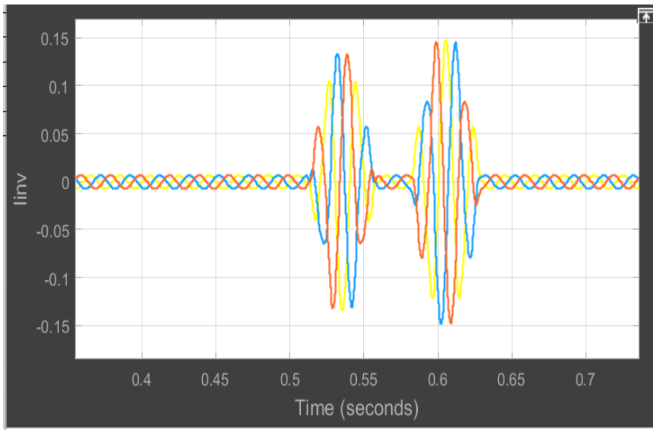

Fig 9 Inverter current waveform using the Discrete PWM Method.

While using the Discrete PWM method it is observed that te load voltage reaches a value of 0.985pu(approx.) and while using the closed loop control method the load voltage reaches upto a value of 0.999pu(approx.). There is an error of 0.014pu which shows that closed loop control method is better than Discrete PWM Method.

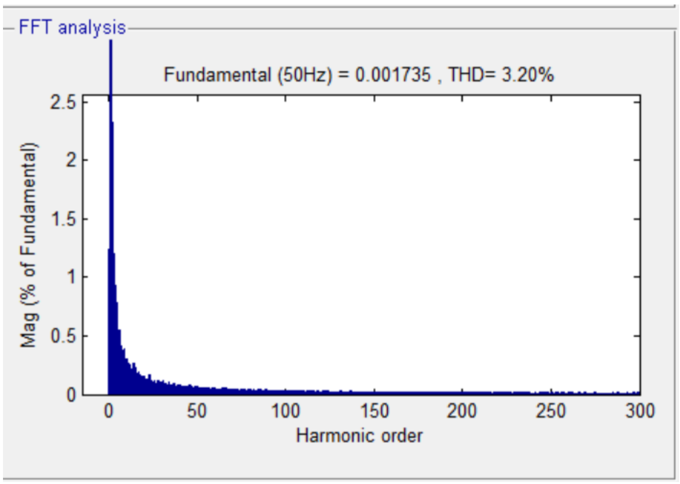

Fig 10 Total Harmonic Distortion using Discrete PWM Method

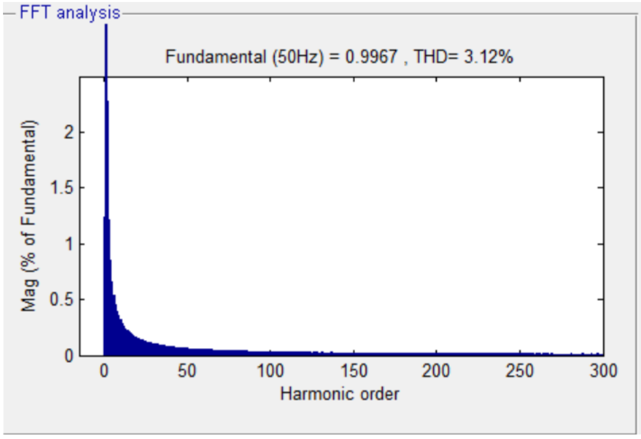

Fig 11. Total Harmonic Distortion using Closed Loop Control Method

Fast Fourier Analysis is done to determine the Total Harmonic Distortion. When it comes to measuring acoustics and audio , the FFT is a crucial tool. Spectral signal distinct elements are broken with technique used here &signal also provided the information about frequency. For quality assurance, defect investigation, and machine or system state monitoring, FFTs are employed. The Total Harmonic Distortion(THD) using both the control methods are shown in Fig 4.3.6. The THD of the load voltage using PWM method is 3.20% whereas for closed loop control method is 3.12% which shows that the harmonics produced in closed loop control method are less than Discrete PWM Method

IV. CONCLUSION

The three-level inverter structure utilized in this study has benefits over the two-level structure, including lower losses and harmonics. According to simulation and experimentation, outstanding Steady-State and dynamic performance is provided by the suggested Closed Loop Control based STATCOM to enhance power factor and to be able to stabilize the unstable voltage, i.e., voltage sag and voltage swell at the point where the D-STATCOM is connected. The benefits of the closed loop control approach the advantages it has over other controllers, such PWM, are response that is more accurate in the steady-state and has an increased response in a dynamic state. With the use of the proposed controller less harmonic distortion is observed in the output signal.

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