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

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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 make power networks sustainable. 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 use a feedback system to automatically control a system that ensures a desirable state or accepted value. Among the improvements are voltage sags and swells. The performance of the suggested controller is explained by contrasting it with both multilevel D-STATCOM and traditional PWM controls. In addition to its simplicity, robustness, and flexibility, the proposed method allows for all defects to be compensated.

1. 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. Future energy needs must be met while addressing environmental concerns, which calls for the utilization of energy from renewable sources and a decrease in the consumption of fossil fuels. Renewable Energy Sources (RES) have expanded significantly during the past several years. Numerous technological obstacles, including issues with voltage stability and power quality (PQ), must be overcome 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. To lessen the impact on the grid, curtailment is therefore frequently required [2].

The prevalence of sensitive loads necessitates paying attention to PQ issues to create sustainable power network. 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. Reactive power compensation has historically been accomplished using switching capacitors and/or inductors to ensure voltage regulation to the electric grid, which minimizes deviations 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. The Static Synchronous Compensator (STATCOM) has been demonstrated to be a useful flexible shunt compensation device in transmission as well as distribution networks to address these problems. 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 work using the principles of solid-state converter topologies, provide excellent dynamic qualities in a variety of operating scenarios, quick response times, a small footprint, and increased operational flexibility.

High rating-Multilevel topologies for medium voltage applications are intriguing because D-STATCOMs use widely available switching components like Insulated Gate Bipolar Transistors (IGBT) and Integrated Gate Commutated Thyristors (IGCT). Since D-STATCOMs based on multilevel converters 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 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.

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The remainder of the content of this paper is divided into the following sections. Section 2 examines D-Design STATCOMs and Development. Testing and Results are presented in Section 3 with the built control for D-STATCOM, and the last section 4 brings the paper to a conclusion followed by references.

2. Design And Development of D-STATCOM

2.1. Introduction

The fast-acting Static Synchronous Compensator (STATCOM) controls the voltage at the point of connection to the power grid by supplying or consuming reactive current. It is a member of the Flexible AC Transmission Systems (FACTS) family. 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. The power system network under consideration and the power grid are essentially connected by this coupling transformer-based derivative switch device. To perform reactive power exchange, a voltage synchronized controller (VSC) develops a voltage waveform by comparing it to the voltage waveform of the electrical system. A D- STATCOM is comparable to an electronic synchronous capacitor. A three-phase D-STATCOM supplies reactive power to each phase by reversing active power between the other phases.

2.2. Design of Multilevel D-STATCOM

The block diagram displayed in Figure 1 is a typical D-STATCOM interfaced with an electrical distribution network. Figure 1 shows how a coupling transformer interfaces D-STATCOM in shunt with the rest of the network. The Voltage Source Converter (VSC) and a DC link Capacitor coupled to the converter constitute the D-STATCOM. The converter's output is controlled using Closed Loop Control.

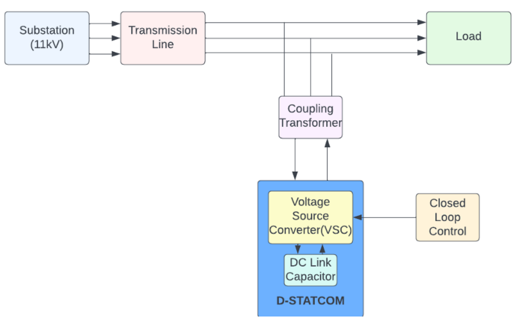

Fig 1. Integration of D-STATCOM with the Distribution Network

Following the system voltage, the D-STATCOM injects current into the network that changes the voltage; when the voltage is low, the current is increased, and when the voltage is high, the current is decreased. To eliminate flicker, harmonics, and other anomalies in the grid voltage, the current injected by D-STATCOM should be adjusted to a near-sinusoidal voltage within a range of one per unit. The D-STATCOM shown in Figure 1 employs a three-level clamp diode inverter as VSC, which may trade reactive power with the system to control the power factor or voltage at the load terminal. The magnitude and angle of the voltage at the terminals need to be adjusted to manage the reactive and active power components of D-STATCOM. The suggested technique employs closed-loop control to alter the amount and angle of the D-STATCOM voltage.

2.3. Development of the Multilevel DSTATCOM

A Voltage Source Converter (VSC), a DC link capacitor, a harmonic filter, and inductive reactance are the essential components of a multilevel D-STATCOM. A VSC, which consists of semiconductor valves that are self-commutating along with a capacitor on the DC bus, is the main component of a DSTATCOM. The capacity to create the necessary current at practically any system voltage, improved dynamic responsiveness, and the integration of a relatively small capacitor on the DC bus are the main advantages of D-STATCOM over a traditional static VAR compensator (SVC). 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.

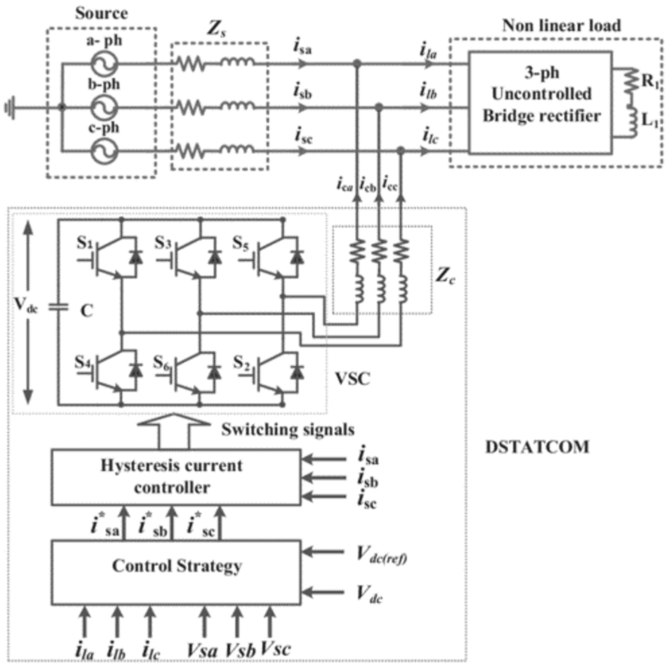

Fig 2. Schematic diagram of a DSTATCOM

Table 1. SYSTEM PARAMETERS.

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

Figure 2 depicts how a D-STATCOM is set up when it is connected to a three-phase power source that is powering a three-phase load. The three-phase load may be balanced or linear. Inductors are employed in series with the VSC to reduce the ripples in compensatory currents. The voltage's high-frequency switching noise is filtered by an RC filter that is connected in a shunt with the loads and VSC. Due to the DSTATCOM injecting the reactive and harmonic currents to cancel the reactive and harmonic power component of the load currents, harmonic-free source currents and load reactive power correction are produced.

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 are computed using the formulas given below.

The magnitude of the DC bus voltage (Vdc) depends on the voltage that exists at the Point of Common Coupling (PCC) and is required to be greater than the magnitude of the AC mains voltage for appropriate PWM control of the VSC of the DSTATCOM. For a three-phase VSC, the voltage across the DC bus is calculated as follows:

$$V_{dc}=2\sqrt{2}V_{Line\text{-}Line}/(\sqrt{3}M) \quad (1)$$

Here $V_{Line\text{-}Line}$ 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:

$$0.5\ C_{dc}\ \{(V_{dc}^2)-(V_{dc1}^2)\}=k\{3V_{ph}(a\ I)t\} \quad (2)$$

Here V_{dc} is the reference DC voltage, which is selected to be 32,700V, V_{dc1} denoted the DC bus's minimum voltage level, I denote the phase current of the VSC, Vph 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.

2.4. 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. The controller consists of three parts: an inner current control loop, an outer DC voltage control loop, and an outer reactive power control loop.

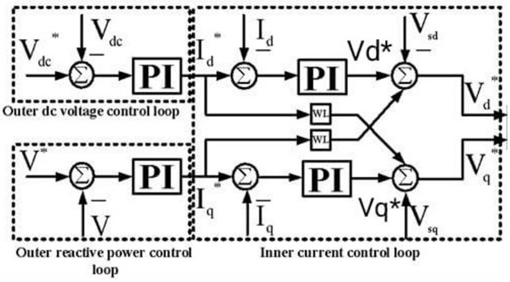

Fig 3. Block Diagram for a Closed Loop Controller

The outer DC voltage control loop compares the voltage of the D-STATCOM to a reference voltage, and the difference is given to a PI controller as the error value. An output Id* is generated by this PI controller. 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 this Vd* 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 giving 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 the 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.

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

3.1. 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 connects 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 helps in sustainability obj.

3.2. Simulation Results

A Source-Load system is considered with the parameters 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 the inverter are given by two methods. By Discrete PWM Method and by Closed Loop Control (CLC) Method. Later the output waveforms of both methods are compared.

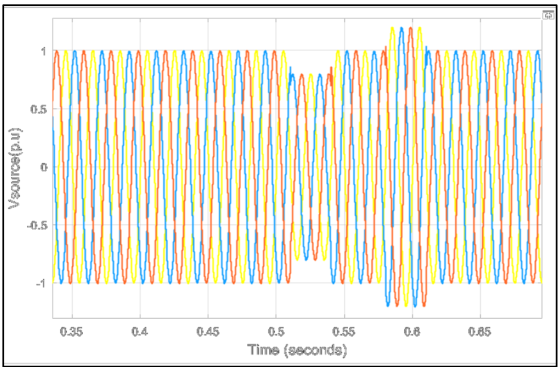

Fig 4. Source voltage waveform with the proposed CLC Control Method

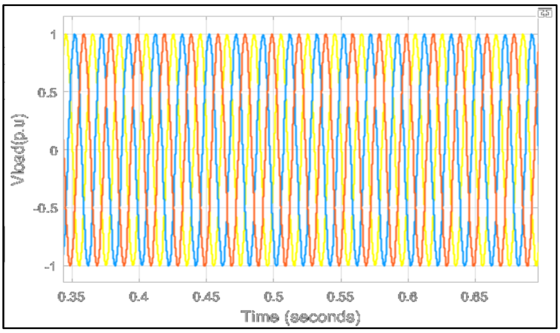

Fig 5. Load voltage waveform with the proposed CLC Method

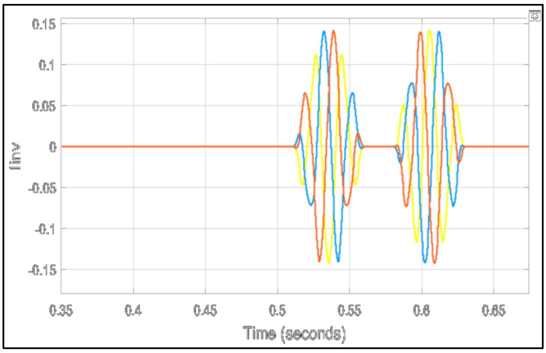

Fig 6. Inverter waveform with the proposed CLC Method

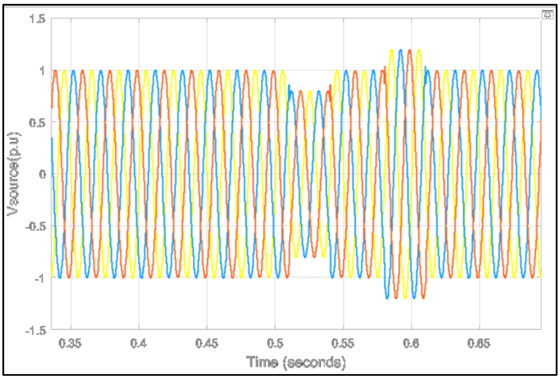

Fig 7. Source voltage waveform with Discrete PWM Method

Figures 4-9 show 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 shown in Fig 6 and Fig 9. It is observed that while using the 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 the discrete PWM method there is some injection/absorption even though no voltage sag or swell is observed.

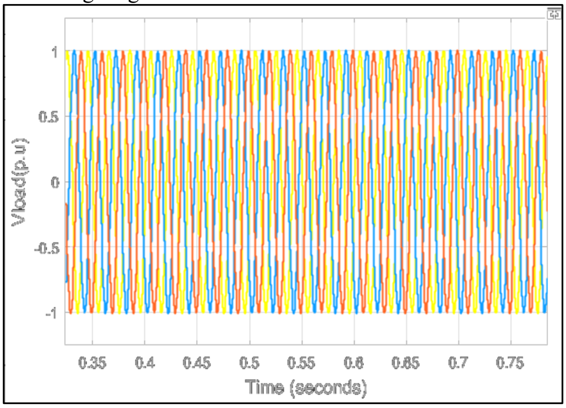

Fig 8. Load voltage waveform with Discrete PWM Method

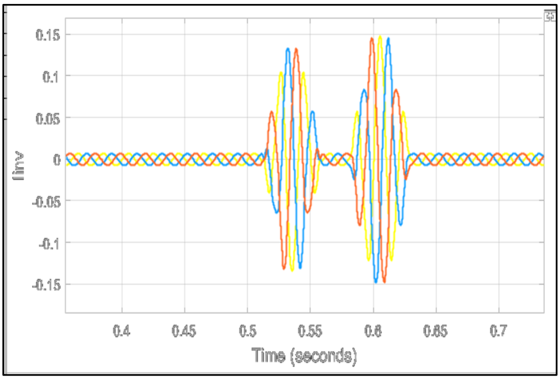

Fig 9 Inverter current waveform using the Discrete PWM Method.

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

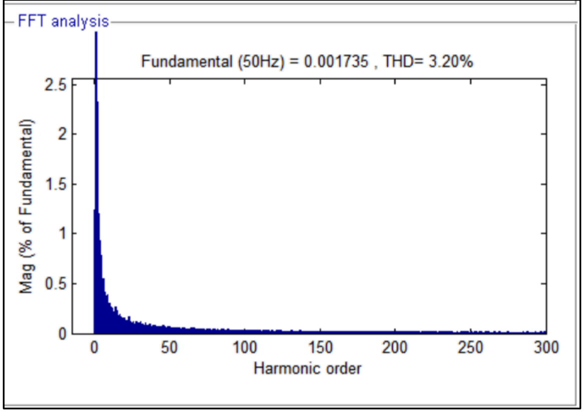

Fig 10 Total Harmonic Distortion using Discrete PWM Method

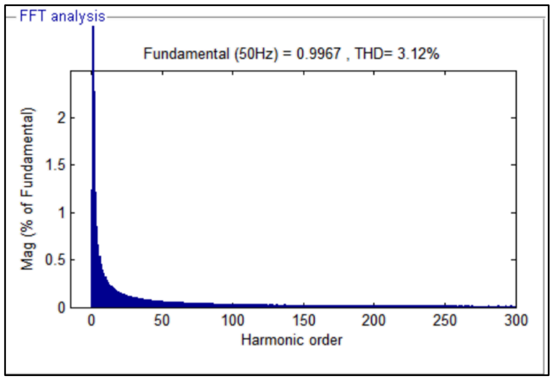

Fig 11. Total Harmonic Distortion using Closed Loop Control Method

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 the technique used here & the signal also provided information about frequency. For quality assurance, defect investigation, and machine or system state monitoring, FFTs are employed. The Total Harmonic Distortion(THD) using both control methods is shown in Fig 4.3.6. The THD of the load voltage using the PWM method is 3.20% whereas for the closed-loop control method is 3.12% which shows that the harmonics produced in the closed-loop control method are less than in Discrete PWM Method

4. 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 are 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 are the advantages it has over other controllers, such as PWM, which are response that is more accurate in the steady state and increased response in a dynamic state which make the power network more sustainable. With the use of the proposed controller less harmonic distortion is observed in the output signal.

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