STATIC REACTIVE POWER COMPENSTOR BASED ON THREE PHASE VOLTAGE CONVERTER

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Title of Project Paper/Research Report/Dissertation/Thesis ("**STATIC REACTIVE POWER COMPENSTOR BASED ON THREE PHASE VOLTAGE CONVERTER**"):
Field of Study: Power Quality Problems and STATCOM OR SVC comparisons.

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ABSTRACT

The stability of the electricity grid is essentially about the highest significance because of the rising desire for electricity and the implementation of decentralized production with sustainable energy sources. During research, we analyze the STATCOM, the derivation function of the FACTS controller or its operation enhances network utilization working normally and reactive power regulation. Phase angle control and PWM approaches are studied in relation to STATCOM's operating and control concepts. We also examine charge flow calculations, which are required for any solution associated with the power system, and conduct an extensive analysis of the manually operated active and reactive formula technique of load flow. Aside from this, we also investigate how power systems manage stability during brief events might be used to predict system performance. It is finish initially using a STATCOM, after that, a STATCOM controller remains put into operation, the features in the phase angle chart as well as errors on different Buses are visible. The primary objectives of this thesis are the implementation impact of STATCOM on a system's bus voltage and angle. The analysis of the applied STATCOM bus charts follows; he remains demonstrated that the angles' plots in phase exhibit a modified representative as a result within the STATCOM. A converter's parameters were examined and created to satisfy the specifications. In MATLAB and Simulink, we created the model's electrical and control circuits in order to analyse the device behavior in various reactive power consumption and generation modes. Utilizing the MATLAB Software/Simulink, all of the mathematical formulae and the optimization controller have been created.

Keywords: STATCOM; (Static Synchronous Compensators); FACTS; SVC; CAPACITOR; PAHSE LOCKED LOOPS; THREE PHASE TRANSFORMER.

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الْحَمْدُ لِلَّهِ رَبِّ الْعَلَمِينَ

"All the praises and thanks be to Allah who is the Lord of the universe."

(SURAH E FATEHA 1:2)

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LIST OF SYMBOLS AND ABBREVIATIONS

LIST OF SYMBOLS and Abbreviation

MO	Modulation optimum
PCC	Point of common coupling
SO	Symmetric optimum
VSC	Voltage source converter
vabc	Three-phase source voltages
f	Supply frequency
iabc	Three-phase source currents
R, *L*	Resistance and inductance of coupling reactor
MI	Modulation index
VDC	DC capacitor voltage
a	Overload factor
Kpi	Proportional gain of current Controller
Kii	Integral gain of current PI controller
L	Coupling inductance
R	Internal resistance of coupling inductance
C	DC link capacitor
a v , *b v* , *c v*	Supply voltages
a e , *b e* , *c e*	Terminal voltages of STATCOM
a i , *b i* , *c i*	STATCOM currents
dc i	DC link current

dc v	DC link voltage
λ	Leakage Inductance
ω	Synchronously angular velocity
θ	Angular position
δ	Load angle
P	Active power
Q	Reactive power
STATCOM	Static Synchronous Compensator
SC	Synchronous Compensators
TCSC	Thyristor controlled Series Compensator
SSSC	Static synchronous Series Compensator
SVC	Static Var Compensator
FACTS	Flexible Alternating Current Transmission System
AVR	Automatic Voltage Regular
HS	Harmony Search
PSO	Particle Swarm Optimization
VSC :	voltage source Converter,
IGBT :	insulated gate bipolar transistor,
HD :	Harmonic distortion
VSC:	voltage source converter
Us:	voltage network
Ust:	STATCOM voltage

CHAPTER 1: INTRODUCTION

1.1 Background

Because voltage collapse occurs frequently as a result of disturbances, overloaded systems, And shifting operation conditions maintaining voltage the power system's stability is one of main problems. [1] Multiple cutting-edge protective technologies have been created to provide proper monitoring and management. Similar to this, global trends have transformed the administration of electric power generation and transmission into an increasingly successful industry. [2] The system's principal fault is what causes the voltage profile to degrade failure to supply the demand for reactive power. When a bus's voltage magnitude declines and the system are for the same bus, the system's reactive power rises is considered unstable. [3] The growth of these networks is continuously driven by shifts in demand, compliance on environmental norms and high prices; it severely limits the practicality of establishing additional power lines. As earlier mentioned, this is what has contributed to Electrical Power Systems (EPS) in certain areas where the total capacity is higher or lower than the total capacity. Electromechanical oscillations may also be poorly dampened or unstable, which may result in high operating costs and progressive wear and tear on system components. [4]

Modern control systems that consider the dynamics of the equipment and the gearbox network have been developed to ensure the proper operation of the EPSs. When put correctly in the electrical system, Flexible AC Current Transmission (FACTS) devices can deliver a safe and affordable solution. Across all of the FACTS devices, to improve the network voltage profile, this equipment absorbs or provides reactive power as well as higher or lower voltage. Photovoltaic systems are just operative during the daytime and are turned off at night. As a result, they won't supply the grid with constant active power, and therefore have a lower availability rate than conventional power plants. [5]

1.2. Related Work

Furthermore, STATCOM permits power factor correction, reactive power control, damping of low frequency power variations via reactive power modulation, harmonic filtering, and reduction of flicker and improvement of power quality. Similar to a synchronous compensator, STATCOM operates. It functions as an inductive charge, take reactive power take-up of the network independently of the fact that the voltage generated by the converter is lower than the voltage of the transmission system. In contrast, STATCOM functions as a capacitor and provides reactive power for the system. when the converter output voltage is in excess of the network voltage. These devices work well with coupled nonlinear and/or unbalanced charges. [6] This equipment has been used successfully utilized in the electrical power grid. power stations because to their more relevant faster reaction times, compact constructions, greater compensation ranges, and lack of requirement for wide regions. As a result, Synchronous static compensators are highly ideal to compensate for the load in current three-phase energy distribution systems that utilize renewable energy sources. [7]

They can be classified as parallel or series networks depending on how they link to the network. As the proposed device mutes the massive capacitors and reactors of the Static Var Compensator (SVC), it arose as a remedy to the constraints that the SVC exhibits. A 20MVA prototype is shown, with an output VAR loss of about 3%, and further commercial development is advised as a result. The lack for switching power components decreased Focus on the study of this technology. However, with the development of self-switching devices, research projects that had been placed on hold in Asia, America, and Europe were reactivated. As a result, the true potential of these gadgets has now come to light. [8] In order to correct for electrical quality problems at the electrical network's load connection point, a static synchronous compensator

(STATCOM) can either provide or absorb reactive energy. Its technique is based on the Voltage Source Converter (VSC), which provides maximum power compensation and little harmonic injection in converters using IGBTs. The STATCOMs' architecture allows them to respond quickly by adding current to the network to maintain a constant system voltage issues, thereby boosting the stability of short-term voltage. [9]

To reduce problems with power quality including harmonics, transients, voltage dips, and damping vibrations, the FACTS such STATCOM and SVC are applied. It has to be highlighted. The second generations of SVCs are STATCOMs. Several studies have been conducted that compare the two in order to pinpoint the specific areas where the second exhibits superior performance. Some interesting results indicate that STATCOM may attain greater reactive power under the same position and compensatory capacity. Also, it can give more dizzying recovery of voltage. [10]

They can also be used in the power system to prevent three-phase short-circuits, which will save resources. As a result of increased loads and oscillations that these systems are able to produce, a further impressive benefit that these systems offer to electricity networks is reducing of harmonic distortion in line voltage. A number of papers with various focuses have been created. Using a multilayer modular converter (MMC), STATCOM may reduce harmonics till the 13th order while maintaining a low switching frequency, which lowers losses. [11] The construction of a static VAR compensator grounded on a cascade H-bridge is also described, and simulation results for a three-phasic inverter are used to support the theoretical assertions. The H-bridge Cascade Multilevel Converter (CHBMC) topology is used to assess the extent to which this type of device connects to a single-phase 220V network. [12]

Their implementation in the field of resources for renewable energy sources (RES) has been made possible because of the aforementioned advantages**.** For this reason, it is essential to assess the need for increasing the stability of electrical systems during transient events related to renewable power sources. In, it is evident how these innovations improve the caliber of the wind energy supply as determined by the outcomes of simulations. In, the idea of using STATCOMs to handle solar and wind energy is put out, and simulations confirmed the viability of this hybrid system. [13] System modeling and impedance management were done to minimize the network electrical resonance in the wind power plant simulation. This explanation explains how combining STATCOM and a PID control to reduce voltage fluctuation and account for its reactive power, wind farm's stability may be improved. In, the simulation results showed that integrating a STATCOM into a wind-photovoltaic system improves the quality of the electricity in a distribution network. [14]

It is recommended to optimize the quality of the energy received during the day, where the real energy comes from the SPS (simulated photovoltaic system), and at night, when it is not. Through the use of three simulation models, these technologies are also utilized both balance the current and voltage from the three-phase grid of electrified railways. This literature review conducted a thorough review of STATCOMS optimization based on FACTS and its applications. A three-phase static voltage converter can be used as a reactive power compensation device on transmission lines to regulate the flow of reactive power. Reactive power compensation helps to maintain the desired voltage levels and improve the power factor in an electrical system. In this system, standard voltage sources are used on the DC side of the static reactive power compensator. These voltage sources can be in the form of capacitors or inductors, depending on whether reactive power needs to be injected or absorbed. The compensator adjusts the amount of reactive power flowing into or out of the system based on the requirements. The voltage difference between the converter and the network plays a crucial role in determining the direction of reactive power flow. If the converter's voltage is higher than the network voltage, it tends to inject reactive power into the system. This can help to compensate for a lagging power factor or excess inductive loads. On the other hand, if the converter's voltage is lower than the network voltage, it tends to absorb reactive power from the system. This helps to compensate for a leading power factor or excess capacitive loads. By controlling the voltage difference and adjusting the operation of the static voltage converter, the system can effectively manage reactive power and improve the overall power quality on the transmission lines.

1.2 Problem Statement

The problem statement for Design of the static reactive power compensator, based on a 3-phase voltage converter, involves designing a system that can compensate for reactive power in a three-phase power system using a static compensator. The compensator is based on a voltage converter that can adjust system voltage for controlling the reactive power stream.

- The goal of the design is to ensure that the power factor of the three-phase power system is improved, leading to a more efficient and reliable system. The design must take into account the load characteristics and the voltage profile of the system to ensure optimal performance.
- The static reactive power compensator design must also meet the requirements for reliability, efficiency, and cost-effectiveness. The design should be easy to install, operate, and maintain while providing reactive power compensation required for system power factor improvement.
- The final design should include specifications for the voltage converter, control system, and any other necessary components. The design must be tested and verified to ensure that it meets the required specifications and is compatible with the existing power system.

- The main objective of this project is to design and implement an advanced power quality (PQ) improvements event detection system that offers high accuracy in identifying various PQ events occurring in electrical power systems. PQ events refer to disturbances in the voltage, current, or frequency characteristics of the power signal that can negatively impact the performance and reliability of electrical equipment.

1.3 Research Objective:

This research paper's goal is to use adaptable AC gearbox system devices to make up for the reactive power. We have streamlined STATCOM (Static Synchronous Compensator) & SVC (Source Voltage Converter) out of a variety of FACTS devices. Due to the fact that these two methods are the most modern and effective, reactive power compensation.

1. The first goal is to conceptually comprehend reactive power compensation using simple mathematical formulas for shunt and series compensation.

2. Using STATCOM and VSC, the reactive power in a three-phase AC system will be compensated.

3. To perform STATCOM and VSC analysis in a three-phase AC system using Simulink.
4. To do the comparison of active and reactive power by using formulas.

5. The performance of power system will be examined.

1.4 Motivation

The following serve as the driving forces behind this initiative.

1. Enhancements to the power's quality.

2. Power factor improvement of the system

3. The network's losses being cut down

4. Increase in client income while reducing costs.

5. Enhancements to the power system's voltage control.

6. Increase the availability of power.

1.5 Thesis's Organization:

- Chapter 1 is Introduction that represents background, Problem statement and research objectives.
- Chapter 2 includes literature review in which we have PQ or STATCOM events and their impacts and different approaches for STATCOM OR SVC in PQ prediction and identification and Previous Studies on static reactive power based on STATCOM.
- Chapter 3 includes methodology which has simulation on Matlab and that simulation itself creating synthetic data and performs waveforms and testing procedures and then Perform Evaluation Metrics.
- Chapter 4 includes experimental results and analysis that includes Evaluation of static reactive power of voltage and current in it.
- Chapter 5 is discussion that includes Interpretation of Experimental Results, Strengths and Limitations of static reactive power for Power Quality Monitoring and Management and Future Research Directions.

- In the end chapter we have conclusion that includes Summary of Findings, Contributions to the Field, Practical Recommendations and Final Remarks.

SUMMARY

This Chapter explains the general concept of transmission line and distribution network and also describes the importance of transmission line generation voltage in power system. This also describes the major problems in power network system and also provides an appropriate solution to this problem as well as explains the objectives of this research work.

CHAPTER 2: LITERATURE REVIEW

Power quality compensator problems are a major concern in modern power systems as they can cause severe damage to the electrical equipment and affect the reliability, protection of the power supply. Classification of static reactive power compensator problems using controller has been extensively studied in the last decade. In this literature review, we will discuss almost 30 research papers from the year 2015 to 2022 on the Classification of reactive power compensator problems using three phase voltage converter.

“Technical description of static compensators (STATCOM). Flexible AC Transmission Systems” by Davidson in 2020 [15]: Transmission lines respond to sudden increases in power, and if the fluctuations in power are not controlled, certain lines will become overloaded on particular routes. Devices that use flexible alternating current transmission systems (FACTS) may modify the voltage range and phase angle, which allows them to regulate the power flow. The static var compensator (SVC) is a parallel compensator that is used in conjunction with high voltage direct current (HVDC) bonding in this paper's appropriate mathematical modeling of FACTS devices. Furthermore, a complete modeling of the bonding between SVC and HVDC is done using concurrent applications for power flow, and the outcomes of compensations are contrasted. When the entire model was used in MATLAB software to apply the Newton-Raphson technique to the 5-bus test system, it was found that generators required providing more power. Additionally, the installation of these components stabilizes the voltage and manages the network's active and reactive power.

“SVC versus STATCOM for improving power system load ability” by Al-Jufout, S. in (2020) [16]: To ensure voltage stability under severe load demand, it is crucial to identify probable voltage collapse in power systems. The voltage collapse prediction index and the voltage stability margin factor (dS/dY) are two stability indices that are proposed in this research as a means to identify weak buses in power systems (VCPI). By positioning FACTS devices in the ideal locations and with the ideal dimensions, the article aims to boost the voltage stability of the Iraqi transmission grid. In this study, thyristor-controlled series compensators (TCSC) and static var compensators are the two types of FACTS that are employed (SVC). Particle swarm optimization fits the problem's objective function (PSO). Utilizing a simulation test on the Diyala-132 kV network, a component of the Iraqi electricity system, the proposed method is validated. The findings showed that the voltage stability margin had improved, the Diyala-132 kV voltage profile had grown, and power losses had decreased.

“A comprehensive comparison of STATCOM versus SVC-based fuzzy controller for stability improvement of wind farm connected to multi-machine power system**.**” By Rezk, H. in (2020) [17]: The two significant issues that might result from reactive power shortfalls brought on by increasing load or contingencies are voltage instability and voltage collapse. Maintaining voltage stability during periods of heavy demand requires the ability to identify possible voltage collapse in power systems. Power system stability is a crucial concern in the design and management of these systems.

“A comparison study of reactive power control strategies in wind farms with SVC and STATCOM” by Cherkaoui, N. in (2020) [18]: This study established the best position and size for a FACT STATCOM device to increase a transmission system's static voltage stability margin. The IEE New-England transmission network serves as the study network. The goal of the multi-criteria optimization used to solve the problem is to maximize load margin, reduce power losses, and reduce voltage deviation. The analysis and optimization method is used to modify the problem's objective function

(CPF). The CPF approach is used to determine the STATCOM values and placement depending on the aforementioned goals. The simulation's outcomes demonstrated the CPF's effectiveness for nominal values and the STATCOM's ideal placement. The findings indicated that the voltage stability margin had improved, the IEEE-100 kV voltage profile had grown, and power losses had decreased. Finally, STATCOM guarantees the transportation network'.

“Comparative study of SVC and STATCOM reactive power compensation for producer micro grids with DFIG-based wind farm integration” by Bian, X. (2020) [19] Power quality concerns including voltage drops, harmonics, transients, and damping oscillations are reduced by using FACTS like STATCOM and SVC. The fact that STATCOMs are SVC second-generation devices must be highlighted. In order to pinpoint the areas where the seconds do better than the first, several studies have been conducted that compare the two. Interesting results show that STATCOM can give more vertiginous voltage recovery and greater reactive power while preserving the same stand and the same ability to compensate.

“Study on STATCOM principle and control strategy under short circuit fault” by Zhang, X. in (20217) [20]: A limitation on voltage and small-signal stability is used to frame maximum load ability as an optimization problem. For safe operation at maximum load, stability ratings are displayed and integrated into the optimization problem. Both test networks experienced improved voltage regulation under various loading conditions thanks to the assistance of the STATCOM that was installed in the best possible location. Additionally, it allows 50% more output capacity in each test system to accommodate active power and loads.

“High order voltage and current harmonic mitigation using the modular multilevel converter STATCOM” by Bauer, P. in (2017) [21]: Photovoltaic inverters are now employed in the generation of power. As a result, they must satisfy the specifications and needs of the power grid. In addition to supplying active and reactive power, they also help with other functions like power quality, frequency control, and voltage regulation. This study describes a photovoltaic system that uses an inverter to connect to the grid. The approach attempts to supply the grid with both active power and reactive power with higher power efficiency.

“Selective harmonic elimination technique with control of capacitive DC-link voltages in an asymmetric cascaded H-bridge inverter for STATCOM” by Farhangi, S. in (2018) [22]: It has become difficult for utilities to operate safe and secure networks with acceptable voltage levels, necessitating the implementation of remedial measures. The use of flexible AC transmission devices to enhance the network is studied for this function. In order to improve the power transmission capabilities with less voltage variation, optimal allocation of the static synchronous compensator (STATCOM) is proposed.

“Design, Optimization and Experimental Verification of a Low Cost Two-Microcontroller Based Single-Phase STATCOM” by Vural, A. M. in (2021) [23]: STATCOM comes in a variety of shapes, but for the majority of practical applications, the fundamental square is an inverter, often known as a Voltage Source Inverter (VSI) in 3-stage design. The primary concept of a Voltage Source Inverter (VSI) is to utilize a DC voltage source, such as a charged capacitor or a DC power supply, to generate a regulated three-phase output voltage at the desired frequency of the AC power system. The VSI is a power electronic device that converts DC power into AC power. The VSI can control the magnitude and phase angle of the output voltage and current, allowing it to transfer active/reactive power between the DC source and the AC power system.

“Mitigation of power quality issues due to high penetration of renewable energy sources in electric grid systems using three-phase APF/STATCOM technologies” by Baig, N. A. in (2018) [24]: In the study mentioned in, the authors compared the use of STATCOMs (Static Synchronous Compensators) and SVCs (Static VAR Compensators) for low voltage ride through (LVRT) in wind farms. The objective was to examine how to integrate a large wind farm into a weak electrical infrastructure while maintaining a stable power supply. To address the issue of temporary voltage drops, a centralized STATCOM was constructed after analyzing the field supervisory control and data acquisition (SCADA) data to detect power quality problems.

“Design and analysis of a transformer less STATCOM based on hybrid cascaded multilevel converter” by He, Z. in (2019) [25]: The STATCOM is a power electronic device that can provide reactive power compensation and voltage support. By deploying a centralized STATCOM, the researchers aimed to mitigate the effects of voltage fluctuations caused by the wind farm. The study also involved system modeling and recommended the use of a STATCOM in conjunction with the wind farm. The proposed design was validated by comparing it with real field data, ensuring its feasibility and effectiveness in enhancing power quality. Furthermore, discusses the advantages of the supplied STATCOM and its control system. However, the provided information does not specify the specific content of these advantages. In a separate context, to improve the effectiveness of a photovoltaic (PV) system, various cooling techniques and reflectors were employed. One of the techniques involved using aluminum (Al) foil as a reflector, which increased the output power of the PV system by 20-35%. Additionally, when combined with a cooling system, the output power further increased by 22.75 to 38.55%.

“Stability enhancement of wind energy integrated hybrid system with the help of static synchronous compensator and symbiosis organisms search algorithm. Protection and Control of Modern Power Systems” by Banerjee, A. in (2020) [26]: Software-based sensors The STATCOM's performance in imbalanced circumstances has improved thanks to STATCOM control. A state observer (software sensor) was employed in the study work's recommended approach to approximately measure the voltages at the STATCOM interface point. This rendered the hardware obsolete and eliminated the need for physical voltage sensors. The transformer-less solar PV inverter eliminates the need for a transformer by implementing innovative circuit topologies.

“Interfacing of hybrid power system to grid using STATCOM & power quality improvement” by Chavan, G. P. in (2017) [27]: By utilizing advanced power electronic components and control techniques, the inverter can directly interface with the grid at higher frequencies. This allows for a smaller and more cost-effective design, while still meeting the necessary grid connection requirements. One control topology that has shown good performance in grid-connected PV systems is the 12-pulse Static Synchronous Compensator (STATCOM) controlled by a digital signal processor (DSP).

“STATCOM and PID controller based stability enhancement of a grid connected wind farm” by Khan, M. H. in (2019) [28]; The STATCOM controller consists of a phase-locked loop (PLL) module and a pulse generator module. The PLL module ensures synchronization between the inverter's output and the grid, while the pulse generator module regulates the inverter's firing angle. This control mechanism enables the exchange of reactive power, helping to stabilize the grid voltage and improve power quality. In addition to the control aspects, the design of solar-wind hybrid energy systems (HES) can be optimized to increase output power.

“Photovoltaic-STATCOM with low voltage ride through strategy and power quality enhancement in a grid integrated wind-PV system” by Kalian nan, P. in (2018) [29]: This analysis can provide valuable information on the implementation and optimization of STATCOM controllers for grid-connected PV systems. Overall, grid-connected PV systems offer high operational reliability, efficiency, and cost-effectiveness despite their higher initial startup costs. The advancements in transformer-less solar PV inverters and control topologies, such as the 12-pulse STATCOM, contribute to the continuous improvement and widespread adoption of grid-connected solar power plants.

“A comparative performance analysis of PV grid interface STATCOM control algorithms” by Nair, M. G. in (2017) [30]: In order to balance voltages at the point of common coupling (PCC) in the grid, a solar power plant (SP) was constructed as a Flexible Alternating Current Transmission System (FACTS) device, specifically a Static Synchronous Compensator (STATCOM). The study highlighted that the dual-purpose operation of the photovoltaic solar farm (SF) as a generator during the day and a regulator at night would enable the integration of new wind farms into the grid without the need for additional compensatory equipment. To validate this approach, simulations were conducted using MATLAB/Simulink.

“STATCOM simulation models for analysis of electrified railways” by Martins, A in (2019) [31]: For the implementation of building-integrated photovoltaic (BIPV) designs, a special bifacial reflector PV system (BRPVS) was developed. Aluminum foil was used as a reflector due to its low cost, allowing for increased power production. Experimental results showed a significant 28.47% increase in output power using the proposed strategy. In another study, a STATCOM was connected to the terminals of cage induction motors that were grid-connected during the grid failure recovery process.

“Power system loading margin enhancement by optimal STATCOM integration–A case study” by Joseph, T. in (2020) [32]: The objective was to temporarily announce a new voltage reference for the STATCOM control design, aiming to reduce torque transients of induction machines following grid faults. In the context of reactive power compensation for a wind farm with constant speed turbines, researchers investigated the feasibility of using One Cycle Control (OCC) and a multiple-level, hexagram converter-based STATCOM. Various types of multi-level voltage source converters were compared for STATCOM applications, and simulation results were validated through experimental findings.

“The use of battery energy storage systems (BESS) in combination with Static Synchronous Compensators (STATCOMs) to enhance the performance of STATCOMs in various power system applications” by Joseph, S. in (2019) [33]: One of the advantages of integrating BESS with STATCOMs is the reduction of power system transients. By deploying a STATCOM and a BESS in the electrical system, power fluctuations can be mitigated, leading to improved system stability. This is particularly beneficial during three-phase faults and when utilizing renewable energy sources. By controlling both active power (P) and reactive power (Q) in the power grid, a BESS-based STATCOM can effectively suppress electrical system oscillations.

“A review of strategies to increase PV penetration level in smart grids” by Ustun, T. S. in (2020) [34]: The proposed control approach, validated through simulations, demonstrated the effectiveness of incorporating a BESS-based STATCOM as a compensating device for wind plants. Overall, the literature underscores the benefits of utilizing BESS in conjunction with STATCOMs to enhance power system performance, including improved stability, reduced transients, power quality preservation, and efficient integration of renewable energy sources.

“A comparative study of super capacitor-based STATCOM in a grid-connected photovoltaic system for regulating power quality issues” by Rhee, S. B. in (2020) [35]: This configuration enabled harmonic cancellation, reactive power control, and load balancing. The D-STATCOM supplied actual power (P) and maintained energy under normal circumstances when the load exceeded the generator's capacity. The study employed a least mean square (LMS) methodology based on a hyperbolic tangent function. For large-scale multi-machine electrical systems incorporating synchronous generators (SGs) and doubly fed induction generators (DFIGs).

“Technical comparison of FACTS controllers in parallel connection” by Ángeles-Camacho, C. in (2017) [36]: The key findings of this study are: (1) A BESS-based STATCOM was deployed to provide voltage control for SG and DFIG operation. (2) The inclusion of a stabilizing feedback controller in a large electrical network enhanced transient system performance by utilizing control theory. (3) The study explored the potential benefits of leveraging the degrees of freedom in large electrical networks to improve transient performance.

“Photovoltaic-STATCOM with low voltage ride through strategy and power quality enhancement in a grid integrated wind-PV system” by kalian nan, P. in (2018) [37]: The simulation outcomes highlighted the advantages of the suggested PV-based STATCOM, and a careful comparison was made between the performance of superconducting magnetic energy storage (SMES) and battery energy storage systems (BESS)-based STATCOM. To deliver the required amount of active power (P) and reactive power (Q), the DC connection of the STATCOM was interfaced with BESS and SMES. Control of the STATCOM was achieved using a simple hysteresis controller. Experimental findings were utilized to validate the simulation results and confirm the effectiveness of both energy storage devices.

Carrier-phase-shifted rotation pulse-width-modulation scheme for dynamic active power balance of modules in cascaded H-bridge STATCOMs by Dai, K. in (2020) [38]: To prevent widespread blackouts, a specific protection strategy (SPS) incorporating loads shedding and generator tripping was implemented. STATCOMs were utilized on the producing side of the Korea Electric Power System to enhance the SPS. A unique control mechanism based on the equal area criterion (EAC) approach was implemented for the STATCOMs, which also served to estimate the STATCOM capacity. The construction of a modular, layered medium voltage inverter was developed for the grid integration of PV power plants. The modular and multilayer converter designs improved switching techniques by replacing a common DC link with a high-frequency-based magnetic connection, thereby reducing leakage inductances. However, the addition of more windings, rectifiers, and high-frequency magnetic linkages led to increased losses.

2.1 Reactive Power

Reactive capability is the source of energy stored within the reactive components. Reactive and active powers are the two halves of power, as is common knowledge. Amount of power that is both reactive and active combined is known as apparent power.

The direction of energy flow in AC circuits is occasionally reversed between the source and the load due to the transient energy storage of inductive and capacitive components. Reactive power is the percentage of power flow that, due to inductive and capacitive network elements, is momentarily stored as magnetic or electric fields and alternately flows back and forth in the transmission line. Real power, which is the system's useable energy and is utilized to do work, is the average power after one full cycle of the AC waveform. Reactive power is associated with the storage and absorption of energy in electrical components such as inductors (reactors) and capacitors. Inductors store energy in the form of a magnetic field, which causes a delay in the peak value of current when a voltage is applied across the coil. This results in a phase shift between voltage and current. On the other hand, capacitors store energy in the form of an electric field. When current flows through a capacitor, it creates a charge that gradually builds up the complete voltage difference across the capacitor. In an AC network, the voltage across a capacitor is constantly changing as it charges and discharges. Due to its nature, the capacitor tends to resist this change and causes the voltage to lag behind the current in terms of phase.

The instantaneous reactive power is given by:

Where:

$V_{max}\ I_{max/2\ sin}\ \theta \cos \omega t$

p = instantaneous power

V_{max} = Peak value of the voltage waveform

I_{max} = Peak value of the current waveform

ω = Angular frequency

f = $2\pi f$ where f is the frequency of the waveform.

t = Time period

θ = Angle by which the current lags the voltage in phase.

2.4 STATCOM: A Static Synchronous Compensator (STATCOM) consists of several key components. It starts with a three-phase inverter that utilizes semiconductor devices like Silicon-Controlled Rectifiers (SCRs), Metal-Oxide-Semiconductor Field-

Effect Transistors (MOSFETs), or Insulated-Gate Bipolar Transistors (IGBTs). This inverter converts DC power to AC power, allowing control over the voltage and frequency. The DC capacitor plays a crucial role in the STATCOM. It absorbs reactive power from the AC system when charged and supplies reactive power when discharged. This bidirectional flow of reactive power helps regulate voltage and improve the power factor. By regulating the inverter and controlling the flow of reactive power, the STATCOM can maintain voltage stability, improve power quality, and support the AC system's operation.

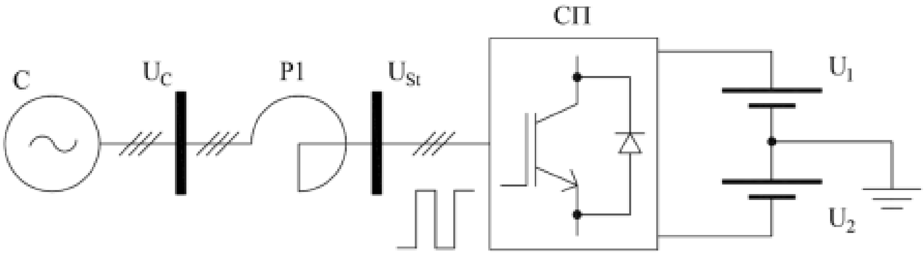


Fig2.5

When two AC sources are connected in series and have the same frequency, in a power system, active power flows from the leading source to the trailing source, while reactive power flows from the source with a higher voltage magnitude to the source with a lower voltage magnitude. The magnitude difference between the sources determines the flow of reactive power. On the other hand, the phase angle difference between the sources determines the flow of active power. A Static Synchronous Compensator (STATCOM) can be employed by adjusting the amplitude of the Voltage Source Converter (VSC) voltage in relation to the voltage at the source bus. By controlling the voltage magnitude, the STATCOM can effectively regulate the flow of reactive power in the system. It also assists in avoiding gearbox system disturbances such as transients, rapid voltage changes, and voltage sags.

2.5 FACTS devices used

Flexible AC transmission system or FACTS devices used are:

1) VAR generators.
    - a) Fixed or mechanically switched capacitors.
    - b) Synchronous condensers.
    - c) Thyristorized VAR compensators.

2) Thyristor switched capacitors (TSCs).

    - a) Combined TSC and TCR.
    - b) Thyristor controlled series capacitor (TCSC).
    - c) Thyristor controlled reactor (TCRs).

3) Self Commutated VAR compensators.
    - a) Static synchronous compensators (STATCOMs).
    - b) Static synchronous series compensators (SSSCs).
    - c) Unified power flow controllers (UPFCs).
    - d) Dynamic voltage restorers (DVRs).

2.6 Need to Compensate For Reactive Power

Reactive power compensation is typically used in systems for the following reasons: 1) voltage control; 2) greater system stability; 3) higher machine utilization; 4) reduction of system losses; and 5) prevention of voltage collapse and voltage sag. Reactive power is consumed as a result of impedance of transmission lines and the necessity to offset

VAR by the majority of the 18 machines in a producing system, which affects both the system's and the lines' stability limitations. Unnecessary drops in voltage increase the amount of losses that the source must supply, which in turn causes line outages since the system must work harder to bear the extra load. Thus, we may conclude that compensating reactive power both lessens all of these impacts and aids in providing a better transient reaction to faults and disturbances. The methods utilized for compensation have received greater attention in recent years, and the compensation is now more effective thanks to technology that includes improved equipment. Reactive power has to be taken off the lines' transportation duties since it works best when it is delivered near to the generators and charges. Shunt compensation can be put close to the load, at a transmission grid, or at a distribution power grid.

2.7 Phase angle control

The phase angle is being managed through the control of the DC link voltage in a Static Synchronous Compensator (STATCOM). The fundamental voltage component of the STATCOM is regulated by adjusting the DC link voltage while keeping the modulation index "m" constant. When the DC link voltage is increased, it causes additional charging of the DC link capacitor. As a result, the reactive power provided or absorbed by the STATCOM increases. This increase in reactive power is observed in the capacitive operating mode. By manipulating the charging and discharging of the DC link capacitor, the reactive power output of the STATCOM can be controlled. This control mechanism allows for the regulation of the phase angle, helping to manage the power flow and improve the stability and efficiency of the electrical system. The STATCOM voltage trails the AC line voltage (> 0) for steady-state capacitive and inductive processes.

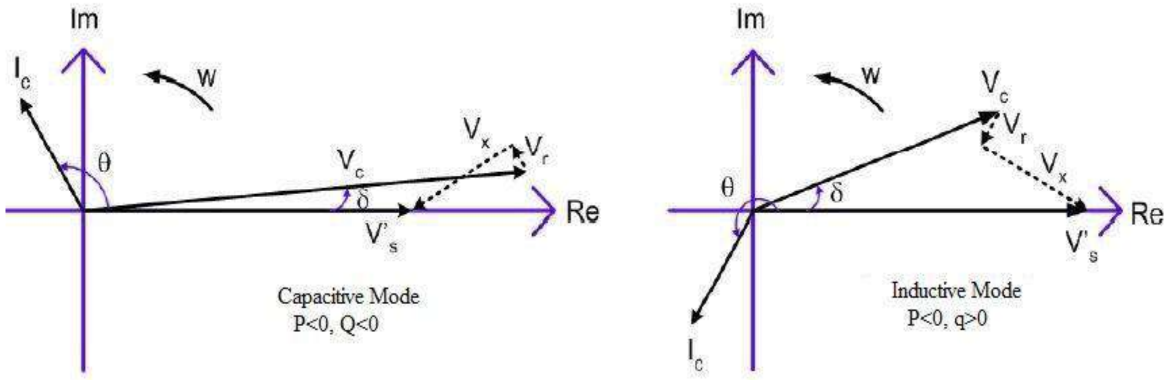


Fig 2.6

The power flow between the transient DC connection and the ac supply is shown in the phasor graphs above. Fig.2.6

Power may be drawn from a DC connection by making the phase angle negative. Pc in turns negative, Vd progressively drops throughout this transient state operation. Comparison is made between the measurement of reaction power (Q) and reference reaction power (Qref). The PI controller's output, which it produces after receiving the reactive power error as an input, defines the phase angle of the STATCOM base voltage in relation to the source voltage.

Summary:

This chapter explains the work of our proposed model. Literature review show that relate work of STATCOM and reactive power in pervious paper and future work on it.

CHAPTER 3: METHODOLOGY

3.1 MATERIALS AND METHOD

On completely controlled semiconductor valves, the STATCOM operating theory is built. STATCOM is an often linked over the AC grid using reactors P1, which have been responsible for restricting electrical currents and to achieve Electromagnetic compatibility (EMC) is an important consideration when integrating a converter, such as the voltage source converter (VSC) in a STATCOM, with the power grid. EMC refers to the ability of different electrical and electronic systems to coexist and operate without causing interference or experiencing disturbances, higher harmonic currents must be reduced.

3.2PROBLEM FORMULATION

Figure 1 below, a STATCOM system typically consists of several components, including the voltage source converter (VSC), control module, and connections to both the AC and DC networks. The control module plays a crucial role in regulating the operation of the STATCOM..

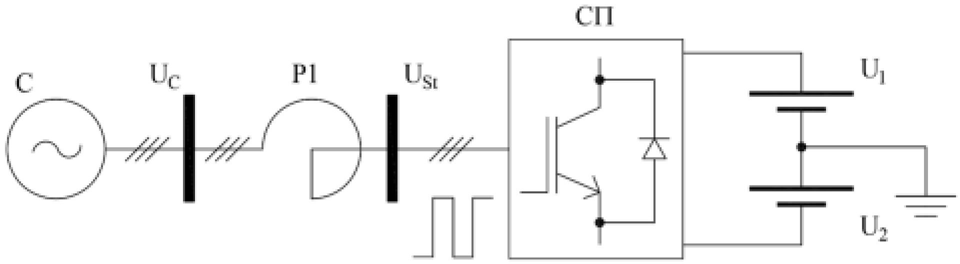


Fig 3.1: Concept of a static synchronous compensator (STATCOM) with a voltage converter is a power system device.

The STATCOM is used to regulate voltages in the network. Let's break down the description and provide an explanation:

UC: Represents the voltage in the AC network.

USt: Represents the STATCOM voltage in the converter (DC) network.

The STATCOM serves as the electrical functional connection between the AC and DC voltage networks. It facilitates the exchange of power and reactive power between these networks. U1 and U2 are the sources of DC voltage, which provide the input power for the converter. P1 is a reactor that is connected to both an AC supply and the converter. It has inductive reactance (XL) and resistance (R) values, which determine its impedance characteristics.

To calculate the apparent power (S), we consider the voltage (UC) in the AC network and the reactive power exchange between the AC and DC networks. The STATCOM is capable of providing or absorbing reactive power to regulate the system voltage. where UC is the voltage in the AC network and I is the current flowing between the AC and DC networks.

The STATCOM, by controlling the reactive power flow, helps in maintaining the desired voltage levels in the network and improves overall power system stability and performance.

The apparent power S can be calculated using the formula

$$S = \frac{U_C U_{St}}{X_L}\sin(\alpha) - j\left(\frac{U_C U_{St}}{X_L}\cos(\alpha) - \frac{U_C^2}{X_L}\right) = P - jQ \tag{1}$$

They are P represents the active power, Q represents the reactive power, and the phase difference between the bus voltages affects the flow of reactive power in the system the static converter.

$$X_L = \frac{U_C^2 - U_C \cdot U_{St}}{S} \tag{2}$$

Where S is the apparent power and the inductive reactance is XL.

$$L = \frac{X_L}{\omega} \tag{3}$$

Where L is represents the reactor inductance value. The frequency value of 50 Hz corresponds to an angular frequency of 314 rad/s, which is commonly used for electrical power systems operating at 50 Hz.

$$R = \frac{X_L}{q} \tag{4}$$

Where Q, or the Power factor, is equal to 20 for 50 Hz frequency and R, or the reactor resistance value, is 4, respectively.

Reactive power and nominal voltage are set by the operator for STATCOM. After that, a measure of inductance for the group of the three-phase reactor computed using the data that had already been assigned. Given that = 0, Equation (1) may thus be reduced as illustrated in Equations (5) through (7) below.

$$S = \frac{U_C U_{St}}{X_L}\sin(\alpha) - j\left(\frac{U_C U_{St}}{X_L}\cos(\alpha) - \frac{U_C^2}{X_L}\right) = P - jQ \tag{5}$$

$$S = -j\left(\frac{U_C U_{St}}{X_L} cos(\alpha) - \frac{U_C^2}{X_L}\right) = -jQ \tag{6}$$

When is equal to 0, the real component of the equation is eliminated, power is also just Reactive. As a result of this situation and the STATCOM nominal power of 41 MVA, it has been determined that

$$|S| = 41 \to Q = -41 \tag{7}$$

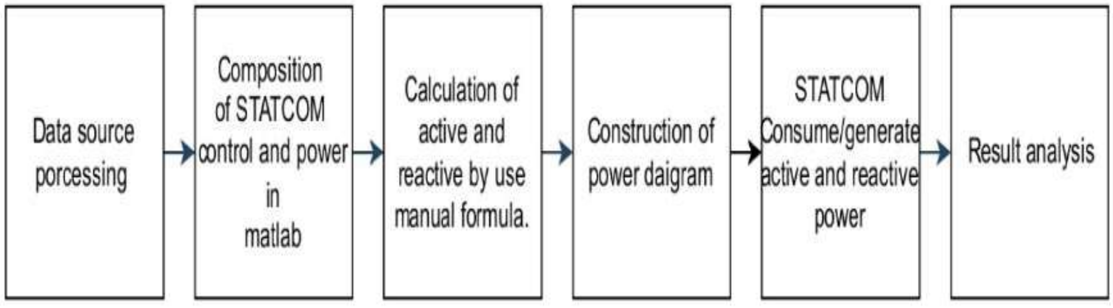
In contrast to converter voltage USt, which the network provides, we shall see later that the operating condition of the STATCOM determines the UC voltage. The multiplicity factor f enables the definition of USt in terms of UC.

$$U_{St} = f\, U_C \tag{8}$$

Table 3.1 Nominal and calculated data.

VOLTAGE(KV)	*POWER(MVA)*	*XL*	*L*	*R*
20	41	1.951	0.006214	0.0975

BLOCK DIAGRAM



3.2 METHOD

Figure 3.2 presents a flowchart for the suggested technique. Point 1 provides an explanation of the input data and computes the model parameters.

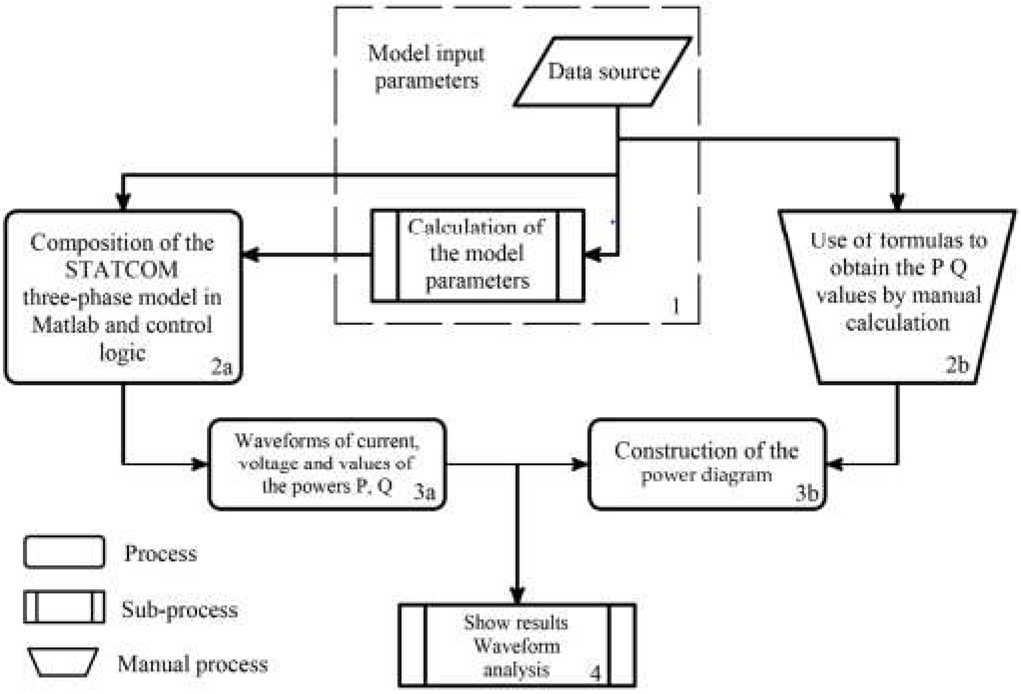


Fig 3.2.: Method flowchart.

Point 2a: In this step, the construction of the STATCOM model is performed in MATLAB Simulink, specifically focusing on the logic control aspect. Simulink is a graphical programming environment for modeling, simulating, and analyzing dynamic systems.

Point 2b: Here, the manual calculation of active power (P) and reactive power (Q) values takes place. It implies that the programmer or user performs calculations outside of the Simulink model to determine these power quantities.

Point 3a: At this stage, the current and voltage waveforms are obtained. It's likely that the Simulink model is used to simulate the behavior of the STATCOM system.

Point 3b: A power diagram is created in this step. It suggests that the active and reactive power levels, obtained either from the simulation or calculated manually, are plotted or visualized in some form.

Point 4: Finally, the examination of current and voltage waveforms is completed. This step likely involves analyzing and interpreting the behavior and characteristics of the waveforms, possibly to validate the effectiveness of the STATCOM model or understand its performance.

3.3 OPERATING PRINCIPLE

Electrical networks frequently employ static synchronous compensators (STATCOM) to account for reactive power. Currently, electrical substations are where these devices are most often deployed. A measuring block, the sources of DC voltage, and the control module are all displayed. Insulated gate bipolar transistors, which function remains governed Using the control system that's produced Transistors are activated and deactivated by pulses, convert the input voltage from DC to AC. At the STATCOM output, a three-phase voltage that is balanced is produced in this fashion.

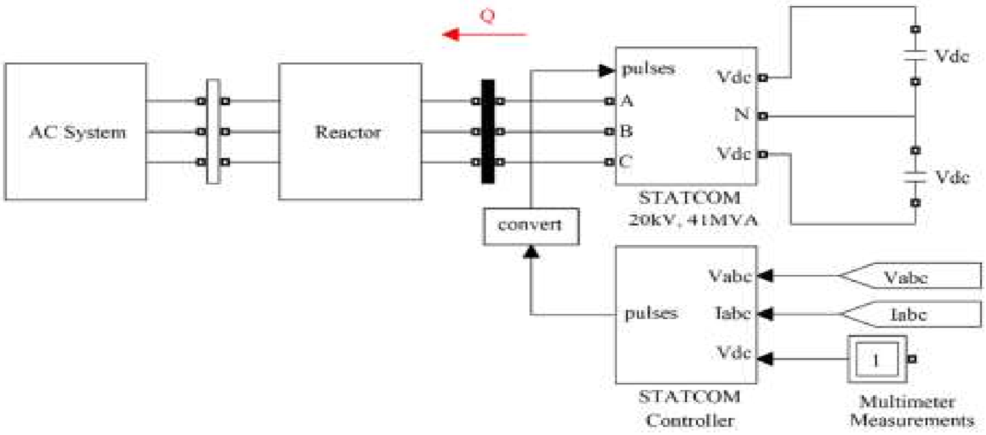


Figure 3.3 STATCOM concept

The measurements of the power regulator's AC input mechanism (outside loop) are represented by both the voltage input Vabc and the current input Iabc (Fig. 3.3). The parts of the control system are shown in Fig 3.3.2. The essential components of it are a voltage and current measurement block, an inner and outer loop voltage and current regulators, The pulse generator generates pulses that control the switching of the STATCOM system. These pulses determine the timing and duration of the power electronic devices within the STATCOM. The PLL is a control mechanism that ensures synchronization between different components of the system. In this context, the PLL is used to compare the reference power Vref with the measured voltage Vm. By comparing these values, the PLL determines the phase difference or angle called alpha. The control system calculates the reference current for the reactive component based on the comparison between the reference power Vref and the measured voltage Vm. This reference current enters the existing regulator, where it is combined with the measured current Iqm. The combination of these currents determines the value of alpha. VAC represents the output voltage of the STATCOM system. In a network of suppliers, the STATCOM and VAC are separated by an angle called alpha. This indicates that there is a phase shift between the output voltage of the STATCOM and the voltage of the suppliers in the network. The value of Alpha is almost 0 in steady conditions. Depending on the voltage modulus and regulate phase angle between the network's voltage and a STATCOM system outputs, the STATCOM system has the capacity to generate and consume both reactive and active energies are present. When the phase difference (Δ) is 0 and Vm is greater than Vref: In this case, reactive power consumption occurs. Reactive power is the component of power that oscillates between source and load due to the phase difference between voltage and current. When Vm exceeds Vref, it indicates that the load is drawing more power than the source is supplying. When the phase difference (Δ) is greater than 0 and Vm is greater than Vref:

In this scenario, reactive generation of electricity takes place. It means that the load is supplying reactive power back to the source. This situation often occurs when there is excess capacity in the load or when there are power factor correction devices in place. When the phase difference (Δ) is greater than 0 and Vm is greater than Vref: Here, active power generation occurs. Active power represents the real power that is consumed or generated by a device or system. When Vm exceeds Vref and there is a positive phase difference, it indicates that the load is generating more power than it consumes. Are Four operational modes that may be obtained by altering these parameters in the STATCOM By changing these settings on the equipment, the user can control the operational status. When reference angle t is used with PLL, or phase-locked loop, which is a synchronizer of phases, the necessary pulses for STATCOM may be produced. As a last active power control to minimize system losses, the DC regulator.

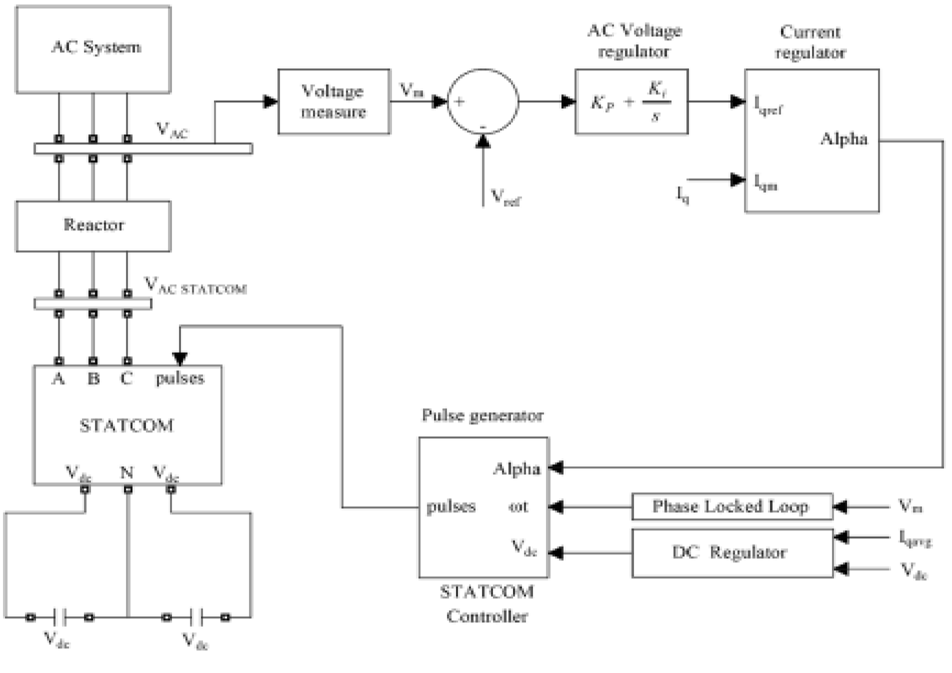


Fig 3.4: STATCOM control scheme

When reference angle t is used with PLL, or phase-locked loop, which is a synchronizer of phases, the necessary pulses for STATCOM may be produced. As a last active power control to minimize system losses, the DC regulator.

3.4 STATCOM simulation

In accordance with the STATCOM's power rating, It seems like you're discussing various aspects of Static Synchronous Compensators (STATCOMs) and their power converter technologies. I can provide some information based on your statements.

The choice of power converter technology for STATCOMs depends on the power rating. For low power STATCOMs (tens of MVAr), Pulse-Width Modulation (PWM) Voltage-Sourced Converters (VSC) are commonly used. These converters utilize Insulated Gate Bipolar Transistors (IGBTs) or Integrated Gate-Commutated Thyristor (IGCTs). In the case of large power STATCOMs (several hundreds of MVAr), a GTO (Gate Turn-Off thyristor)-based square-wave VSC is frequently employed. GTOs are power electronic devices that can handle high power levels, making them suitable for such applications. The Static Synchronous Compensator (Phasor Sort) block from the FACTS (Flexible AC Transmission Systems) library is used for investigating electromechanical oscillations in large power systems. It operates within a frequency range of 0.02 Hz to 2 Hz, allowing analysis of low-frequency phenomena.

STATCOM Model Complexity: The STATCOM model used in your example appears to be relatively simple, lacking detailed power electronics representation. However, it incorporates harmonic neutralization through the use of an interconnecting transformer and a square-wave, 48-pulse VSC. The specific configuration and control strategies may vary depending on the application and desired performance.

Please note that the information provided is based on the details you provided and the field of power systems and FACTS technologies can be quite extensive and subject to ongoing research and advancements. This situation often occurs when there is excess capacity in the load or when there are power factor correction devices in place. When the phase difference (Δ) is greater than 0 and Vm is greater than Vref: Here, active power generation occurs. Active power represents the real power that is consumed or generated by a device or system. When Vm exceeds Vref and there is a positive phase difference, it indicates that the load is generating more power than it consumes. Are Four operational modes that may be obtained by altering these parameters in the STATCOM By changing these settings on the equipment, the user can control the operational status.

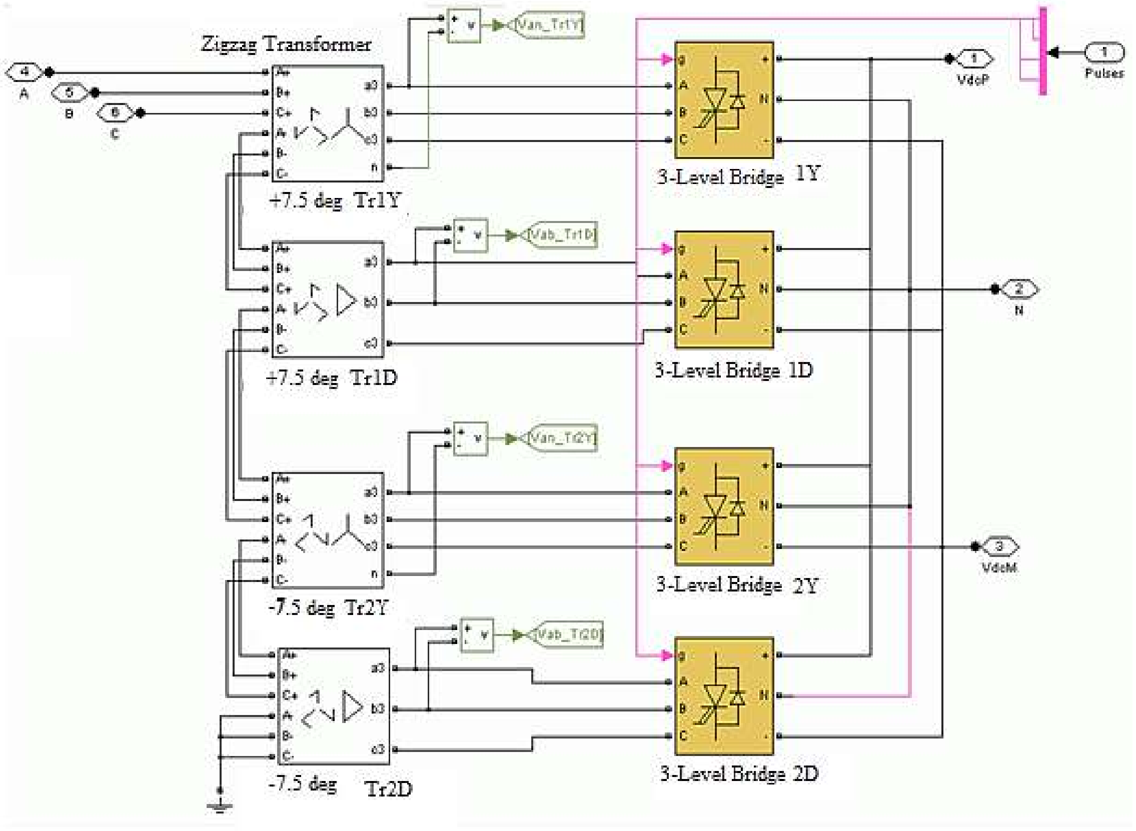


Fig.3.5. Control Circuit on a 20 kV Power System using STATCOM at 41 MVAr

Based on the information provided, it appears that you are discussing the control circuit of a 41 MVAr STATCOM (Static Synchronous Compensator) in a 20 kV power system. Here are some key points based on your statements:

The model of the STATCOM you mentioned requires discrete simulation at specific time steps, with a step size of 25 seconds in this example. Discrete simulation involves modeling the system behavior at discrete points in time rather than continuously. This approach is commonly used for analyzing the performance of power system components like STATCOMs. The model you described is typically used to examine the performance of the STATCOM over a narrower time range, typically a few seconds. This suggests that the focus is on studying the transient behavior and dynamic response of the STATCOM during specific events or disturbances in the power system. One common application of such a model is control system optimization. By analyzing the performance of the STATCOM's control circuitry, researchers can optimize the control algorithms to enhance the overall stability and performance of the system.

It's important to note that the specific control circuit and control algorithms used in the STATCOM model can vary depending on the application and design requirements. Additionally, advancements in control strategies and simulation techniques may lead to different approaches and capabilities in the field. By analyzing the performance of the STATCOM's control circuitry, researchers can optimize the control algorithms to enhance the overall stability and performance of the system.

The information you provided describes a transformer configuration that is designed to cancel out specific harmonics in the system. Here's a breakdown of the key points:

The transformer configuration you mentioned is designed to cancel out odd harmonics up to the 45th harmonic, except for the 23rd and 25th harmonics. By using Y and D transformers with appropriate phase differences, certain groups of harmonics can be canceled out. For example, the harmonics of the form 5+12n and 7+12n can be canceled. The 15° phase difference between the two groups of transformers (Tr1Y and Tr1D leading by 7.5°, Tr2Y and Tr2D lagging by 7.5°) plays a role in canceling harmonics. This phase difference allows cancellation of harmonics like 11+24n and 13+24n. The transformers, in their delta and ungrounded Y configurations, do not transmit all 3n harmonics. As a result, harmonics like the 23rd, 25th, 47th, and 49th are not canceled by the transformers.

To further reduce the 23rd and 25th harmonics, a three-level inverter with an appropriate conduction angle (σ = 172.5°) is used. This inverter produces a 48-step voltage waveform similar to a sine wave using a bipolar DC voltage. By carefully choosing the conduction angle, the 23rd and 25th harmonics can be reduced. With the cancellation techniques employed, the 47th and 49th harmonics become the first substantial harmonics produced by the inverter. Another common application is to investigate the effect of harmonics produced by the converters in the STATCOM. Power electronic converters, such as the ones used in STATCOMs, can introduce harmonics into the power system.

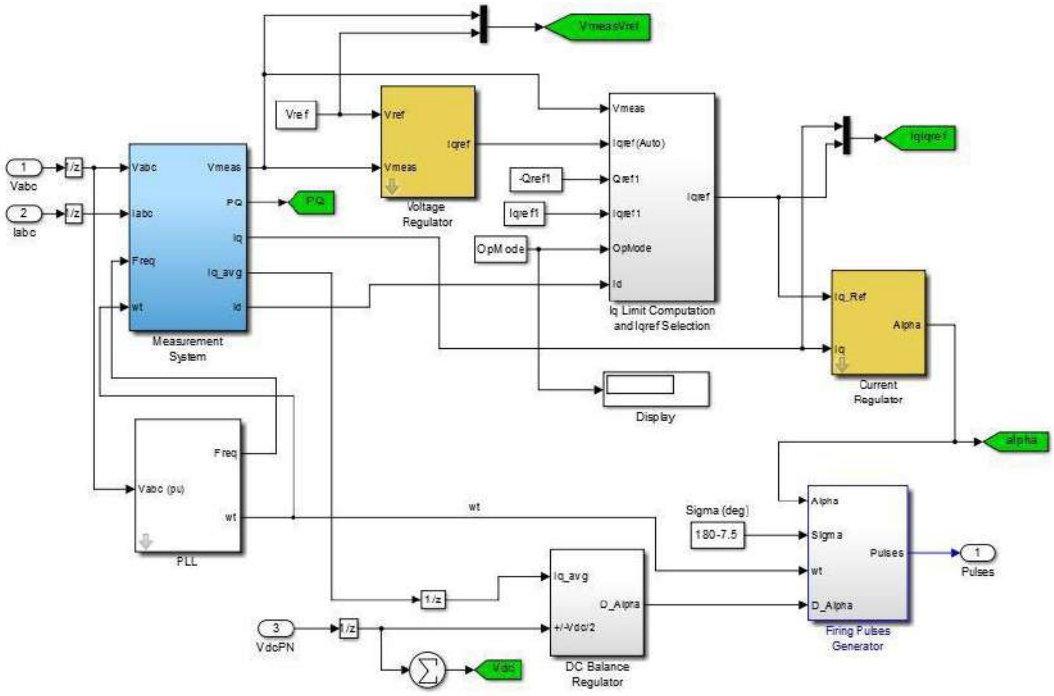


Figure 3.6: Simulink model of STATCOM Controller.

Fig. 3.6 illustrates the waveforms showcasing an example of how the STATCOM responds to system voltage steps. The STATCOM is a power electronic device used for reactive power compensation and voltage control in electrical power systems. The GTO (Gate Turn-Off thyristor) pulses are timed to the system voltage using a PLL (Phase-Locked Loop). The PLL ensures synchronization between the STATCOM and the system voltage by providing a reference angle to the measuring system. Through a phase-to-dq translation and running-window averaging, the Measurement System calculates the positive-sequence components of the STATCOM voltage and current. This process helps determine the behavior of the system under normal operating conditions. Two PI regulators are used to control the voltage of the STATCOM. The reference voltage (Vref), measured voltage (Vmeas), and reactive current reference (Iqref) are inputs to the Current Regulator block (inner loop), which calculates the reactive current reference (Iqref) to achieve the desired voltage control. The output of the current regulator is the angle, or phase shift, of the inverter voltage relative to the system voltage. The passage mentions that, except for brief intervals, this angle remains extremely close to zero, indicating that the STATCOM tries to align its voltage with the system voltage. The voltage control mechanism incorporates a voltage droop feature. A voltage droop introduces a linear relationship between the reactive power and voltage magnitude. In this instance, the slope of the V-I (voltage-current) characteristics is mentioned to be 0.03 per unit (pu) for a 41 MVA (Mega Volt-Ampere) system. When the operating point of the STATCOM changes from fully capacitive (+41 Mvar) to fully inductive (-41 Mvar) reactive power, the SVC (Static Var Compensator) voltage fluctuates between 0.97 pu and 1.03 pu. This indicates that the voltage magnitude varies within this range as the STATCOM adjusts its reactive power output. Please note that the passage may be context-specific, and without further information, it's challenging to provide additional details or explanations.

The firing pulse generator generates pulses for the four inverters based on the output of the present regulator (angle) and the PLL output (t). These pulses control the switching of the inverters to regulate the reactive power flow.

Voltage drop and voltage regulator response: Assuming a voltage drop between the reference voltage (Vref) and the system voltage (Vmeas), the voltage regulator responds by seeking a higher reactive current output (positive Iq, indicating capacitive current). This increase in reactive current output causes a phase lag between the inverter voltage and the system voltage, enabling the generation of additional capacitive reactive energy. Active power flow and voltage increase The brief active power flow from the AC system to the capacitors (in the form of capacitive reactive energy) increases the DC voltage. Consequently, the AC voltage is also increased. Conduction angle and harmonic reduction The conduction angle for the three-level inverters is fixed at 172.5°, as discussed previously. This conduction angle helps reduce the 23rd and 25th harmonics in the square-wave inverters' voltage waveform. DC balance regulation The DC Balance Regulator module ensures that the positive and negative voltages on the DC bus of the STATCOM remain equal. This balance is necessary to minimize non-typical harmonics. VAR control mode The STATCOM control system allows the selection of VAR control mode. In this mode, the voltage regulator no longer produces the reference current (Iqref). Instead, the Qref or Iqref references entered in the dialogue box (presumably a control interface) are more crucial in determining the behavior of the system.

Summary:

Methodology of the proposed work has been explained in this chapter. Block diagram and flow chart of the proposed work have been explained in detailed in this chapter.

CHAPTER4SIMULATIONANDRESULTS

4.1CIRCUIT DIAGRAMS

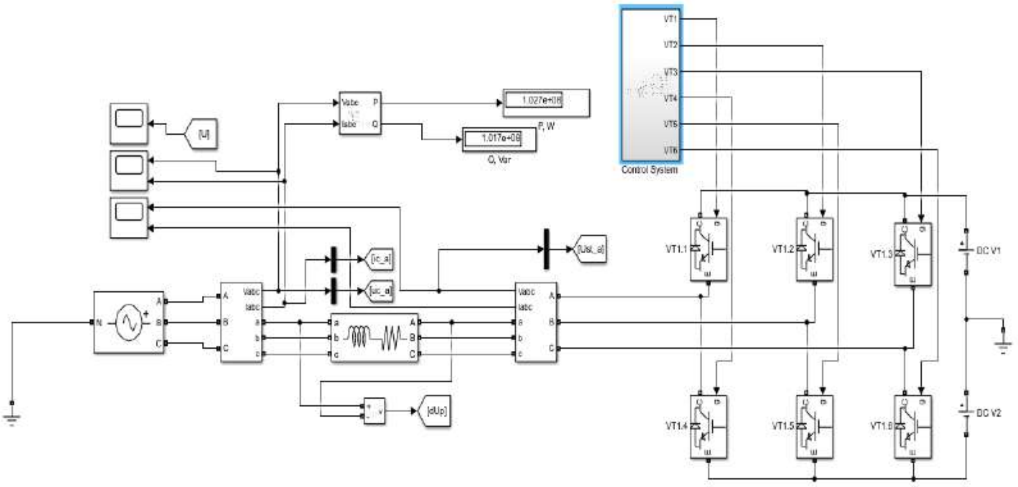


Fig 4.1. STATCOM

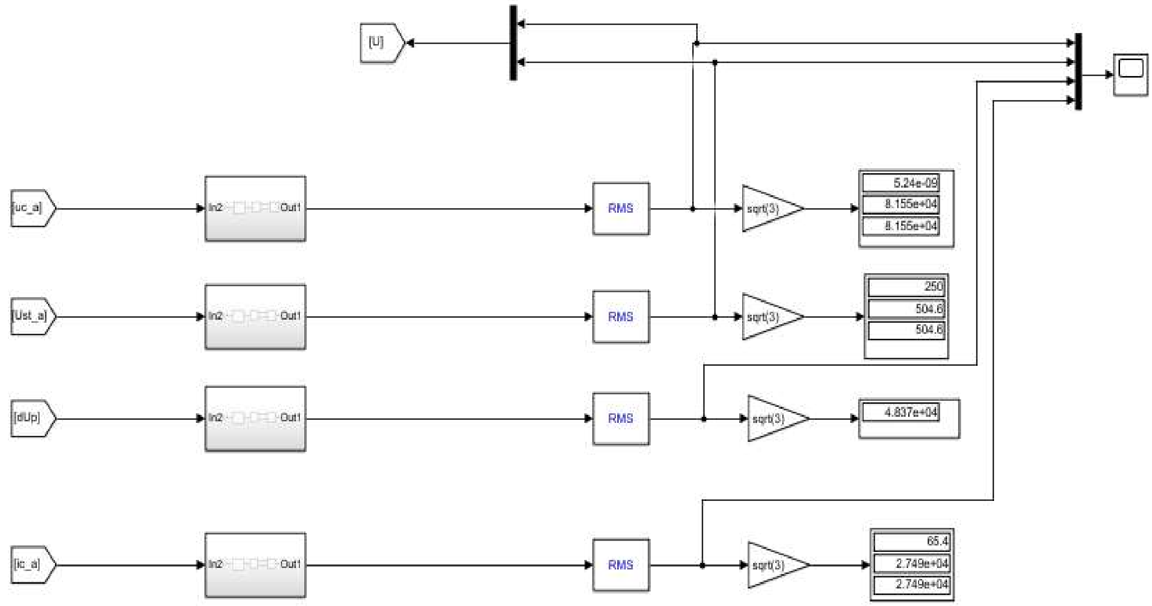


Fig 4.2. Measurement Module

Table 4.1. Parameters of the PI Voltage Regulator AC.

Ki_AC	Kp_AC
(W/s)	(W)
600	0.75

Table 4.2. Current PI Regulator Parameters.

Ki	Kp
(W/s)	(W)
120	0.5

4.2 COMPONENTS WORKING

4.2.1 Static Synchronous compensator (STATCOM): The STATCOM is an immediate instrument that can generate or consume reactive current, regulating the voltage at the grid connection point. It is under the FACTS (Flexible AC transmission system) category. A modular, multi-level VSC structure with semiconductor valves serves as the technique's foundation. A STATCOM system's job is to give the grid reactive compensation when it's most needed, which is during faults and transient conditions.

4.2.2 PHOTOVOLTAIC SYSTEM: A photovoltaic (PV) system converts light energy into electricity, and a photovoltaic cell is the fundamental component of a PV system. To create PV arrays or PV panels, these PV cells may be grouped or merged. Lighting systems and dc motors can be directly fed by the voltage and current that are available at a PV device's terminals [3]. Several types of semiconductors are used in the construction of photovoltaic cells, which are produced using various techniques. If the cell is shorted out, the incidence of light on it creates charge carriers that start an electric current. Depending on the level of light.

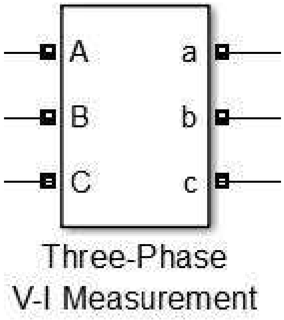
4.2.3 CONVERTER: AC electricity is transformed into DC power using converters. The majority of electrical gadgets need converters. They are also used to find radio signals using amplitude modulation. Additionally, they are utilized to provide polarized voltage for welding. The batteries in the cars are charged using the DC-to-AC Converters. These circuits are used in solar power systems primarily to drive low-power AC motors. It is possible to transport power to loads using DC transmission lines and DC to AC converters.

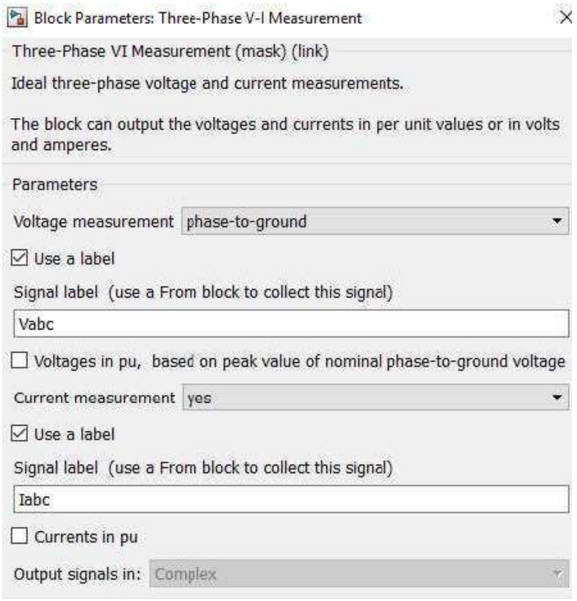
4.2.4 MUX AND DEMUX: A multiplexer chooses one input from several inputs, and then it transmits it as a single line. The multiplexer is sometimes known as a mux or data... A multiplexer is a sort of combinational circuit that accepts several data inputs but only produces one output. A combinational circuit known as a de multiplexer receives only one input but routes it through several outputs. From parallel to serial conversion is carried out via a multiplexer.

4.2.5 REACTOR: The reagents are combined and given a set length of time in a batch reactor to react. There is no progression during the procedure, yet the compositions alter with time. As the reaction progresses, more reagents and temperature adjustments may be performed.

4.2.6 DC VOLTAGE SOURCE: The most frequent sources of this kind of electricity batteries, solar panels, and thermostats are among examples. DC power is widely used in low voltage, low current applications, such as battery charging, automotive, and aircraft systems. In distribution systems, DC voltages are frequently employed as capacitors and reactive power sources.

4.2.7 THREE PHASE V-I MEASUREMENT: The Three-Phase V-I measuring block is used to measure instantaneous three-phase voltages and currents. It allows for the measurement of both voltage (V) and current (I) in a three-phase system. In order to obtain the root mean square (RMS) values of the system and converter voltages, as well as the voltage difference and the flow of electricity through the system, a measuring block is utilized. The modulus represents the amplitude or magnitude of the signal, while the phase angle indicates the signal's relative position in the waveform.





Block Parameters: Three-Phase V-I Measurement

Three-Phase VI Measurement (mask) (link)

Ideal three-phase voltage and current measurements.

The block can output the voltages and currents in per unit values or in volts and amperes.

Parameters

Voltage measurement: phase-to-ground

☑ Use a label

Signal label (use a From block to collect this signal): Vabc

☐ Voltages in pu, based on peak value of nominal phase-to-ground voltage

Current measurement: yes

☑ Use a label

Signal label (use a From block to collect this signal): Iabc

☐ Currents in pu

Output signals in: Complex

Fig 4.4: *V-I measurement block.*

Fig 4.5: *V-I measurement parameters.*

4.2.8 AC GRID SYSTEM: The term "alternating current" (AC) refers to a current that is continually changing direction. The UK's mains supply of electricity, which is an AC supply, has a voltage of roughly 230 volts. Its frequency is 50Hz (50 hertz), which indicates that it reverses direction 50 times every second. These systems are connected to the public electrical grid and operate without the need of batteries, solar converters.

4.2.9 VOLTAGE MEASUREMENT: The standard method for measuring voltages is to connect the measuring device in parallel with the circuit or component that needs to be measured (the load). The measuring instrument must have an infinite input impedance (resistance) in order to measure the correct voltage and not absorb any energy from the circuit being tested. Voltage measurement may be necessary to evaluate the reliability or safety of an electrical equipment. Voltage must be measured with testers, or multi-meters. These instruments come in analogue and digital forms, and many of them have a variety of useful capabilities.

4.2.10 ALPHA: Voltage VACSTATCOM, The STATCOM (Static Synchronous Compensator) output voltage and the network power supply voltage (VAC) can be separated by an angle called alpha. This angle represents the phase difference between the two voltages. It indicates the time shift between the voltage waveforms of the STATCOM output and the network power supply. The value of Alpha is almost 0 in steady conditions.

4.2.11 WIRIHG PULSES GENERATOR: Wiring Pulses generator its input is alpha and other input is form PLL block the output of the PLL synchronizer single and hence this pulses are than finally given to over main system we can see the main task of over control now how does it work basically what is regulator principle on this works on, Let's say that the voltage regulator requests a higher reactive power output if the system voltage Vm rises over the system voltage Vref.

4.2.12 CONTROL SYSTEM: The control system of an SVC monitors the system conditions, such as voltage and current, and regulates the reactive power output of the VSC accordingly. It ensures that the SVC responds quickly to changes in system conditions and maintains the desired reactive power compensation.

4.2.13 CURRENT REGULATOR: In the control system, the reference voltage (Vref) is compared with the observed voltage (Vm) before calculating the source current for the reactive element (Iqref). This process helps in regulating the reactive power flow and maintaining voltage stability.

4.2.14 PULSES GERENATOR: A rectangular pulse generator is either an electrical circuit or a piece of electronic test equipment. Working with analogue circuits generally requires associated function generators, whereas working with digital circuits mostly requires pulse generators. A function generator is an electrical testing tool that produces and transmits standard waveforms, most often sine and square waves, to the item being tested. It can be used to check the functionality of an electrical device or to test a design.

4.2.15 Voltage Source Converter (VSC): The VSC is the heart of the SVC and is responsible for generating the reactive power compensation. It consists of power electronic devices, such as insulated gate bipolar transistors (IGBTs), that convert the DC voltage into a three-phase AC voltage with controllable magnitude and phase.

4.2.16 SCOPE: Signal lines have scope viewers connected to them. The majority of signals, including referenced models and State flow diagrams, are accessible within the model hierarchy. Optimized signals are not accessible. logging data. Save data as an array, structure, or object to a MATLAB variable.

4.2.17 Capacitor Bank: The SVC includes a capacitor bank connected in parallel with the VSC. The capacitor bank provides the reactive power support during voltage sags or dips, compensating for the reactive power demands of the system.

4.2.18 PHASE LOCKED LOOPS: When combined with the reference angle t, PLL, or phase-locked loop, which is synchronizer for phases, enables the generation of the pulses required by STATCOM. The DC regulator, as a last power management measure, actively reduces system internal losses.

4.2.19 THREE PHASE PROGRAMMABLE VOLTAGE SORCE:

A three-phase programmable voltage source is a device that can generate three-phase AC voltages with programmable with adjustable AC magnitude, frequency, and phase shift is modeled by the adjustable Voltage Source (Three-Phase) block. To define these values using the physical input signals M, F, and Phi, select the external mode. A three-phase programmable source with a voltage of 20 kv, a power output of 41 mva, and a frequency of 50 Hz is utilized as the source for the AC generator.

4.2.20 GRID VOLTAGE SOURCE

If the root mean square (RMS) value of the phase voltage of the grid used in simulation is 380 Volts, then the line voltage of the grid can be calculated by multiplying the phase voltage by √3. Therefore, the line voltage would be approximately 658.17 Volts. (Fig.4.7).

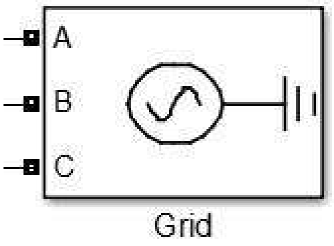


Fig4.7: *Voltage source*

4.3 RESULTS

Fig 4.3.1 Control system Graphs

Fig4.3.1. represents the production of active power and reactive power produce by STATCOM Via control system. There is a continuous steady state error with respect to reference power and the output active power is not settled within the time frame. There are lot of transients the actual output power. Rise times is reached at 3.55 sec but system has lot of oscillations. When the control system has been used to remove the active power losses as well as to integrate the distributed generation deriving from renewable energy.

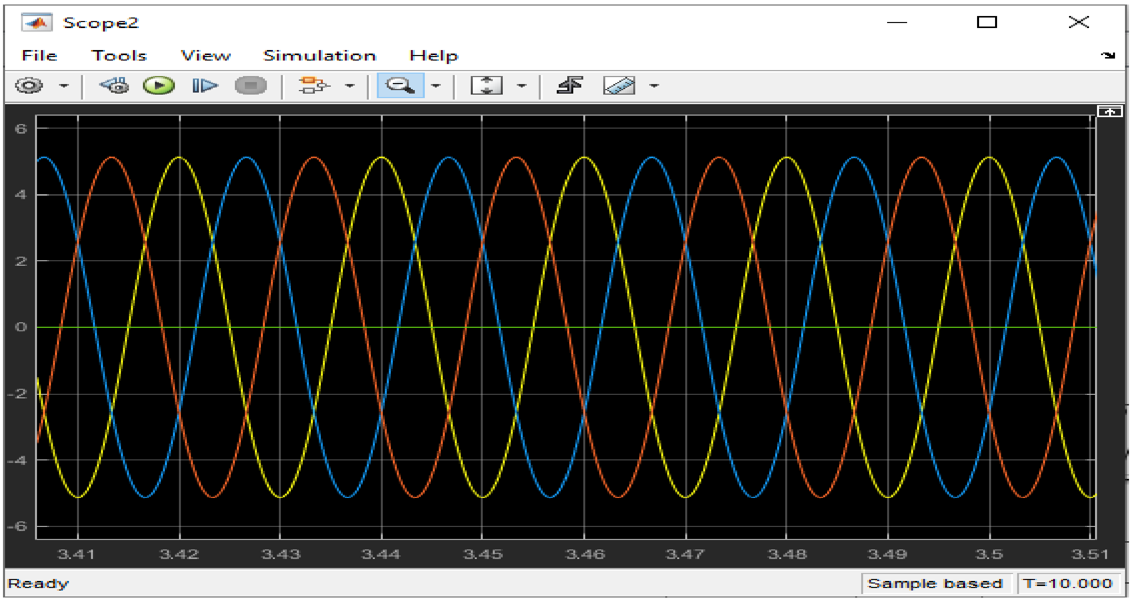


Fig 4.3.2 Control System Module Graphs

Fig4.3.2 represents the production of reactive power of distributed generation Via control system. There is a There is a continuous steady state error with respect to reference power and the output reactive power is settled within the time frame. There are lot of transients the actual output power. Rise times is reached at 3.44 sec but system has lot of oscillations. When the control system has been used to remove the active power losses as well as to integrate the distributed generation deriving from renewable energy. The system become unstable and provides the worst results of reactive power produced by VSC using control system.

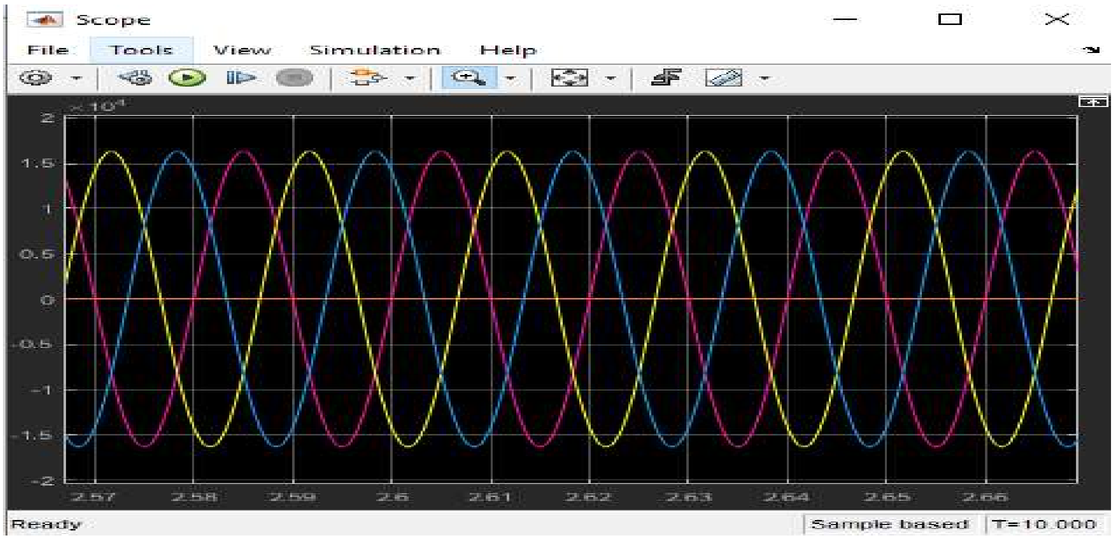


Fig 4.3.3 Control System Module Graphs

Fig 4.3.3 represents the production of three phase voltages of distributed generation Via control system. There is a continuous steady state error with respect to reference power and the output reactive power is settled within the time frame. sample times is reached at 10.000 sec but system has lot of oscillations. There are the stable waveform voltage because they provided the worst reactive power produced by VSC using controller.

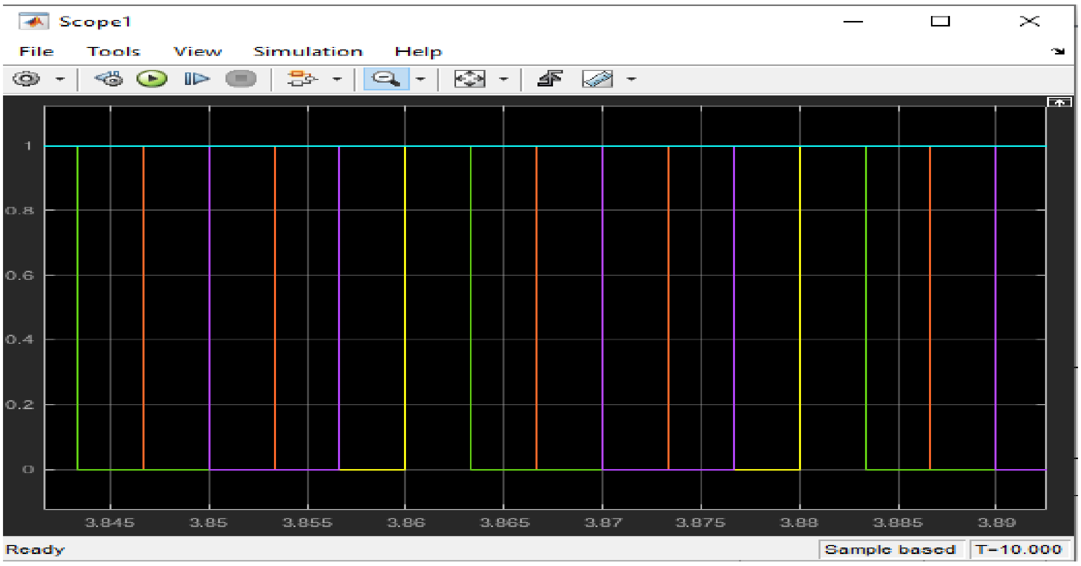


Fig 4.3.4 Control System Module Graphs

Fig 4.3.4 represents the production of PWM (Pulses width modulation) waveform of distributed generation Via control system. The reference active power of distributed generation is 10kw. The optimized STATCOM controller is utilized in the converter control and minimizing the difference between reference power and actual power which is error control the output optimized power.

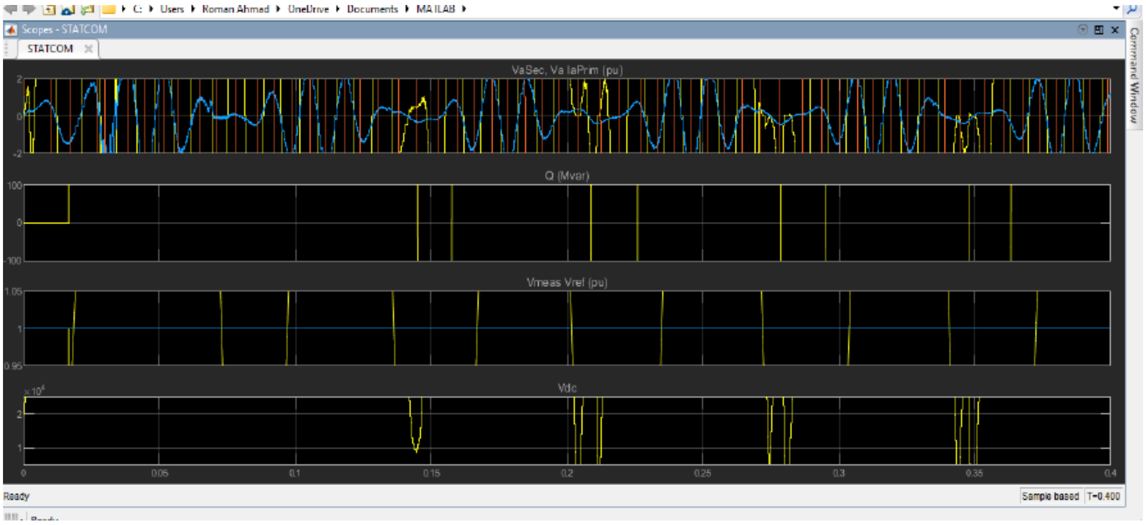


Fig 4.3.5 STATCOM System Module Graphs

Fig 4.3.5 represents the production of PWM (Pulses width modulation) waveform of distributed generation Via control system. The reference active power of distributed generation is 10kw. The optimized STATCOM controller is utilized in the converter control and minimizing the difference between reference power and actual power which is error control the output optimized power.

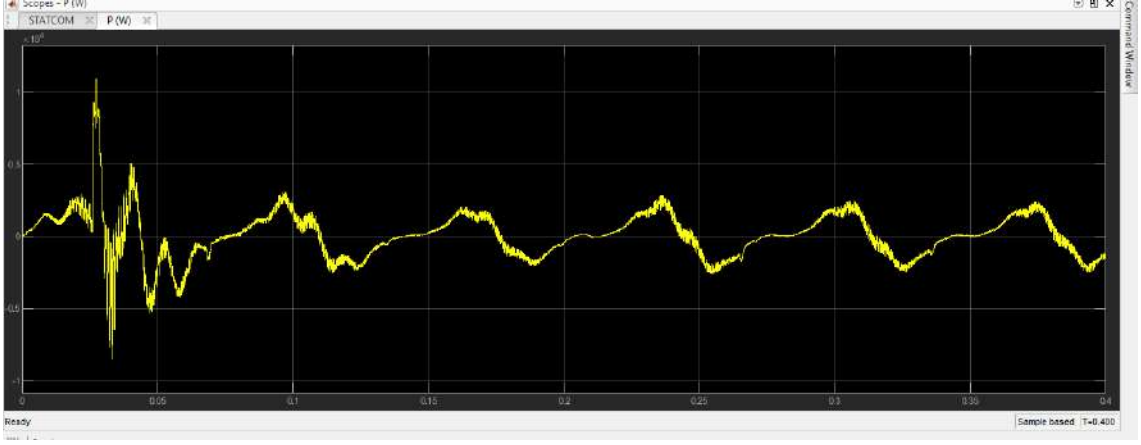


Fig 4.3.6 Active power System Module Graphs

Fig 4.3.6 represents the production of PWM (Pulses width modulation) waveform of distributed generation Via control system. The reference active power of distributed generation is 10kw. The optimized STATCOM controller is utilized in the converter control and minimizing the difference between reference power and actual power which is error control the output optimized power.

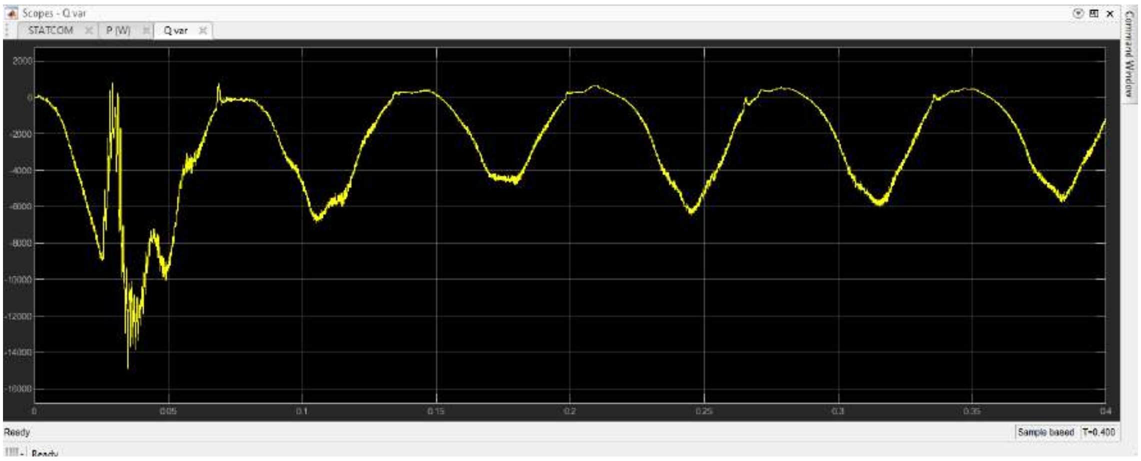


Fig 4.3.7 Active power System Module Graphs

Fig 4.3.7 represents the production of PWM (Pulses width modulation) waveform of distributed generation via control system. The reference active power of distributed generation is 10kw. The optimized STATCOM controller is utilized in the converter control and minimizing the difference between reference power and actual power which is error control the output optimized power.

Summary:

This chapter explains the simulated results of our proposed model. Results show that control system provides more robust results in order to remove line losses and provide results according to the requirements.

Table 4.3. Active and reactive power values.

		MATLAB Simulink Power Obtained data		Power Manually calculated data	
Multiplicity Factor	**Lag Angle**	**P. MW**	**Q. MVAr**	**P. MW**	**Q. MVAr**
1	0	3.97	-4.098	0.00	0.00
	45	-136.3	-67.05	144.97	-60.05
	90	-191.2	-210.1	205.02	-205.02
	135	-127.8	-352.3	144.97	-350.00
	180	17.98	-405.9	0.00	-410.05
	225	158.4	-342.2	-144.97	-350.00
	270	211.4	-196.9	-205.02	-205.02
	315	148.5	-60.14	-144.97	-60.05
	360	3.97	-4.097	0.00	0.00
1.2	0	2.687	35.95	0.00	41.00
	45	-165.7	-39.58	173.97	-31.06
	90	-231.5	-211.2	246.03	-205.02
	135	-155.5	-381.9	173.97	-378.99
	180	19.49	-446.2	0.00	-451.05
	225	188	-369.7	-173.97	-378.99
	270	251.6	-195.5	-246.03	-205.02
	315	174	-27.98	-173.97	-31.06
		2.678	35.95	0.00	41.00
0.8	0	5.254	-44.15	0.00	-41.00
	45	-107	-94.51	115.98	-89.04
	90	-150.9	-208.9	164.02	-205.02
	135	-100.2	-322.7	115.98	-321.00
	180	16.46	-365.6	0.00	-369.04
	225	128.8	-314.6	-115.98	-321.00
	270	171.2	-198.4	-164.02	-205.5

CHAPTER 5: Engineer & Society and Discussion

5.1 DISCUSSION

The reactive power produced at the terminals of a STATCOM described during study, which is a VSC-based apparatus, is dependent on the amplitude of the voltage source. A STATCOM produces reactive electricity if the VSC voltage at the connecting point exceeds the AC voltage. On the other hand, because of the quick switching speeds offered by IGBTs, its reaction time is lower than that of an SVC. The suggested approach is able to handle voltage dips brought on by electrical demands changing or when the power supply is lowered as a result of intermittent renewable energy sources.

Additionally, for big controls, they remain frequently combined with super capacitor energy storage systems (SCESS) otherwise Battery Energy Storage Systems (BESS), which may stabilize phase voltages. It is advised to look into a methodology for scaling particular circumstances because this idea is constrained by the requirement for large systems to carry out the compensation.

Regardless of the degree of realist work, the situation remained confirmed if the converter supplies the needed reactive power to the grid and that this is stable the system responds suitably when the voltage amplitude and transfer angle of the phase are altered. The simulations also showed that the converter's Values for inductance and capacitance were determined. Correctly then they keep the electrical energy levels wi STATCOMs can handle a lot of power. The authors of discussed fully operational 100 MVA South Korea and electronic devices the USA that make sure undergone effective operational testing. An inductive or capacitive STATCOM with a shunt connection compensation for a VAR can also be operated independently of the network voltage, as is discussed in.

It has been shown that one of the key advantages of these systems is the decrease in harmonics in the voltage lines. This leads to their identification with photovoltaic, solar, or wind-based simulated renewable energy sources, even if they are used in electrified railroads. According to the application and case study provided, each of these suggestions offers promising outcomes for both the reduction, the phenomenon of total harmonic distortion (THD) and the maintenance of synchronization in renewable energy systems. As a result of the disparate points of view used in the investigations, it is difficult to compare their findings. However, they have provided the research's bibliographic foundation, acted as a guide, and provided evidence of their effective functioning in clean energy models.

5.2 ENGINEER & SOCIETY

Engineering plays a vital role in society, shaping and influencing the world we live in. Engineers are professionals who apply scientific and technological knowledge to design, create, and improve various systems, structures, and products that benefit society. However, the relationship between engineers and society is complex, as engineers have both tremendous potential to positively impact society and a responsibility to consider the ethical and social implications of their work

Engineers and society can greatly benefit from the implementation of a static reactive power compensator based on a three-phase voltage converter. Here are some ways in which engineers and society depend on this technology:

Electrical system efficiency: The static reactive power compensator improves the efficiency of electrical systems by correcting the power factor. Engineers can design and implement these compensators to ensure that power systems operate at a power factor close to unity (1.0). By reducing reactive power flow and minimizing energy losses, the compensator helps optimize the use of electrical energy, leading to cost savings and improved overall system efficiency.

Grid stability and reliability: The compensator plays a crucial role in maintaining grid stability and reliability. It actively regulates voltage levels and minimizes voltage fluctuations, ensuring a consistent and reliable power supply. This stability is essential for the smooth operation of electrical equipment and prevents power outages or disruptions that can impact society and economic activities.

Renewable energy integration: Engineers rely on static reactive power compensators to facilitate the integration of renewable energy sources into the power grid. As more renewable energy systems such as solar and wind farms are connected to the grid, the compensator helps manage the intermittent nature of these sources by dynamically balancing reactive power. This enables a seamless integration of renewable energy, reduces reliance on fossil fuel-based generation, and supports the transition towards a more sustainable energy mix.

Reduction of environmental impact: By improving power system efficiency, the compensator helps reduce environmental impacts associated with energy generation. It minimizes losses in transmission and distribution networks, leading to lower energy waste and reduced greenhouse gas emissions. Additionally, by facilitating the integration of renewable energy sources, the compensator contributes to the reduction of carbon emissions and promotes a cleaner and greener environment.

Equipment longevity and cost savings: The compensator's ability to regulate voltage levels and mitigate harmonic distortions helps protect electrical equipment from stress, overheating, and premature failures. This extends the lifespan of equipment, reduces maintenance costs, and improves the overall reliability of electrical systems. Engineers can design and implement compensators to ensure optimal performance and protection of equipment, resulting in long-term cost savings for society.

Power quality improvement: The compensator contributes to improving power quality, ensuring a stable and clean power supply. It actively controls voltage and current waveforms, reducing harmonics and other power quality issues that can affect sensitive equipment. This is particularly important in sectors such as healthcare, telecommunications, and manufacturing, where the reliability and quality of power supply are critical for operations.

In summary, the use of static reactive power compensators based on three-phase voltage converters benefits both engineers and society by improving energy efficiency, grid stability, renewable energy integration, reducing environmental impacts, enhancing equipment longevity, and ensuring a reliable power supply. These compensators play a vital role in achieving a sustainable and technologically advanced society.

CHAPTER 6 CONCLUSION AND FUTURE WORK

6.1 CONCLUSION

Based on the project of designing a three-phase voltage converter-based static reactive power compensator, we can draw the following conclusions:

- Static reactive power compensators are used to improve the power factor of electrical systems, which is important for efficient power transmission and distribution. A static reactive power compensator may be designed effectively using a three-phase voltage converter. It is a piece of power electronics that has the ability to change the input voltage into a regulated output voltage.
- The design of a three-phase voltage converter-based static reactive power compensator, involves selecting the appropriate topology, choosing the right components, and implementing control algorithms. The topology of the three-phase voltage converter can be either a diode rectifier or an active rectifier. The active rectifier is preferred because it offers better control over the output voltage.
- The control system used in the design of a static reactive power compensator includes the voltage control loop, the current control loop, and the PWM (Pulse Width Modulation) technique. These algorithms ensure that the output voltage is stable and that the compensator provides the required reactive power. Simulation and experimentation are important parts of the design process. The use of simulation software such as MATLAB/Simulink can help to verify the design before implementation.

In conclusion, a three-phase voltage converter may be used to create a static reactive power compensator, which is an efficient technique to raise the power factor of electrical systems. The design entails picking the ideal topology, selecting the ideal components, and putting control algorithms into practice. The design process also includes essential elements like simulation and experimentation.

6.2 FUTURE WORK

It is recommended that further work on the proposed DG distribution generation include the following recommendations.

1. Currently ideal situation is used for AC sources real time case study can also be used.

2. This work can be extended to a higher-level network system.

3. Another possibility for the future is the inclusion of various renewable energy sources and devices.

4. The proposed STATCOM and controller are designed in MATLAB/Simulink and can also design in other software’s.

5. It is also possible to develop a hardware model in the future.

6. Other intelligent components can also be implemented for the performance comparison.

7. Others controllers can be implemented for performance comparison.

The elimination of harmonics in the voltage lines is one of these systems' key advantages, as has already been shown. As a result, whether solar or wind turbines are included in the simulation, they are associated with renewable energy sources. According to the application and case study established, all of these approaches give favorable outcomes, likewise in the management of total harmonic distortion (THD) or to continue synchronizing systems using renewable energy. As a result of the disparate viewpoints in the investigations, it is difficult to compare their findings. However, they have provided a bibliography, a roadmap for this study, and validation of their successful operation in clean energy models.

6.3 ENVIRONMENT AND SUSTAINABILITY

In recent years, the importance of environmental conservation and sustainability has gained significant recognition across the globe. As human activities continue to have profound impacts on the natural world, it has become imperative to understand, protect, and restore our environment. This note aims to provide a detailed overview of environment and sustainability, highlighting key concepts, challenges, and strategies for a more sustainable future.

A static reactive power compensator based on a three-phase voltage converter can play a crucial role in improving the environmental sustainability of power systems. Reactive power compensation is necessary to maintain voltage stability, reduce line losses, and enhance the overall efficiency of the electrical grid.

By using a three-phase voltage converter, the compensator can dynamically control the reactive power flow in the system. It can either generate or absorb reactive power to maintain a desired power factor or voltage level. This helps in optimizing the power flow, reducing transmission losses, and improving the overall system performance.

Here are some ways in which such a compensator contributes to environmental sustainability:

Power factor correction: The static reactive power compensator helps in maintaining a desirable power factor in electrical systems. Power factor is a measure of how effectively electrical power is being used, and a low power factor indicates inefficient use of energy. By correcting the power factor, the compensator reduces the reactive power component, leading to higher overall system efficiency and reduced energy consumption. This, in turn, reduces the environmental impact associated with electricity generation.

Renewable energy integration: As renewable energy sources like solar and wind power become more prevalent, static reactive power compensators play a crucial role in integrating these intermittent energy sources into the grid. By dynamically compensating for reactive power imbalances, the compensator ensures stable voltage levels, minimizes voltage fluctuations, and helps maintain grid stability when renewable energy sources are connected. This facilitates the widespread adoption of renewable energy, which is vital for a sustainable energy future.

Voltage regulation: Voltage fluctuations and instability can have detrimental effects on electrical equipment, leading to increased energy losses and reduced equipment lifespan. A static reactive power compensator based on a three-phase voltage converter can actively regulate the voltage levels, ensuring a stable and reliable power supply. This improves the overall efficiency of electrical systems, reduces energy waste, and minimizes the need for equipment replacement, thereby reducing environmental impact.

6.4 LINEMENT AND ENGINEERING SOCIETY

Both the power industry and the engineering society heavily rely on the implementation of static reactive power compensators based on three-phase voltage converters. Here's how these technologies impact both sectors:

Power industry efficiency: Static reactive power compensators enhance the efficiency of the power industry by improving power factor correction and reducing reactive power losses. This leads to reduced energy consumption, optimized power transmission, and distribution, resulting in lower operational costs for power utilities. The compensators also contribute to voltage regulation, ensuring stable power supply and minimizing power outages. By enhancing the overall efficiency and reliability of the power industry, these compensators benefit both utility providers and consumers.

Grid stability and power quality: Static reactive power compensators are essential for maintaining grid stability and ensuring high-quality power supply. They actively regulate voltage levels, balance reactive power, and mitigate voltage fluctuations. This helps prevent voltage sags, surges, and flickering, which can cause disruptions and damage to electrical equipment. By maintaining a stable and reliable grid, these compensators support the uninterrupted operation of critical infrastructure, industries, and residential areas.

Integration of renewable energy: With the increasing penetration of renewable energy sources such as solar and wind power, static reactive power compensators play a crucial role in their effective integration into the electrical grid. These compensators assist in managing voltage fluctuations, reactive power imbalances, and harmonics that can arise from the intermittent nature of renewable energy sources. By ensuring a seamless integration process, they facilitate the growth of renewable energy generation, contributing to a more sustainable energy mix.

Sustainable development: The implementation of static reactive power compensators aligns with the goals of sustainable development. By optimizing power factor correction and reducing reactive power losses, these compensators contribute to energy efficiency and conservation. They promote responsible energy consumption, lower greenhouse gas emissions, and reduce the dependence on fossil fuel-based power generation. This supports global initiatives to combat climate change and create a more sustainable future.

CHAPTER 7: Sustainable Development Goals

As part of the 2030 Agenda for Sustainable Development, the United Nations (UN) established a set of 17 global goals known as the Sustainable Development Goals (SDGs) in 2015. They provide a framework for holistic and integrated solutions to the world's most pressing economic, social, and environmental issues. By balancing the three dimensions of development, the SDGs aim to direct efforts to achieve sustainable development: social, environmental, and economic, without putting anyone behind.

Here are a few potential SDGs relevant to Static reactive power compensator based on three phase voltage converter:

Goal 7: Affordable and Clean Energy (SDG 7):

This goal aims to ensure access to affordable, reliable, sustainable, and modern energy for all. Static reactive power compensators can contribute to this goal by improving power quality, reducing energy losses, and facilitating the integration of renewable energy sources into the grid.

Goal 9: Industry, Innovation, and Infrastructure (SDG 9):

Industry, Innovation, and Infrastructure are fundamental elements in achieving the Sustainable Development Goals (SDGs) through static reactive power compensator projects based on three-phase voltage converters. These projects foster innovation in the energy sector by deploying advanced technologies, optimizing power system infrastructure, and promoting sustainable industrialization. By improving the efficiency, stability, and reliability of electrical grids, these projects support the development of resilient infrastructure. By aligning with SDGs related to affordable and clean energy, responsible consumption and production, climate action, and sustainable cities and communities, static reactive power compensator projects contribute to building a more sustainable and innovative future.

Goal 11: Sustainable Cities and Communities (SDG 11):

This goal aims to make cities and human settlements inclusive, safe, resilient, and sustainable. Static reactive power compensators can contribute to this goal by improving the reliability and stability of power supply in urban areas, promoting efficient use of energy, and supporting the development of sustainable urban infrastructure.

Goal 12: Responsible Consumption and Production (SDG 13):

Responsible Consumption and Production is a critical aspect in static reactive power compensator projects based on three-phase voltage converters to achieve the Sustainable Development Goals (SDGs). By promoting energy efficiency, reducing waste, and optimizing resource utilization, these projects contribute to sustainable consumption and production patterns. Through partnerships and collaborations, stakeholders can share best practices, implement sustainable procurement strategies, and promote responsible use of materials and resources throughout the project lifecycle. By prioritizing responsible consumption and production, static reactive power compensator projects align with SDGs related to affordable and clean energy, industry innovation, climate action, and sustainable cities and communities, fostering a more sustainable and environmentally conscious approach to energy infrastructure.

Goal 13: Climate Action (SDG 13):

Climate change and its impacts is vital in static reactive power compensator projects based on three-phase voltage converters to achieve the Sustainable Development Goals (SDGs). By integrating renewable energy sources, reducing greenhouse gas emissions, and enhancing energy efficiency, these projects contribute to mitigating climate change effects. Additionally, collaborations and partnerships play a key role in sharing knowledge, resources, and best practices, enabling the development and implementation of sustainable energy solutions.

Goal 17: Partnerships for the Goals (SDG 17):

Emphasizes the importance of Partnerships and collaboration are of utmost importance in static reactive power compensator projects based on three-phase voltage converters to achieve the Sustainable Development Goals (SDGs). By working together, stakeholders can share knowledge, expertise, and resources, facilitating technology transfer, policy alignment, and capacity building. These collaborations enable the development and deployment of efficient and sustainable energy solutions, promoting affordable and clean energy access, resilient infrastructure, climate action, and sustainable cities and communities, thereby contributing to the overall achievement of the SDGs.

The project can promote knowledge sharing and capacity-building initiatives by sharing best practices, lessons learned, and technological advancements related to the implementation of the static reactive power compensators. This contributes to strengthening the collective knowledge base and facilitates the replication of successful practices in other contexts.

The project can contribute to global cooperation by aligning with international frameworks and standards related to sustainable urban development. This ensures that the project's outcomes and methodologies are in line with global objectives, fostering global cooperation towards achieving the Sustainable Development Goals.

STUDENT’S CONTRIBUTION

Candidate Name	**Contribution In Project & Project Report (Chapter Wise)**
MUHAMMAD HABIB-UR-REHMAN	**Chapter ,3,4,6**
SHAHERYAR GHAFFERI	**Chapter 3,5**
UMERFAROOQ	**Chapter 1,5**
FAHEEM KHAN	**Chapter 2,7**

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