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Six Pulse Type Segmented Thyristor Controlled Reactor with Fixed Capacitor for Reactive Power Compensation

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Abstract:- This article presents a Six Pulse Type Segmented Thyristor Controlled Reactor (TCR) integrated with a Fixed Capacitor (FC) for reactive power compensation. The primary objective is to improve voltage stability and power factor in electrical networks, addressing issues related to reactive power imbalance and harmonic distortion. The proposed configuration combines the advantages of segmented TCR and FC, providing a flexible and efficient approach to reactive power management. The novelty of this work lies in the segmentation of the TCR, which enhances the dynamic control of reactive power by allowing more precise regulation and reduced harmonics compared to conventional TCR systems. This segmented approach also minimizes switching losses and thermal stress on thyristors, leading to enhanced reliability and longevity of the system. Additionally, the integration of a fixed capacitor optimizes the overall power factor correction, contributing to improved system efficiency. Key findings from simulation and experimental results demonstrate that the Six Pulse Type Segmented TCR with FC significantly reduces reactive power, stabilizes voltage levels, and effectively suppresses harmonics within permissible limits, adhering to IEEE standards. The system shows a marked improvement in power quality, making it a viable solution for industrial applications where reactive power control is critical. This innovative approach not only provides superior compensation characteristics but also offers a scalable and adaptable framework for modern power systems, highlighting its potential to enhance operational performance and energy efficiency in various electrical grids.

Keywords:- *Power Systems, Power Electronics, Flexible AC Transmission System, Reactive Power.*

I. INTRODUCTION

The stability and efficiency of electrical power systems are critical for ensuring reliable electricity supply in modern industrial and residential sectors. Power systems are inherently complex, involving the generation, transmission, and distribution of electrical energy over vast networks. A significant challenge within these systems is the management of reactive power, which plays a vital role in maintaining voltage stability and efficient power flow. Uncompensated reactive power can lead to voltage instability, power losses, increased transmission line congestion, and diminished overall system performance, often resulting in costly operational inefficiencies[1].

One of the primary solutions to mitigate these issues is the implementation of reactive power compensation devices. These devices help in maintaining an optimal power factor, reducing losses, and stabilizing voltage profiles across the power grid. Power electronics technology has become integral in developing advanced compensation techniques, providing precise control over power flow and enhancing the dynamic response of power systems. Among these technologies, Flexible AC Transmission Systems (FACTS) devices have emerged as pivotal solutions, offering real-time control capabilities to mitigate various power system problems[2].

FACTS devices, including Thyristor Controlled Reactors (TCRs), Static Synchronous Compensators (STATCOMs), and Static Var Compensators (SVCs), play a crucial role in improving power quality by dynamically managing reactive power. The Six Pulse Type Segmented Thyristor Controlled Reactor with a Fixed Capacitor represents an innovative approach within the FACTS family, designed to address reactive power imbalance and harmonic

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distortions effectively. By segmenting the TCR and integrating it with a fixed capacitor, this configuration offers improved regulation of reactive power, enhanced voltage control, and reduced harmonic content, directly tackling power system challenges. This approach not only boosts system reliability but also contributes to the overall efficiency and stability of electrical networks, highlighting the transformative role of power electronics in modern power systems[3].

A. Role of Reactive Power Control in Power System

Reactive power control plays a critical role in the efficient and reliable operation of electrical power systems. It is essential for maintaining voltage stability, improving power quality, and reducing losses in transmission and distribution networks. Understanding reactive power and its control is fundamental to addressing challenges in modern power systems, especially with the growing integration of renewable energy sources, increased demand for electricity, and evolving smart grid technologies. This essay delves into the role of reactive power control in power systems, highlighting its importance in ensuring grid stability, improving system efficiency, and enabling the proper functioning of electrical devices.[4].

In an alternating current (AC) power system, electrical power is divided into two components: active power (measured in watts) and reactive power (measured in volt-amperes reactive or VAR). Active power is responsible for performing actual work, such as lighting a bulb, driving a motor, or heating a space. Reactive power, on the other hand, does not perform useful work but is necessary for maintaining the electric and magnetic fields required for the proper operation of inductive loads like motors, transformers, and transmission lines. These loads generate and consume reactive power, which needs to be controlled to avoid undesirable effects on the power grid.[5].

While active power is essential for the operation of most electrical devices, reactive power ensures the efficient delivery of that active power by maintaining voltage levels. Without sufficient reactive power control, voltage instability, power losses, and equipment malfunctions can occur, leading to inefficient and unreliable power system operation.[6].

Reactive power control is a cornerstone of modern power system operation, ensuring voltage stability, improving power factor, and reducing transmission losses. As the demand for electricity grows and power grids become more complex with the integration of renewable energy, the importance of reactive power control will only increase. By employing a combination of traditional methods, such as capacitor banks and reactors, alongside advanced technologies like FACTS devices, power system operators can maintain efficient and reliable grid operation, even in the face of new challenges.[7].

B. Reasons Why Reactive Power is Important

There are mainly 3 reasons why reactive power is important.

➢ *Voltage Control*

Reactive power is essential for maintaining voltage levels within the power system. Insufficient reactive power can cause voltage drops, which may result in the malfunctioning of electrical equipment and instability in the power grid. Proper management of reactive power ensures stable and reliable voltage levels across the network.[8].

Reactive power plays a key role in controlling voltage levels within an electrical system. Voltage stability is essential for the safe and efficient operation of power grids and electrical devices. When there is a deficiency of reactive power, voltage levels may drop, causing voltage instability or even collapse. In power systems, devices like transformers and generators require both active and reactive power to maintain desired voltage levels. Without sufficient reactive power, the voltage can fall below safe operational limits, which could lead to equipment failure or cause protection systems to trip, disrupting the power supply.[9].

To overcome this, reactive power should be supplied to the load by putting reactive inductors or reactors in transmission lines. The capacity of these reactors depends on the amount of apparent power to be supplied[10].

If the power demand is less than reactive power supplied, the load voltage rises to a higher level which leads to automatic tripping of transmission equipment, low power factor, insulation failures of the cables and windings of various mechanical devices[11].

To overcome this, additional reactive power available on the system must be compensated. Various compensation equipment is synchronous condensers, shunt capacitors, series capacitors, and other PV systems. These devices inject the capacitive reactive power to compensate inductive reactive power in the system[12].

Therefore, we can say that apparent power is required to maintain voltage levels within limits for the stability of the transmission systems.

➢ *Electrical Blackouts*

Reactive power is critical to preventing electrical blackouts. If the power grid experiences a significant drop in reactive power, it can lead to system-wide voltage collapse, causing blackouts. Proper regulation of reactive power helps avoid these disruptions and ensures continuity of electrical supply.[13].

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Reactive power is crucial in maintaining the stability of the entire power grid. During high demand or transmission over long distances, reactive power losses occur, which, if not managed, can result in voltage collapse. If voltage levels fall too low, the system may experience cascading failures, leading to widespread blackouts. For example, major power blackouts in the past, like the 2003 Northeast blackout in the U.S., were partly attributed to a lack of reactive power support, which caused voltage instability and eventually a system-wide failure. Therefore, having enough reactive power generation, compensation, and control mechanisms is necessary to keep the system running reliably and avoid blackouts.[14].

- *Proper Working of Various Devices*

Many devices, such as motors and transformers, rely on reactive power to function efficiently. Reactive power provides the necessary magnetizing force for these devices to operate. Without sufficient reactive power, these devices may not work properly, leading to overheating, reduced efficiency, and potential damage[15].

Many electrical devices, such as induction motors, transformers, and other equipment, depend on reactive power for proper operation. These devices use reactive power to create the magnetic fields necessary for their functionality. For instance, induction motors require reactive power to establish the rotating magnetic field that allows the motor to generate torque and perform mechanical work. If there is insufficient reactive power, these devices may experience reduced performance, overheating, or damage due to excessive current draw. Reactive power ensures that such devices operate within their optimal parameters, thus extending their lifespan and improving efficiency.

II. PROPOSED FACTS DEVICE

The segmented TCR-FC is on e of the Static Var Compensator classification device. A Static Var Compensator (SVC) is a shunt-connected device used in power systems to provide dynamic voltage control and reactive power compensation. It plays a crucial role in improving power quality, voltage stability, and the overall efficiency of the transmission network. SVCs are widely used in electrical power systems for industrial applications, transmission lines, and substations. Segmented Thyristor-Controlled Reactor (TCR) consists of a reactor connected in series with thyristors that control the current flow by adjusting the thyristor firing angle. Provides variable inductive reactive power by dynamically adjusting the reactor’s impedance. Fixed Capacitors (FC) Provides a constant level of capacitive reactive power. Often used alongside TCRs and TSCs to provide baseline compensation. Passive harmonic filters are included to reduce harmonic distortion generated by the switching operations of thyristors.

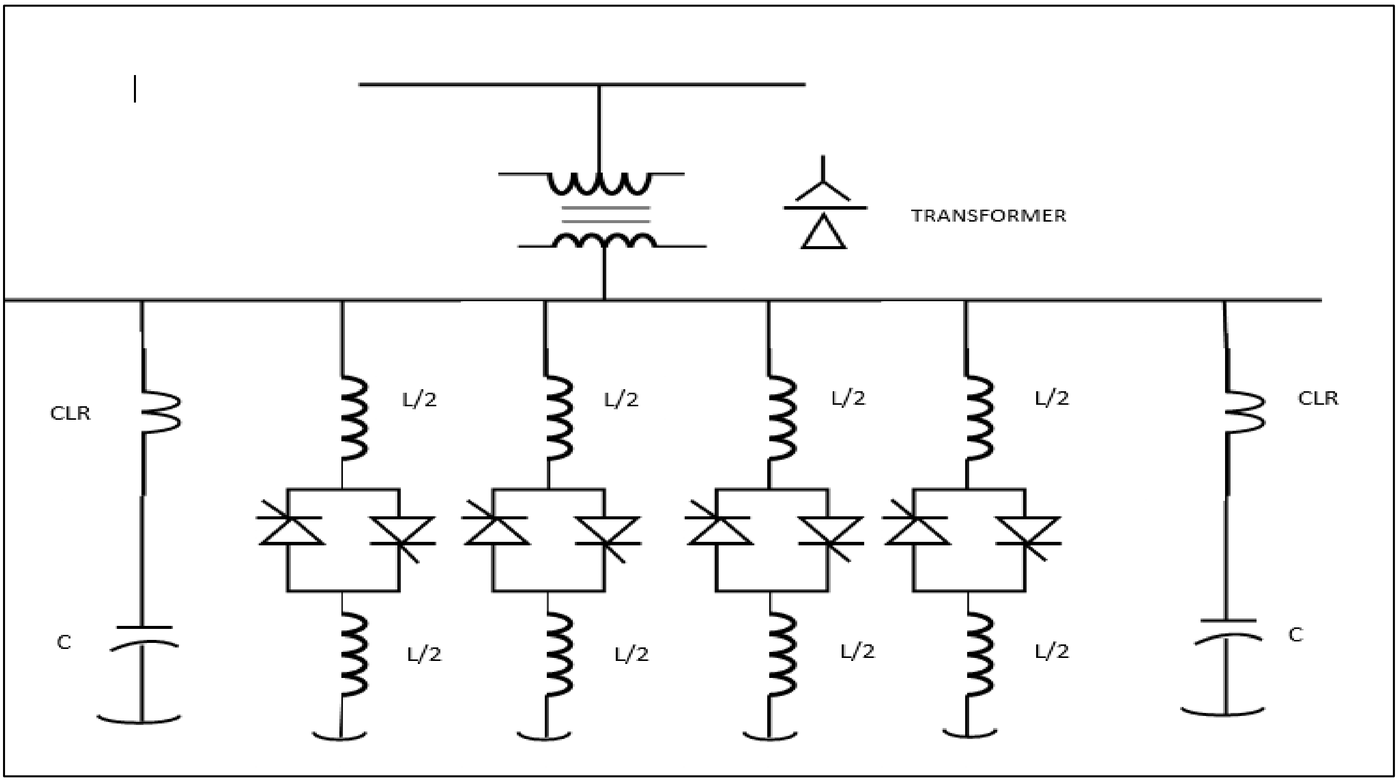

Fig 1: Segmented TCR-FC Six Pulse

The TCR-FC is connected in shunt (parallel) to the power system, directly injecting or absorbing reactive power to stabilize voltage. Shunt compensation helps reduce voltage fluctuations, enhance power factor, and minimize line losses. Which provide fast, dynamic reactive power compensation in response to system conditions, typically in milliseconds. The fast response helps in stabilizing the system during transient events like faults, load changes, or switching operations.

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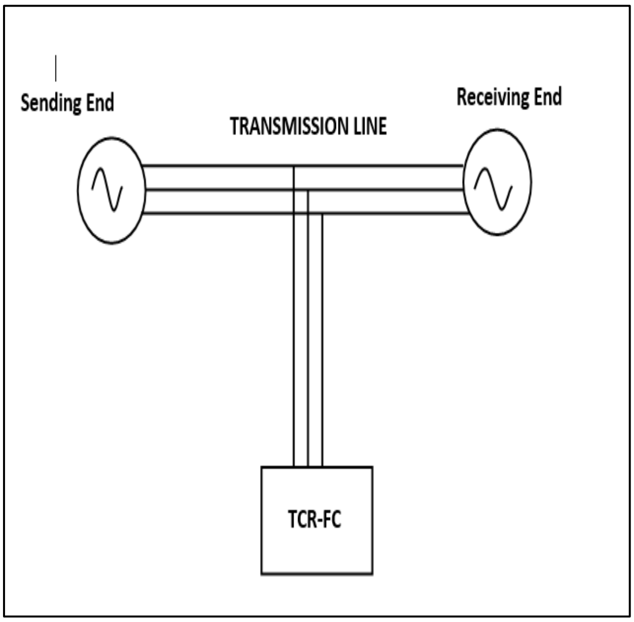

Fig 2: Block Diagram of TCR-FC

A. Working of TCR-FC

In transmission applications, the proposed device is used to regulate the grid voltage. When the system voltage drops below the desired level, indicating a reactive power deficit (inductive load conditions), the proposed device compensates by switching in the thyristor-controlled switch and reducing the thyristor-controlled reactor conduction. This action injects capacitive reactive power, raising the voltage back to its setpoint. Conversely, when the system voltage is higher than required (excess reactive power), the proposed device increases the conduction angle of the thyristor-controlled reactor to absorb more reactive power, lowering the voltage.

The dynamic nature of the proposed device allows it to respond almost instantaneously to voltage changes, typically within a few milliseconds. This rapid response is crucial during transient events such as load switching, faults, or other disturbances, where voltage stability needs to be quickly restored.

B. Advantages & Applications

- *Dynamic Reactive Power Compensation:*

The combination of a thyristor-controlled reactor (TCR) and fixed capacitors provides dynamic control of reactive power. This enables the system to quickly adjust to changing reactive power demands in the grid, helping to maintain voltage levels and system stability.

- *Improved Power Factor:*

By compensating for reactive power, the system improves the power factor of the network. A better power factor reduces transmission losses and improves the overall efficiency of the electrical system, lowering energy costs and optimizing power delivery.

- *Reduction of Harmonics:*

The segmented design of the reactor allows for better harmonic filtering, reducing the harmonic distortion that can cause inefficiency or equipment malfunction in the grid. This design ensures that the system complies with power quality standards by minimizing harmonics.

- *Modularity and Flexibility:*

The segmented TCR design allows for modularity, meaning the system can be tailored to specific reactive power needs by adjusting the number of segments used. This flexibility makes it suitable for various grid conditions and requirements, and it can be easily expanded or upgraded over time.

- *Voltage Control in Transmission and Distribution Systems:*

The six-pulse segmented TCR with FC is widely used in high-voltage transmission and distribution systems to regulate voltage levels by dynamically compensating for reactive power. This helps stabilize voltage during load changes and prevents voltage sag or rise.

- *Power Factor Correction in Industrial Grids:*

In industrial environments where large inductive loads such as motors and transformers are present, the system is used to improve power factor by supplying or absorbing reactive power as needed. This reduces energy costs, enhances equipment performance, and lowers the risk of penalties from utility companies.

- *Stabilization of Renewable Energy Systems:*

In renewable energy grids, such as wind or solar farms, where output can fluctuate, this system stabilizes voltage and reactive power levels. It ensures that power quality is maintained, despite the variable nature of renewable energy generation.

- *Improved Stability in Microgrids:*

In microgrid applications, particularly those with distributed generation sources like solar panels or batteries, the TCR with FC helps balance reactive power and ensure voltage stability, enhancing the reliability of the microgrid during varying load conditions.

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III. RESULTS

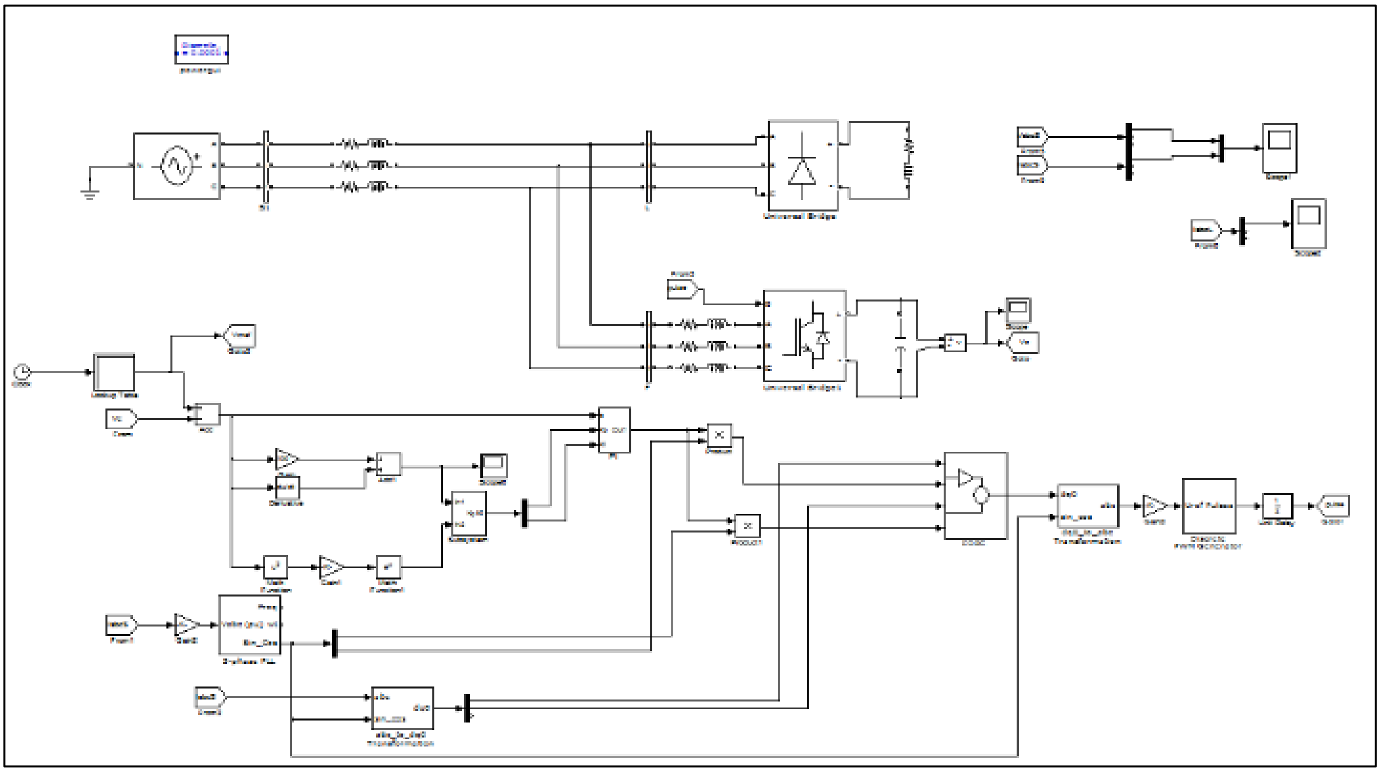

Fig 3: Simulation Design of the Proposed System

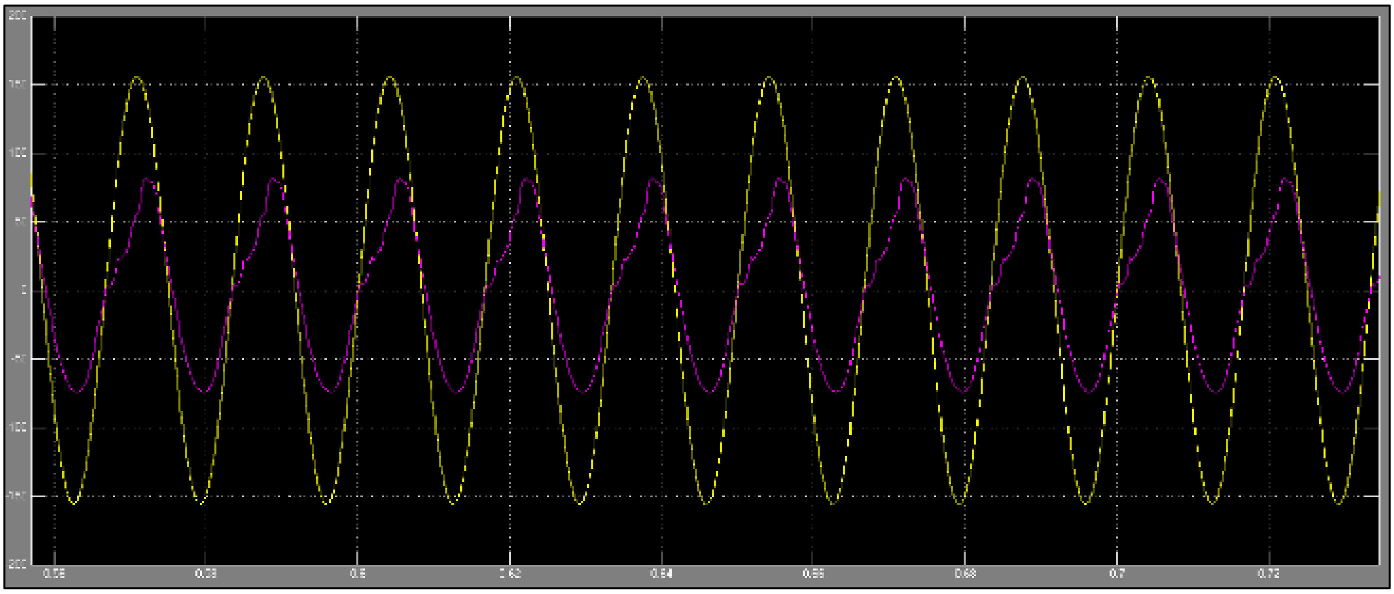

Fig 4: Voltage and Current Waveforms of Grid Side

IV. CONCLUSION

The Six Pulse Type Segmented Thyristor Controlled Reactor (TCR) with Fixed Capacitor (FC) configuration offers a highly efficient and flexible solution for reactive power compensation in electrical power systems. This combination effectively addresses the dynamic requirements of reactive power, improving power factor, voltage stability, and overall system reliability. By employing a segmented TCR, the system can finely control the inductive component of reactive power in response to varying load conditions, thus ensuring better control and stability compared to traditional fixed compensators. Moreover, the combination of segmented TCR and FC plays a significant role in mitigating issues such as voltage sags, swells, and fluctuations caused by variable loads. The static nature of the fixed capacitor contributes to a constant source of leading reactive power, while the thyristor-controlled reactor dynamically adjusts to meet the real-time reactive power demands. This synergy reduces energy losses, improves transmission efficiency, and ensures optimal performance of power transmission and distribution networks.

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V. FUTURE SCOPE

In practical applications, such as industrial plants, renewable energy integration, and utility grids, the Six Pulse Type Segmented TCR with FC stands out as a reliable and cost-effective solution. It not only enhances system stability but also prolongs the lifespan of electrical equipment by minimizing voltage variations. In conclusion, the Six Pulse Type Segmented TCR with FC is an indispensable technology in modern power systems, contributing significantly to efficient and stable power delivery, especially in environments with fluctuating reactive power demands.

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