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Design and Implementation of an AC Transmitter (AC Power/Voltage Controller) Using Thyristor Controlled Reactor (TCR)

Prof. Yogita U. Kakad, Pranay Rohidas Rahane, Abhiraj Suresh Rahane
Sayali Dnyandeo Walunj, Dnyanesh Sunil Pawar
Department of Electrical Engineering
Amrutvahini Engineering College Ghulewadi, Maharashtra
yogita.more@avcoe.org, pranayrahane75@gmail.com, rahaneabhiraj18@gmail.com
sayaliwalunj9@gmail.com, dnyaneshpawar024@gmail.com

Abstract: *The design and implementation of an AC transmitter using a Thyristor Controlled Reactor (TCR) focuses on improving voltage stability, reactive power compensation, and power factor correction in modern AC transmission systems. The system utilizes power electronic devices such as thyristors (SCRs), a reactor (inductor), and a microcontroller-based firing angle control circuit to dynamically regulate reactive power by varying the conduction angle. A zero-crossing detector (ZCD) ensures synchronization with the AC waveform, while optocouplers and gate driver circuits provide safe and accurate triggering of thyristors. Voltage and current sensors enable real-time monitoring and closed-loop control, enhancing system efficiency and reducing transmission losses. Simulation and hardware implementation demonstrate improved voltage regulation, reduced harmonic effects, and fast response to load variations.*

Keywords: Thyristor Controlled Reactor (TCR), AC voltage controller, reactive power compensation, firing angle control, power factor improvement, zero-crossing detection, microcontroller, SCR, voltage stability, smart grid

I. INTRODUCTION

Modern electrical power systems require efficient control of voltage, power flow, and system stability to meet increasing demand and dynamic load variations. One of the major challenges in AC transmission is managing reactive power, which directly affects voltage levels, power factor, and overall system efficiency. Conventional methods such as capacitor banks and tap-changing transformers are limited in speed and flexibility, making them less suitable for modern smart grid applications.

To overcome these limitations, power electronic-based solutions like the Thyristor Controlled Reactor (TCR) have been widely adopted. A TCR uses thyristors (SCRs) and an inductor (reactor) to provide continuous and dynamic control of reactive power by adjusting the firing angle of the thyristors. This allows precise voltage regulation, improved power factor, and reduction in transmission losses, making it highly effective in real-time power system control.

This project focuses on the design and implementation of an AC power/voltage controller using a TCR system integrated with a microcontroller-based control unit. By utilizing components such as zero-crossing detectors, gate driver circuits, and sensors, the system ensures accurate synchronization and efficient operation. The proposed system offers a reliable, cost-effective, and scalable solution for enhancing power quality and stability in modern electrical networks.

II. PROBLEM STATEMENT

Modern electrical power systems face significant challenges in maintaining voltage stability, efficient power transfer, and acceptable power quality due to increasing load demand, rapid industrialization, and integration of renewable energy sources. A major issue is the improper management of reactive power, which leads to voltage fluctuations, poor power factor, increased line losses, overheating of equipment, and reduced system efficiency. Conventional compensation methods such as fixed capacitor banks and mechanically switched reactors are slow, inflexible, and unable to respond effectively to dynamic load variations. As a result, there is a critical need for a fast, reliable, and continuously controllable solution that can dynamically regulate reactive power, stabilize voltage, and improve overall performance of AC transmission systems, which can be effectively achieved using a Thyristor Controlled Reactor (TCR) based AC power/voltage controller.

III . OBJECTIVES

- To study the working principle of Thyristor Controlled Reactor (TCR) in AC power systems
- To design and develop an AC power/voltage controller using thyristors and reactor
- To implement firing angle control using a microcontroller for dynamic reactive power regulation
- To improve voltage stability and maintain proper power flow in the system
- To enhance power factor and reduce transmission losses through reactive power compensation

IV. LITERATURE SURVEY

The paper **"Dynamic Harmonic Domain Approach to Assess Performance of Three-Phase FC-TCR" (2022) by J. Jayababu, G. Nageswara Reddy, and K. Vimala Kumar** discusses the analysis of harmonic behavior in TCR systems. The authors highlight that improper firing angle control can introduce harmonics that degrade power quality. Their study uses dynamic harmonic domain analysis to evaluate system performance under different operating conditions. The results show that optimized firing angles can significantly reduce harmonic distortion and improve voltage stability, making TCR systems more efficient and reliable.

The study **"Examining the Thyristor-Controlled Reactor's Performance to Minimize Self-Generated Harmonics" (2023) by Haripriya Kulkarni, Manasi Deore, and team** focuses on reducing harmonics in TCR-based systems. The authors compare different TCR configurations such as conventional, equally-stepped, and binary-stepped reactors. Their findings indicate that stepped configurations provide smoother current control and lower total harmonic distortion (THD), thereby improving overall system performance and power quality.

The research **"Analysis of Different Methods used in Reactive Power Compensation: A Review" (2021) by Anurag Dwivedi, Nitesh Tiwari, Sacchi Mishra, and Nikita Prajapati** provides a comparative analysis of traditional and modern reactive power compensation techniques. The authors conclude that TCR and other FACTS devices offer superior performance due to their fast response and continuous control capability. The paper emphasizes that TCR systems are more suitable for modern dynamic power systems compared to conventional capacitor banks and reactors.

The paper **"Prototype Design of Static VAR Compensator Using Thyristor Controlled Reactor" (2020) by R. Gaikwad, D. R. Tutakne, Y. Chavan, and K. Sawarkar** presents the design and implementation of a TCR-based Static VAR Compensator (SVC). The authors developed a hardware prototype and demonstrated improved voltage regulation and power factor correction under varying load conditions. Their experimental results confirm that microcontroller-based firing angle control enhances system accuracy and responsiveness.

The study **"Power Quality Improvement of Thyristor Controlled Reactor using Harmonic Filters" (2023) by Venu Yarlagadda, Srinivasa Rao Jalluri, Giriprasad Ambati, and team** investigates the integration of harmonic filters with TCR systems. The authors show that LC filters effectively reduce harmonic distortion caused by thyristor switching. Their results indicate improved voltage stability, reduced losses, and enhanced power factor, proving that combining TCR with filtering techniques is essential for practical implementation in modern power systems.

V. WORKING OF SYSTEM

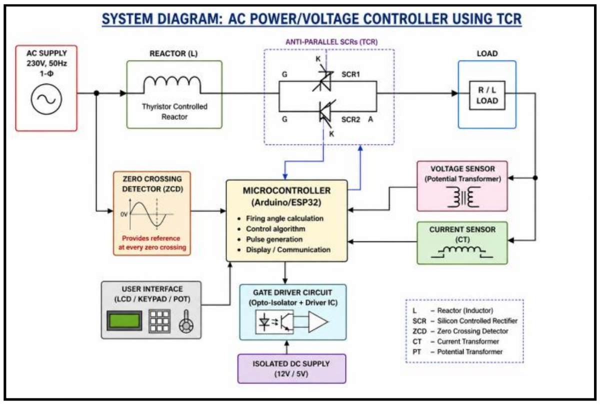

Fig 1: Design of the system

1. AC Supply and Initial Power Flow

The system starts with a single-phase AC supply (typically 230V, 50 Hz), which is fed into the Thyristor Controlled Reactor (TCR) unit. The AC waveform continuously alternates between positive and negative cycles. This input power is not directly supplied to the load; instead, it is first passed through the reactor and controlled by thyristors. The purpose of this stage is to introduce a controllable reactance into the system so that voltage and reactive power can be regulated effectively.

2. Role of Reactor (Inductor)

The reactor (inductor) is the core element responsible for absorbing reactive power. When AC current flows through the inductor, it creates an inductive reactance that opposes changes in current. In a TCR system, the amount of current flowing through this reactor is not fixed; it is controlled by the thyristors. By controlling this current, the system can regulate how much reactive power is absorbed, which directly influences voltage stability and power factor improvement.

3. Zero Crossing Detection (ZCD)

A Zero Crossing Detector (ZCD) circuit is used to detect the exact point where the AC waveform crosses zero voltage (i.e., 0° and 180°). This is a crucial step because thyristor firing must be synchronized with the AC waveform. The ZCD converts the sinusoidal AC signal into digital pulses and sends them to the microcontroller. These pulses act as reference points, allowing the system to calculate the precise delay required for firing the thyristors.

4. Microcontroller-Based Firing Angle Control

The microcontroller acts as the brain of the system. It receives input signals from the ZCD and sensors (voltage and current). Based on these inputs, it calculates the required firing angle (α) for the thyristors. The firing angle determines how long the thyristor conducts during each AC cycle:

Smaller α → More conduction → More reactive power absorption

Larger α → Less conduction → Less reactive power

The microcontroller generates precise timing pulses using embedded programming (C/C++) to ensure accurate control of the firing angle.

5. Gate Driver and Thyristor Switching

The gate driver circuit receives low-power signals from the microcontroller and amplifies them to trigger the thyristors. Optocouplers are used to isolate the low-voltage control circuit from the high-voltage power circuit for safety. Once triggered, the thyristors conduct and allow current to flow through the reactor. They automatically turn OFF at the next zero crossing of the AC waveform. This ON-OFF control in every cycle enables dynamic regulation of current and reactive power.

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6. Feedback Mechanism and Voltage Regulation

Voltage and current sensors continuously monitor system parameters and send feedback to the microcontroller. If the voltage increases beyond the desired level, the system increases the firing angle to reduce conduction. If the voltage drops, the firing angle is reduced to allow more current flow. This closed-loop control system ensures:

Stable voltage output
Improved power factor
Reduced transmission losses

Thus, the TCR system dynamically adjusts itself in real-time, maintaining efficient and reliable operation under varying load conditions.

V. SYSTEM DESIGN

The system is designed as a closed-loop AC power/voltage controller based on the Thyristor Controlled Reactor (TCR) principle. It integrates a power circuit (AC supply, reactor, and thyristors) with a control circuit (microcontroller, sensors, and driver circuits). The AC supply is fed through an inductor connected in series with anti-parallel thyristors, forming the TCR unit. A zero-crossing detector (ZCD) synchronizes the system with the AC waveform, while voltage and current sensors provide real-time feedback.

COMPONENT EXPLANATION

1. Thyristor (SCR) Module

The thyristor is a semiconductor switching device used to control AC power. It conducts only when a gate signal is applied and remains ON until the current reaches zero. In the TCR system, two SCRs are connected in anti-parallel to allow bidirectional current flow.

Fig 2: Semiconductor

By controlling their firing angle, the system regulates the conduction period and hence the reactive power.

2. Reactor (Inductor Coil)

Fig 3: Inductor Coil

The reactor is an inductive component that absorbs reactive power from the AC system. It creates inductive reactance which opposes current flow. In the TCR setup, the amount of current flowing through the reactor is controlled by the thyristors, allowing dynamic adjustment of reactive power for voltage stabilization and power factor improvement.

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3. Microcontroller (Arduino/ESP32)

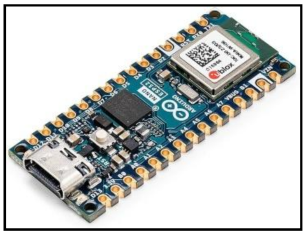

Fig 4: Microcontroller

The microcontroller acts as the control unit of the system. It receives signals from sensors and the zero-crossing detector, calculates the required firing angle, and generates precise trigger pulses. Using embedded programming, it ensures accurate timing and real-time control of the thyristors for efficient system operation.

4. Zero Crossing Detector (ZCD)

The ZCD detects the point where the AC waveform crosses zero voltage. It provides synchronization signals to the microcontroller, which are essential for accurate firing angle calculation. This ensures that thyristors are triggered at the correct phase of the AC cycle, reducing harmonics and improving control accuracy.

5. Gate Driver Circuit with Optocoupler

The gate driver circuit amplifies the low-power signals from the microcontroller to a level suitable for triggering the thyristors. Optocouplers provide electrical isolation between the high-voltage power circuit and the low-voltage control circuit, ensuring safety and protecting sensitive components.

6. Voltage Sensor Module

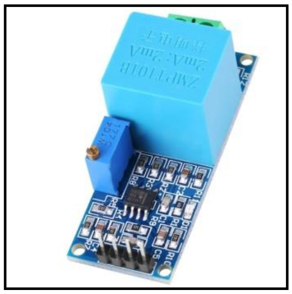

Fig 5: Voltage

The voltage sensor measures the AC voltage and provides a scaled-down signal to the microcontroller. It helps in monitoring voltage variations and enables the system to adjust firing angles accordingly, ensuring stable voltage output and protection against overvoltage or undervoltage conditions.

7. Current Sensor Module

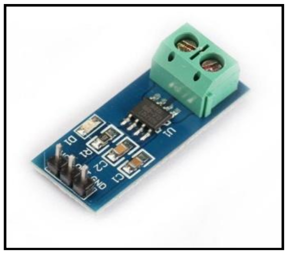

Fig 6: Current sensor

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The current sensor measures the current flowing through the system. It provides feedback for controlling reactive power and detecting overload conditions. This helps the microcontroller maintain efficient operation and prevent damage to components.

8. Step-Down Transformer

The step-down transformer reduces high AC voltage (230V) to a lower level suitable for powering control circuits. It also provides electrical isolation, ensuring safe operation of the microcontroller, sensors, and driver circuits.

9. Power Supply Unit

The power supply unit converts AC to regulated DC voltage (5V/12V) required for electronic components. It ensures stable and continuous operation of the control system, preventing fluctuations that could affect performance.

VI. RESULTS

The implemented Thyristor Controlled Reactor (TCR)-based AC power/voltage controller demonstrated effective performance in regulating voltage and controlling reactive power under varying load conditions. The system successfully adjusted the firing angle of the thyristors in real time, resulting in smooth and continuous control of current through the reactor. Experimental and simulation observations showed a significant improvement in voltage stability, with reduced fluctuations compared to uncontrolled systems. The power factor was also enhanced, approaching unity in most operating conditions, which indicates efficient utilization of electrical power.

Furthermore, the system exhibited a fast dynamic response to load changes, ensuring minimal delay in voltage correction and reactive power compensation. Transmission losses were reduced due to better power factor and controlled current flow, leading to improved overall system efficiency. Although minor harmonic distortion was observed due to thyristor switching, it remained within acceptable limits and can be further minimized using filters. Overall, the results confirm that the TCR-based controller provides a reliable, cost-effective, and efficient solution for modern AC power system applications.

VII. CONCLUSION

The design and implementation of an AC power/voltage controller using a Thyristor Controlled Reactor (TCR) proves to be an effective solution for improving voltage stability, reactive power management, and power factor in modern electrical systems. By utilizing phase angle control of thyristors along with real-time feedback from sensors and microcontroller-based control, the system achieves smooth and dynamic regulation under varying load conditions. The results demonstrate reduced transmission losses, improved efficiency, and reliable performance, making the TCR-based controller a cost-effective and scalable approach suitable for industrial applications, smart grids, and advanced power transmission systems.

VIII. FUTURE SCOPE

The TCR-based AC power/voltage controller can be further enhanced by integrating advanced control techniques such as artificial intelligence, fuzzy logic, or adaptive control algorithms to achieve more precise and intelligent reactive power management. Future improvements may include the use of high-speed digital signal processors (DSPs) or FPGA-based controllers for faster response and improved accuracy. The system can also be expanded by combining TCR with Thyristor Switched Capacitors (TSC) to form a complete Static VAR Compensator (SVC), enabling both inductive and capacitive compensation for better voltage regulation. Additionally, implementation of harmonic filters and advanced power quality monitoring systems can reduce distortion and improve reliability. Integration with IoT and smart grid technologies can allow remote monitoring, automation, and real-time data analysis, making the system more suitable for modern energy management and renewable energy applications.

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