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Modelling And Simulation Based Mitigation of Ferranti Effect in Long Transmission Lines Using a Thyristor Controlled Reactor

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ABSTRACT

The Ferranti effect is a phenomenon observed in long transmission lines under light or no-load conditions, where the receiving-end voltage becomes higher than the sending-end voltage due to the line's distributed capacitance. This excessive voltage can cause insulation stress, equipment damage, and instability in power systems. This paper presents an effective method for mitigating the Ferranti effect using a Thyristor Controlled Reactor (TCR). The TCR is a shunt-connected FACTS device that provides smooth and rapid control of inductive reactive power by adjusting the firing angle of thyristors. By absorbing the surplus reactive power generated by the transmission line capacitance, the TCR reduces over-voltage at the receiving end. The proposed approach enhances voltage regulation, improves system stability, and ensures reliable operation of the transmission network. Simulation analysis confirms that the use of TCR significantly minimizes voltage rise under light load conditions, making it a practical and efficient solution for modern high-voltage power transmission systems.

Keywords:- Ferranti Effect, Thyristor Controlled Reactor (TCR), Voltage regulation, Reactive power compensation, Transmission lines, Power system stability, Modelling and simulation, FACTS devices.

1. INTRODUCTION

The Ferranti effect poses significant challenges in long transmission lines, causing receiving-end voltage rise under light load or no-load conditions due to line capacitance. This overvoltage can compromise system stability and equipment safety. To address this, our paper proposes a modelling and simulation-based approach leveraging Thyristor Controlled Reactors (TCR). By dynamically absorbing reactive power through controlled thyristor firing angles, TCR effectively regulates voltage. The simulation model, developed using MATLAB/Simulink, demonstrates the TCR's ability to mitigate voltage rise under varying load conditions. Results show significant improvement in voltage profile, ensuring system stability and equipment safety. The proposed approach offers a viable solution for modern power transmission systems

In modern power systems, long transmission lines play a vital role in delivering electrical energy over large distances. However, these lines suffer from several technical issues, one of the most significant being the Ferranti Effect.

The Ferranti Effect occurs when the receiving-end voltage becomes higher than the sending-end voltage, particularly under light-load or no-load conditions. This happens due to the distributed capacitance of the transmission line, which generates excess reactive power.

This overvoltage condition can lead to:

- Insulation failure
- Equipment damage

Reduced system reliability. To overcome this issue, Thyristor Controlled Reactor (TCR), a type of FACTS device, is used. It provides dynamic reactive power compensation by controlling the firing angle of thyristors.

2. NEED FOR MODELING AND SIMULATION

Modelling and simulation play a crucial role in TCR implementation, allowing us to test control strategies, predict system behaviour, and optimize design parameters. This upfront effort pays off in real-world performance, reducing risks and ensuring smoother deployment. By simulating various scenarios, we can fine-tune TCR's reactive power compensation, ultimately enhancing grid stability and reliability. The simulation model, typically developed using tools like MATLAB/Simulink or PSCAD, helps validate the proposed

approach before actual implementation.
Modelling and simulation are essential in power system analysis because:
Real-time testing is expensive and risky Systems are complex and nonlinear
Helps in understanding system behaviour before implementation Benefits:

- Predict voltage variations
- Optimize TCR parameters
- Test different load conditions
- Improve system stability Tools Used:
- MATLAB/Simulink
- PSCAD
- ETAP
- Simulation ensures that the proposed system works efficiently before practical deployment.

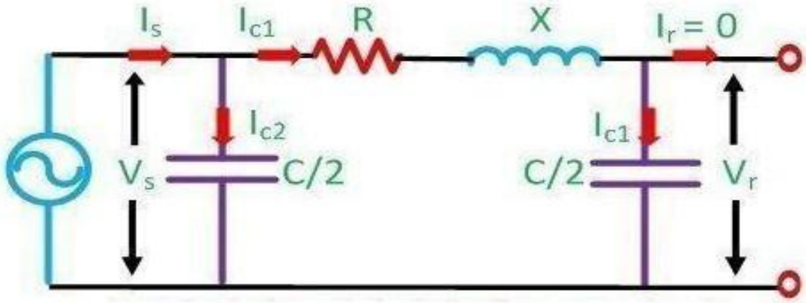

Fig. 2. Nominal pi modal of the line at no load

3. DETAILED LITERATURE REVIEW

A comprehensive literature review reveals TCR as an effective solution for mitigating Ferranti Effect in long transmission lines. Various studies demonstrate TCR's ability to regulate voltage and improve system stability. Research focuses on optimizing TCR design, control strategies, and exploring applications in modern power systems .

Various researchers have studied the Ferranti Effect and its mitigation techniques:
Traditional methods include shunt reactors, which provide fixed compensation Advanced methods use FACTS devices like TCR, SVC, and STATCOM Studies show that TCR provides fast and flexible reactive power control Research also focuses on improving control strategies and reducing harmonics
This study builds upon previous work by implementing a simulation-based approach using TCR.

4. FERRANTI EFFECT CAUSES AND CONSEQUENCES

Ferranti Effect occurs due to line capacitance in long transmission lines, causing overvoltage under light load conditions. This leads to equipment damage, system instability, and reactive power issues. The effect is prominent when load is light or absent, causing receiving end voltage to exceed sending end voltage .
Causes:
Consequences:

- Distributed capacitance of transmission line.
- Light or no-load condition.
- Long transmission distance.
- Overvoltage at receiving end.
- Stress on insulation.
- Equipment overheating.
- System instability.

5. THYRISTOR CONTROLLED REACTOR OVERVIEW

Thyristor Controlled Reactor (TCR) is a type of Flexible AC Transmission System (FACTS) device that controls reactive power flow in transmission lines. It consists of a reactor connected in series with bidirectional thyristor valves. By controlling the firing angle of thyristors, TCR's effective reactance is varied, allowing it to absorb or supply reactive power. This helps regulate voltage, improve stability, and mitigate issues like Ferranti Effect .

6. MODELING OF TRANSMISSION LINE AND TCR

Transmission line modelling uses π-model or distributed parameter models to represent line capacitance and inductance, while TCR modelling includes an inductor for the reactor and switching functions for thyristor valves, enabling effective simulation and analysis of Ferranti Effect mitigation .

Definition:

- A TCR is a shunt-connected FACTS device used to control reactive power in transmission lines.

Construction:

- Reactor (Inductor)
- Anti-parallel thyristors
- Control circuit

Working Principle:

- The firing angle (α) of thyristors controls the current flow
- By adjusting α, the TCR absorbs excess reactive power Operation Range:
- A = 90° → Maximum conduction • A = 180° → No conduction
- Applications:
- Voltage regulation
- Power factor improvement
- Stability enhancement

7. CONTROL STRATEGIES FOR MITIGATION

Control strategies for mitigating Ferranti Effect using TCR include voltage regulation, reactive power compensation, and adaptive control techniques. These strategies adjust TCR's firing angle to consume excess reactive power, regulate voltage, and improve system stability .

To control the Ferranti Effect, TCR uses:

- **Voltage Control Method**
  - ✦ Measure receiving-end voltage
  - ✦ Compare with reference value
  - ✦ Adjust firing angle accordingly
- **Reactive Power Compensation**
  - ✦ Absorb excess reactive power generated by line capacitance
- **Closed- loop Control**
  - ✦ Uses feedback system for accurate control

8. SIMULATION RESULTS AND ANALYSIS

Simulation results show TCR effectively mitigates Ferranti Effect by regulating receiving end voltage and consuming excess reactive power. Analysis indicates improved voltage profile, reduced overvoltage, and enhanced system stability under various load conditions.

Without TCR:

- Voltage rises significantly at receiving end
- System becomes unstable

With TCR:

- Voltage is regulated within limits
- Reactive power is absorbed System stability improves Analysis:
- Reduction in overvoltage
- Improved voltage profile
- Better system performance

9. DISCUSSION AND COMPARISON

Discussion: TCR-based mitigation effectively reduces Ferranti Effect, improving voltage stability and system performance. Comparison with other methods (e.g., shunt reactors) shows TCR offers faster response and better adaptability to changing system conditions.

Method	Response	Flexibility	Cost
Shunt Reactor	Slow	Low	Low
TCR	Fast	High	Medium
STATCOM	Very Fast	Very High	High

10. ADVANTAGES AND LIMITATIONS

TCR offers effective voltage regulation, fast response, and flexibility in power system applications, making it a viable solution for mitigating Ferranti Effect. However, it has limitations like harmonics generation, higher cost and complexity, and limited operating range, which need consideration. Advantages: Fast response, Smooth control of reactive power, Improves voltage stability, Flexible operation. Limitations, Generates harmonics, Requires filters, High initial cost, Complex control system

11. FUTURE WORK

Future work includes exploring advanced control algorithms integrating TCR with other FACTS devices and investigating TCR's impact on power system harmonics and resonance. Additionally, real-time simulation and hardware implementation can validate TCR's effectiveness in practical scenarios .
Integration with other FACTS devices, Use of AI-based control systems, Real-time hardware implementation, Harmonic reduction techniques, Integration with Advanced FACTS Devices, Future work can focus on combining TCR with other FACTS devices such as: Static VAR Compensator (SVC), STATCOM (Static Synchronous Compensator) Why important?, TCR provides good reactive power control but has slower response compared to STATCOM, Hybrid systems (TCR + STATCOM) can: Improve dynamic response,Enhance voltage stability, Provide better compensation under transient conditions Application of Artificial Intelligence and Smart Control, Modern power systems are moving toward smart grids, so intelligent control techniques can be applied., Possible approaches: Artificial Neural Networks (ANN), Fuzzy Logic Controllers,
Machine Learning algorithms Benefits: Automatic tuning of firing angle, Adaptive response to changing load conditions, Improved accuracy and efficiency Real-Time Hardware Implementation, most studies (including yours) are simulation-based.
Future work should include: Hardware implementation using: DSP (Digital Signal Processors),FPGA (Field Programmable Gate Arrays)
Hardware-in-the-loop (HIL) testing Importance: Validates simulation results. ,Helps in practical deployment, Identifies real-world challenges

Harmonic Reduction Techniques

One major limitation of TCR is harmonic generation due to thyristor switching.
Future improvements: Design of advanced harmonic filters: Passive filters, Active filters, Use of PWM-based control techniques
Outcome: Improved power quality, Reduced distortion in voltage and current

12. CONCLUSIONS

TCR-based mitigation effectively addresses Ferranti Effect in long transmission lines, improving voltage stability and system performance. Simulation results demonstrate TCR's ability to regulate voltage and consume excess reactive power, making it a viable solution for modern power systems .
The Ferranti Effect is a serious issue in long transmission lines that can affect system stability and equipment safety. The use of a Thyristor Controlled Reactor (TCR) provides an effective solution by absorbing excess reactive power.
Simulation results show that TCR successfully: Reduces overvoltage, Improves voltage regulation, Enhances system stability. Thus, TCR is a practical and efficient solution for modern power transmission systems.

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