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Analysis of IEEE 5 Bus Power Quality by 48 Pulse STATCOM

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Abstract – *A Static Synchronous Compensator (STATCOM) is a type of shunt-connected device under the Flexible AC Transmission System (FACTS) umbrella, designed to manage reactive power in power systems. It operates through a Voltage Source Converter (VSC) equipped with Gate Turn-Off thrusters (GTOs). A primary use of the STATCOM is to stabilize voltage at the center of long transmission lines, thereby improving power transmission capacity and maintaining reactive power balance at the load end. While conventional Proportional-Integral (PI) controllers are commonly used for reactive current regulation, they can induce oscillations and instability, especially when the STATCOM functions in inductive mode. To overcome this limitation, nonlinear feedback control methods offer a more stable alternative. The overall dynamic performance of a STATCOM is highly sensitive to its control parameters, and is typically evaluated through transient simulation analysis. In this work, a STATCOM system based on a two-level inverter is modelled to generate both 18-pulse and 48-pulse waveforms. Of these, the 48-pulse variant yields a higher quality and more efficient output. The project explores the application of both configurations in mitigating different types of short-circuit faults on transmission lines, followed by a post-fault performance comparison to assess their relative effectiveness.*

Keywords- *FACTS devices; STATCOM; voltage source converter; multilevel converter; Fuzzy logic controller; power system stability; Power quality*

INTRODUCTION

In recent years, the rising demand for electricity has placed increasing pressure on power systems, complicating their operation and reducing overall system security. In the context of a deregulated electricity market, ensuring reliable and stable power delivery has become a significant challenge. To address these concerns, Flexible AC Transmission System (FACTS) devices have been introduced to improve grid performance and extend transmission capacity. These technologies play a vital role in controlling voltage profiles and regulating both active and reactive power flows. Of particular importance is reactive power, as it directly influences voltage stability and determines the extent to which transmission lines can be loaded efficiently.

FACTS technology offers several key advantages
i)Enhanced controllability
ii)Faster response times
iii)Reliable and adaptable operation
iv) Lower system stress and reduced power losses

As depicted in Figure 1, FACTS controllers are generally divided into three primary categories. Among the shunt-connected devices, the Static Synchronous Compensator (STATCOM) stands out due to its ability to inject or absorb reactive power regardless of the prevailing system voltage. Another widely used shunt device is the Static Var Compensator (SVC), which helps stabilize voltage at the Point of Common Coupling (PCC). Devices like Thyristor Switched Reactors (TSRs) and Thyristor Controlled Reactors (TCRs) are typically employed on underloaded transmission lines to keep voltage levels within the desired range. Additionally, Thyristor

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Switched Capacitors (TSCs) are used to supply reactive power in discrete steps by integrating power capacitors with thyristor-controlled switches [5], [6].

FACTS controllers also include series devices, which may incorporate capacitive or inductive components, variable impedances, or power-electronic-based voltage sources. These are inserted in series with the transmission line to control power flow. When the injected voltage is oriented at 90 degrees to the line current (i.e., in quadrature), the device either supplies or absorbs reactive power. An example of this is the Static Synchronous Series Compensator (SSSC), which offers full control over its injected voltage without requiring an external energy source, adjusting dynamically based on PCC voltage conditions.

Other series compensation devices include:

- Thyristor Controlled Series Capacitor (TCSC)
- Interline Power Flow Controller (IPFC)
- Thyristor Switched Series Capacitor (TSSC)
- Thyristor Switched Series Reactor (TSSR)
- Thyristor Controlled Series Reactor (TCSR)

These devices function by either supplying or absorbing reactive power to regulate voltage levels along transmission lines. In particular, the Thyristor Controlled Voltage Limiter (TCVL) incorporates a metal-oxide varistor combined with thyristor switching to protect the system from transient over-voltages. Similarly, the Thyristor Controlled Voltage Regulator (TCVR) utilizes thyristor-controlled transformers to provide a variable output voltage. Given the ever-changing nature of power systems, disturbances are inevitable and can threaten overall stability. Reactive power compensation is essential in maintaining both synchronous stability and voltage control. Devices such as the STATCOM are particularly crucial, as they dynamically support voltage regulation by modulating reactive power.

To ensure the continuous flow of active power, the transmission line voltage must be maintained within acceptable thresholds. Capacitors are commonly employed for reactive power compensation due to their ability to store energy as an electrostatic field. When energized, they generate a voltage differential that varies over time and resists rapid changes in system voltage, causing the voltage to lag behind the current.

Figure 1 represents the IEEE 14-bus test system integrated with a 138 kV, 100 MVA STATCOM. This model incorporates both a 2-level Voltage Source Converter (VSC) and a 3-level Diode-Clamped Multilevel Converter (DCMC). Based on economic considerations and system loss sensitivity, bus 14 is identified as the most suitable location for STATCOM deployment [15]–[17]. The entire system is developed using MATLAB/SIMULINK, leveraging the SimPower Systems toolbox. Sinusoidal Pulse Width Modulation (SVPWM) techniques are applied to control both VSC and DCMC converters. The study further evaluates and compares the voltage regulation capabilities of the 2-level and 3-level STATCOM designs under various loading scenarios, including both linear and nonlinear loads.

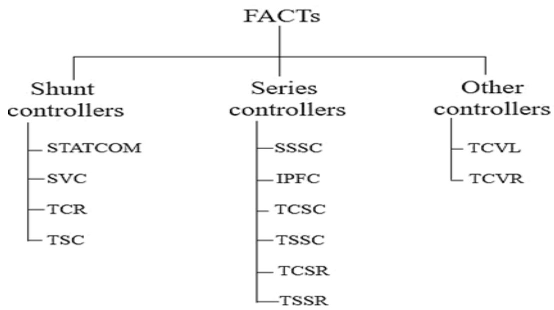

Fig. 1: Classification of FACTs devices

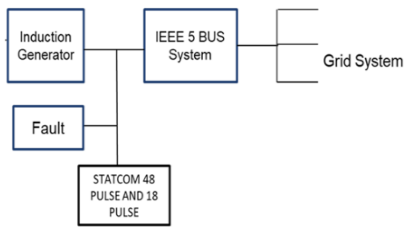

Figure 2 block diagram of proposed work

The main goals of reactive power compensation in power systems are:
i) to improve system stability,
ii) to maintain voltage levels within desired limits, and
iii) to reduce power losses across the network.

By addressing these areas, reactive power compensation significantly enhances transient response and boosts the overall reliability of the grid. To facilitate this, various FACTS devices are employed, with the Static Synchronous Compensator (STATCOM) being a central component.

As a solid-state member of the FACTS family, STATCOM can both absorb and inject reactive power as needed. It delivers real-time reactive power support to help stabilize voltage at the Point of Common Coupling (PCC). Through continuous adjustment of its output, STATCOM keeps system operation within stable bounds. This study presents a STATCOM model that uses a 2-level, 12-pulse Voltage Source Converter (VSC) controlled by a Type-2 control strategy. The Type-2 controller modulates the phase angle of the converter's output voltage in relation to the bus voltage, thereby regulating the STATCOM's reactive current injection. However, under inductive mode operation, using a conventional Proportional-Integral (PI) controller for reactive current feedback can introduce instability into the system. To overcome this issue, the study also examines an enhanced STATCOM design featuring a three-level, 18-pulse VSC in conjunction with a Type-3 controller. This advanced configuration offers higher precision in control and improved system stability across a wide range of operating conditions.

RESULT

Case 1: - 18 pulse

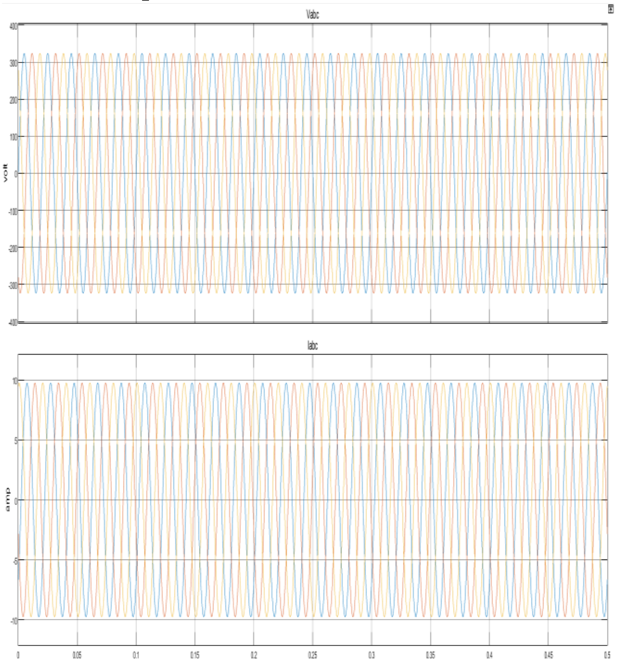

Figure 7:-Grid voltage and current waveform at LG fault condition with STATCOM

Figure 7 shows the waveform of BUS with the LG fault having little sag during the fault time. 3 level provide compensation the voltage magnitude. Fault time is 0.2 to 0.3 sec at that time STATCOM is applied with the breaker act as a switch.

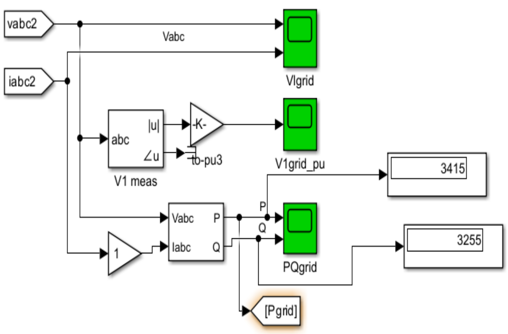

Figure 8 power display of LG FAULT ieee 5 bus condition

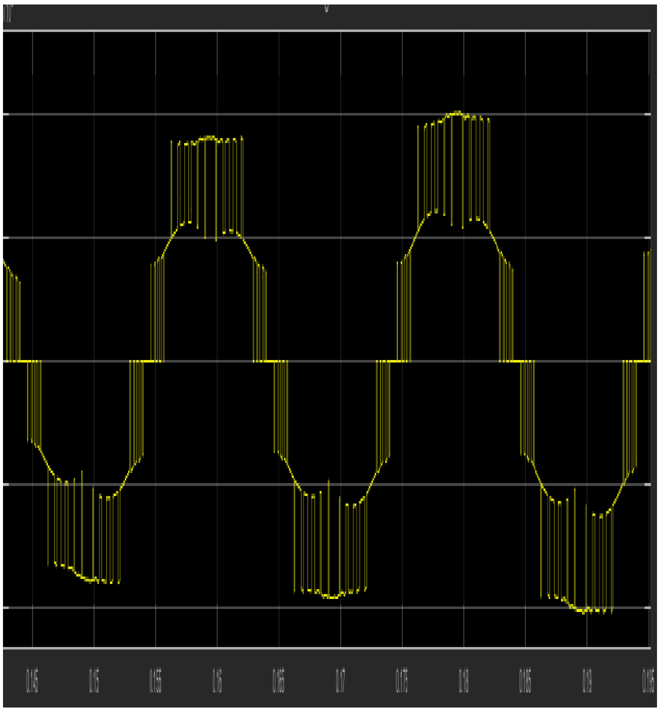

Figure 10 waveform of 18 pulse

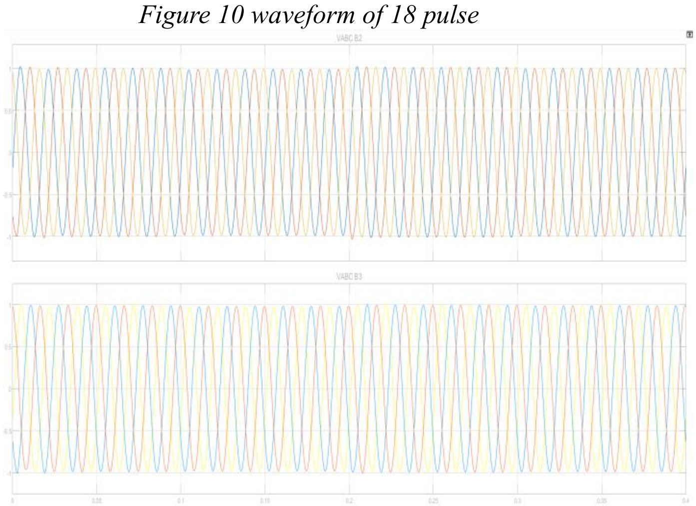

Fig.11 Vabc and Iabc of 2nd bus

Fig.12 48 pulse of statcom i.e. 24 in half cycle

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Figure 10 and figure 12 show the waveform of 18 and 48 pulse, in figure 9 from 0.2 sec to 0.4 sec 11 pulse is get and in figure 10 from 0.165 to 0.175 48 pulse is seen.

CONCLUSION

Parameter	18-Pulse STATCOM	48-Pulse STATCOM
Number of Converters	Typically consists of 3 six-pulse VSCs	Typically consists of 4 twelve-pulse VSCs
Transformer Configuration	Three-phase transformer with phase-shifting	Multi-winding transformer with finer phase-shifting
Harmonic Performance	Higher harmonic content compared to 48-pulse	Lower harmonic distortion, improved waveform quality
THD (Total Harmonic Distortion)	Moderate (~8-10%)	Lower (~3-5%)
Filtering Requirements	Requires larger filters to meet grid standards	Requires smaller filters due to reduced harmonics
Complexity	Less complex in design and control	More complex due to increased number of pulses
Efficiency	Slightly lower due to higher losses	Higher efficiency due to reduced harmonics and losses
Control Performance	Adequate for moderate dynamic compensation	Superior for fast and precise voltage regulation
Cost	Lower due to fewer components	Higher due to complex transformer and control requirements
Application	Suitable for medium voltage applications	Preferred for high-power, high-voltage applications

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