Harmonic Compensation in Statcom based Micro Grid Systems

CHIKKAVARAPU HARI SRINIVAS , KOLLURU NAVEEN CHAND , KAGITHA SAI VENKATESH, BANDARU LEELA ANUSHA and Mr.D.VIJAY ARUN
Department of Electrical and Electronics Engineering , Seshadri Rao Gudlavalleru Engineering College , Gudlavalleru , Krishna district ,
Andhra Pradesh , India – 521356

ABSTRACT

This Project presents an advanced control strategy for Voltage Source Converter (VSC)-based Shunt Active Power Filters (SAPF) to enhance power quality in grid-integrated systems. SAPFs play a crucial role in mitigating power quality issues such as harmonics and unbalanced load conditions. The proposed control scheme ensures robust performance by accurately generating gate signals for the VSC-based active power filter, effectively compensating for harmonics and improving the overall system stability. A detailed performance analysis of the control strategy is conducted through modeling and simulation in MATLAB-Simulink using the Simpower System block set. The simulation results validate the effectiveness of the proposed approach in enhancing power quality in grid-integrated systems.

1.INTRODUCTION

Modern distribution systems face significant power quality challenges due to the increasing use of power electronics-based loads such as electric arc furnaces, uninterruptible power supplies (UPS), computer power supplies, and adjustable speed drives (ASD). These nonlinear loads inject current harmonics into the system, adversely affecting both the performance and lifespan of electrical equipment. To mitigate these harmonics, it is essential to install harmonic filters at the point of common coupling in the proposed test model.

Various technical solutions have been explored to address power quality issues, with shunt-connected active filters proving to be highly effective due to their superior dynamic performance. The efficiency of voltage source converter (VSC)-based shunt active power filters (SAPF) largely depends on the implemented control strategy, which governs the generation of gate signals. While several existing control strategies have demonstrated satisfactory performance under balanced load conditions, their effectiveness diminishes under unbalanced load scenarios. Some recently proposed control approaches have shown promise in overcoming these limitations.

2.Working Principle of STATCOM

A STATCOM operates based on a Voltage Source Converter (VSC) that converts a DC voltage into an AC voltage. By adjusting the magnitude and phase angle of the output AC voltage relative to the system voltage, the STATCOM can either absorb or inject reactive power into the system. When the STATCOM's output voltage magnitude is greater than the system voltage, it supplies reactive power (capacitive mode); when it's less, it absorbs reactive power (inductive mode). This bidirectional reactive power capability enables the STATCOM to maintain voltage stability and compensate for voltage fluctuations in the power system.

ADVANTAGES

Effective Hormonic Reduction
Improved Power Factor

Dynamic Voltage Regulation
Fast Response Time
Increased System Efficiency
Flexibility and Scalability

DISADVANTAGES

Higher Switching Losses
Limited Compensation Range
Susceptible to Grid Disturbance

3.STATCOM Topologies and Control Strategies

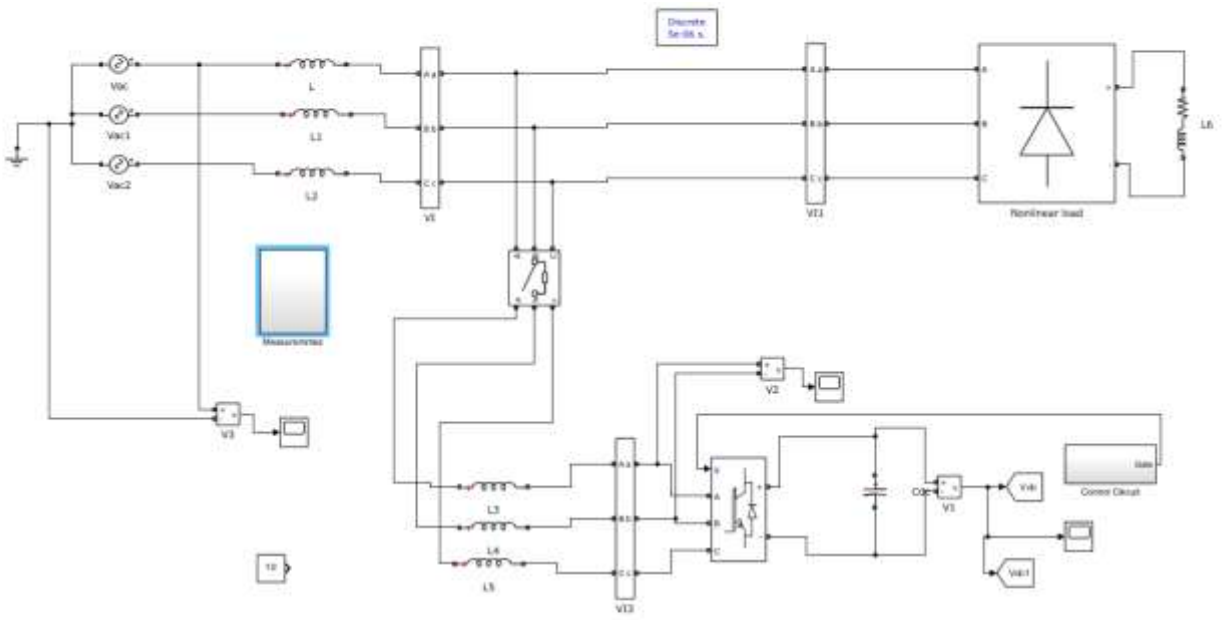
STATCOMs can be configured using various topologies, each with its own advantages and applications.

- **Two-Level Converter:** This basic topology uses a simple on-off switching mechanism to generate a two-level voltage waveform. While straightforward, it produces significant harmonic content, necessitating extensive filtering.
- **Three-Level Converter:** By introducing additional voltage levels, this topology achieves a waveform closer to a sinusoidal shape, thereby reducing harmonic distortion. It offers improved performance over the two-level converter.
- **Modular Multilevel Converter (MMC):** Comprising multiple submodules, each generating small voltage steps, the MMC produces a near-sinusoidal waveform with minimal harmonics. Its modularity enhances scalability and reliability, making it suitable for high-voltage applications

Control Strategies

Control strategy is the heart of active filters. To generate the required compensation current, the control strategies are playing an important role in the designing of shunt AF`s. There are several control strategies like instantaneous reactive power theory (p-q theory),synchronous reference theory (Id-Iq theory) , perfect harmonic cancellation method (PHC) , Unity power factor method (UPF) etc. are there to extract the reference current for SAF`s connected to 3-phase source which supplies to the distorting loads. This paper the mainly demonstrates on the p-q theory and Id-Iq theory.

4.Result Analysis : Simulink Diagram



The Result Analysis section presents the outcomes of the STATCOM-based harmonic compensation system implemented in MATLAB Simulink. The simulation results validate the effectiveness of the proposed model in mitigating harmonics and improving power quality in a Micro Grid environment. Various performance parameters, including total harmonic distortion (THD), voltage stability, reactive power compensation, and system efficiency, are analyzed. The results compare the system's performance with and without STATCOM to highlight its impact. Additionally, different control strategies such as PI, hysteresis, and adaptive controllers are evaluated for their response time and effectiveness. The waveform analysis of voltage and current signals demonstrates the reduction in harmonic distortion. Frequency spectrum analysis is conducted to examine the harmonic content before and after compensation. The improvements in power factor and system voltage regulation are also discussed. Finally, the effectiveness of multi-level STATCOM configurations is compared with conventional approaches to provide a comprehensive performance assessment.

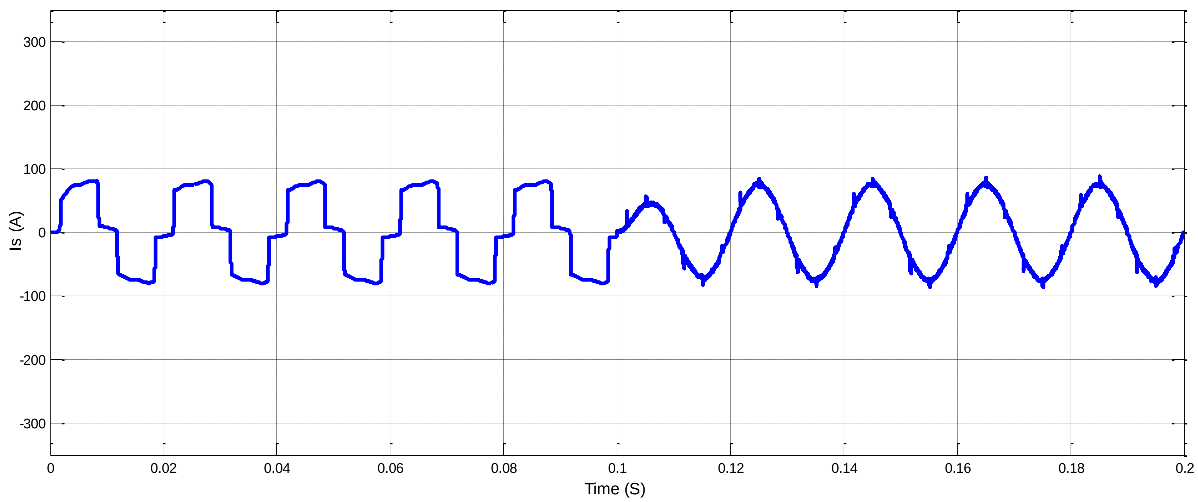


Fig 5.4: Source Current with & without Harmonics in the proposed system.

This waveform represents the source current (isi_sis) over time, highlighting the impact of harmonics before and after the activation of the STATCOM (Static Synchronous Compensator)**.** The behavior of the waveform can be analyzed in two distinct time intervals:

Before 0.1s: STATCOM is OFF

1. **Highly Distorted Current**: The waveform exhibits a **non-sinusoidal shape**, with sharp edges and irregular variations.
2. **Presence of Harmonics**: The current contains multiple harmonic components, as seen from the abrupt changes in amplitude. This distortion is typically caused by **non-linear loads**, such as power electronic devices, rectifiers, or industrial drives.
3. **Poor Power Quality**: The presence of harmonics can lead to issues such as voltage distortion, increased losses, overheating of electrical equipment, and reduced efficiency**.**

After 0.1s: STATCOM is ON

4. **Harmonic Compensation Applied**: Once the **STATCOM is activated**, it starts injecting compensating currents to **neutralize the harmonic content** present in the system.
5. **Smooth Sinusoidal Waveform**: The waveform gradually transitions into a clean sinusoidal shape**,** indicating that the **harmonics have been effectively mitigated**.
6. **Improved Power Quality**: With the harmonics nullified, the system current waveform becomes stable and pure, leading to reduce power losses, enhanced equipment lifespan, and better system performance**.**

Table-I: performance axnalysis of STATCOM

Measuring Factor	Without STATCOM	With STATCOM
% THD in Source Current	29.14%	3.68%
Harmonic component	Not Mitigated	Mitigated

5.Conclusion

In this study, the effectiveness of a **STATCOM-based Micro Grid system** for harmonic mitigation was analyzed. The results demonstrated that before STATCOM operation, the source current was heavily distorted due to the presence of nonlinear loads. However, after STATCOM activation, the harmonic components were effectively nullified, leading to a nearly sinusoidal waveform. This improvement significantly enhances **power quality**, reduces system losses, and ensures stable operation of sensitive electrical loads.

The key findings from the simulation results can be summarized as follows:

- The **load current** remained non-sinusoidal due to the nonlinear nature of power electronic loads.
- The **source current**, which was initially affected by harmonics, showed substantial improvement after STATCOM operation.

- The **STATCOM injected compensating current**, dynamically adjusting to mitigate harmonics effectively.
- The overall **THD (Total Harmonic Distortion) was significantly reduced**, ensuring compliance with IEEE-519 standards for power quality.

The study confirms that **STATCOM is a highly effective solution** for improving power quality in Micro Grids, particularly in scenarios involving nonlinear loads. The results validate the importance of integrating power electronic compensation techniques in modern electrical systems to ensure stable and efficient operation.

6.Future Scope

While this study has successfully demonstrated the impact of STATCOM on harmonic mitigation, there are several areas for further research and development, including:

1. Experimental Validation – The results obtained through MATLAB/Simulink simulations can be verified using hardware implementation with a real-time Micro Grid setup.
2. Optimization of Control Strategies – Advanced control techniques such as Artificial Intelligence (AI) and Machine Learning (ML)-based controllers can be explored to improve STATCOM performance under dynamic conditions.
3. Integration with Renewable Energy Sources – The impact of STATCOM in renewable-based Micro Grids, especially solar and wind energy systems, can be studied for ensuring grid stability.
4. Adaptive Filtering Techniques – The use of adaptive harmonic filtering in conjunction with STATCOM can be investigated to further enhance power quality.
5. Impact of Varying Load Conditions – The performance of STATCOM under various loading conditions, such as sudden load variations and unbalanced loads, can be analyzed for real-time adaptability.
6. Hardware-in-the-Loop (HIL) Simulations – To further validate the findings, a HIL setup can be used to test STATCOM performance in real-world scenarios before deployment.
7. Cost-Benefit Analysis – A study on the economic feasibility of STATCOM deployment in industrial and commercial applications can be performed to evaluate practical implementation.
8. Multi-functional STATCOM Applications – Future work can explore the use of STATCOM not only for harmonic mitigation but also for voltage regulation, reactive power compensation, and fault ride-through capability in smart grids.

By implementing these future enhancements, STATCOM technology can be further improved and optimized for widespread adoption in modern power systems, contributing to efficient, stable, and high-quality power distribution networks**.**

7.References

[1] Sharad w. mohod, and mohan v. aware "A statcom control scheme for grid connected wind energy system for power quality improvement ."IEEE systems journal, vol. 4, no. 3, SEPTEMBER 2010.

[2]. Bhim Singh, Sabha Raj Arya* "Design and control of a DSTATCOM for power quality improvement using cross correlation function approach" International Journal of Engineering, Science and Technology Vol. 4, No. 1, 2012, pp. 74-86 .

[3]. Lakshman Naik Popavath, K. Palanisamy and D.P. Kothari "Research and Topology of Shunt Active Filters for Quality of Power" Information Systems Design and Intelligent Applications, Advances in Intelligent Systems and Computing 433, Springer India 2016.

[4]. Munoz Antonio Moreno. Power Quality: Mitigation Technologies in a Distributed Environment, Springer-Verlag, London, 2007.

[5]. Lakshman.Naik and K.Palanisamy, "A Dual Operation of PV-Statcom as Active Power Filter and Active Power Injector in Grid Tie Wind-PV System "INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH Vol.5, No.4, 2015.

[6] .Fuchs Ewald F. and Mausoum Mohammad A. S.,. Power Quality in Power Systems and Electrical Machines, Elsevier Academic Press, London. 2008

[7]. Bhim Singh, S. S. Murthy, and Sushma Gupta,Analysis and Design of STATCOM-Based Voltage Regulator for Self-Excited Induction Generators IEEE transactions on energy conversion, vol. 19, no. 4, december 2004.

[8]. Harbin, China.Guizhen Tian, Shengtie Wang, Guangchen Liu Design and Realization of STATCOM for Power Quality Improvement of Wind Turbine with Squirrelcage Induction Generator , 2012 IEEE 7th International Power Electronics and Motion Control Conference - ECCE Asia June 2-5, 2012,

[9]. N M. I. Milands, E. R. Cadavai, and F. B. Gonzalez, "Comparison of control strategies forshunt active powerfilters In three phase four wiresystem,"IEEETrans.PowerElectron.,vol.22,no.1,pp.236,J an. 2007.