Improved Control Method for Hybrid Reactive Power Compensation System Based on FC and STATCOM

Md.Qutubuddin, *Associate Professor EEE, TKR College of Engineering and Technology (Autonomous), India.*
Ch. Shiva Sagar, *UG student, EEE, TKR College of Engineering and Technology (Autonomous), India.*
J. Nikhil, *UG student, EEE, TKR College of Engineering and Technology (Autonomous), India.*
B. Raju, *UG student, EEE, TKR College of Engineering and Technology (Autonomous), India.*
E. Aravind, *UG student, EEE, TKR College of Engineering and Technology (Autonomous), India.*

Abstract— Modern electrical power systems are getting increasing enormously, which poses a difficult challenge to the stability of the power system. This complexity is affecting the increased line loss and reduced power supply quality caused by insufficient capacitive reactive power. To reduce the capacitive voltage and current stress and improve the cost performance of the device, "AN IMPROVED HYBRID REACTIVE POWER COMPENSATION SYSTEM BASED ON FIXED CAPACITOR (FC) AND A STATIC SYNCHRONOUS COMPENSATOR (STATCOM)" can be incorporated. In this study the topological structure and operating principle of the different reactive power compensation techniques are introduced. Furthermore, the key parameters of the power system network will be designed and the combined control strategy of the FC and STATCOM is studied. The correctness and effectiveness of the proposed topology structure and control methods are verified by simulation.

Keywords—DSTATCOM, power quality, total harmonic distortion, fuzzy logic controller.

1. INTRODUCTION

In modern electrical power systems, maintaining high-quality power is crucial for the reliable and efficient operation of equipment and devices. However, power quality issues such as voltage fluctuations, harmonics, and interruptions continue to pose significant challenges.

The integration of renewable energy sources, such as wind and solar, alongside the increasing complexity of grid infrastructure, has introduced new challenges to the efficient operation of power networks [1]. Addressing these challenges requires innovative solutions that can enhance voltage stability, mitigate grid disturbances, and ensure optimal power flow management. Among all of the technologies available for achieving these goals, the Static Synchronous Compensator (STATCOM) stands out as a versatile and effective solution. The STATCOM, a member of the Flexible AC Transmission Systems (FACTS) family, has gained significant attention from researchers, engineers, and industry practitioners due to its ability to provide rapid and precise reactive power compensation [2,3].

Unlike other traditional devices such as capacitor banks and static VAR compensators (SVCs), which offer fixed or stepwise reactive power support, STATCOMs provide dynamic voltage support and are capable of continuously regulating grid voltage in response to varying load conditions and disturbances. This dynamic capability makes STATCOMs well-suited for modern power systems characterized by fluctuating demand and intermittent renewable generation [4]. The primary objective of this thesis is to investigate the application, control strategies, and performance evaluation of STATCOMs in modern power systems. By leveraging advanced control algorithms, simulation techniques, and real-world case studies.

At present, reactive power compensation technology, as one of the important applications of power electronics technology, has an important role in power system operation. Therefore, it has been widely studied, and various types of reactive power compensation device have been proposed. Among them, a shunt capacitor is an example of early reactive power compensation technology. It has a simple structure and can improve the voltage quality and reduce the power loss. A thyristor switched capacitor (TSC) can effectively reduce the impulse current when the capacitor bank is mechanically switched. However, the mentioned compensation technologies can only achieve graded compensation but cannot continuously adjust the reactive power, and, generally, overcompensation or under compensation occurs. To compensate for that the inability of the shunt capacitor and TSC to achieve continuous compensation, a thyristor-controlled reactor (TCR) and a fixed capacitor (FC) or a TSC and a TCR can be used together. In such a combination, a TCR controls the current flowing through the reactor to provide reactive power continuously by adjusting the trigger angle of a thyristor. However, the adjusting TCR generates harmonics, and the compensation range of the two devices is limited [10-11]. With the development of power electronics technology, a static synchronous compensator (STATCOM) has been proposed. The STATCOM represents an advanced and continuously adjustable static reactive power compensation device. However, the STATCOM has certain disadvantages, such as high DC-link voltage, large capacitance, and high cost. Therefore, how to achieve continuous but economical compensation for high-capacity reactive power has become a leading research topic in the field of electrical engineering.

A Fuzzy Logic control theory-based control algorithm for D-STATCOM with Mamdani type fuzzy logic controller is employed for this work. This paper presents the implementation of Fuzzy controlled D-STATCOM distribution system. The proposed D-STATCOM's performance under nonlinear load situations is evaluated using harmonic mitigation and DC link voltage controls. For increasing power quality and dynamic performance of a distribution power system, a comparison study is also conducted between the performance of PI controller and the fuzzy logic controller-based D-STATCOM.

2. STRUCTURE OF THE SYSTEM

To mitigate the power quality issues caused by the nonlinear load a Voltage source Inverter based DSTAT-COM through a coupling transformer is connected in shunt at the source side as shown in figure 1.

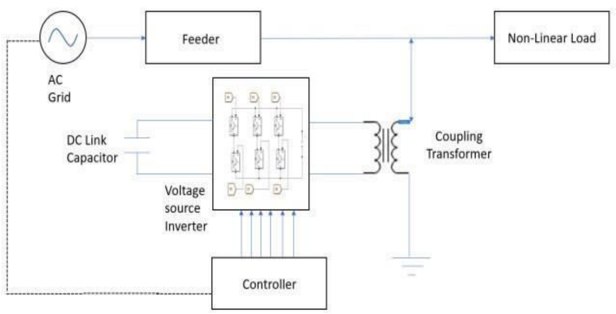


Fig1.Structure of the system

In classical control systems, linear PI controllers are well-established and frequently used as a standard by which to compare other controller types. Strongly nonlinear systems are typically not a good fit for this controller because it is linear. In certain situations, fuzzy logic controllers, or FLCs, are an alternative to classical PI controllers. Because FLC does not require a mathematical model of the controlled system, it has been widely used in systems with complicated structures. A schematic illustration of FLC is shown in Figure-16. FLC is divided into five primary components. These are fuzzification, knowledge base, rule base, inference and defuzzification.

3. DESIGN AND PROPOSED ALGORITHM

A. *Selection of DC bus voltage (V_{DC})*

The DC bus voltage is calculated as

$$V_{DC} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}V_m} \qquad (1)$$

where, V_m is the modulation index and V_{LL} is the AC line output voltage

B. *Selection of DC bus capacitor (C_{DC})*

The value of the energy storing capacitor is calculated by using the equation:

$$C_{DC} = 2\left[\frac{3K_1 \mathrm{VaIt}}{V_{DC}^2 - V_{DC1}^2}\right] \qquad (2)$$

Where, V_DC is the nominal DC voltage, V_DC1 is the minimum voltage level of DC bus, a is overloading factor, V is the phase voltage, I is the phase current and t is time taken by the DC voltage to recover.

L_f is the interfacing inductor which acts as coupling transformer and provides the connection between distribution line and voltage source inverter.

C. *Control Algorithm*

The SRF-based control method is shown in Figure 2. The control algorithm is used to extract the basic reference control signals during balanced nonlinear load circumstances in order to switch VSI-based D-STATCOM for harmonic and reactive power rectification. In a three-phase system, the nonlinear load currents are made up of active, reactive, and harmonic currents. As feedback signals, the D-STATCOM's load currents (i_{La}, i_{Lb}, i_{Lc}), PCC voltages (v_{sa},v_{sb},v_{sc}), and DC bus voltage (V_{DC}) are monitored. Equation (3) is used Park's transformation is used to transform the load currents in the three phases into the dq0 frame.

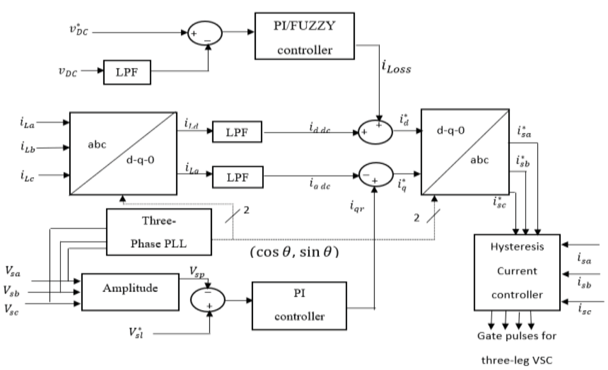


Fig 2. Block diagram of dq based control algorithm

The signals are time-locked to the PCC voltages using a three-phase phase locked loop (PLL). The DC components of i_Ld and i_Lq are then separated from these d-q current components using an LPF. The fundamental and harmonic components of the d-axis and q-axis currents are as follows:

$$i_{Ld} = i_{d\,dc} + i_{d\,ac}$$
$$i_{Lq} = i_{q\,dc} + i_{q\,ac} \qquad 3(a).3(b)$$

Loss component is obtained as

$$i_{Loss}(n) = i_{Loss}(n-1) + K_{pd}\{v_{de}(n)\ v_{de}(n-1)\} + K_{id}v_{de}(n) \qquad (4)$$

Therefore, the reference value of direct-axis supply current is:

$$i_d^* = i_{dDC} + i_{Loss} \quad (5)$$

Harmonics and power factor are compensated using the direct axis reference current component (i_d*) Similar to how direct current axis components are added to the average reactive reference current of the q-axis in the d-q frame, the source must provide the reactive current (i_{qr}) in order to regulate the voltage at the PCC. The following equation provides the reference quadrature-axis supply current.

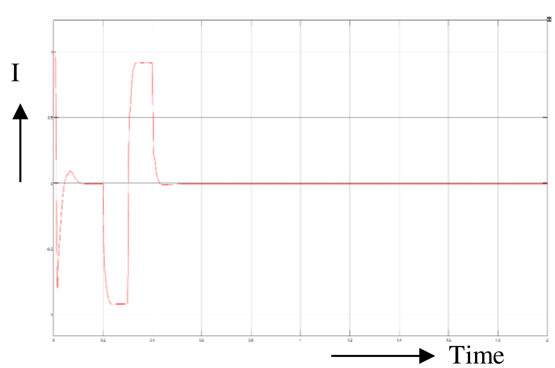
$$i_q^* = i_{qr} - i_{qDC} \quad (6)$$

The PCC voltage's amplitude is indicated here as

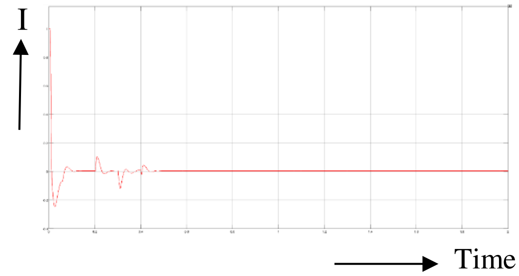
$$V_s = \sqrt{\frac{2}{3}\left(v_{sa}^2 + v_{sa}^2 + v_{sc}^2\right)} \quad (7)$$

4. SIMULATION RESULTS

To verify the proposed control algorithm in order to regulate the reactive power and improve the power quality a system is simulated using MATLAB Simulink. The three-phase power supplies the nonlinear load which is connected through feeder. Due to the presence of non-linear loads, it was observed that there are power quality issues and distortion takes place in voltage and current waveforms. The distortion which is observed in voltage and current waveforms without any compensator is as shown below. Total harmonic distortion (THD) is the measurement of harmonic distortion present in a signal which gives the ratio of the sum of powers of all harmonic components to the power of the fundamental frequency.



(a) Current output waveforms in AC voltage regulator using PI controller



(b) Current output waveforms in DC voltage regulator using PI controller

Fig 3. Current output waveforms using PI controller

SRF theory-based control algorithm is developed and simulated using a discrete proportional plus integral (PI) controller to check the performance of the system. The designed D-STATCOM is connected in shunt at the source side and is shown in the overall simulation model in figure 4. The parameters as calculated in the design and control algorithm section and is used in this work has been shown in table 1.

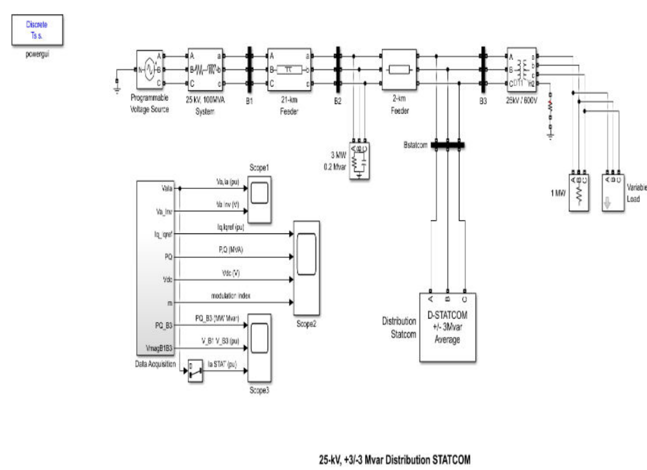


Fig 4. Overall Simulink model

PI controller helps to adjust discrepancies between the required setpoint and the actual value based on some form of feedback. V_{dc} and V_{dc}* are transmitted and errors are adjusted while using the PI controller. The power quality is improved, and distortion is reduced with the D-STATCOM connected.

The distortion reduces drastically, and it was observed that THD of voltage and the current is within permissible limit, however, the THD of voltage is still in the higher side and requires further compensation.

To overcome this problem a D-STATCOM is designed using fuzzy logic controller.

Parameters	Value
Phase to Phase Voltage	600 V
Frequency	50 Hz
DC Link capacitor value	1000 mF
Feeder Resistance	0.1153 R/km
Feeder Inductance	1.048 mH/km

Table-1. System Parameters

A. Fuzzy Logic Controller

In fuzzification part, crisp values of input are converted into fuzzy values, so that thesevalues compatible with the fuzzy set representation in the rule base. The choice of fuzzification strategy is dependent on the interference engine. The knowledge base consists of a database of the plant. It provides all the necessary definitions for the fuzzification process. Rule base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristic as a set of IF-THEN rules. The rules are basedon the fuzzy inference concept and the precedes and consequents are associated with linguistic variables. Inference called fuzzy model applies fuzzy reason to rule base to obtain a proper output. Mamdani and Takagi-Sugeno fuzzy systems are the most commonly used fuzzy inference mechanism. Mamdani is more suitable the systems with slow-changing dynamic and Takagi-Sugeno for systems with fast-changing dynamic. Results obtained from fuzzy process are converted into crisp values by using the any defuzzification method like maxima methods and center of area.

V / Δ V	N	Z	P
N	Z	N	P
Z	N	Z	P
P	N	P	Z

Table-2. Rule base for Fuzzy controller

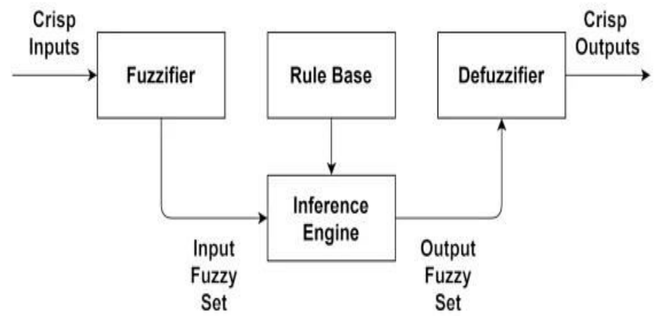
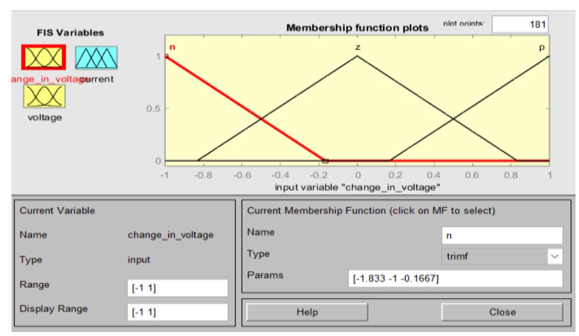
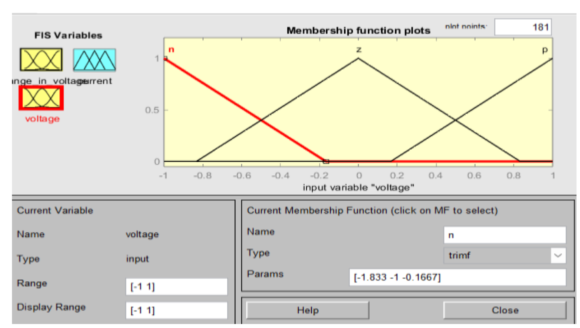


Fig 5. Schematic representation of FLC

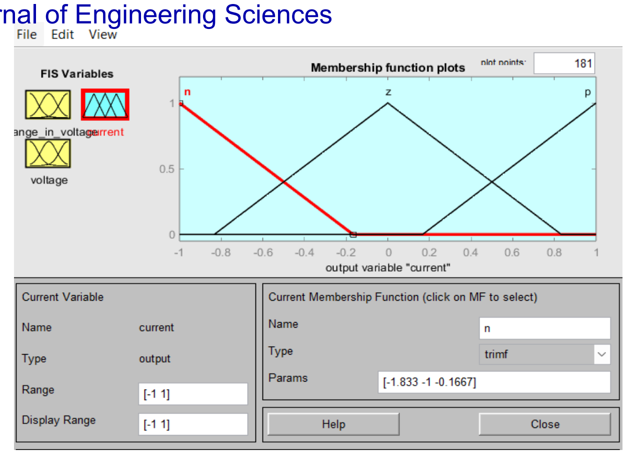
In this study, triangular membership functions are preferred for input variables and output variable as shown Figure-6. Rule base for Fuzzy-PI controller composes of 9 rules and are given in Table 1.



(a)



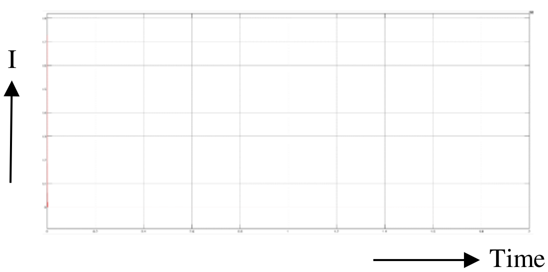
(b)



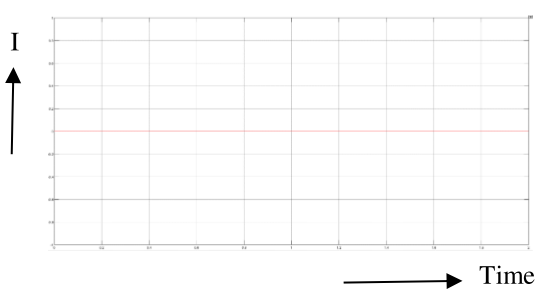
(c)

Figure-6. Triangular membership functions, **(a), (b)** for input variables, (**c**) for output variable

The proposed fuzzy logic control algorithm is implemented in the D-STATCOM and is connected in shunt. The power quality is observed to be improved, and distortion is reduced with the D-STATCOM connected. Output waveforms in AC and DC voltage regulators using Fuzzy logic controller are shown in Figure-7.



(a) Current output waveforms in AC voltage regulator using FL controller



(b) Current output waveforms in DC voltage regulator using FL controller

Figure-7. Current output waveforms using FL controller

After the connection of fuzzy logic controlled DSTATCOM to the system, the THD values decrease as the D-STATCOM provides an effective solution for reactive power compensation.

5. CONCLUSION

This thesis examines the design and implementation of a fuzzy logic control-based D-STATCOM (Distribution Static Synchronous Compensator). Fuzzy logic control has been shown in studies to improve D-STATCOM's performance in reducing power quality problems such voltage swings, harmonics, and reactive power imbalance in distribution networks.

The fuzzy logic control technique has demonstrated promising results in enabling robust and adaptive control of the D-STATCOM under varied operating circumstances and disturbances through thorough simulations and perhaps experimental validations. To ensure optimal compensation performance, the D-STATCOM's voltage-source inverter switching is efficiently managed by the control technique.

REFERENCES

[1] Juan Shi, Amin Noshadi, Akhtar Kalam and Peng Shi, "Fuzzy logic control of DSTATCOM for improving power quality and dynamic performance" 2015 IEEE

[2] Duy-Hung Dam, Hong-Hee Lee and Heung-Geun Kim, "Effective output voltage quality control under non-linear loads in islanded microgrid" IEEE 2nd Inter-national Future Energy Electronics Conference (IFEEC), Taiwan, 2015.

[3] Khushbu Chaturvedi, Garima Goswami, Pankaj Kr. Gowasmi," A Review on power quality control for nonlinear loads" International Journal of innovative research and growth (IJIRG), July-2018.

[4] Tanam Karthik, Mummadi Prathyusha, R Thiruma-laivasan, "Power quality improvement using DSTAT-COM", 2019 Innovations in Power and Advanced Computing Technologies (i-PACT).

[5] S.M. Kalidasan, S. Selvakumaran, "Power Quality Improvement in Transmission Systems Using Facts Devices", 2016 Online International Conference on Green Engineering and Technologies (IC-GET).

[6] D. Prasad, T. S. Kumar, B.V. Prasanth, and K.S.G. Sankar, Fuzzy Logic Control of DSTATCOM for Power Quality Improvement, Int. Journal of Engi-neering Research and Applications, ISSN: 2248-9622, vol. 3, no. 6, pp.398-403, 2013.

[7] S.R Reddy, P.V Prasad, G.N Srinivas "Design of PI and fuzzy logic control for distribution static compensator" International Journal of Power Electronics and Drive system (IJPEDS), Jan 23rd 2018.

[8] Sinha, R., Vidya, H.A. (2022). Power Quality Improvement of Railway Traction System Using D-STATCOM. In: Khosla, A., Aggarwal, M. (eds) Smart Structures in Energy Infrastructure. Studies in Infrastructure and Control. Springer, Singapore. https://doi.org/10.1007/978-981-16-4744-4_6.

[9] G. Gangil, S.K. Goyal, A. Soni and M. Srivastava, "Power quality improvement using DSTATCOM in distribution network"2021 International Conference on con-trol, Automation, power and signal processing (CAPS), Jabalpur, India.

[10] J. Shi, A. Noshadi, A. Kalam, and P. Shi, Genetic Algorithm Optimized Fuzzy-PID Control of DSTATCOM for Improving Power Quality, IEEE Proceedings of Australasian Universities Power Engineering Confer-ence, pp. 1-7, 2014.

[11] Mikkili Suresh, Panda AK. Real-time implementation of PI and fuzzy logic controllers-based Shunt active filter control strategies for power quality improvement. Int J Electr Power Energy Syst 2012; 43(1):1114–26.