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Fuzzy Logic Controller-Based STATCOM for Reactive Power Compensation in a Grid-Connected Wind Power Plant

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ABSTRACT

Wind energy is one of the most prevalent renewable sources nowadays, which has been projected to play an immense role in realizing the clean energy transition. This paper dives into one of the critical challenges in the grid integration of wind power plants, which is reactive power compensation. The static synchronous compensator (STATCOM) is commonly used to inject/absorb reactive power in wind power plants where the device is controlled with the traditional proportional-integral (PI) controller. This article investigates the effectiveness of the fuzzy logic controller (FLC) in managing the STATCOM to compensate and regulate the reactive power in a 9 MW grid-connected wind power plant. Due to its faster and malleable response, the FLC allows for greater flexibility in controlling the STATCOM. According to the findings, the voltage profile at the point of common coupling (PCC) is improved considerably in the case of the FLC compared to the PI controller, demonstrating the efficacy of the employed strategy. MATLAB-Simulink has been used to model and analyze the proposed system. We achieved a 6 percent improvement in voltage regulation when FLC was utilized instead of PI controllers.

Keywords: Fuzzy logic controller; Sustainability; Energy transition; Renewable energy; Voltage regulation; Reactive power compensation.

1. Introduction

Due to concerns such as global warming, the growth of energy demand, the depleting nature of fossil fuels, energy security, and the cost-effectiveness of renewable energy resources (RERs), the generation of electrical power from RERs, especially wind and solar energy, has gained tremendous momentum globally. With benefits, integrating the RERs into the electricity grid leads to various challenges, e.g., system vulnerability due to the intermittent nature of the RERs, system instability because of their malfunctioning operation due to voltage sags/swells at their terminals, and many others. Such challenges may impact the machinery being supplied and lead to a loss of coordination and selectivity of the protection devices in the protection system [1], which may ultimately result in a severe operational problem faced by the grid operators. When RERs are integrated into the grid, the protection devices frequently experience sensitivity loss, making the power system less effective at handling faults [2]. All these drawbacks make it difficult for wind and solar energy systems to be viable long-term options as energy sources without getting too expensive or too nuanced to implement [3]. However, instability due to tripping of the RERs system because of their terminal voltage sags/swells may be prevented by controlling their terminal voltages externally through reactive power compensation.

Depending on the configuration, a wind turbine may use different generators like a squirrel cage induction generator (SCIG) and a doubly-fed induction generator (DFIG). Reactive power control is significantly challenging for wind farms driven by the DFIG. One issue with such wind farms is the DFIG's constant use of reactive power, which can be detrimental to the operation of the power system. With large turbines and a poor distribution system, wind farms may experience voltage sag at the point of common coupling (PCC) due to high starting currents of large loads, distribution network faults, or insufficient voltage regulation equipment [4]. Voltage must be quickly restored to prevent disruptions and equipment damage and maintain stable operation of connected loads. This can lead to voltage and rotor angle instability due to a slow recovery of the PCC voltage, as the DFIG will use reactive power during the voltage restoration process. If the voltage does not recover quickly enough, the DFIG will continue to run faster and use more reactive power, potentially resulting in voltage and rotor angle instability [5]. Wind power plants can also experience voltage sag or swell at the terminal [6], because of factors like reduction/increase in wind speed, disturbances, dynamic wind conditions, and grid integration issues. This requires the injection or absorption of reactive power depending on whether the voltage is sagging or swelling. Voltages increase when reactive power is injected into the system and decrease when reactive power is absorbed. To prevent these types of fluctuations, a shunt capacitor bank is often connected to the PCC of the wind power plant to compensate for the reactive power consumption by the DFIG. A dynamic reactive power adjustment can also reduce the reactive power interchange between the wind farms and the distribution network [7].

A static synchronous compensator (STATCOM) (also known as a static synchronous condenser) is a device used to meet the reactive power requirement in AC electrical transmission networks [8-9]. It is based on a voltage source converter (VSC) and can supply or drain reactive power to or from a network of outlets or deliver active power if connected to an active power source. It is a member of the flexible AC transmission system (FACTS) family of devices and is self-excited and modular [9]. The main components of a STATCOM are a coupling reactor, a capacitor, and a pulse-width-modulation (PWM) converter. At the fundamental frequency of the system, a STATCOM produces a balanced set of three-phase sinusoidal voltages with quickly adjustable amplitude and phase angle. There are different controller topologies for the STATCOM, including but not limited to proportional-integral (PI) control and fuzzy logic control (FLC) [11]. A PI control is often utilized to achieve automatic voltage regulation [11]. The authors in [12] have described that when there are changes in the system operating condition, a PI controller can be used with a STATCOM to achieve the required and acceptable responses in voltage regulation in the power system. However, a PI controller is often insufficient to handle non-linear loads and may suffer from parameter variations, overshoot, and steady-state error [13]. The steady-error problem with stationary frame-based PI controllers can be superseded by the synchronous frame-based PI controller which possesses high-gain characteristics, and this can improve steady-state error. However, the synchronous reference frame-based PI controller is more complex and faces noise problems while obtaining the reference signal which may cause extra errors. In addition, this controller faces difficulties during unbalanced conditions due to disturbances in the power system.

Recently, fuzzy logic controllers [14], artificial neural networks (ANN) [17], and model predictive controllers [19] have been proposed to control STATCOM instead of a PI controller. In [13], a fuzzy logic-based controller for a STATCOM equipped with a battery energy storage system has been designed. The authors in [14] have successfully presented a superior response of a fuzzy logic-based AC voltage controller connected to a current limiter in an IEEE 9-bus system. In [15], the performance of a STATCOM with a decoupled adaptive fuzzy logic control (AFLC) approach and a linear PI-feedforward control strategy has been compared. In [16], it has been suggested to add a fuzzy logic supervisor to the DC link PI controller used in the distribution STATCOM (DSTATCOM). During the transient phase, the supervisor modifies the PI controller's gain in a way that enhances the performance of the controller, which in turn improves the performance of the DSTATCOM. In [17], the authors have presented a self-tuning PI controller. The efficiency of the controller in preserving the system stability when voltage fluctuation occurs was demonstrated through simulation. The authors in [18] have developed a prototype back propagation ANN-based system for the reactive power and voltage control mode of the STATCOM to train and test an Indian Extra High Voltage (EHV) power system. In [19], a unique fixed switching frequency model-based predictive control technique has been proposed and applied to a three-phase cascaded H-bridge multilevel STATCOM to improve the performance of a traditional model predictive controller. The authors in [20] have described a new technique for improving the performance of a grid-tied multilevel inverter that uses a predictive current regulation and a finite control set model (FCS-MPCC). None of these works mentioned above specifically perform controller comparison in a Grid-Integrated Wind Power Plant with STATCOM.

Considering the mentioned notes, this paper proposes a fuzzy logic controller for STATCOM to control the reactive power at the PCC of a 9 MW grid-connected wind power plant. To show the improvement of efficiency in response, the performance of the STATCOM with the FLC-based controller has been compared with that of the PI-based one. The comparative analysis demonstrates that STATCOM with the FLC provides better reactive power support at the PCC of the DFIG-based wind power plant than that of the PI controller.

The paper has been organized as follows. Section II describes the problem statement; Section III shows the analysis of the controllers for STATCOM; Section IV describes the system configuration; Section V analyzes the results obtained from the simulation; Section VI concludes; and Section VII discusses possible future works.

2. Problem Statement

According to the grid codes stipulated by the Australian Energy Market Operator (AEMO) [22, 23], the RERs should remain connected during a short period of voltage sag.

The conditions specified by the grid codes are the time functions of the PCC voltage i.e., $V(t)$, and this can be lower due to voltage sag during a fault, which has to be endured by the RERs. According to the grid codes, RERs must remain connected during this time.

In the German grid code, two borderlines for $V(t)$, as shown in Fig. 1, have been specified. If the magnitude of $V(t)$ at the PCC after the fault occurrence at t_f (fault initiation time) is above borderline1 (zone A in Fig. 1), the RERs might not be disconnected from the grid. However, after $t = 700$ ms, the $V(t)$ should be increased with a gradient of at least 25% per second to maintain the lower limit of the voltage profile at the PCC. On the other hand, borderline 2 indicates that if the magnitude of $V(t)$ at PCC falls to zero for the $t_f \leq t < 0.15$ seconds, the RERs should not be disconnected from the grid. However, after $t = 150$ ms, the $V(t)$ should be increased with a gradient of at least 66.67% per second to maintain the lower limit of the voltage profile at the PCC.

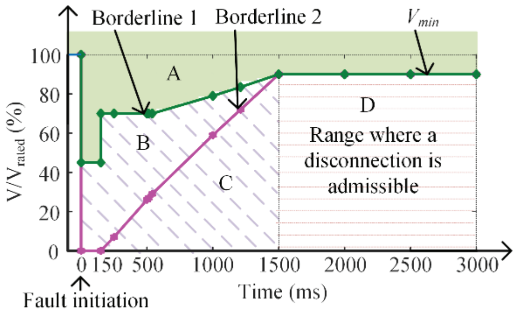

Fig. 1. Voltage ride-through requirement from German grid code 2007.

If the magnitude of $V(t)$ is in Zone B, the RERs should be able to ride through the fault with the low voltage under the conditions which are: (1) the RERs should feed in the short circuit current; (2) the borderline 2 can be adjusted; and (3) the RER can be disconnected for a short duration of time (up to 2 s). In zone C, the RER can be disconnected for a short time by ensuring a negotiable resynchronization time. In zone D, the RER should not remain connected to the grid.

Although the profile of $V(t)$ is a common feature of many grid codes, its application to different types of faults is not consistent. For example, the profile of $V(t)$ applies to any type of fault, such as the symmetrical and asymmetrical faults, for the grid codes of Alberta, Denmark, ENTSO-E, Ireland, and the UK [22, 23]. On the other hand, in Spanish grid code, the RERs will have to withstand for $t = 500$ ms for $V(t) = 20\%$ caused by an asymmetrical fault, and for $V(t) = 60\%$ caused by a double line to ground faults [22, 23].

In some grid codes, up to ±10% voltage changes are allowed. When the grid voltages exceed that limit, the voltage support strategies are activated. A strategy to support the grid voltages during fault is that the RERs should supply a reactive current at a ratio of at least 2% of the injected reactive current percentage to the voltage sag percentage, as per (1) within 20 ms.

$$\eta = \frac{\Delta I_Q / I_{Q-rated}}{\Delta V_t / V_{t-rated}} \geq 2 \tag{1}$$

where $V_{t-rated}$ is the rated terminal voltage of the RER, $I_{Q-rated}$ is the rated injected current by the RER. If $V_{t-prefault}$ and $I_{Q-prefault}$ are the voltage and current before fault, respectively, then $\Delta V_t = V_t - V_{t-prefault}$, and $\Delta I_Q = I_Q - I_{Q-prefault}$. Here, η is the reactive current droop that may vary in the range of 2 ~10%. However, during an emergency condition, if required, the RER must be capable of injecting 100% reactive current.

The allowable dead-band range is $0.9V_{t-rated} \leq V_t \leq 1.1V_{t-rated}$ for the reliable operation of the grid. For symmetrical faults, the RER should inject reactive current according to the droop η to protect the grid from instability. However, in case of asymmetrical faults, the controller of the RER should inject reactive current so that the voltages at the unfaulty phases remain within $1.1V_{t-rated}$.

Grid codes usually allow for the reduction of active power injected by RERs during grid faults. In line with UK and Irish grid codes, active power injection should be proportional to the PCC voltage retained during faults, with a swift restoration of 90% of active power within 1 second of PCC voltage recovery. The German grid code specifies that, if RERs are not disconnected (zone A), active power must be restored at a rate of 20% of rated capacity per second after fault clearance. In the case of temporary disconnection (zones B and C), the restoration rate should be 10% of the rated capacity per second after reconnection.

The above evidence demonstrates the need for a reactive power supply by STATCOM in the event of a voltage sag or swell to ensure the stable operation of the grid and RER.

3. Controllers for STATCOM

This section describes the controllers used for STATCOM, especially PI and FLC types, the flowchart of the fuzzy logic controller, fuzzy membership functions, and the fuzzy inference system.

A. PI-Controller

Due to simplicity and ease of implementation, a closed-loop PI-controller has been extensively used in power electronic converters (PECs) and industrial applications [24-25]. A simple PI-controller is shown in Fig. 2(a). In its operation, a PI-controller uses a reference frame which can be either a stationary reference frame or a synchronous reference frame. Both of the reference frames necessitate a lot of signal processing which increases complexity in its implementation. In addition, due to limited gain, the stationary frame-based PI controller cannot nullify the steady-state errors [26, 27]. To improve the performance of the PI-controller, a feedforward PI controller as shown in Fig. 2(b) has been proposed in the literature [28 - 31]. However, the performance of these controllers deteriorates due to harmonics in measured voltages hence it may cause instability due to disturbances in the power system.

One possible solution here is a fuzzy logic controller with the PEC which can improve the steady-state error as with the PI-controller.

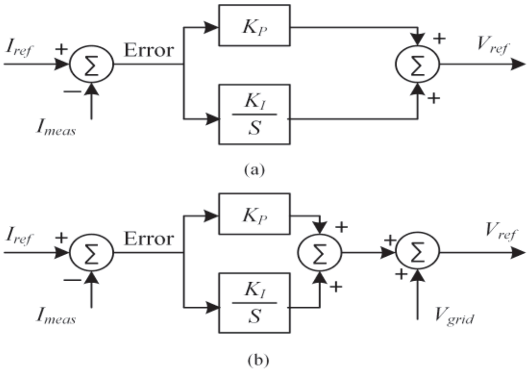

Fig. 2. (a) simple PI-controller and (b) feedforward PI-controller.

B. Fuzzy Logic Controller

In this paper, a fuzzy logic controller (FLC) has been used to model the operation of PECs. An FLC uses linguistic variables and fuzzy sets, where all the necessary variables are defined using membership functions. Modeling of the controller for the PECs using FLC has been presented in the following subsections.

C. FLC Flowchart

Fig. 3 shows the flowchart steps for designing controllers for a PEC. In designing the controller, the inputs, outputs, and state variables of the PEC controller need to be identified. The information of each variable can be divided into several fuzzy subsets which are defined by linguistic variables. Then each fuzzy subset is represented by a membership function. When the membership functions are available, a fuzzy rule base is formulated using the input-output relationship. If it is necessary to normalize the input-output variables, an appropriate scaling factor can be used to normalize the variables between [0, 1]. All these steps mentioned above are done under fuzzification as shown in Fig. 3. After fuzzification, the outputs of the controller are identified using fuzzy inference systems which are de-fuzzified to obtain the output signal as shown in Fig. 3. Each step in the flowchart has been described in the following subsections to develop the fuzzy logic controller for the PECs.

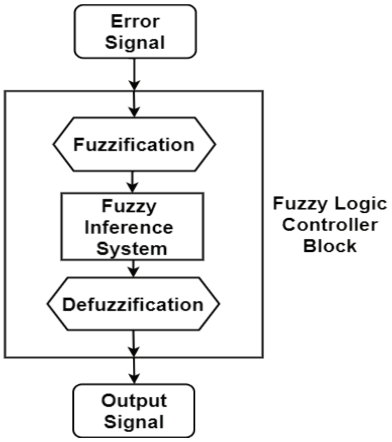

Fig. 3. FLC flowchart.

D. Fuzzy Membership Functions and Ranges

Fuzzy membership functions used by the regulators in the controller have been discussed in this subsection. These functions are defined from the ideal input and output functions of the controller. There are three regulators in the controller part of the PECs: AC voltage regulator, DC voltage regulator, and current regulator. To develop the fuzzy logic controller all the inputs and outputs of these regulators should be identified, and their corresponding membership functions should be developed. The membership functions have been defined linguistically as NL; Negative Low, NS; Negative Small, ZR; Zero, PS; Positive Small and PL; Positive Large. The input and output ranges are mentioned in the following sub-section.

I) Membership Functions of AC Voltage Regulator: The input variables to the AC voltage regulator are reference (V_{ac_ref}) and measured ($V_{ac\_measured}$) voltages whereas the output variable from the regulator is the reference reactive current component (I_{q_ref}) for this controller designed for the STATCOM. These input-output variables of the AC voltage regulator have been defined as the membership functions for the fuzzy logic controller. According to these values, the relation between inputs and outputs is defined and the stability of the system is maintained. As stated above, the linguistic definition of the membership functions represents the nature of the inputs and the outputs. The input and output ranges selected for these membership functions for the fuzzy logic controller have been presented in Table 1.

Table 1: AC Voltage Regulator Membership Functions

Function Name	Input Range	Output range
NL	-0.1032 to 1	-1 to 1
NS	-0.1032 to .04	-1 to -0.1
ZR	1 to -61	-0.1 to -0.7
PS	9 to 86	-0.7 to 0.9
PL	-3 to 3	-0.003 to 0.003

II) Membership Functions of DC Voltage Regulator: The input variables to the DC voltage regulator are reference (V_{dc_ref}) and measured ($V_{dc\_measured}$) DC voltages whereas the output variable from the regulator is an active current component (I_{d_ref}) for this controller designed for the STATCOM. These input-output variables of the DC voltage regulator have been defined as the membership functions for the fuzzy logic controller. The input and output ranges selected for these membership functions for the fuzzy logic controller have been presented in Table 2.

Table 2: DC Voltage Regulator Membership Functions

Function Name	Input Range	Output range
NL	-500 to 3000	-0.5 to 1
NS	-500 to 500	-0.5 to .2
ZR	-0.04 to 0.01	-0.1 to -0.7
PS	0.004 to 0.07	0.003 to 0.83
PL	-0.003 to 0.004	-0.003 to 0.004

III) Membership Functions of Current Regulator: The input variables to the current regulator are reference (I_{d_ref}) and measured ($I_{d\_measured}$) direct-axis active current components, reference (I_{q_ref}) and measured ($I_{q\_measured}$) quadrature-axis reactive current components whereas the output variables from the regulator are dq-axes voltage components V_d and V_q for this controller designed for the STATCOM. These input-output variables of the current regulator have been defined as the membership functions for the fuzzy logic controller. The input and output ranges of the membership functions for the fuzzy logic controller have been presented in Table 3.

Table3: Current Regulator Membership Functions

Function Name	Input Range	Output range
NL	-0.2 to 1.5	0.3 to 1
NS	-0.2 to 0.2	0.3 to 0.6
ZR	-0.18 to .003	0.4 to 0.6
PS	0.004 to 0.21	0.65 to 0.9
PL	-0.003 to 0.004	0.63 to 0.7

E. Fuzzy Rule Base

The Mamdani Fuzzy rule-based strategy was utilized at every regulator to represent the relationship. This was created to represent the choices made by operators while managing processes using a set of linguistic IF-THEN rules. A machine could then utilize these descriptions to autonomously manage the same processes. This uses the max-min aggregation method. A mix of trapezoidal and triangular membership functions has been utilized here, with the former working for short periods while the latter working for long periods [21]. The triangular membership function, for example, with a lower limit *a*, peak *b,* and upper limit *c* can be represented as in equation (2).

$$\mu(x) = \begin{cases} 0 & : for\ x \leq a \\ \frac{x-a}{b-a} & : for\ a < x \leq b \\ \frac{c-x}{c-b} & : for\ b < x \leq c \\ 0 & : for\ x > c \end{cases} \tag{2}$$

Due to this rule-based system, output changes accordingly when the input values change, and the system stabilizes itself. The performance of the FLC depends on the fuzzy membership functions and how an operator defines them. In this paper, we tuned them according to previous controller data, but there can be modifications to improve the performance. It comes with the expertise of the user to define a proper fuzzy inference system that can replicate the characteristics of the inputs and outputs of the controller. The fuzzy rule base for the AC and DC voltage regulator and the current regulator for the fuzzy logic controller have been presented in Tables 4, 5, and 6, respectively.

Table 4: Fuzzy Rule Base For Ac Voltage Regulator

Input/Output	NL	NS	ZR	PS	PL
NL	PL	PL	PS	PS	PS
NS	PL	PS	ZR	NS	NL
ZR	PL	PS	ZR	NS	NL
PS	PS	ZR	ZR	NS	NL
PL	PS	PS	ZR	NS	NL

Table 5: Fuzzy Rule Base For DC Voltage Regulator

Input/Output	NL	NS	ZR	PS	PL
NL	PL	PL	PS	PS	PS
NS	PL	PS	ZR	NS	NL
ZR	PL	ZR	ZR	NS	NS
PS	PS	ZR	ZR	NS	NL
PL	PS	NS	ZR	NS	NL

Table 6: Fuzzy Rule Base For Current Regulator

Input/Output	NL	NS	ZR	PS	PL
NL	PL	PS	PS	PS	PS
NS	PL	PS	ZR	NS	NL
ZR	PS	PS	ZR	NS	NS
PS	PS	ZR	PS	PS	NL
PL	PS	NS	ZR	NS	NL

In summary, as in Fig. 3, an error signal is given as input to the fuzzy block. After that, the values are converted to fuzzy variables. The fuzzy variables can have different values depending on the margin of error. Upon that, the fuzzy inference system maps the input error to the output current I_d or V_d depending on the type of regulators. The mapping happens according to the rule-based setup by the operator.

4. System Configurations

Fig. 4 shows the one-line diagram of the test system used in this paper, where an external grid is connected to a 9 MW wind power plant that includes a STATCOM. The system is built and simulated in MATLAB Simulink. The specifications of the test system are as follows:

1. A conventional synchronous equivalent grid operating at 60 Hz, and 25 kV at bus B1 as shown in Fig. 4 has been considered.
2. A 9 MW wind power plant producing power at 575 V is connected to the PCC-bus of the 25-kV grid through a 0.575 kV/ 25 kV step-up transformer.
3. A STATCOM is connected to the PCC-bus. The controller of the STATCOM controls the amount of reactive power from or to the STATCOM.
4. A 9 MW RLC-Load is connected to the PCC-bus.

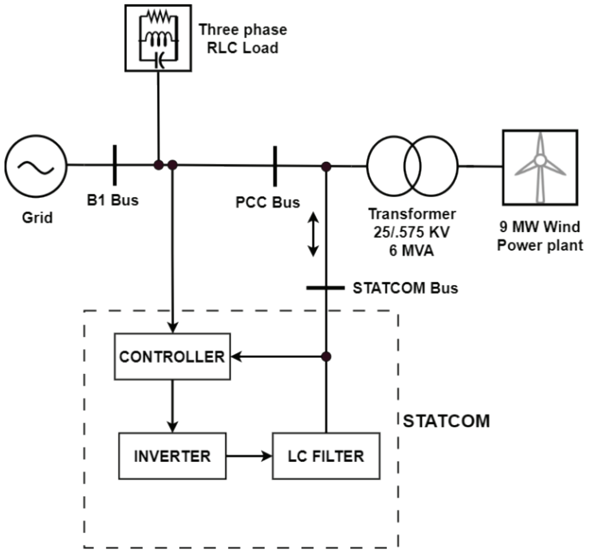

Fig. 4. One-line diagram of the test system.

A. Operation of STATCOM

STATCOM regulates the voltage at the PCC bus by controlling the amount of reactive current injected into or absorbed from the grid. When the grid voltage is below the predefined value, it injects reactive current. On the other hand, it absorbs reactive current from the grid when the grid voltage is above the predefined value. Reactive current generation and absorption alternation are performed utilizing an SVC. It uses an IGBT-based PWM inverter to convert the DC link voltage to AC voltage and supply it to the grid. The IGBT-based inverter circuit is shown in Fig. 5.

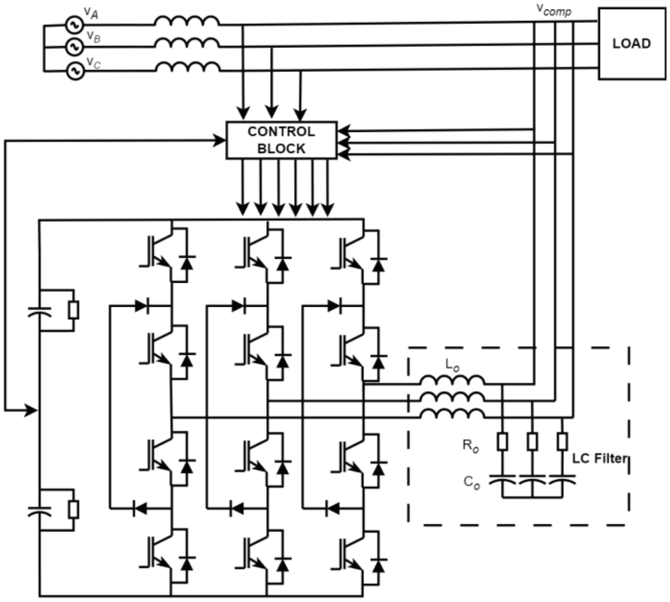

Fig. 5. Operation of STATCOM.

The LC filters cancel the harmonic voltages before connecting them to the grid. The output filters can eliminate the high-frequency harmonics of the inverter output. The modulation index of the PWM generator decides the amount of generation and absorption of reactive current. The inputs of the PWM generator come from the output of the regulators. The controller block consists of the AC and DC voltage regulators, and the current regulator, as shown in Fig. 6.

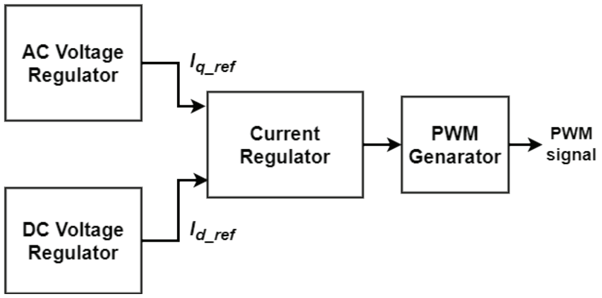

Fig. 6. STATCOM controller block.

B. STATCOM Controller

I) AC Voltage Regulator: The AC voltage regulator of the controller is shown in Fig. 7. We have replaced the PI controller with the FLC, where the reference AC voltage and measured line voltages are taken as inputs. The difference or error signal is calculated and sent to the FLC from these two values. I_{q_ref} is the reference current produced by the AC voltage regulator. This reference current works as the input for the current regulator.

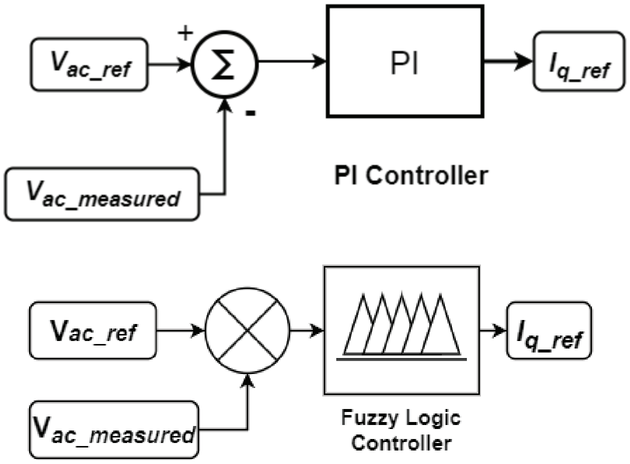

Fig. 7. AC voltage regulator.

II) DC Voltage Regulator: The DC voltage regulator is shown in Fig. 8. The PI controller is replaced with an FLC. This block takes the DC voltage reference and the measured DC link voltages as inputs. A limiter is used in the regulator block to keep the reference DC voltage value within an acceptable range. After that, the error signal is calculated from the two input DC signals and sent to the DC voltage fuzzy logic controller. The output of the controller is the reference I_{d_ref} current, which is then sent as an input to the current regulator.

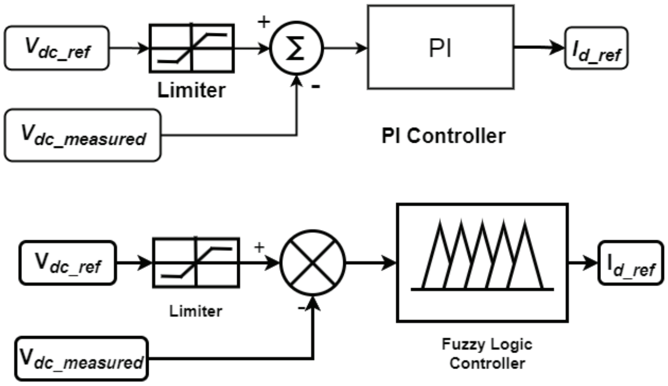

Fig. 8. DC voltage regulator.

III) Current Regulator: The current regulator of the controller block is shown in Fig. 9. Both the PI controllers are replaced with the FLC. As mentioned before, the outputs of the AC voltage regulator and DC voltage regulators are used as inputs to the current regulator. Two FLCs are used, one for I_{d_ref} and one for I_{q_ref}. Along with the inputs of the previous blocks, two separate values are taken as inputs: I_d and I_q. In each case, the error signals are calculated from the summation blocks and sent to the FLC blocks. The outputs are V_d and V_q, which are used to calculate the angle for the PWM generator.

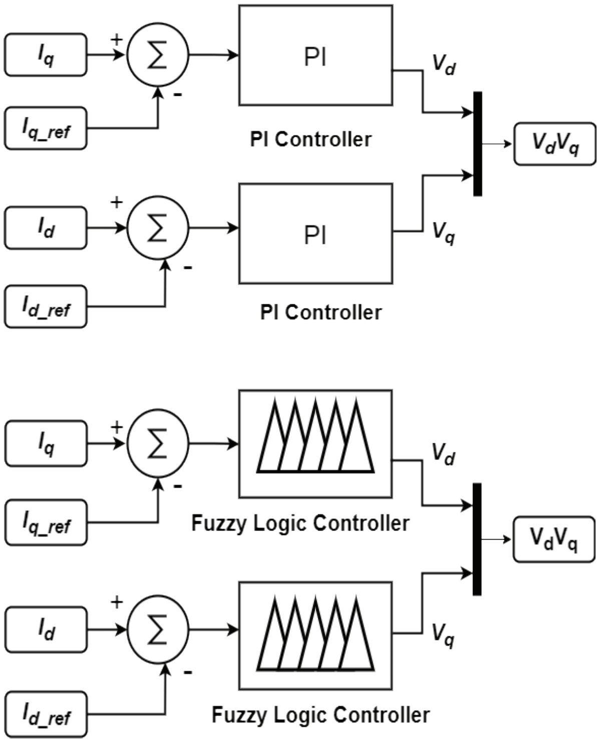

Fig. 9. Current regulator.

5. Result and Discussions

This section represents the results obtained from the simulation. The performance of the PI and the FLC controller is compared on parameters such as voltage regulation, current supply, and reactive power.

A. Voltage Regulation Improvement

It is shown in Fig. 10 that the voltage regulation is much better when a fuzzy logic controller is used. From Fig.10, the voltage fluctuations before using the fuzzy logic controller can be observed in the form of spikes. These spikes in the voltage represent the sudden voltage change due to the grid source fluctuation. The result demonstrates that the fuzzy logic controller, in both the transient and steady state, does a better job than the PI controller in maintaining the voltage profile at 1 pu. At 0.05 seconds, 6% more stability is achieved using a fuzzy logic controller. Stability improves by 3% and 1% during the steady-state phase at 0.22 and 0.3 seconds of the simulation. This is a clear indication that voltage regulation is maintained more efficiently when the fuzzy logic controller is being used.

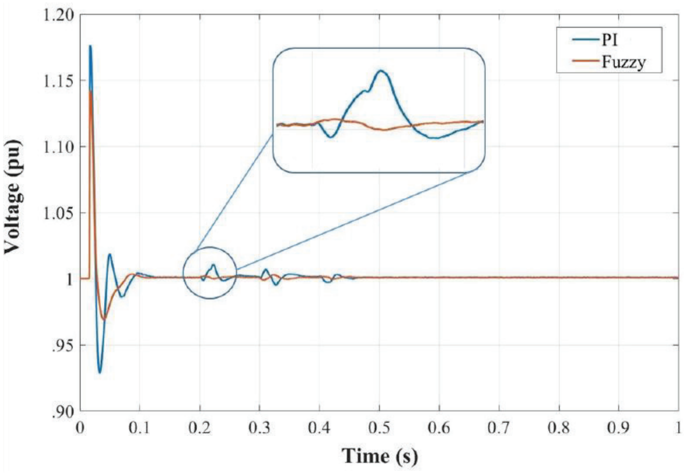

Fig. 10. Voltage regulation improvement.

B. Current Supply Comparison

It is shown in Fig. 11 that the current supply from STATCOM shows better stability when a fuzzy logic controller is used instead of a PI controller. The current supply fluctuates much more when a PI controller impacts the power quality of the grid. With the FLC, a maximum of 10 percent improvement is achieved.

C. Reactive Power Supply and Absorption

It is shown in Fig. 12 that STATCOM is both supplying and absorbing reactive power according to the needs of the grid. The grid voltage profile determines this. When grid voltage drops, STATCOM delivers reactive power to balance the voltage level to 1 pu. Again, when the grid voltage is above the regular value, STATCOM absorbs the reactive power to get the voltage level back to 1 pu value. Using an FLC yields a faster response to the injection and absorption of reactive power.

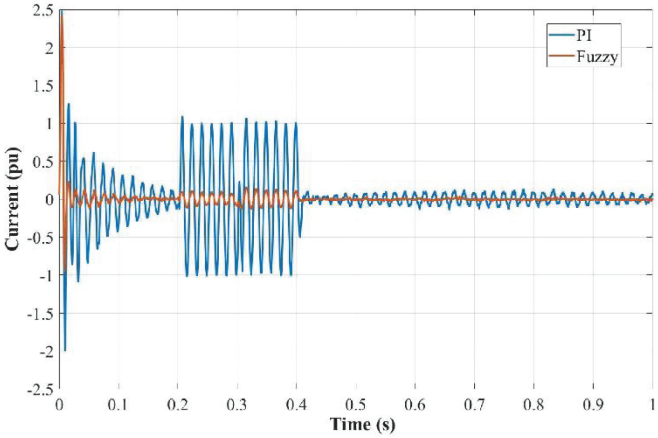

Fig. 11. Current supply comparison.

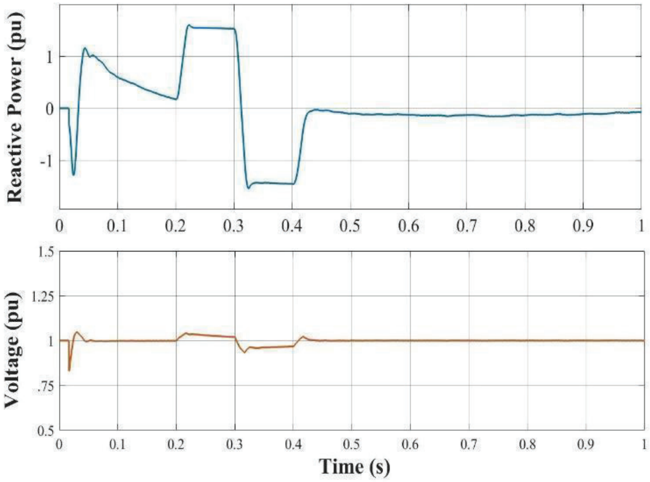

Fig. 12. Reactive Power Supply and Absorption.

6. Conclusions

In this paper, we have analyzed the characteristics of the controller of STATCOM and how it operates to compensate for the reactive power to maintain the voltage level of the grid. Different controller methods have been discussed in detail, and comparisons have been presented. Gradually, we discussed the FLC of STATCOM and simulated a system where a wind power plant is integrated into the grid. Different parameters at the PCC bus have been measured, especially the voltage profile of the grid. These results have been compared with the outputs generated using a PI controller. In section 4, the blocks of the different regulators have been discussed along with their inputs and outputs. Fuzzy membership functions and their relationship in the FLC blocks have also been shown. In the result section, we have demonstrated the grid power quality performance improvement using an FLC. Other vital parameters have been discussed, like the supply current from STATCOM and the wind power plant outputs. The results in sections A and B demonstrate that the FLC improves the voltage regulation by a maximum of 6% and the current supply by a maximum of 10% compared to PI controllers, making it a more optimal option than a PI controller.

7. Future Works

In a previous study, we worked on the impact of STATCOM on the power quality of the grid using a PI controller. This study shows that the FLC performs better if the membership functions are defined well. The results can be further improved using the modifications in the membership functions and adaptive control techniques. We plan to pursue the field of controller design and improvement in future studies. Therefore, we will be working on the modification of the fuzzy logic controller as well as experimenting with other advanced controller methods.

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