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Performance Evaluation of Different Fuzzy Logic Controllers for E-STATCOM

Srinu Bhukya[1], T. Murali Krishna[2], G. Mallesham[3], Ch. Anilbharadwaj[4]
[1]Research scholar, Department of Electrical Engineering, University College of Engineering, Osmania University, Hyderabad, Telangana, India
[2]Assoc. Professor, Department of Electrical & Electronics Engineering, Chaitanya Bharati Institute of Technology (CBIT), Gandipet, Hyderabad, India
[3]Professor, Department of Electrical Engineering, University College of Engineering, Osmania University, Hyderabad, Telangana, India
[4]Staff Engineer, Embedded DVT, Storage Business Unit, Enphase Solar Energy India (Pvt.) Ltd., Bengaluru, Karnataka, India

Abstract: This paper investigates the performance of three different Fuzzy Logic Controllers (FLCs) for an Enhanced Static Synchronous Compensator (E-STATCOM) for reactive power compensation and voltage stability improvement in power systems. The E-STATCOM is a key device in modern power system, ensuring efficient power flow and dynamic voltage regulation. Traditional control methods like Proportional and Integral (PI) Controllers often face drawbacks like inadaptability and robustness under varying load conditions. To address these challenges, three distinct FLCs are implemented and their transient response is compared.

The study assess the controllers' effectiveness in dynamic response. Simulation results, conducted in MATLAB/Simulink, demonstrate that fuzzy logic controller designed with a smaller number of membership functions can provide better transient response. This comparative analysis highlights the potential of intelligent control strategies in enhancing E-STATCOM performance.

Keywords: E-STATCOM, Fuzzy Logic Controller, Membership Functions, Transient response,

I. INTRODUCTION

Over the past few decades, the integration of large-scale renewable energy-based power generation units into the existing grid has been increased.

The primary drivers behind this shift toward renewable energy include a fourfold increase in electricity demand, supportive government policies, and a significant rise in fossil fuel prices [1]-[2]. Power electronic based converters are playing key role in the integration of renewable energy generators because of variations in the input of the renewable energy generators the power output of these sources is inherently variable.

Since large-scale renewable energy sources are predominantly integrated through transmission networks, the grid's inertia is impacted by the injection of substantial unsteady power. Flexible AC Transmission Systems (FACTS) devices play a crucial role in enhancing power system stability and performance.

Among them, the Energy storage Static Synchronous Compensator (E-STATCOM) is widely used for reactive power compensation and voltage regulation near the common point of coupling[3]-[4]. Whenever to integrate Distributed Generation (DG) into the electrical distribution network, an interfacing converter is utilized.The variable power required for the grid due to Maximum Power Point Tracking (MPPT) operation is injected by these power electronic converters. However, their limited capacity prevents them from meeting the necessary grid code requirements at the Point of Common Coupling (PCC), restricting their role to active power injection only.

To fulfil additional grid requirements, supplementary systems must be implemented. Functions such as reactive power support and harmonic filtering can be provided by a Static Synchronous Compensator (STATCOM)[5]-[6]. Additionally, an Energy Storage System (ESS) is required for active power support. The use of separate ESS and STATCOM units reduces overall efficiency. To address this, an Energy storage - STATCOM (E-STATCOM) can be integrated at the PCC to meet grid code requirements effectively.

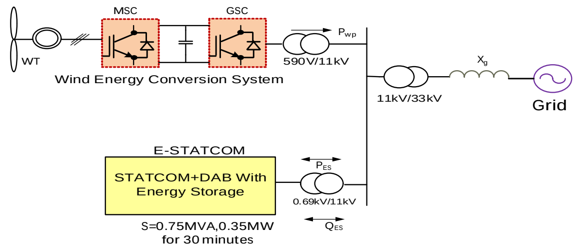

Figure:1 Grid connected large-scale wind-farm with E-STATCOM

An Energy Storage STATCOM (E-STATCOM) is formed by integrating an Energy Storage System (ESS) with a STATCOM, permitting it to provide active power support for a specific duration while addressing power quality issues. In previous studies, a battery-based storage system has been utilized to stabilize the power output from a Wind Energy Generation System (WEGS). This system is connected to the DC link of a two-level converter, ensuring that only active power is supplied at the Point of Common Coupling (PCC). Beyond the control aspect of storage systems in an E-STATCOM, a key function of an ESS is to support loads that require high energy and power density[7]-[8].

To enhance the performance of the considered E-STATCOM the conventional PI controller is replaced with three different fuzzy logic controllers taken from three references [9]. In this paper F-1 is representing the FLC from the reference [10]-[12] implemented in place of the conventional PI controller for generating required I_{dref} signal which consists of two inputs and one output which are further having five membership functions to processes crisp inputs and outputs while performing internal operations on fuzzy variables having a set of 25 fuzzy rules, as detailed below.

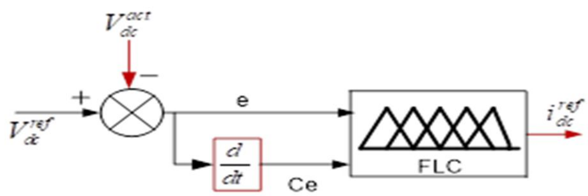

Figure :2 Control strategy of proposed fuzzy

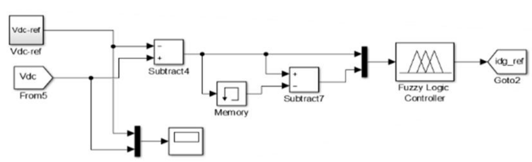

Figure :3 simulation diagram of fuzzy logic voltage controller

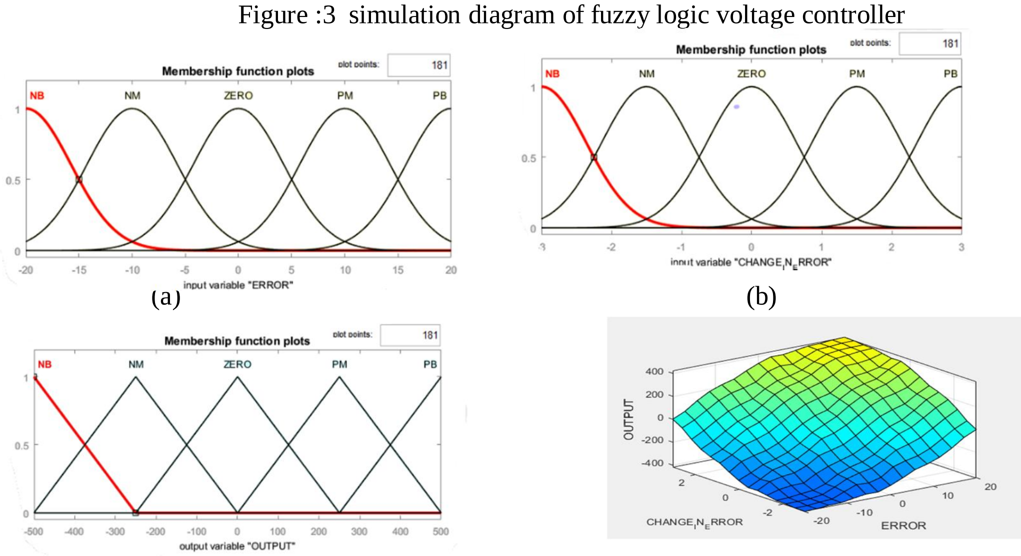

Figure 4: Membership functions and surface viewer of F-1

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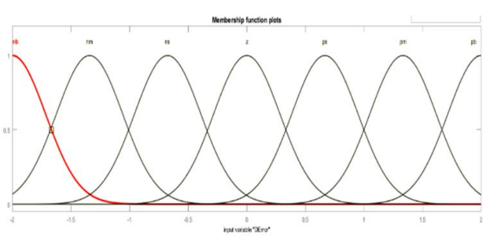
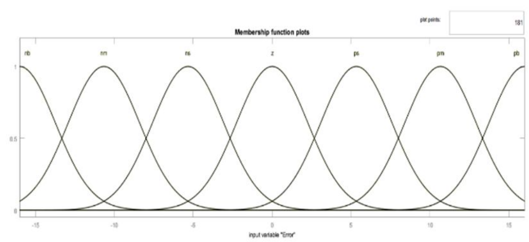
Table :1 Table :1 Rule base

e/ce	NB	NM	Z	PM	PB
NB	NB	NB	NB	NM	Z
NM	NB	NB	NM	Z	PM
Z	NB	NM	Z	PM	PB
PM	NM	Z	PM	PB	PB
PB	Z	PM	PB	PB	PB

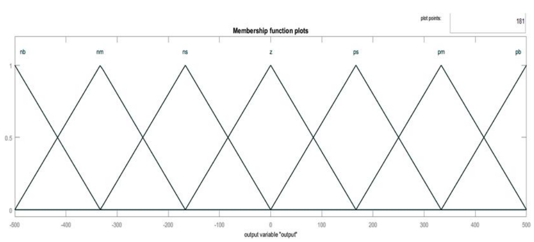
The second fuzzy logic controller is represented as F-2 taken from the reference [13]-[14]. The fuzzy system consists of two input variables, each with seven Gaussian membership functions which are equidistant and one output with triangular membership with 49 rules as given below.



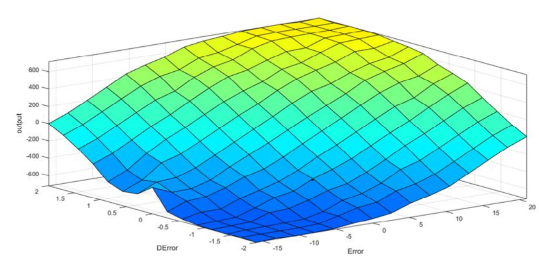
(a)



(b)



(c)



(d)

Figure 5:Membership functions and surface viewer of F-2

Table:2 Table:2 Fuzzy rule base of FLC-2

E_{DC}/CE_{DC}	-EB	-M	-VS	Z	+VS	+M	+EB
-EB	-EB	-EB	-EB	-EB	-M	-VS	Z
-M	-EB	-EB	-EB	-M	-VS	Z	+VS
-VS	-EB	-EB	-M	-VS	Z	+VS	+M
Z	-EB	-M	-VS	Z	+VS	+M	+EB
+VS	-M	-VS	Z	+VS	+M	+EB	+EB
+M	-VS	Z	+VS	+M	+EB	+EB	+EB
+EB	Z	+VS	+M	+EB	+EB	+EB	+EB

The third fuzzy logic controller is represented as F-3 taken from the reference [15]-[18]. The fuzzy system consists of two input variables, each with seven Gaussian membership functions which are not equidistant and one output with triangular membership with 49 rules as given below.

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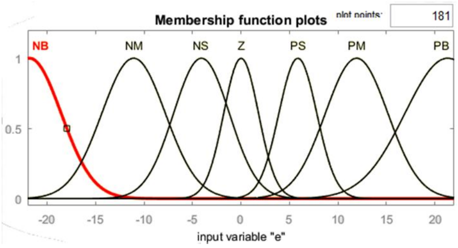
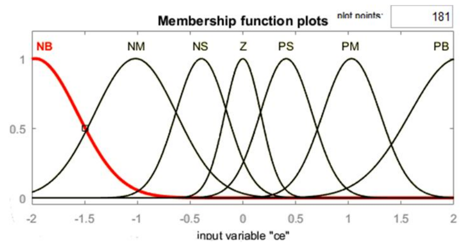


(a)



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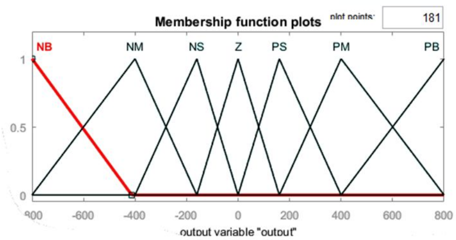

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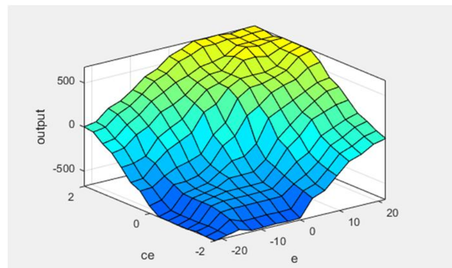

(d)

Figure 6:Membership functions and surface viewer of F-3

Table :3 Table :3 Rule base FLC-3

E_{DC}/CE_{DC}	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

II. RESULTS

The performance of these fuzzy controllers are evaluated based on the following system shown in figure 7.The E-STATCOM control, ensuring stable DC-link voltage (V_{DC}) in the Voltage Source Converter (VSC) while supporting active and reactive power at the Point of Common Coupling (PCC) [8]. The strategy is applied in the synchronous dq-frame, [17] where i_q manages reactive power, and i_d stabilizes V_{DC} figure 8 .

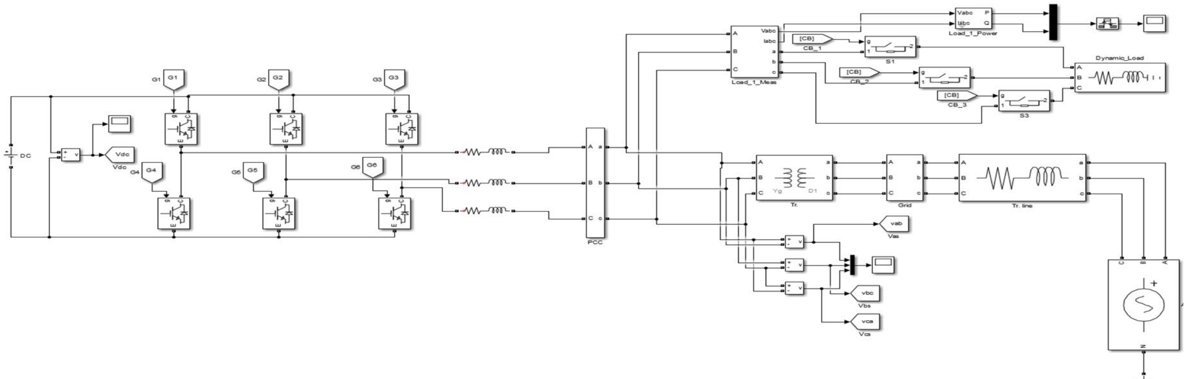

Figure 7.simulation Block diagram of the extended-based fuzzy control

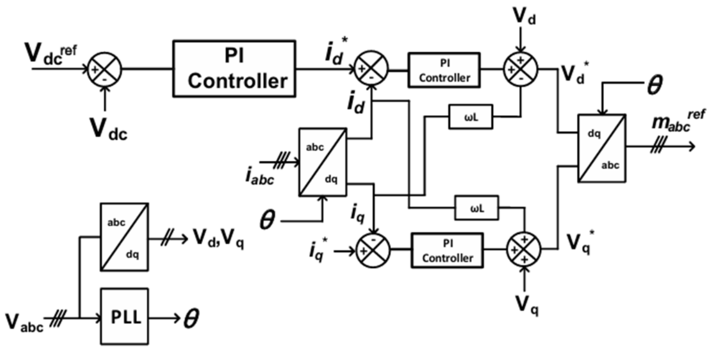

Figure 8.control loop of E-STATCOM

To evaluate the performance of fuzzy logic controllers, a step change at dc link voltage is created from 1650V to 1750 V which is depicted in figure 9.

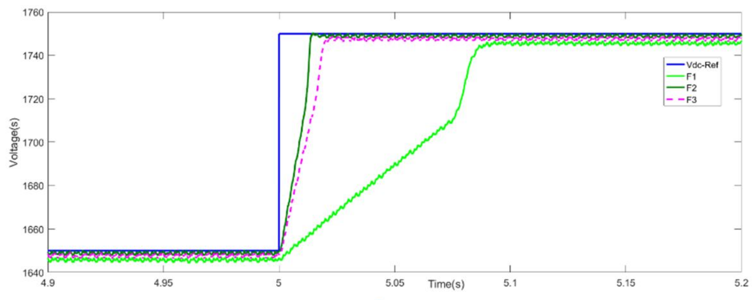

Figure 9:DC-link voltage changes from 1650V to !750V

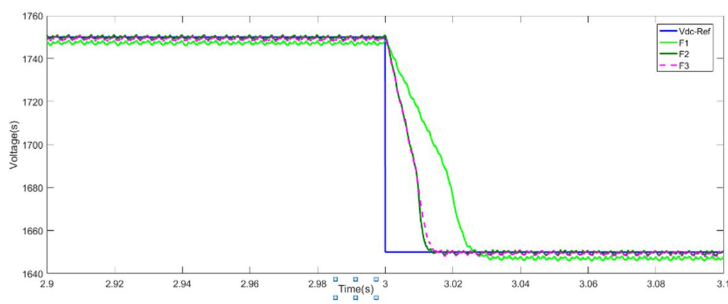

Figure 10:DC-link voltage changes from 1750V to 650V

The figure illustrates the response of three fuzzy logic controllers viz. F1, F2, and F3. From the figure 9 and figure10, it can be concluded that the fuzzy logic controller- F2 is giving very good response than the other two controllers. This graph effectively highlights the dynamic performance of various control strategies in regulating voltage following a disturbance. F-3 is giving sluggish transient response as well as more steady state error whereas F-1 gives quick response but the steady state error than F-2 is more. Hence it can be concluded that the fuzzy logic controller F-2 is giving better response than the two for the system under consideration.

III. CONCLUSION

In this paper the performance of three different fuzzy logic controllers for E-STATCOM are compared for a step change. All controllers effectively regulated the voltage and reactive power during steady state. But the transient performance of F-2 controller is observed to be superior than other controllers which gives low rise time, low peak time and less steady state error than the other controllers. Fuzzy-2 demonstrated superior performance in terms of response time and accuracy.

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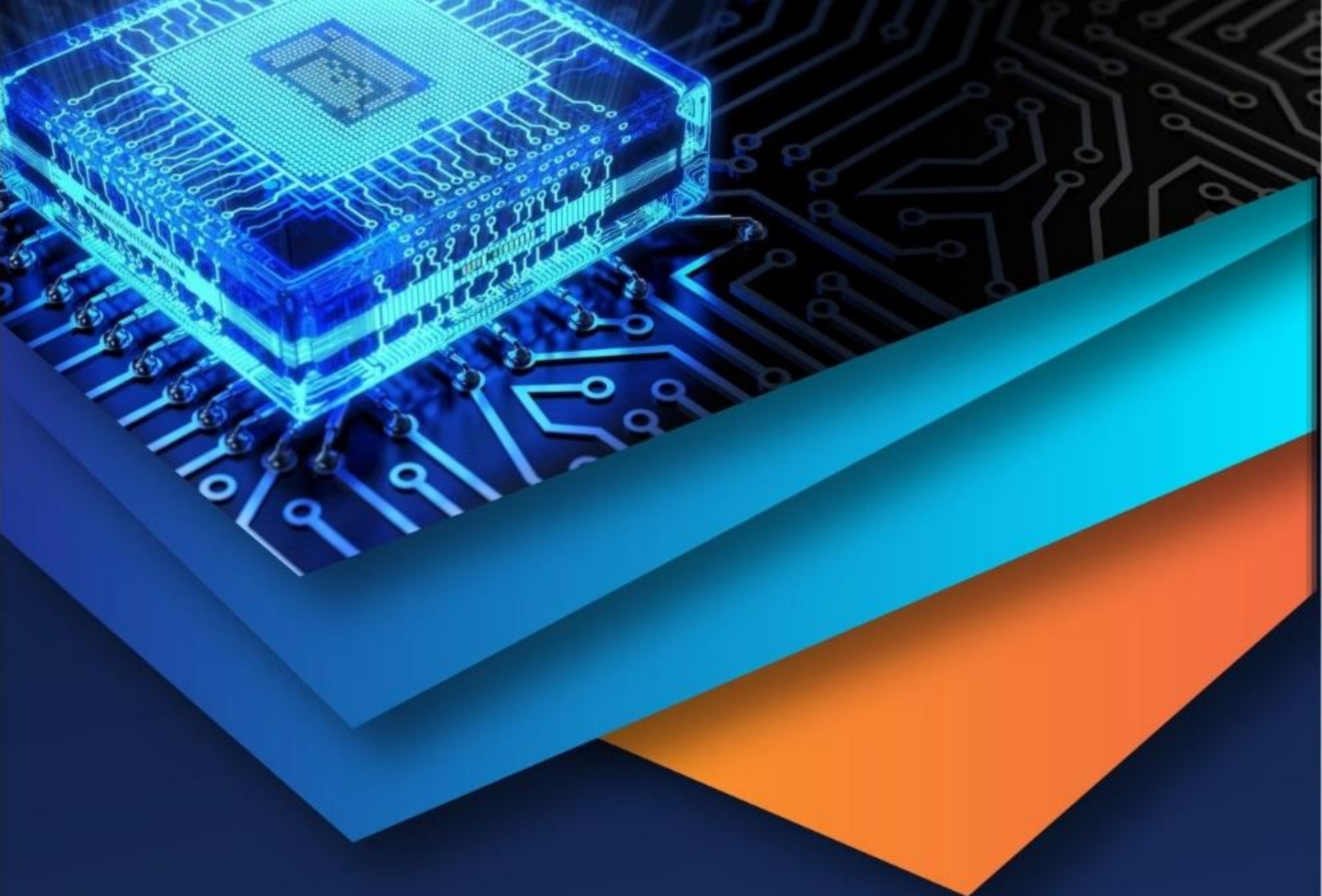

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