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A Comparative Study Of Smart Integrated Unified Power Flow Controller With PI And Fuzzy Logic-Based Controllers During Fault Scenarios

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Abstract— *Modern power systems are evolving rapidly due to growing energy demands, renewable energy integration, and increased complexity of load profiles. Ensuring reliable and stable power system operation under such dynamic conditions especially during faults—has become increasingly challenging. Key operational concerns such as voltage regulation, transient stability, and power flow control necessitate advanced solutions beyond conventional means [1]effects of various controller are observed on*

Keywords—UPFC ,FCTCR, Fuzzy logic controller.

I. INTRODUCTION

Flexible Systems for AC Transmission devices have proven effective in enhancing the controllability and stability of power transmission networks. Among these, the Intergrated Power Flow Regulator is distinguished by its ability to simultaneously control transmission voltage, impedance, and phase angle, providing a holistic approach to power flow management [2]. The UPFC integrates series and shunt compensation in a unified structure, making it highly effective during both steady-state and transient operations.

2 LITERATURE REVIEW

Previous studies have extensively examined the dynamic performance of UPFCs, particularly highlighting the rapid response of the voltage injected in series. The ability of the UPFC to swiftly adjust its output while maintaining voltage stability allows it to transition smoothly between stable operating points. This feature demonstrates the controller's adaptability and reliability under varying system conditions.

UPFCs have demonstrated their effectiveness in managing power flow within a Single Machine with Infinite Bus structure. In such applications, the Hybrid Power Flow Controller (HPFC) has been explored as a complementary approach. The HPFC combines a pair of half-rated voltage source converters arranged in series and parallel configura- tions. These are supported by capacitive energy storage systems that provide substantial reactive power, ensuring the system's operational requirements are met efficiently.

To further enhance control performance, Fuzzy Logic-Based Controllers have been in- targeted with traditional Proportional-Integral (PI) controllers. A robust framework is provided by fuzzy logic for addressing non-linarites and uncertainties inherent in power systems. While FLCs can be implemented on general-purpose processors, their deployment on specialized embedded hardware significantly improves computational speed and cost efficiency. The FLC processes input variables and determines the appropriate control action based on a predefined set of linguistic rules,

Moreover, recent advancements have focused on optimizing FLCs using Genetic Algorithms (GAs). These evolutionary algorithms enhance the fuzzy system's rule base and membership functions, leading to improved performance and adaptability. The integration of GAs with PI-based FLCs results in an intelligent, adaptive control system capable of delivering superior regulation and stability for UPFC-equipped power net- works. Common Control

Strategies for UPFC are PI Control (Proportional-Integral) is Simple and commonly used in industrial applications. It Controls voltage and current in the converter may not perform well under dynamic or nonlinear conditions.

Fuzzy Logic Control Handles system nonlinearities and uncertainties better than PI controllers. There is no need for accurate mathematical model.

Artificial Neural Networks (ANN) learns from data to model and control system be- havior.it is Suitable for adaptive and nonlinear control. It requires training and may have generalization limitations. Model Predictive Control (MPC) method Predicts future behaviour of the system and optimizes control actions. It Handles multiple control objectives and constraints.

3. METHODOLOGY

3.1 PI-Based UPFC's Basic Structure

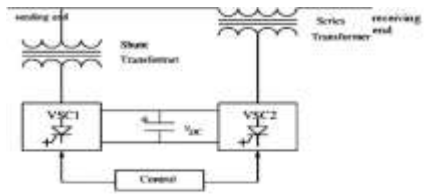

Figure 1 PI-Based UPFC's Basic Structure

Figure 1 shows a PI-based Unified Controller for Power Flow Management in its basic setup. The Unified Controller for Power Flow Management is positioned in this con- figuration between the transmission line's transmitting and receiving ends. The performance of the system is assessed under the influence of a Line-to-Ground (LG) fault in order to determine how well the controller can control power flow and preserve system stability during fault situations.

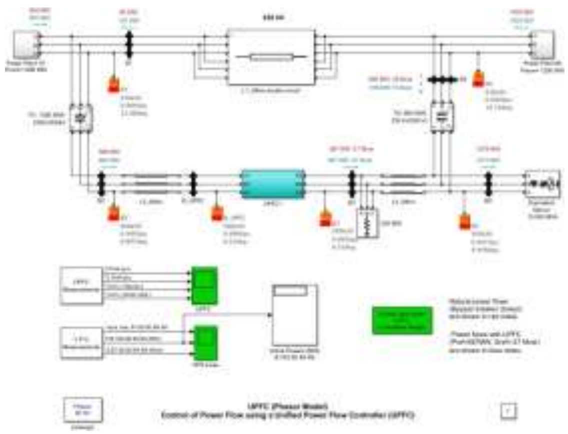

Figure 2: Detailed Architecture of UPFC

The DC voltage controller, which creates an fault signal by comparison the real DC link voltage with a predetermined reference value, is essential to preserving the stability of the DC connection. In electrical and power electronics systems, a DC voltage con- troller is a crucial part that controls the DC voltage level to a predetermined level. DC- DC converters, renewable energy systems, electric cars, and HVDC (High Voltage Di- rect Current) systems are just a few of the many uses for these controllers.

3.2Analysis of Fuzzy Logic Systems

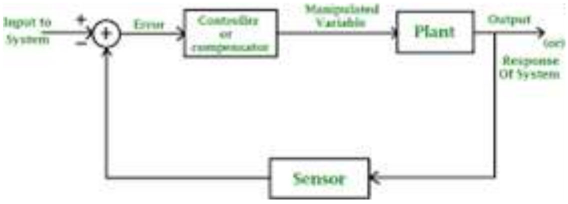

Figure-3: A basic fuzzy logic controller model

A basic fuzzy logic controller model generally involves the following key compo- nents as shown in Figure 3:

1. Fuzzification: This is the process of converting crisp inputs into fuzzy values. Inputs are typically mapped into fuzzy sets, which represent linguistic varia- bles like "low," "medium," or "high."

2. Fuzzy Logic Rule Set: A collection of if-then rules that define the system's behaviour based on fuzzy input

If temperature is "increase" and humidity is "inverse of temperature" then the fan speed should be "fast."

If temperature is "low" and humidity is "high," then the fan speed should be "slow."

3. Inference Mechanism: This module applies the fuzzy-base rules to the fuzzy input values. It generates fuzzy outputs by applying the logical operations on the rules based on the input values.

4. Defuzzification: After the fuzzy outputs are generated, this process converts the fuzzy values back into crisp values that the system can use for control. Methods like the centroid method are often used for this step

3.3AI Tools

Inspired by the structure of biological neurons, an Neural Network with artificial intellligence is made up of a network of interconnected nodes known as artificial neurons. Each link sends impulses to neighbouring neurons, much like a synapse in the human brain. After processing the input, an artificial neuron may send a signal to other neurons that are connected to it, depending on the outcome. Each connection's signal is represented by a real integer, and the biased sum of the neuron's inputs is exposed to a non- linear role to control the neuron's output. Together with the neurons, these connections also referred to as edges—are usually given weights that are modified through- out the learning process.

3.4Training Set

In order to learn (or be trained), neural networks must process samples that have a known "input" and a matching "target result." The network creates probability- weighted correlations between the input and the outcome during this process, which include

The process starts with data preparation, where raw features are normalized (e.g., to [0,1] or zero mean/unit variance) to ensure faster convergence and balanced feature influence. The information is then divided into training, validation, and test sets for model learning, tuning, and final evaluation.

Next, the neural network architecture is defined, comprising an input layer (matching feature dimensions), hidden layers (for pattern learning), and an output layer. Activa tion functions like ReLU (for hidden layers), sigmoid, or SoftMax (for output layers) present non-linearity, allowing the model to learn complex associations.

During training, forward propagation computes outputs layer-by-layer using current weights and biases. These outputs are compared to actual targets using a loss function— MSE for regression or Cross-Entropy for classification— to quantify prediction errors. Gradients, calculated via back propagation, indicate each weight's impact on prediction error in an artificial neural network (ANN). Optimization algorithms like SGD or Adam use these gradients to iteratively update weights and minimize the loss function. Thisprocess—comprising forward propagation, error calculation, back propagation, and weight updates—is repeated over multiple epochs.

An epoch is one full pass through the training data. Model performance is monitored using a validation set to detect over fitting, and final evaluation on a test set assesses generalization.

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To enhance training efficiency and accuracy, techniques like dropout (prevents co-ad- amputation), batch normalization (stabilizes learning), early stopping (avoids over fitting), and learning rate scheduling (balances convergence and stability) are employed. These methods collectively improve the robustness and generalization of the ANN.

4. RESULT

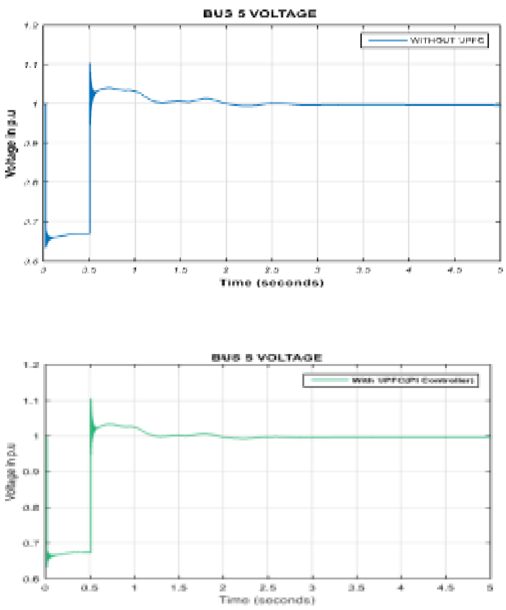

Figure 4: Bus 5's voltage (bus with LG fault)

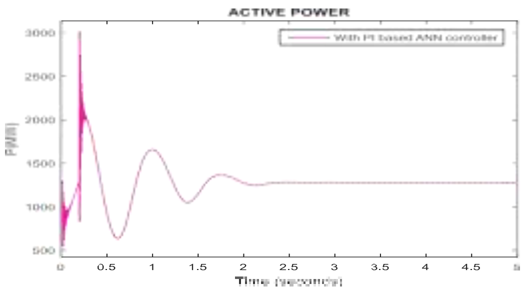

Figure 5: Supplying BUS 5 with active power (bus with LG fault)

Table 1 REACTIVE POWER

Controller	First Peak	Settling Time
Without UPFC	-1.347	Does not settle
UPFC having PI controller	-1.348	2.4sec
UPFC having PI based FLC	-1.348	2sec
With UPFC with PI based ANN	-1.349	1.7sec

5. CONCLUSION

The abilty of the Unified Power Flow Controller (UPFC) in reducing the effects of a line-to-earthing fault at Bus 5 has been verified The study of the system with different controllers, including PI controller, PI-based Analysis of Fuzzy Logic Systems, and PI-based Artificial Neural Network (ANN) controller is done .UPFC supports active power and reactive power during fault conditions

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