Enhancement of Power Quality in Grid-Connected Distribution Systems Employing AI-Based Controllers

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Abstract—The main concerns with electrical distribution networks are the degradation of power quality. The main culprit behind this problem is non-linear technology, specifically switching devices and power electronics converters. Power supply efficiency, system efficacy, power factor loss, etc. Are all adversely impacted by non- linearity. It is necessary to compensate for the reactive power since it has increased as a result of the power factor drop and does not contribute to the transmission of energy. In this project, Artificial Intelligence based controllers have been proposed for improving Power Quality in Grid connected Distribution System. This is used to reduce the harmonics of current and other correlated power quality issues caused by reactive power. With the aid of the MATLAB/ SIMULINK toolkit, these control approaches are to be simulated. In this paper, we examine whether ANN or ANFIS is the most appropriatemethod.

Keywords: DSTATCOM, Power Quality, Voltage Sag, Voltage Swell, Harmonics.

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1. Introduction

It is critical to monitor power distribution systems in order to identify bottlenecks and address them as needed. When faults are identified, they can be corrected to improve the quality ofpower distribution systems. However, improving power quality is a difficult task that necessitates the use of specific procedures to address the issues. Distributed power generation systems are complex due to the large number of heterogeneous devices and different power generation sources. They are prone to various faults such as line to line and line to ground, switching, and so on. As the complexity of the system grows, a data science-based approach to problem solving is required. Advanced Technologies frequently employ power electronic devices. Power electronics devices produce harmonics at the load side while disrupting the supply current, causing the fundamental signal to deviate. And all the while, the increased use of renewable energy sources in the power system, blended with grid- connected power electronics functionalities, has brought up greater power quality (PQ) concerns.AI has make an appearance as one of the speedy expanding fields of technology, with significant implications for electricity, public transit, care services, safety, and other implementations. The majority of power system problems are related to enhancement and forecasting. AI has the potential supply one-of-a-kind determination for producing energy, power network balance, and energy utilization evaluation. AI has grown in importance in the electricity sector. AI is a self- learning and estimation application procedure. It can combine vision system, awareness, knowledge, connectivity, ability to adapt, and other skills with computers' sophisticated role of processing data functions. After recapping the evolution of smart grid and AI,this paper will examine some implementations of AI, such as load power forecasting, generation energy forecasting, system stability control, power system defect detection. Man-made reasoning gadgets are the new objects of interest Artificial Intelligence. Some of the areas of electric force where AI has been researched include voltage stability planning, power system stability, power network analysis, load predictive modelling, and fault detection. There are numerous applications of artificial intelligence in this field. Frameworks for mastery, fuzzy control, and neural networks have also been used in movement governing and power electronics. Artificial intelligence has indeed been recognized as appropriate instrument for analyzing and establishing problems with PQ. In recent years, AI implementations in the domain of power quality have emerged. In terms of a summary of literary works, along with the application of Artificial intelligence techniques to power quality related difficulties. Regarding that is a summary of literary works, along with the implementation of Artificial intelligence techniques to power quality related difficulties. The review has primarily focused on the application of fuzzy logic, DSTATCOM, Artificial neural network and ANFIS based controllers for the improvement of Power Quality.

2. Power Quality

The phrase power quality refers to the extent to which voltage, current, and frequency vary on a power system. Voltage and current can vary in magnitude or waveform shape/distortion. Power quality is any departure from the sine wave shape of the voltage or current waveform. The characteristics of the voltage that have an impact on the customer's highly sensitive equipment are referred to as power quality. Amidst the publication of research articles, publications, and texts on electrical force quality, has Its explanation has not yet been universally believed. Regardless, everyone agrees that it is an essential component of force frameworks and electric devices, with direct implications for efficiency, reliability, and accuracy. Various sources use the phrase "power quality" from different perspectives. We care about force quality primarily for economic reasons. There are economic ramifications for utilities, their consumers, service providers, and load equipment manufacturers. Force can have a direct economic effect on a large group of clients. Private clients rarely suffer direct financial loss or the inability to obtain pay as a result of most influence quality issues, but they do suffer. When they realize that the utility is providing defenseless assistance, they can wield tremendous power. Many designers are also unaware of the types of issues that can arise on force frameworks. The primary responsibility for correcting deficiencies while loading machinery ultimately rests at the conclusion with user who must purchase and operate it including rules for force execution. Because several end users are also unaware of the risk, utilities can offer valuableservice by providing data on Power quality and also the requirements for load machinery to function correctly underreal world conditions.

3. Issues of Power Quality

(a) Voltage Sag

- Ubiquitous application of delicate microprocessor-focused Controllers and power electronics equipment's.
- The difficulties of industrial processes, which result insignificant economic damage if failure happens.
- The distributed of large PC frameworks into variousenterprises and workplaces [6].
- The advancement of developed power electronics hardware grip for improving framework solidity, operation,and efficiency.

(d)

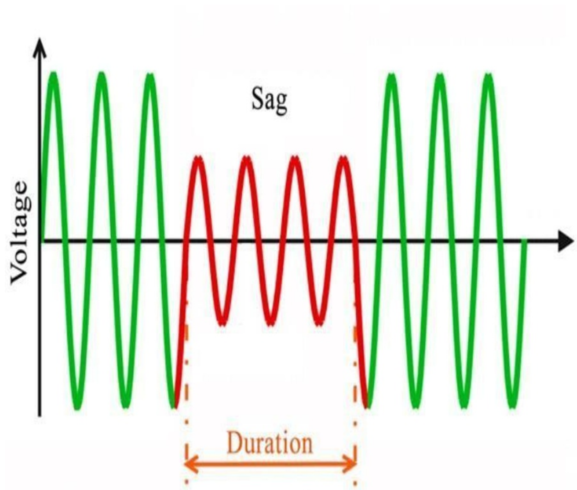

Fig 1: Voltage Sag.

(b) Very Short Interruptions

The lack of electrical force for a milli second affected by the excitation of a diesel generators electrical switch or when thedefective part is disconnected from the foundational elementis defined as Very Short Interference.

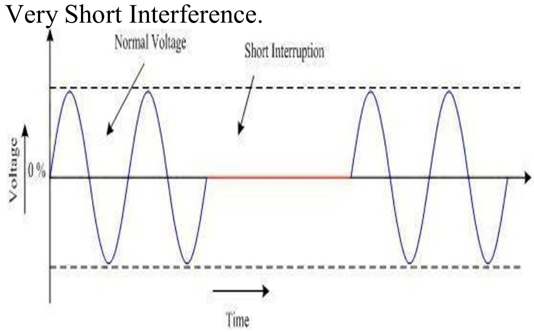

Fig 2: Very Short Interruptions.

(C)LONG INTERRUPTIONS

The absence of power supply for an extended period of time equipment breakdown, protection sadness, or defect is referred to as a long interruption.

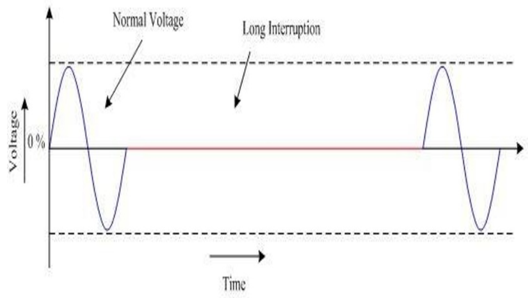

Fig 3: Long Interruptions.

(d) Voltage Rise

A voltage rise is defined as a sudden increase in the considered voltage caused by a lighting stroke.

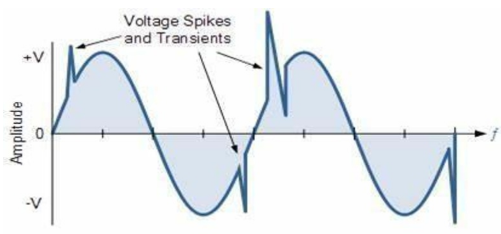

Fig 4: Voltage Rise.

(e) Voltage Swell

Voltage swell is defined as a rise in voltage caused by suddenmassive pile separation or by an extremely capacitive load.

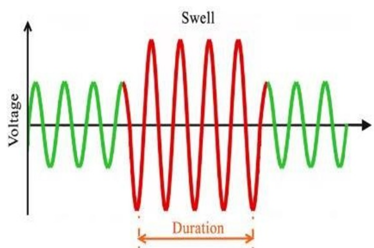

Fig 5: Voltage Swell.

DISTORTION OF HARMONICS

The disrupted sinewave of the normal waveform caused by the load is referred to as distortion of harmonics. Noises are waveforms with frequencies that are integral multiples of thebasic waveform.

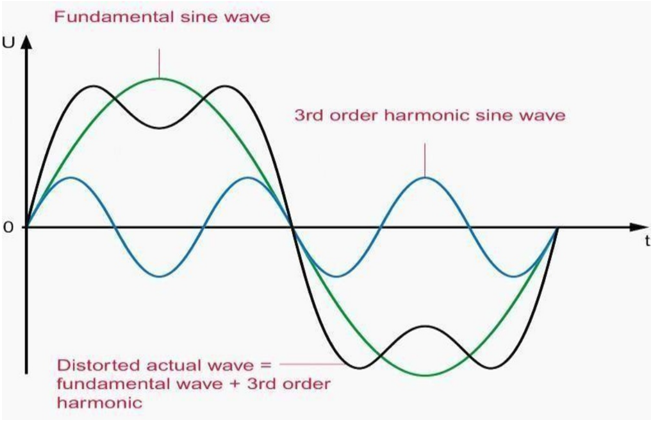

Fig 6: Harmonic Distortion.

4. POWER QUALITY IMPROVEMENTARTIFICIAL INTELLIGENCE(AI)

AI is the discipline of investigation that depicts the ability [4] to behave like individuals and to respond to particular customs. An example of AI could be the robotization of human-thinking exercises such as dynamic, critical thinking, learning, perception, and reasoning. FL, AFL, DSTATCOM, ESs, ANNs, and genetic algorithms are among the AI tools used in the electric force area.

A distribution system with three phases and three wires has areactive load connected to it. A Voltage Source Controller connects the DSTATCOM to a DC bus (VSC) [1]. The Voltage Source Controller is recognized using 3 shielded- gate bipolar transistors with trigonal diodes. A usual coupling point and loads are connected to the alternating current ends. To generate pulses, a Pulse Width Modulating controller wasused.

The MATLAB / Simulink environment is constructed of DSTATCOM similar to the one shown above, with the source, load, DSTATCOM, and other components. [5]. The foremost section of the controller is a power distribution circuit. that includes inductance, resistance, and a diode, resulting in a nonlinear load [9]. The previously mentioned Artificial neural networks, and Adaptive network based fuzzy inference system theories are used to simulate this.

A. Artificial Neural Network

An artificial neural network is a model of computational thatconsists of several processing elements that acknowledge inputs and generate outcomes based on predetermined activation functions.

A three-layer artificial neural network is used.

The input layer comes first, then the hidden layer, and then the output layer. We have applied the tangent sigmoid activation function to generate hidden layer output.

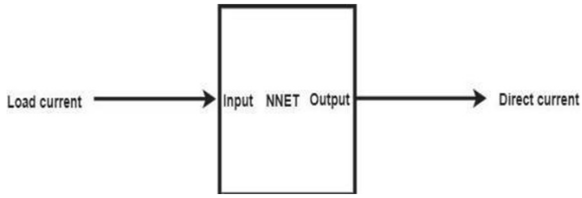

Fig 7: Layout of Neural Network.

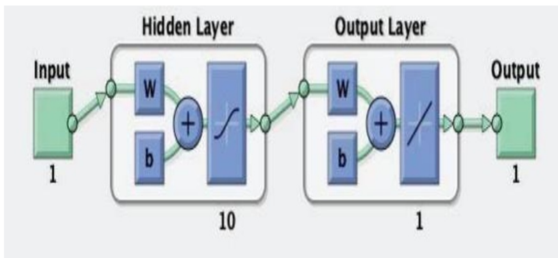

Fig 8: ANN Controller Simulation Model.

Ten neurons make up this buried layer. To produce the output, a function of linear activation is used to coach the neurons in the output layer.

B. Applications of Neural Networks

ANNs are among the most experienced AI techniques; They have long utilized in the domain of power analysis. Neural enterprises are frequently employed.

1. Creating harmonic patterns from single fluorescent lighting frameworks.
2. Creating a monitoring equipment to assist the force structure engineer in dealing with Various power qualityissues.
3. Performing harmonic distortion and PQ calculations in military organizations.
4. Deconstructing consonant twisting while avoiding the effects of commotion and subharmonics.
5. Identifying high-impedance problems, fault stress, as well as normal stress current examples.

C. Fuzzy Logic

The phrase fuzzy tends to refer things that are unclear or blurry. It considers the inconsistencies and instabilities of any situation. In the Boolean system, truth value 1 represents absolute truth value and truth value 0 represents absolute false value. However, there is no logic in a fuzzy system forabsolute truth and absolute false value. Fuzzy logic is a computing approach that uses "degrees of truth" rather than thetraditional "true or false" (1 or 0) Boolean logic that moderncomputers are based on. It is applied to the concept of partial truth, where the truth value can range from completely true tocompletely false. Crisp input refers to data supplied by the consumer. The fuzzification step aids in the conversion of inputs. This enables user to transform crisp numbers into fuzzy sets. Sensors measures Crisp inputs and sent to the control system for further processing. For example, room temperature, pressure, and so on.

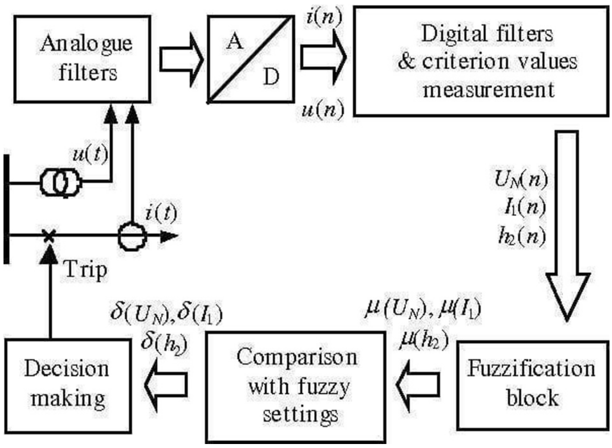

Fig 9: Architecture of Fuzzy Logic.

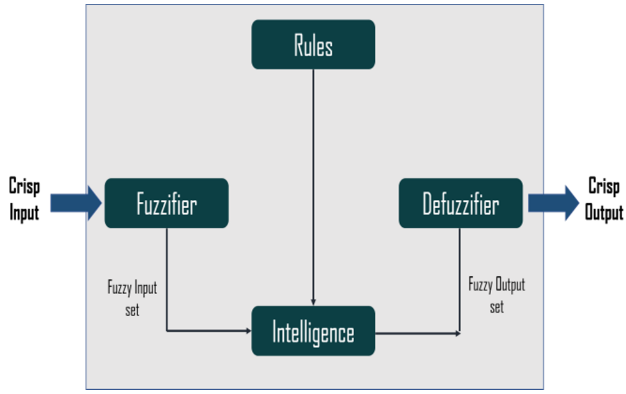

Fig 10: Fuzzy Logic Approach to Over current Protection.

D. Intelligence (Inference Engine)**:** This is an important part where it will match your fuzzy input to each rule and produce an output**.**

E. Defuzzification:

Eventually, the Defuzzification procedure is accustomed to transform the fuzzy sets into a crisp value. There are numerous approaches available; therefore, you must pick theone that is best fit to be employed with an expert system.

Rule Base: It is composed of a set of guidelines as well as IF- THEN requirements established by professionals to regulate system for making decisions using linguistic information. Technological improvements in fuzzy theory offer various sophisticated techniques for developing and adjusting fuzzy controllers. The majority of these advancements diminish the number of fuzzy rules.

F. Over Current Protection Using a FuzzyApproach

This paper investigates a fuzzy approach to MV feeder over current protection. To issue trip decisions, the developed protection solution makes use of fuzzy signal processing and Fuzzy comparisons.

In modern digital protection relays, the first three blocks namely analogue filters, A/D converters, and digital signal processing units, are typically used. At the end of this path, certain criterion values are returned, on the basis of which the protection decision is made, typically by comparing themto predefined thresholds or characteristics. Additional signal processing is used here to obtain a fuzzified criterion. We willcollect data from CTs and PT's. All of the relays we use are fuzzy and numerical resulting in them being converted to digital through the use of an A/D converter. Current or voltage values are measured in digital filters and criterion value measurement blocks. The crisp data is fed into the fuzzification block, which converts it to fuzzified data. In contrast to fuzzy settings, a block inference engine isused, where the data is checked against your fuzzy-based rules and the last conclusion is reached. A trip signal will beissued based on the outcome.

G. Adaptive Network-Based Fuzzy InferenceSystem (ANFIS)

Zadeh proposed fuzzy logic in 1965, and it is a popular computing framework that includes fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. Combining fuzzy systems and ANN models results in an efficient tool that takes advantage of the ANN models' learning features while outperforming an inference fuzzy model. The neuro-fuzzy system corresponds to a Takagi-Sugeno fuzzy model, with the weights of the ANN model being similar to the parametersof the fuzzy system. Jang developed this structure, named ANFIS, in 1995, as well as solve engineering problems [8]. ANFIS is made up of an adaptive ANN and a fuzzy inferencesystem, and it determines a set of parameters by combining gradient descent, back propagation, and a least- squares algorithm. ANFIS is a responsive mathematical structurecapable of computing-level estimation of a wide range of complex nonlinear systems. Fig.11 represents the architecture of ANFIS controller. There are five layers in the ANFIS structure

Layer 1: This layer's nodes are all adaptive. Membership functions such as the generalize bell membership function as well as the Gaussian membership function are employed in node functions.

Layer 2: The firing strength of a directive is characterized byeach node output in this layer.

Layer 3: Each node represents the rule's normalized firing strength.

Layer 4: Each adaptive node in this layer has a node functionthat indicates how the rules contribute to the overall output. This layer's parameters will be indicated as subsequent parameters.

Layer 5: The sum of all rule outputs is computed by a singlenode.

As a result, precision improves. The ANFIS structure was trained with ten epochs and triangular membership functions. There are 78 nodes with twenty-seven linear and twenty-seven non-linear parameters each. There are a total of 200001 training data pairs. Twenty-seven fuzzy directives were utilized in training.

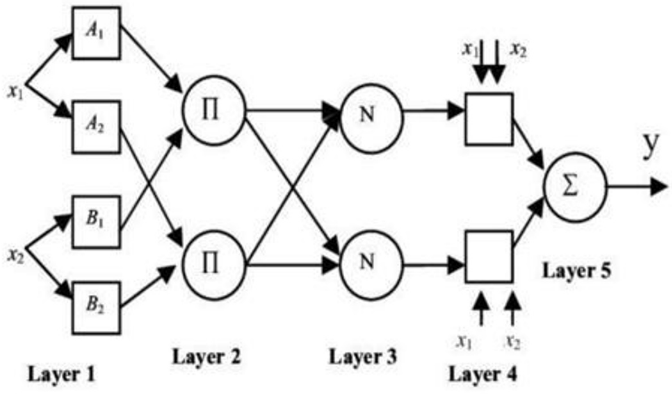

Fig 11: Architecture of ANFIS.

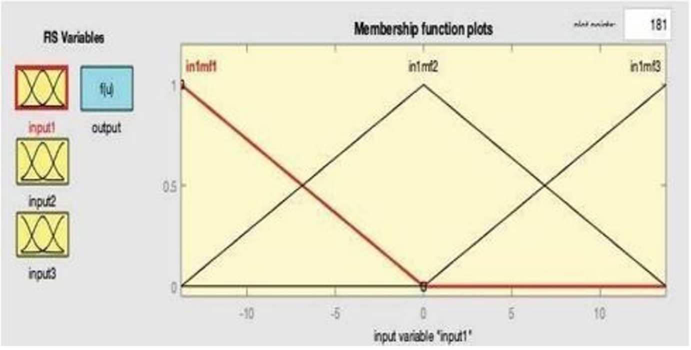

Fig.12: Input 1 of the controller.

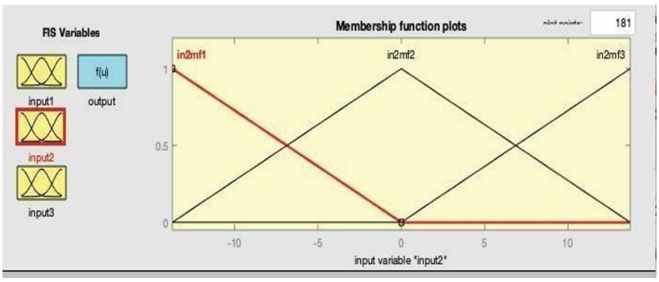

Fig.13: Input 2 of the controller.

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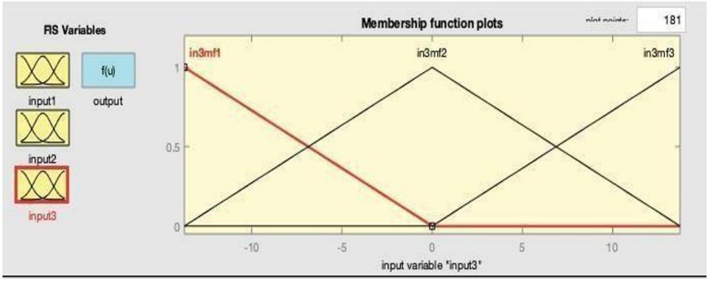

Fig.14 Input 3 of the controller.

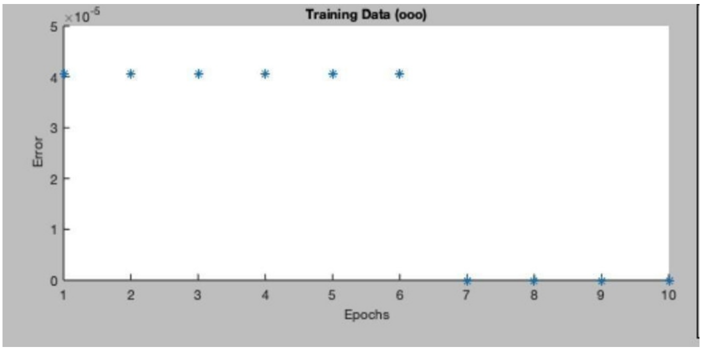

Fig 15: 10 Epochs error in training.

5. Results

The results of monitoring the DSTATCOM with an ANFIS-based technique are presented. At the common coupling point, the source current and voltage are also in phase. As a result, the unit power factor is obtained. The harmonic distortion total of the source current observed is 1.51%, which is less than the ANN result. Table.1 shows the Comparative analysis between ANN and ANFIS [7].

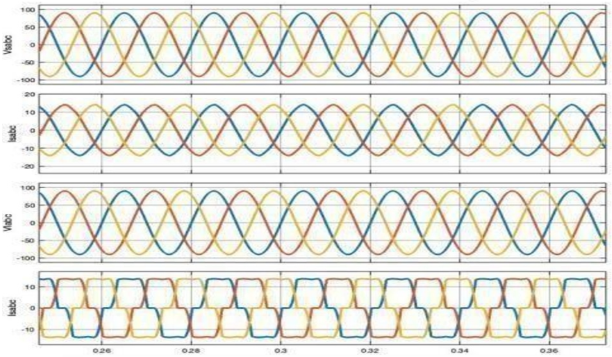

Fig 16: Waveforms generated by ANFIS.

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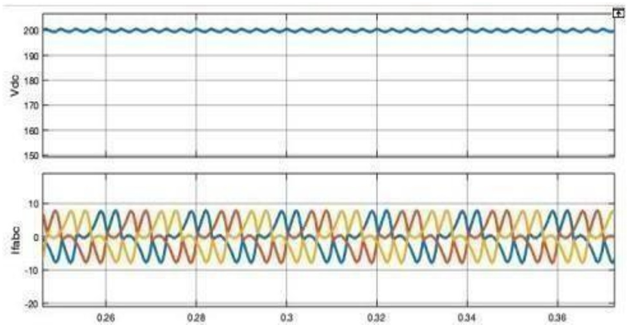

Fig 17: Waveforms generated by ANN.

Table.1 Comparative analysis of ANN & ANFIS Controller

DSTATCOM Control Algorithm	Rise Period	Maximum Overshoot	Resolving ng Period	THD(%)	Convergence Rate
ANN	0.0013	4.421	0.0139	1.65	minimal
ANFIS	0.0014	4.021	0.0135	1.51	minimal

1) RISE PERIOD

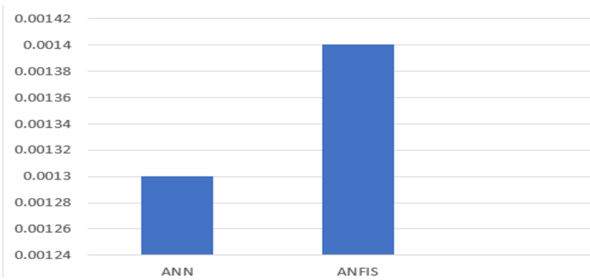

Fig 18: Comparison based on Rise Period.

2) Maximum Overshoot

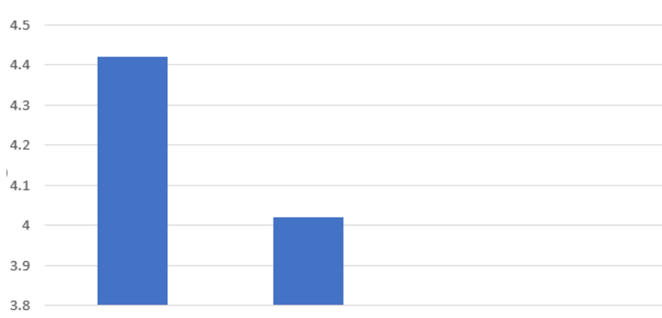

Fig 19: Comparison based on Maximum Overshoot.

3) Resolving Period

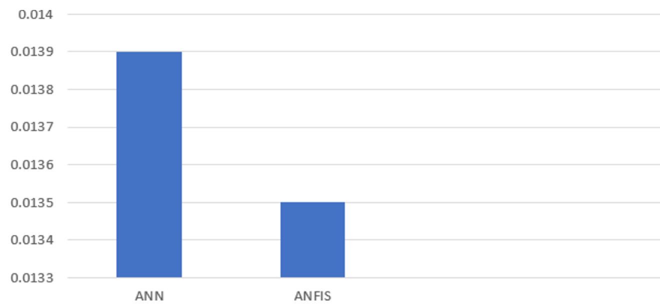

Fig 20: Comparison based on Resolving Period.

6. Conclusion

In this paper, we used Artificial Neural Network (ANN) andAdaptive Neuro Fuzzy Inference System (ANFIS) control methods to improve power quality compensation. In terms of performance, the ANFIS control technique outperformed the ANN technique. The ANFIS-based technique employs both Fuzzy Logic and the ANN algorithm to provide greater accuracy and lower THD in source current under varying load conditions. As a result, ANFIS has proven to be a more efficient and effective method of increasing power quality. This method yields better results and power quality.

References

[1] Bhim Singh and Jitendra Solanki," A Comparison of Control Algorithms for DSTATCOM," IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 7, pp. 2738 – 2745, JULY 2009.
[2] Alka Singh and Bhim Singh, "Power Quality Issues related to Distributed Energy Source Integration to Utility Grids," Annual IEEE India Conference (INDICON), December 2010.
[3] R. Deepak Singh, T. Praveen Kumar, Dr. K. Sumanth," Simulation of SRF Based DSTATCOM With Grid Connected PV Generation System Using Fuzzy Logic Controller For Reactive Power Management," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol 5, NO.7,pp 6493-6501,July 2016.
[4] H. Prasad and T. D. Sudhakar, "Power Quality Improvement by Mitigation of Current Harmonics using D – STATCOM," Third International Conference on Science Technology Engineering & Management (ICONSTEM), March 2017.
[5] Bhim Singh and Sabha Raj Arya, "Back-Propagation Control Algorithm for Power Quality Improvement using DSTATCOM," IEEE Transactions on Industrial Electronics, vol. 61 ,No. 3 , pp. 1204– 1212, March 2014.
[6] B. Singh, A. Chandra and K. Al-Haddad, Power Quality: Problems and Mitigation Techniques, John Wiley and Sons, U.K., 2015.
[7] Ankita Arora and Prerna Gaur," Comparison of ANN and ANFIS based MPPT Controller for grid connected PV systems," Annual IEEE India Conference (INDICON), December 2015.
[8] Manoj Badoni, Alka Singh and Bhim Singh, "AdaptiveNeuro Fuzzy Inference System Least Mean SquareBased Control Algorithm for DSTATCOM," IEEE Transactions on

https://doi.org/10.1051/e3sconf/202454010015

Industrial Informatics, vol. 12, no. 2, pp. 483 – 492, April 2016.
[9] Yang Xiao-ping, Zhong Yan-ru and Wang Yan," A Novel Control Method for DSTATCOM Using Artificial Neural Network," CES/IEEE 5th International Power Electronics and Motion Control Conference, August 2006.
[10] Kandi Bhanu Prakash, "Modeling and Control of UPQC", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 8, Issue. 11, pp. 1-5, Nov. 2022.