A NOVEL APPROACH FOR ISLANDING DETECTION FOR GRID CONNECTED PV SYSTEM USING ANFIS CONTROLLER

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ABSTRACT

This project proposes a novel approach to detect islanding in grid-connected photovoltaic (PV) systems using ANFIS controller. Islanding occurs when a portion of the electrical grid becomes electrically isolated from the main power grid, which can cause voltage and frequency deviations, leading to potential safety hazards. The proposed approach utilizes ANFIS controller to detect islanding in PV systems quickly and accurately under various operating conditions. The aim is to provide a reliable and efficient solution for islanding detection in PV systems, ensuring the safety and stability of the power grid.

The project involves simulations to evaluate the performance of the proposed approach. The results show that the proposed approach provides a robust and efficient solution for islanding detection in PV systems, enabling prompt disconnection from the main grid, thus ensuring safety and stability. The proposed approach can be applied to other renewable energy systems and has significant potential to contribute to the sustainable development of the power grid.

Keywords:- Photovoltaic (PV), Low Voltage Ride Through Capability (LVRT), Adaptive Neuro-Fuzzy Inference System (ANFIS).

I. INTRODUCTION

For the past decade, the penetration of Renewable Distributed Energy Resources (R-DERs) such as solar photo voltaics, and wind energy systems in the distribution systems has significantly increased. One of the most serious issues in grid-connected R-DERs is the unplanned islanding formation and its operational issues. Islanding[2] is a situation in which a distributed energy resource continues to energize a portion of an Area Electric Power System (EPS) through the Point of Common Coupling (PCC) while this portion is electrically disconnected from the rest of the area EPS. Failure to detect the islanding will not only create risks to the working personnel but also to the electric equipment.

The islanding detection methods are classified into local and remote methods. The local methods are based on measurement of electrical parameters, i.e., voltage, current, frequency and phase at the point of common coupling (PCC) and are further divided into passive and active methods. The passive methods are simple and do not affect the power quality at PCC, whereas the active methods inject the disturbance at the inverter's output and the islanding event is detected by taking measurement of electrical parameters i.e., voltage, frequency and impedance at PCC. The remote methods are based on the communication infrastructure between main grid and microgrid. The remote methods require large amount of investmentand are suitable for multi-inverter systems. The recently developed hybrid methods are based on passive and active methods and utilizes the benefits of both methods.

Methods

A. Passive Islanding Detection Techniques

B. Active Islanding Detection Techniques

Passive Islanding Detection Techniques

This method measures the system parameters and compares them with a predetermined threshold value for islanding detection. The measured system parameters at the DG terminal or PCC include voltage, frequency, phase angle and harmonics. The passive islanding detection techniques[4,5] working principle is depicted. Passive islanding detection techniques are mostly used by power utilities as they are simple, low cost, do not degrade the power quality and have a fast detection speed within 2 s, as recommended by IEEE 1547. However, these methods have a large NDZ, the error detection rate is high and setting the threshold requires special consideration. Some of the popular passive IDMs are described below.

Harmonic Detection (HD)

The HD method is based on comparing the Total Harmonic Distortion (THD) measured at the PCC and a predefined THD to detect islanding. When the microgrid is operated in grid-connected mode, the PCC voltage is a normal sine wave, and the harmonics generated by the load and the inverter are negligible.

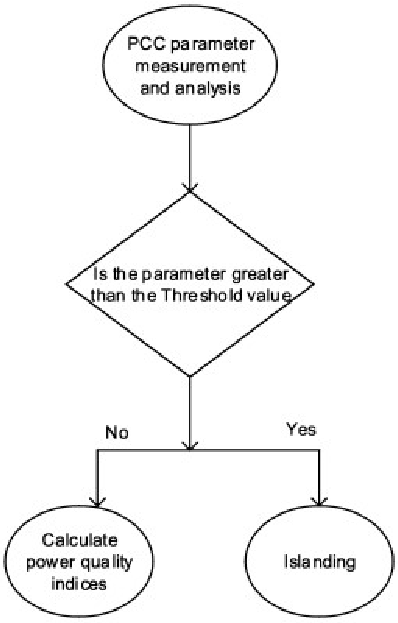

Fig.1. Passive Islanding Detection technique

However, during islanding mode of operation, the harmonics produced by the inverter will distort the PCC voltage and, hence, islanding will be detected. This method is easy to implement and is also effective for multiple DGs connected to the same PCC with a detection time of 45 ms. However, selecting the threshold is difficult since grid disturbance can cause error detection, and it might fail to detect islanding for loads with a large quality factor Q and a large NDZ.

Rate of Change of Frequency (ROCOF)

When the microgrid is disconnected from the main grid with a power mismatch, the frequency will change. The ROCOF method works by measuring df/dt for a few cycles and comparing it with a setting threshold. Islanding will be detected if the measured df/dt exceeds the predefined threshold Compared to OUV/OUF, this method has a fast detection time of 24 ms, is more sensitive and highly reliable

Rate of Change of Power Output (ROCOP)

This method measures the changes in the DG power output (dP/dt) over a few cycles and compares it with a setting threshold to detect islanding. Generally, a loss of the main grid produces load changes, and dP/dt measured after the microgrid is islanded is greater than dP/dt measured before the microgrid is islanded. This method has a fast detection, with a detection time of between 24 and 26 ms, and the power imbalance between the DG units and the load does not affect the detection speed.

Phase Jump Detection (PJD)

The working principle of PJD is to monitor the phase jump between the inverter's terminal voltage and the current for islanding detection. During grid-connected mode, the inverter's current will be synchronized with the voltage at the PCC using a Phase Locked Loop (PLL) to detect the zero crossing of the voltage. In islanding operation, since PLL works only at the zero crossing of the voltage, the inverter output current remains unchanged. However, the voltage will have a sudden jump due to the load phase angle. Comparing the measured phase difference with a predefined threshold can detect islanding.

Active Islanding Detection Techniques

The performance of active detection[6] methods is based on the perturbation and observation concept. These methods perturb system parameters such as frequency, voltage, currents and harmonics. In the presence of a stiff grid, the amplitude of the variation at the PCC is negligible since the grid parameters are dominant.

However, during the islanding phenomenon, injecting[7] a disturbance at the PCC results in a significant variation in the DG parameters. Figure 2 shows the basic working principle of active islanding detection techniques

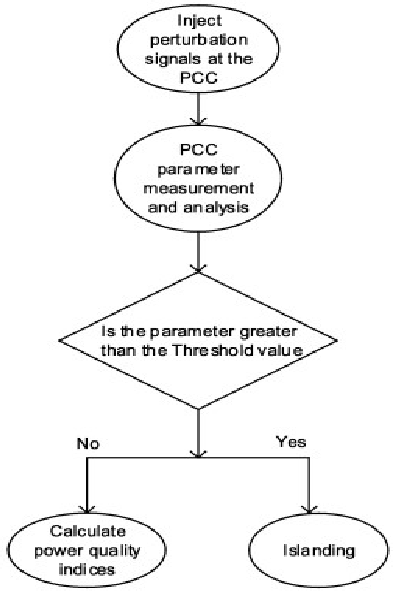

Fig.2. Active Islanding Detection technique

Compared to passive islanding techniques, active techniques have a reduced NDZ and low error detection rate. However, active techniques deteriorate the power quality, and additional power electronic circuits are required to inject the perturbations. Some of the popular active IDMs are described below

Active Frequency Drift (AFD)

An AFD works by slightly distorting the inverter current waveform injected into the PCC. In grid-connected mode, the voltage and frequency are controlled by the grid and are stable. When islanding occurs, the voltage zero crossing occurs earlier than expected because of the distortion of the injected current waveform. This results in a phase error between the inverter's output current and the voltage, which makes the frequency of the inverter output current drift to eliminate the phase error. This drift in frequency again causes an earlier zero crossing than expected..

Frequency Jump (FJ)

Frequency jump is a modified version of AFD, as it also inserts dead zones into the current waveform. However, unlike AFD, where dead zones are inserted into every cycle, in FJ, it is inserted in every three cycles. In grid-connected mode, the waveform of the voltage at the PCC is not distorted, despite the inverter's distorted current. During islanding, there will be a variation in voltage frequency that will be used to detect islanding . Similar to AFD, this method might fail to detect islanding for multiple inverters working in parallel.

Active Frequency Drift with Positive Feedback (AFDPF)

This method is an extension of AFD and works by applying a positive feedback to increase the chopping fraction, which in turn accelerates the frequency deviation to detect islanding more effectively compared to AFD, this method has a small NDZ however, it still affects the power quality .

Sandia Frequency Shift (SFS)

SFS is also an extension of AFD and works by applying a perturbation to the frequency of the inverter's voltage with a positive feedback. In grid-connected mode, the voltage frequency of the PCC is maintained by the grid, even if the method attempts to change it. However, during islanding the chopping fraction increases with the increase of f at the PCC, which also increases the frequency of the inverter.

Sandia Voltage Shift (SVS)

The working principle of SVS and SFS is similar, in that it perturbs the voltage amplitude of the PCC with a positive feedback to change the inverter's output current and power. In grid-connected mode, the power change does not affect the voltage amplitude of the PCC, whereas in island mode, the power change affects the voltage amplitude, which can be used to detect islanding . SVS is easy to implement; however, its disadvantage are that it lightly degrades the power quality, and the inverter's operation efficiency might be reduced because of the change in the output power

Sliding Mode Frequency Shift (SMS)

SMS perturbs the voltage phase of the PCC with a positive feedback and monitors the frequency deviation to detect islanding. In grid-connected mode, the microgrid injects active power to the main grid, and its power factor is close to unity, with the phase angle between the inverter current and the PCC voltage close to zero. During islanding operation, the phase angle of the load and the frequency will vary, and if the frequency variation exceeds the threshold, islanding can be detected.

- In the Island mode, the microgrid is operated as an independent power source by controlling its own voltage and frequency. The Distributed Generation (DG) units in this mode are controlled and operated in voltage control mode.
- In Microgrid, Islanding occurs when the main grid power is interrupted but, at the same time, the microgrid keeps on injecting power to the network, which can be intentional or unintentional.
- Intentional Islanding is a controllable operation mode required for the maintenance of the main utility.
- Unintentional Islanding is an uncontrollable operation caused by regular faults such as line tripping, equipment failure, or other un-certainties in the power system and may degrade the power quality, overload the system, damage equipment and cause safety hazards.
- Therefore, detecting the Islanding condition and effectively disconnecting the microgrid within a specified time interval from the distribution network is a necessity.

The main objective of this research is to protect the grid connected PV systems from un-intentional Islanding formation by using adoptive Islanding detection methods.

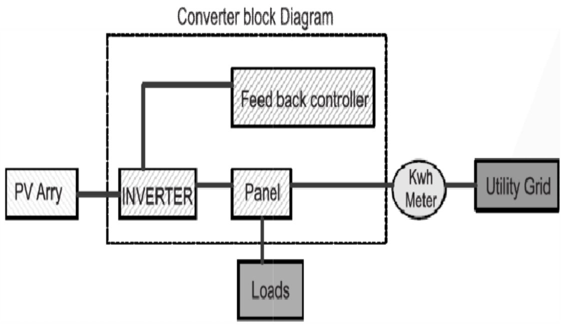

Fig.3. Block diagram of grid-connected photovoltaic system

The following steps are taken in order to finish the donations listed above: Section II and Section III provides the explanation and of two methods named as PI converter and Adaptive Neuro-Fuzzy Inference System (ANFIS) along with the results respectively. The key conclusions, comments, and methodology comparisons are presented in section IV. Conclusions and future scope are provided in section V.

II. GRID CONNECTED PHOTOVOLTAIC SYSTEMS BY USING PI CONTROLLER

Proportional-Integral (PI) controllers are a type of feedback control system commonly used in industrial automation and process control. They are a combination of two basic control techniques: proportional control and integral control.

Proportional control is a type of control that adjusts the output of a system in proportion to the difference between the desired set point and the actual output. The proportional controller calculates an error signal by subtracting the desired set point from the actual output and then multiplies this error signal by a proportional gain. The proportional gain determines how much the output should be adjusted for a given error signal.

Integral control, on the other hand, is a type of control that considers the accumulated error over time and adjusts the output accordingly. The integral controller calculates the integral of the error signal over time and multiplies this integral value by an integral gain. The integral gain determines how much the output should be adjusted for a given integral error signal.

A PI controller combines proportional and integral control to provide a more effective control system. The proportional component provides a fast response to changes in the error signal, while the integral component eliminates any steady-state error and ensures that the output converges to the set point over time.

PI controllers are widely used in process control applications, such as temperature, pressure, and flow control in chemical and manufacturing industries. They are also used in motion control systems, such as robot control and servo systems.

TYPES OF PI CONTROLLERS

There are several variations of PI controllers that are commonly used in industrial control systems. Some of the most common types include:

Standard PI Controller:

This is the most basic type of PI controller, which combines proportional and integral control. The result produced by the controller is the combination of the proportional and integral components.

Series PI Controller:

In this type of controller, the integral term is placed in series with the proportional term, rather than adding the two terms together. This type of controller is used when the system dynamics are slow compared to the rate of change of the input signal.

Parallel PI Controller:

In this type of controller, the integral term is added in parallel with the proportional term. This type of controller is used when the system dynamics are fast compared to the rate of change of the input signal..

In recent years, advancements in computing and machine learning have enabled the development of more sophisticated control systems, including model-based predictive controllers and adaptive controllers. However, PI controllers continue to be widely used and are often the first choice for many engineering applications.

To improve the power connectivity of the PV systems into the grid, the PI controller for only the LVRT has been made available in all of these published studies. In addition, they arrived at the PI control parameters by a process of trial and error. Instead of relying just on trial and error, various optimisation techniques were applied to achieve the best possible tuning of the PI control settings.

- The 100 kW Grid-Connected PV Array (R-DER) detailed model is depicted in the picture. It is made up of a dc-dc boost converter, a Voltage Source Converter (VSC), an MPPT controller, and a 100 kW photovoltaic (PV) array. STC: 1000W/m2 solar irradiance, 25°C PV module temperature
.

- The PV array is made up of 330 Sun Power modules, with 66 strings of 5 series-connected modules connected in parallel to deliver a maximum power of 100.7 kW (66 strings × 5 modules × 305.2 W/module) and 273.5 V (5 modules × 54.7V/module).

- At the PV array's output, a 5-kHz dc-dc boost converter is utilised to increase the DC voltage to 500 V. A DC-DC MPPT Boost Control subsystem, which automatically adjusts and optimises the switching duty cycle to produce the necessary voltage to extract the most power, is used to implement the MPPT in the boost converter.

- A three-level, three-phase VSC operating at 1.98 kHz transforms 500V DC into 260V AC while preserving unity power factor.

- The VSC's harmonics are filtered using a filter that has a 10kVAr capacitor bank (C) and a 25 µH inductor (L).
- To step the voltage to 25 kV and connect to a 25 kV distribution system, a 100 kVA, 0.26 – 25 kV transformer is utilised.

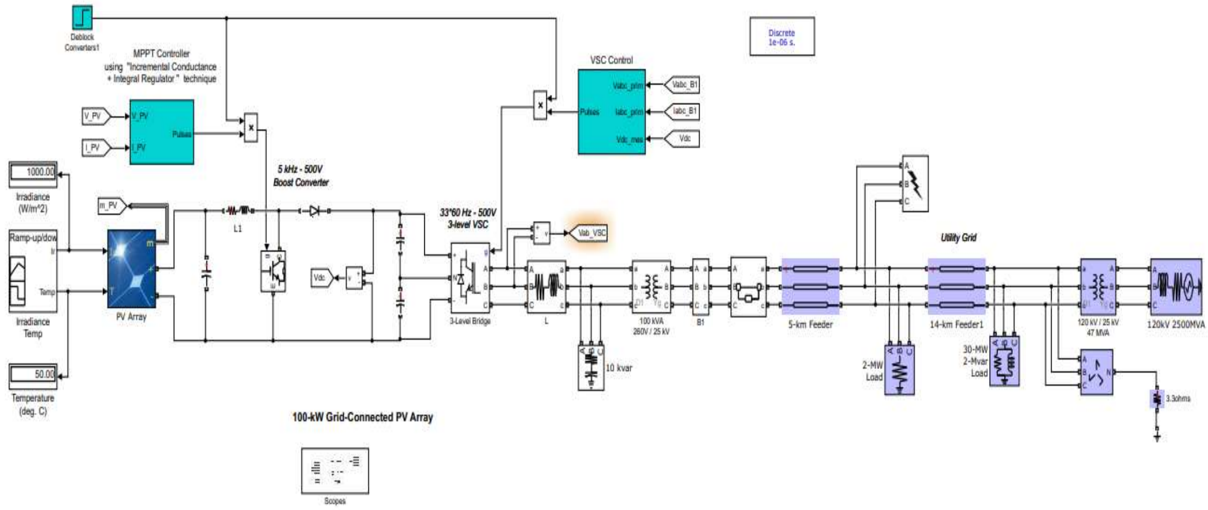

Fig.4. Simulink model of Grid-connected Photovoltaic system

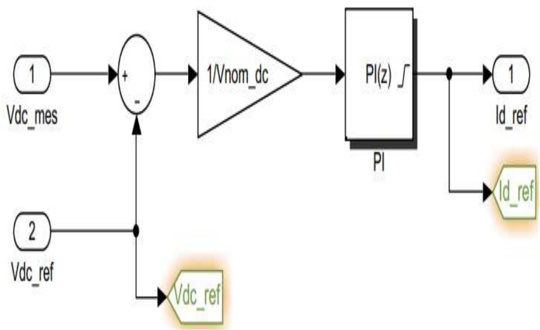

Fig.5.Grid-connected Photovoltaic system using PI Controller

Due to this shortcoming, the PI controller parameters will need to be adjusted, which cannot be done via an online method. Furthermore, a major drawback of using a traditional PI controller as a DC link controller is that low bandwidth is preferred in order to avoid low frequency ripples that could affect the DC bus voltage feedback control . The primary motivations for employing adaptive control techniques are the aforementioned limitations.

RESULTS

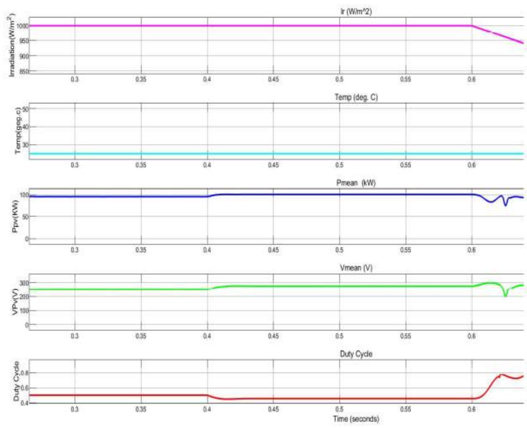

Fig.6. Different parameters with respect to time

From the above figure, we can observe the duty cycle, voltage, power and temperature. For PI controller with respect to the time and changes occurred at 0.6 sec in all parameters.

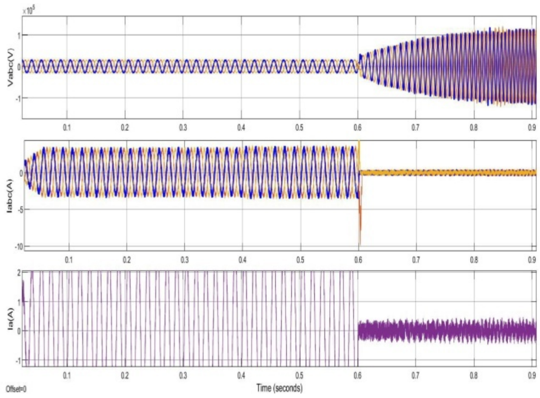

Fig.7. 3-phase voltage variation by using PI-controller

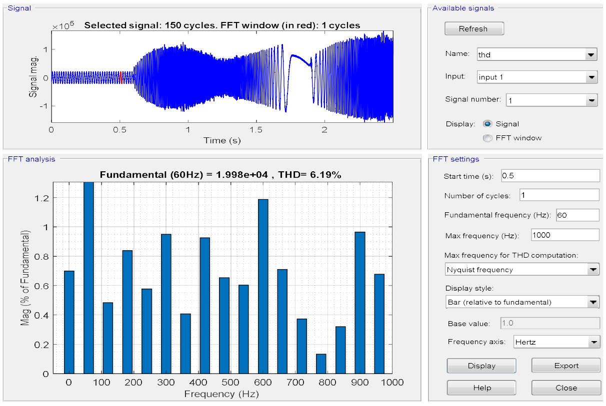

Fig.8. Voltage THD (Total Harmonic Distortion) using PI controller

From the above, we can observed the voltage Total Harmonic Distortion(THD) is 6.19% by using PI-controller.

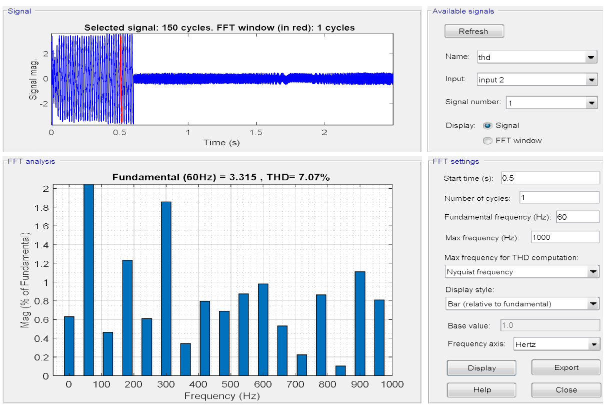

Fig.9. Current THD (Total Hormonic Distortion) by using PI-controller

7.07% of current Total Harmonic Distortion (THD) observed in the above figure by using PI-controller.

III. ISLANDING DETECTION APPROACH USING ANFIS CONTROLLER

Popular soft computing methods fuzzy logic and artificial neural networks are used in the Adaptive Neuro-Fuzzy Inference System (ANFIS). The neural system[17] has many inputs and various outputs, while the fuzzy logic system has many inputs and just one output. This combination is used in nonlinear applications and is referred to as ANFIS. It gives accuracy to non-linear systems. This makes ANFIS the most widely used controller and makes it better than other controllers.

ANFIS is capable of learning from data and utilising the data to predict results. The learning algorithm has the ability to modify the weights of the connections among the neurons in the network.

Adaptive network-based fuzzy inference system (ANFIS) is the name given to an artificial neural network that is built upon the Takagi-Sugeno fuzzy inference system. The approach was developed in the early 1990s. It integrates both neural networks and fuzzy logic, thus it can combine their benefits into a single framework.

There are two distinct parts of the network structure: the premise and the and the sections that come after. More precisely, the architecture is composed of five layers. The first Which membership functions match the input values are determined by the layer. It's called the fuzzification layer a lot. The membership degrees of each function are computed using the premise parameter set, {a, b, c}.

The second layer is responsible for generating the firing strengths of the rules. Because of its purpose, the second layer is referred to as the "rule layer". The third layer's job is to normalise the calculated firing strengths by dividing each value for the overall firing strength. The fourth layer receives the normalised values along with the 23 consequence parameter set {p,q,r}. The final layer receives the defuzzified values returned by this layer and uses them to generate the final output.

Structure Of ANFIS:

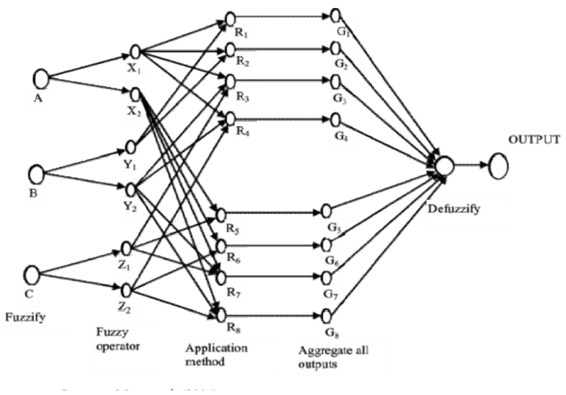

Fig. 10: Structure of ANFIS

The node functions in each layer are as described below.

Fuzzification Layer:

The input variables in this layer are moved to fuzzy sets using membership functions. The fuzzy sets represent the language variables that convey the ambiguity and imprecision of the system.

Rule Layer:

The rule layer applies fuzzy if-then rules to the input variables. The rules are expressed as a set of fuzzy if-then statements that are derived from data or developed based on expert knowledge.

Normalization Layer:

In this layer, the firing strength of every rule is normalised to ensure that the overall firing strength equals one.

Defuzzification Layer:

The defuzzification layer combines each rule's output to provide a distinct output value. A number of defuzzification methods, such as weighted average, maximal defuzzification, and centre of gravity, may be used, depending on the application.

Learning Layer: In the learning layer, the ANFIS controller adapts to system changes. The learning layer consists of a neural network that has been trained to comprehend membership functions and fuzzy rules. The neural network is trained using a hybrid learning strategy that blends back propagation and least squares methods. 24 When the ANFIS controller is in operation, it takes in input data and outputs a value based on the fuzzy rules. The output value is then fed back into the system as feedback to change the input values. The ANFIS controller adapts to system changes by updating the membership functions and fuzzy rules through the learning layer.

All things considered, the ANFIS controller uses fuzzy logic to represent the uncertainty and imprecision of the system and neural networks to learn from and adapt to changes in the system. Because of its hybrid approach, the ANFIS controller is a useful tool for managing complex systems with nonlinear or unpredictable dynamics

Total Harmonic Distortion (THD)

THD is a key metric used in this paper to assess the performance of the PI controller and the ANFIS controller in the power system. The comparative analysis in your paper shows the following results for THD: With the use of PI controller, then THD was reduced to 7.07%. The ANFIS controller achieved a further reduction, bringing the THD down to 3.73%. These results indicate the effectiveness of both controllers in reducing harmonic distortion in the system, with the ANFIS controller being particularly effective in minimizing THD.

THD Formula:

The formula for calculating the THD of a waveform (either voltage or current) is expressed as:

$$\text{THD (\%)} = \frac{\sqrt{\sum_{n=2}^{\alpha} Vn^2}}{|V1|}$$

Where, Vn is the RMS (Root Mean Square) value of the n-th harmonic.

- V1 is the RMS value of the fundamental frequency (1st harmonic).

The sum is taken from the 2nd harmonic to the highest significant harmonic

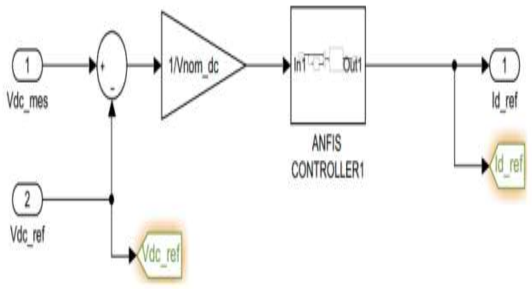

Fig.11. Grid-connected photovoltaic system using ANFIS Controller

IV. RESULTS AND DISCUSSION

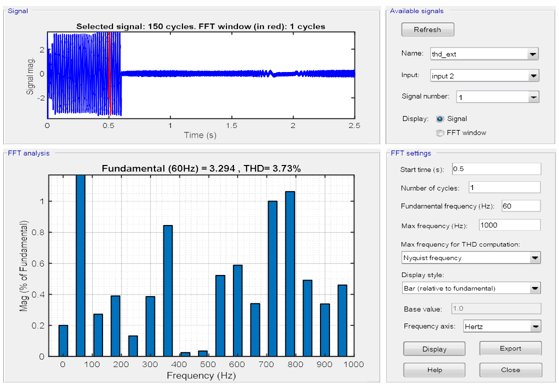

Fig.12. Voltage Total Hormonic Distortion(THD) by using ANFIS based controller

From the above figure, we observed the duty cycle, voltage, power and temperature with respect to time and we can observe that the changes occurred at 0.6 sec in all parameters.

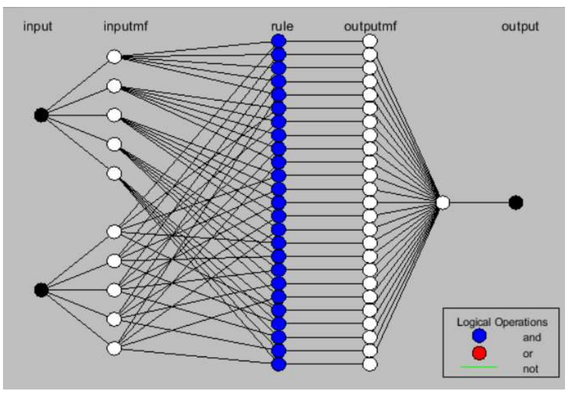

Fig.13. Output result of ANFIS controller

By using ANFIS based controller, we observe that the THD value of 2.51%. Then we said that, ANFIS based controller is the best controller compared to PI controller, because we can reduce 6.19% of THD(PI) to 2.51% of THD(ANFIS).

Note: According to IEEE standard, THD value is less than or equal to 5%.

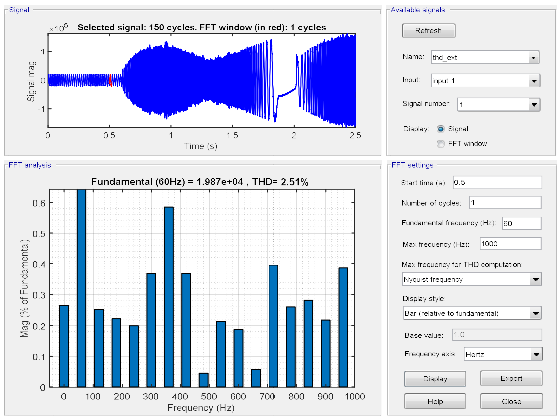

Fig.14. Current Total Hormonic Distortion(THD) by using ANFIS based controller

We can observed that, the Total Hormonic Distortion is 3.73% by using ANFIS based controller is the best when compared with PI controller, because THD reduced from 7.07% to 3.73% by using the ANFIS controller.

COMPARISON TABLE:

CONTROLLER	VOLTAGE THD (%)	CURRENT THD(%)
PI CONTROLLER	6.19	7.07
ANFIS CONTROLLER	2.51	3.73

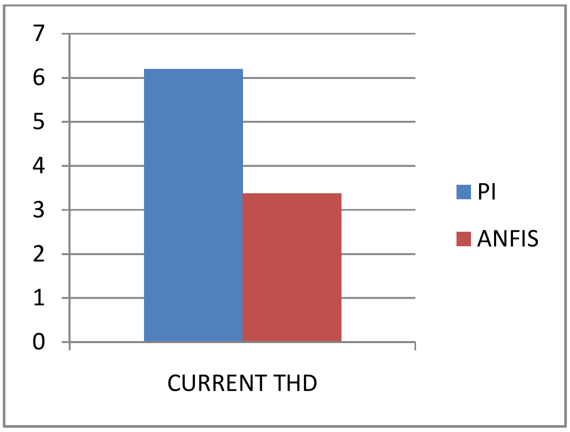

Fig.15. Graphical Representation of Current THD

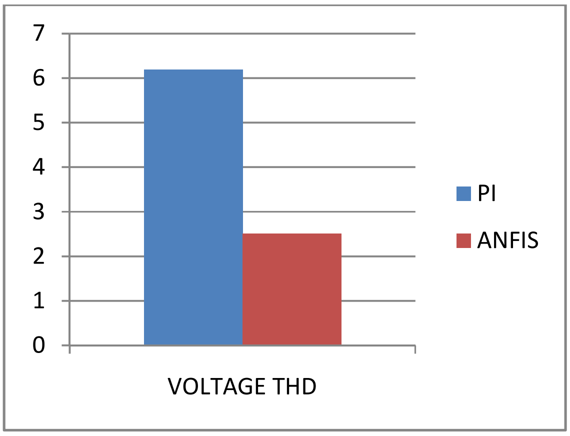

Fig.16. Graphical Representation Of Voltage THD

V. CONCLUSION AND FUTURE SCOPE

Based on the information provided in the title, it appears that a novel approach for islanding detection for grid-connected PV (photovoltaic) systems has been developed using adaptive techniques. Islanding refers to the situation when a portion of the power system continues to generate power even though it has been disconnected from the rest of the system. This can create safety issues and damage equipment if not detected and addressed quickly.

However, detecting islanding in such systems can be challenging, and traditional methods may not be effective. Harmonics is the instance of the growing intricacy of power quality problems. Artificial intelligence-developed solutions used by active filters are very good at reducing harmonics and balancing THD.

We suggest using the ANFIS based control approach as a substitute to the PI CONTROLLER within the context of this paper. Two distinct scenarios are simulated using Matlab-Simulink,which then displays results. Simulation results show that in terms of lowering THD in the source current, the suggested ANFIS based control performs better than alternative scenario.

In this work it has been observed THD with Grid connected PI based controller is reduced to 7.07% and with ANFIS based control further THD reduced to 3.73% as CURRENT THD and with Grid connected PI based controller is reduced to 6.19% and with ANFIS based control further THD reduced to 2.51% as VOLTAGE THD.The performance of these two Controllers has been studied and compared in MATLAB. It has been seen that, ANFIS based controller is more efficient to reduce THD than Grid connected PI Controller.

The ANFIS based controller has the disadvantages of slow converagence and unable to easy localization, in order to improve these we can refer ADVANCED ANFIS based controllers.

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