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PERFORMANCE ANALYSIS OF ANFIS CONTROLLER BASED VSC IN GRID CONNECTED SOLAR PV SYSTEM

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Abstract
The Adapative Neuro-Fuzzy Inference System (ANFIS) controller for DC Micro-grid protection is presented in this paper. This ANFIS controller is used to control the voltage source converter's (VSC) pulses while also lowering harmonic voltages. When a fault develops on the DC-Micro grid side of the proposed system, VSC is employed to protect the main grid and isolate it .The MATLAB/SIMULINK 2018b programme is used to design and test the complete proposed system .According to the simulation results, the ANFIS controller has given less THD values of voltages when compared to traditional PI controller.
Keywords: Fault protection ,Voltage Source Converter(VSC),ANFIS controller

1.Introduction
In recent years, there has been a lot of interest in microgrids because of the huge advantages they provide to users and power grid managers. With the aim of improving energy quality, lowering emissions, reducing grid congestion and energy loss, and most importantly improving the economics of the overall network system, scientific research and studies have lately tended to concentrate on the creation of tiny networks. In order to provide loads remotely, new production and transmission infrastructure is not always necessary. Small networks significantly reduce this demand. To further assure the dependability and resilience of the network and clients, it is simple to connect small networks with one another inside a single network in the event of faults or disruptions [1],[2].
The microgrid must be disconnected from the main network and run separately from the local load in the event of any failure when operating in the grid-tied mode [5]. Grid-connected mode can therefore be categorised as either island-mode or transitioning between these two modes [6].
The bus voltage in a DC microgrid fluctuates in response to changes in load demand or electricity production. Because of this, controlling the voltage requires a reliable control system. The voltage of the DC micro grid is frequently controlled by PI controllers [7]. The ANFIS, on the other hand, provides significant benefits over conventional controllers.
Numerous systems in a variety of technical and scientific fields have been successfully controlled using neural network controllers [10].Due to its capacity to map nonlinear "input-output" by a series of "qualitative/quantitative" if-then rules, the ANFIS controllers are among those neural network-based controllers that are most frequently utilised in nonlinear classification applications [11], [12]. The HESS of a PV microgrid is controlled by the ANFIS controller in the current study. The ANFIS controller's performance is compared to that of various currently used controllers, including the fuzzy controller [10], [15] and the traditional PI controller [17].

2.Problem Identification
A Direct Current Micro-Grid has been favoured when developing, manufacturing, and distributing DC systems. One of the common problems with this type of DC system is the protection and operation of the DC microgrid when the load changes. To solve this, a PI controller is used with the PWM technology in a voltage source converter (VSC) to produce pulses, but the harmonics across the VSC is 68.65% [18], so an ANFIS controller is used to lower these harmonics.

3.System Modelling

3.1.PV Array

A PV array is made up of several solar cells that work in accordance with the photovoltaic effect.In this PV array, a single diode is modelled. A MATLAB function is developed for an ideal PV array that performs as a controlled current source with output current. To make this system function, resistance is connected in series with the output of the regulated current source. It is expected that the PV array has relatively little parallel resistance. The open-circuit voltage, short-circuit current, number of solar cells, temperature, and ideality factor must be set to the desired value in order to provide the controllable current output [11].

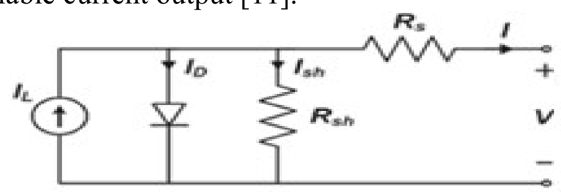

Fig 1: Single diode model of a PV cell

$$I= I_L-I_D-I_{sh} \quad (1)$$

$$V_{sh}=V+IR_s \quad (2)$$

The shunt branch current and the diode current of the PV cell is shown as,

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V+IR_s}{R_{sh}} \quad (3)$$

The current through the diode is given by

$$I_D = I_0[e^{\frac{V_{sh}}{nV_t}} - 1] \quad (4)$$

$$V_t = \frac{KT}{q} \quad (5)$$

$$I = I_L - I_0\left[e^{\frac{V_{sh}}{nV_t}} - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (6)$$

Where,

I_{sh} -Current through the shunt resistor(A)
I_L-Current generated by PV(A)
I –Current through load(A)
I_D-Current through diode(A)
R_s - Equivalent circuit series resistance(Ω)
R_{sh}- Equivalent circuit shunt resistance(Ω)
V –Voltage across load(V)
V_{sh}-Shunt voltage(V)
T-Temperature of solar cell (kelvin)
n-ideality factor of solar cell
k-Boltzmann constant ,(k= 1.3806488* 10^{-23}) J.K^{-1}
q-electron charge,(q =1.602176565*10^{-19}) C

3.2.Battery

When load demand increases, the BES offers supply by storing grid-supplied electricity and solar energy. Lithium-ion batteries are employed in BES due to its high power density, good energy density, long life cycle, low self-discharge, safety features, economic advantages, and low risk of explosion in the event of overload and unintentional short-circuiting [12].A bi-directional DC/DC converter is used by BES. The bi-directional DC/DC converter runs in buck mode when the battery is charged by the grid and solar panels. The battery functions in boost mode when it is depleted by the charging station.

3.3.Converters

The word "Converters" refers to a system that changes one type of electrical energy into another type of energy. DC to AC or AC to DC, for instance. Here, ac to dc conversion is referred to as "rectification," and dc to ac conversion is referred to as "inversion."

According to the type of input and output power, the power conversion systems can be divided into four categories:

- AC to DC (rectifier)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)
- DC to AC(Inverter)

Voltage Source Converter(VSC)

VSC is used for DC-AC conversion, and in this case, in addition to the conversion, it is also utilised for fault protection .When a fault develops, the switches' connected diodes go into conduction mode and stop working, separating the main grid from the problematic area[11].

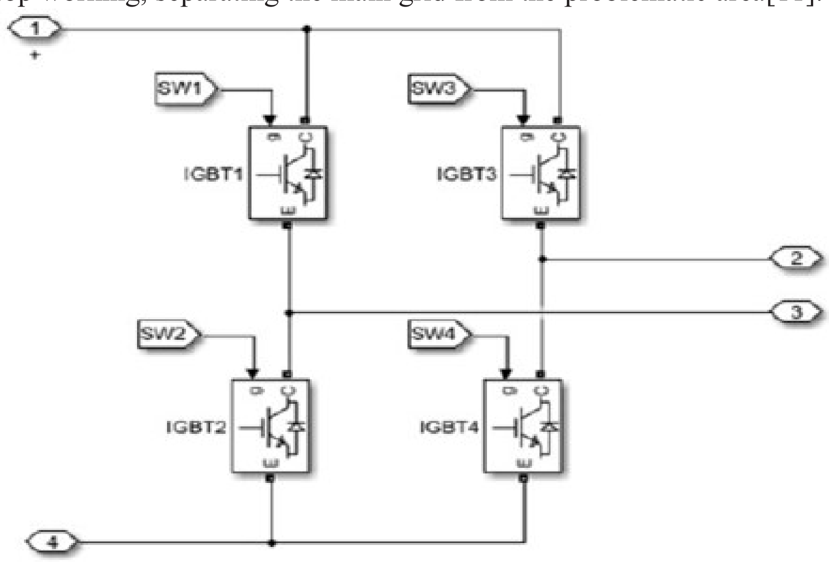

Fig 2:Basic structure of VSC(Inverter)

4.Proposed Method

When system characteristics vary, using ANFIS control rather than a traditional PI controller can be a good solution. Consequently, superior control performance is possible. Therefore, it is suggested in this study that the ANFIS controller be used to the DC-AC converter controller system. The ANFIS controller's merits include being simple, reliable, and adaptable [17].

An ANFIS-Adaptive Neuro-Fuzzy Inference System based on Takagi-Sugeno fuzzy inference system and artificial neural network technology was used to construct the novel controller[14]. It combines the advantages of neural networks and fuzzy logic in a single framework since it encompasses both of these concepts, and it works well by controlling both current and power even in the situation of an unbalanced grid voltage.

A fuzzy collection of IF-THEN rules that can approximate non-linear functions serve as the foundation of the inference system. Fuzzy rule bases are simple to comprehend since they use the IF-THEN-ELSE rule and language notions. In contrast to neural networks, fuzzy logic cannot learn on its own. Learning is a function of neural networks. It has been challenging to comprehend the information that neural networks have gathered.

Data-driven tactics are used in the ANFIS neural network methodology. The foundation of the ANFIS synthesis technique is a clustered training set of numerical samples. In this work, the input and output data from the proportional and integral controllers are used to train the ANFIS. ANFIS's inputs are the error and the change in error.

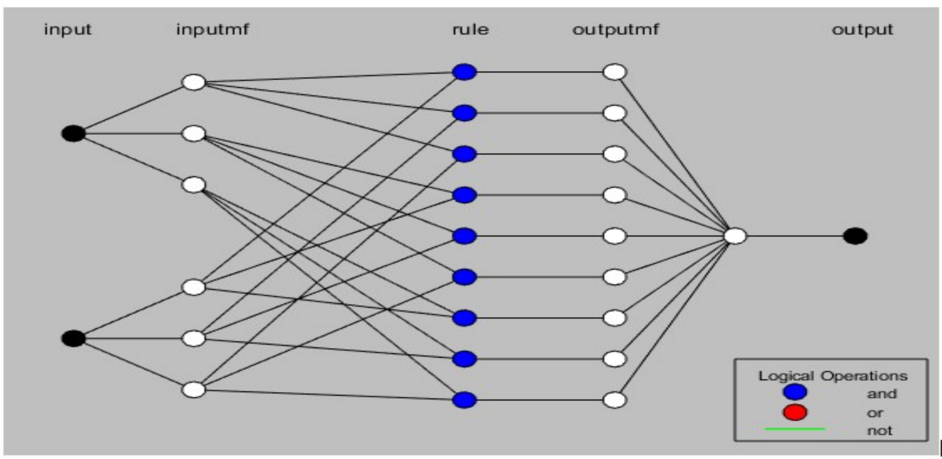

Fig 3: Structure of ANFIS Controller

5.SIMULATION AND RESULTS

A DC Micro-grid is created in MATLAB Simulation using a solar system, batteries, converters, and transformer.Both buck and boost converters are connected across the solar and battery systems, respectively.When the voltages of these two systems are the same and they are connected across a voltage source converter (VSC), they are connected in parallel.The entire system is referred to as a DC micro-grid and is connected to an AC micro-grid; a simulation of the aforementioned system is shown in Figure 4 along with the step-up transformer used to boost the voltage level and match it with grid voltage.

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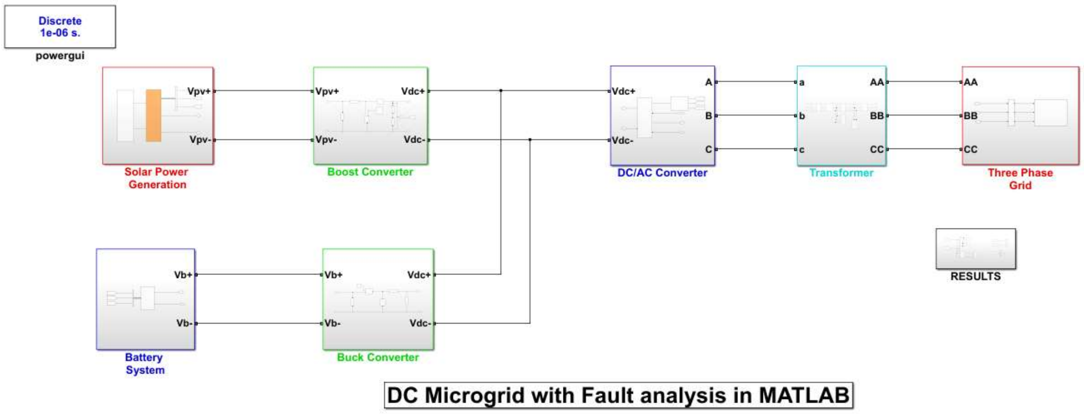

Fig 4: DC MICRO GRID WITH FAULT ANALYSIS

The table 1 shows the specifications of the components in the solar system used in the simulation[11].

Table 1: PV Array specifications

Parameters	Values
Rated Capacity of PV Array(Kw)	20
Parallel strings	66
Series strings	4
Maximum power(W)	305.226
Open circuit Voltage(V)	64.2
Short circuit Current(A)	5.96
Voltage at Maximum power(V)	54.7
Current at Maximum power(A)	5.58

The Lithium ion battery of rated capacity of 7.2Ah, Nominal voltage of 1000v and cut off voltage of 750 V is used and the transformer of rating 100kVA,frequency of 60Hz, primary and secondary voltages are 260V and 25kV respectively[18].

Among all the faults three-phase fault are more severe in nature , so three phase fault is created at the instant of 0.5-1 sec with fault impedance of 0.001 Ohm and with ground impedance of 0.01 Ohm[18].

The figures show the results of the voltages across the buses and also powers across the grid.

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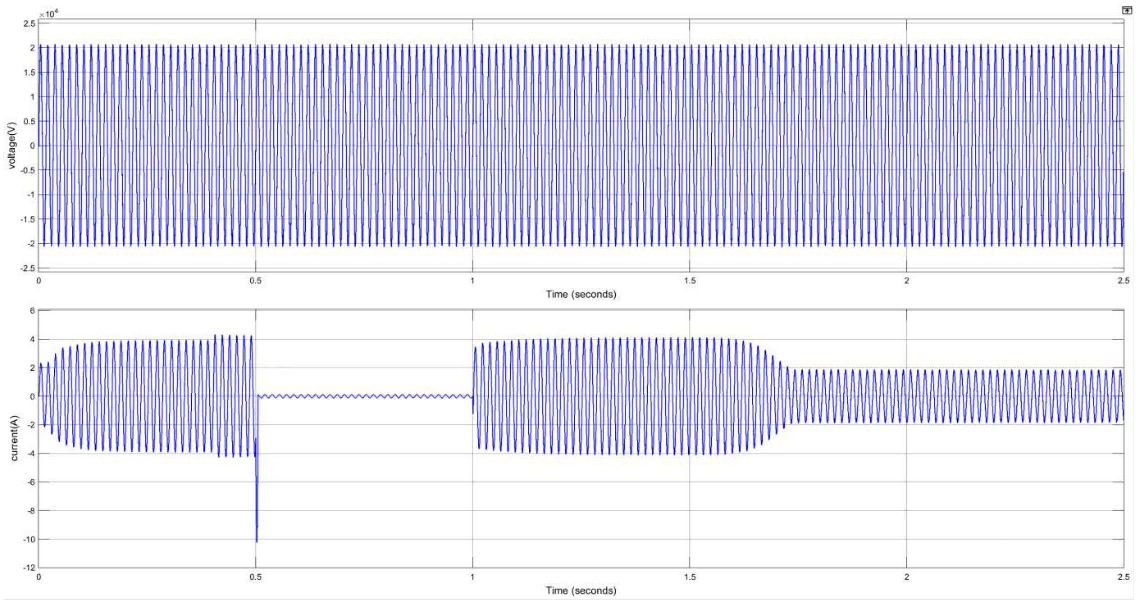

Fig 5: Voltage and Current for main grid

The Active and Reactive powers across the main grid during,before and fault is shown below,when ever the fault is created between 0.5-1 sec active power is zero.

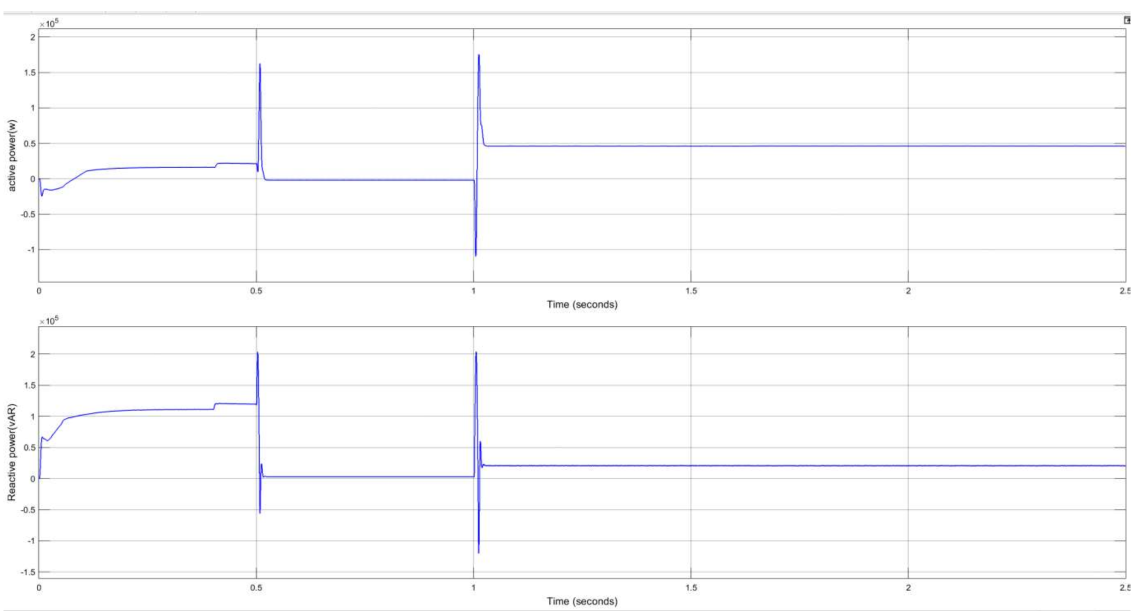

Fig 6: Active and Reactive powers at main grid

The voltages across the different buses and also voltage across Voltage Source Converter is shown below.

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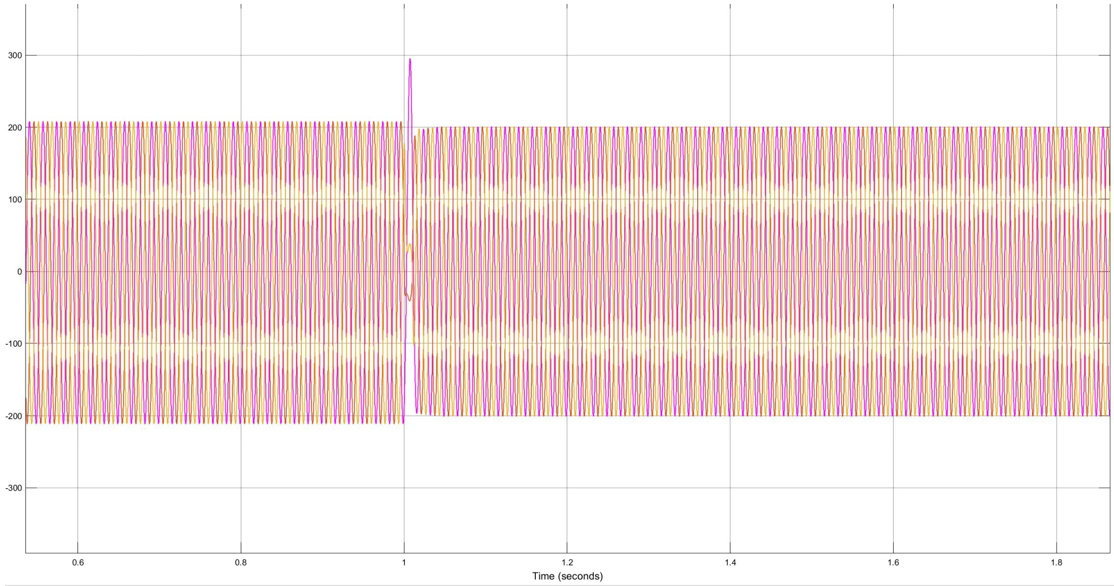

Fig 7: Voltage after the fault location

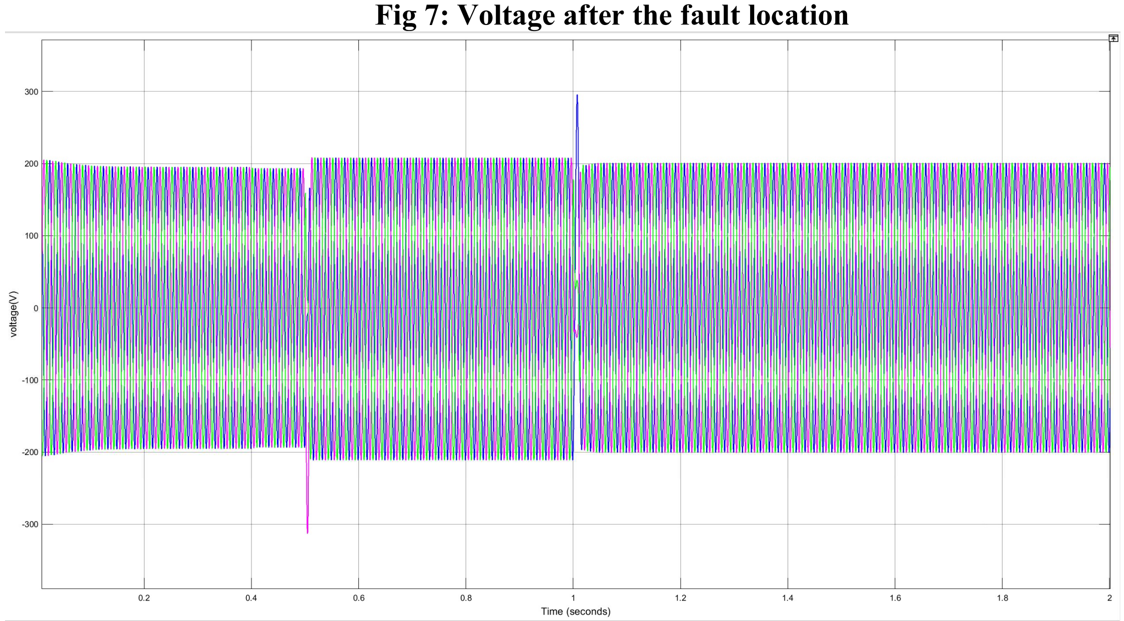

Fig 8:Voltage after the converter(VSC)

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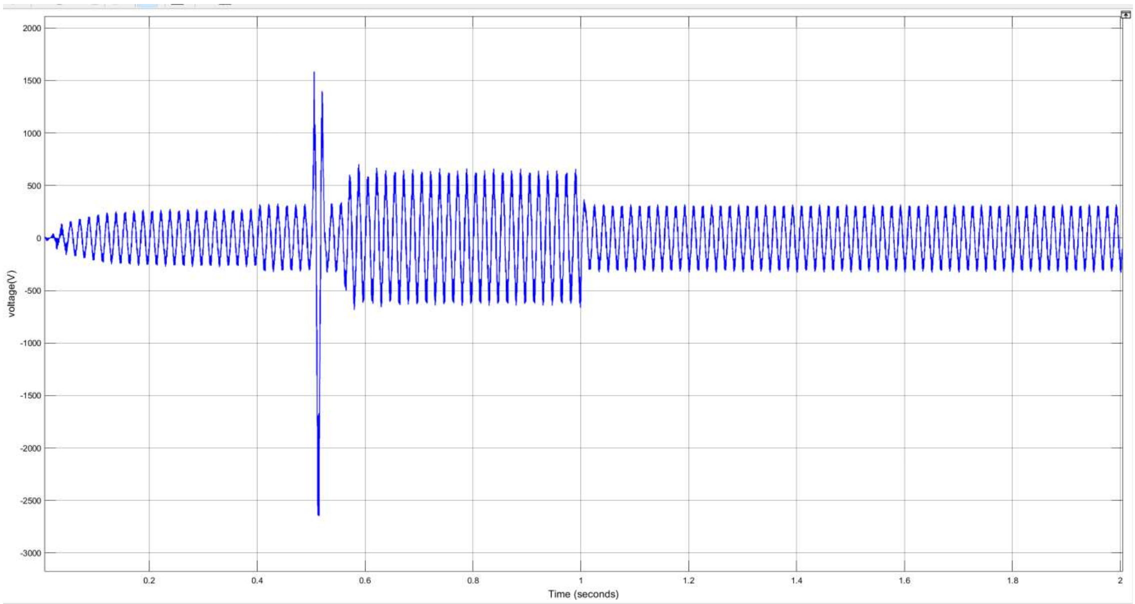

Fig 9: Voltage across VSC

The voltages across various buses are acquired from the simulation results, and the figures are displayed below along with the Total Harmonic Distortion (THD) of the figures.

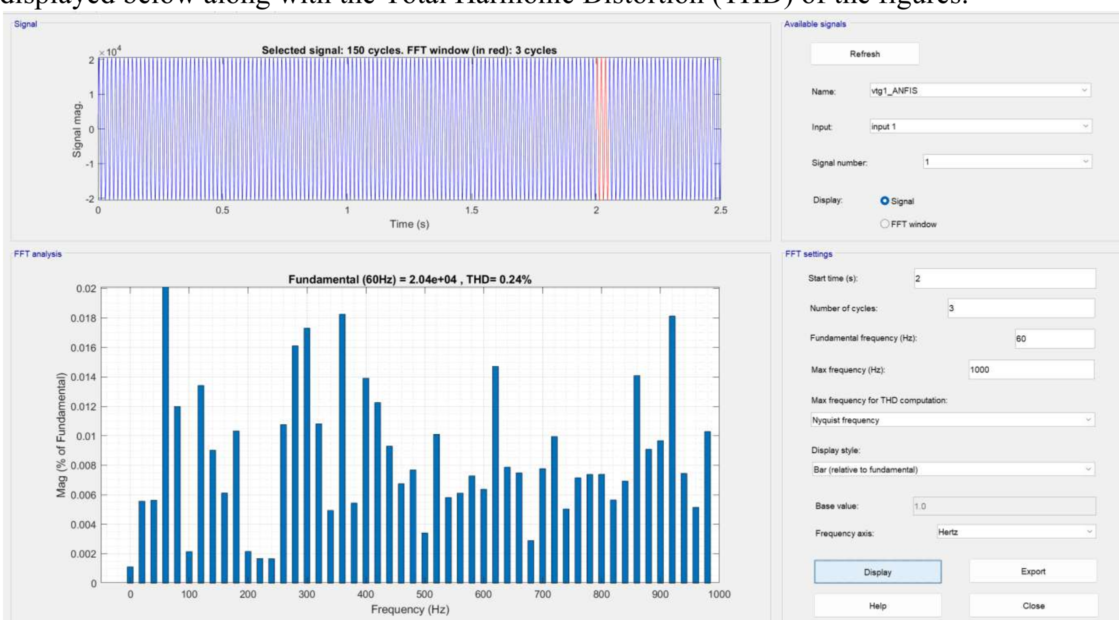

Fig 10: THD for Voltage across main grid

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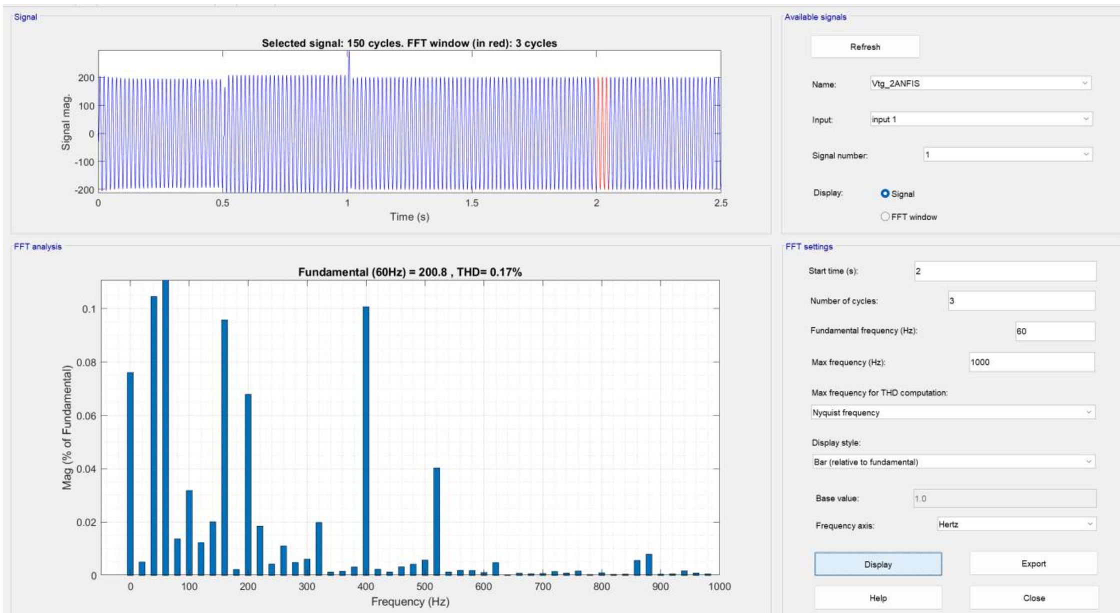

Fig 11: THD for Voltage after the fault location

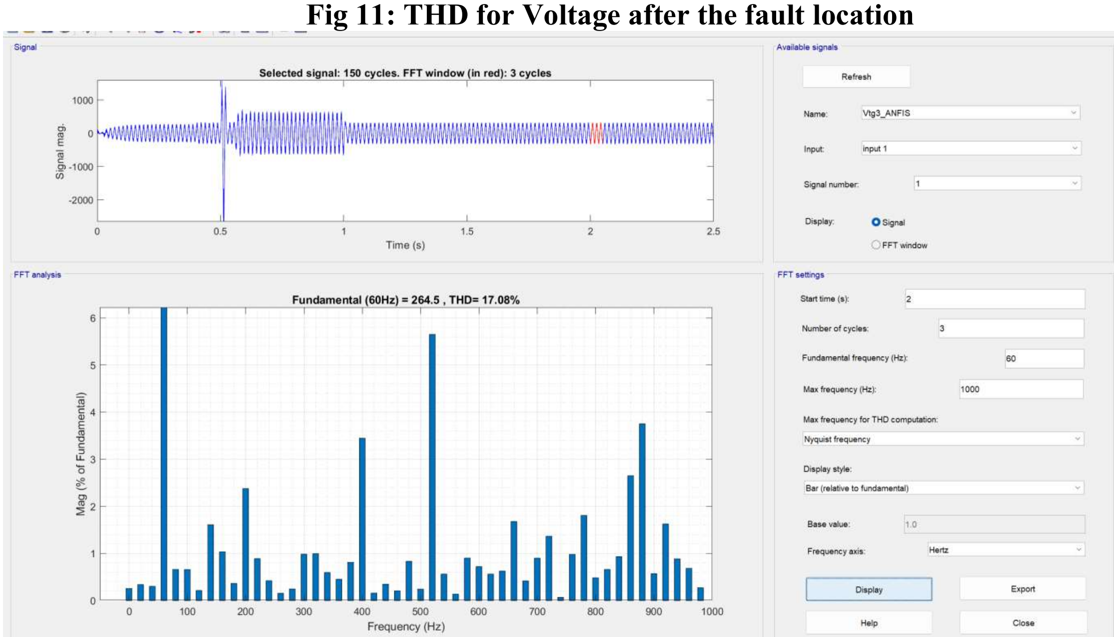

Fig 12: THD for Voltage across VSC

The table below compares the THD between the bus voltages with PI, FLC, and ANFIS controllers. It also demonstrates that ANFIS controller has lower harmonics than both PI and Fuzzy Logic Controller.

Table 2: Comparison between ANFIS,PI and Fuzzy Logic Controllers:

Parameter	**% of THD obtained by using PI Controller[18]**	**% of THD obtained by using Fuzzy Logic Controller**	**% of THD obtained by using ANFIS Controller**
Voltage at main grid	1.20%	0.42%	0.24%
Voltage after the	10.42%	0.26%	0.17%

fault location			
Voltage across VSC	68.65%	31.875	17.08%

6.Conclusion

The effectiveness of the ANFIS controller in controlling the DC link voltage and active power flow between a solar PV system and the grid has thus been demonstrated by the performance study of an ANFIS controller-based VSC in a project including a grid-connected solar PV system. The results of the experiment demonstrate that the ANFIS controller is a dependable control method for grid-connected solar PV systems since it can operate stably even under changing operating conditions such as variations in solar irradiance, temperature, and grid voltage. The work has provided crucial insights into the development and application of ANFIS controllers for solar PV systems that can be applied to develop more dependable and effective solar PV systems in the future.

The THD of the voltages across the buses reduces and also voltage across the VSC is reduced to 17.08%, which shows that ANFIS controller gives good results compared to PI and FUZZY Logic Controllers.

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