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ANFIS-BASED GRID-INTEGRATED SOLAR PHOTOVOLTAIC SYSTEM WITH BATTERY STORAGE AND FUEL CELL INTEGRATION FOR POWER CONDITIONING

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Abstract: Global energy demand is accelerating daily which is resulting very hugeenergy crisis and environmental pollution has to make focus to move towards integrating renewable energy sources like solar photovoltaic (SPV), wind, fuel, etc. SPV is intermittently overcome by Battery Energy Storage System (BESS) along with fuel cell. The hybrid generation with DC-link is integrated with the SPV, Fuel cell, and battery energy storage system to maintainconstant DC link voltage. To capture maximum available solar power using an adaptive Neuro-fuzzy information system (ANFIS) based maximum power point tracking technique (MPPT). Battery Energy Storage System which is activated based on the state of charge. PI controller monitors the state of charge through a bidirectional converter. DC link is integrated with the grid through a Three-phase voltage source converter. A three-phase voltage source converter adaptive Neuro-fuzzy information system (ANFIS) is used to control volatile changes in grid parameters rising by its variable demand. Grid synchronization can be achieved when dynamics variation of load. MATLAB/Simulink software simulated under different dynamic variations in load and volatile changes in a grid linkedto the hybrid system under different supply conditions.

Keywords: Solar photovoltaic (PV), Voltage Source Converter, Battery energy storage system, Fuel cell, Power conditioning

I. INTRODUCTION

Future substantial growth and unexpected challenges in energy production, transmission, and utilization technologies are to be witnessed. Awareness of people about the pollution due to the usage of fossil fuel for energy production and initiatives by many countries to scale back environmental pollution has increased the use of green energy sources for power generation [1]. Despite this, India faces a 929MW shortage in order to meet the power demand. The discovery of renewable energy sources such as solar, wind, and tidal power, could reduce the problem. The intermittent nature of the solar photovoltaic system is overcome by adding more renewable energy sources. A hybrid generation is one that draws its power from a combination of two or more different power sources. The behaviour of the PV module is nonlinear in nature and hence exhibits nonlinear PV curves. There exists only a unique point of maximum power in each PV curve, which needs special techniques called maximum power point tracking (MPPT) techniques to track it. Therefore, MPPT can be used to increase the system efficiency by fully utilizing the PV modules. Artificial intelligence-based techniques such as the fuzzy logic controller (FLC), artificial neural networks (ANNs), and adaptive neuro-fuzzy inference systems (ANFIS) can be used as a controller to extract the maximum power that the PV modules are capable of producing under changing weather conditions. This is because they have advantages such as they are robust, relatively simple to design, and they do not require the knowledge of an exact model [2, 3]. The intermittent solar power has extracted the usage of unique kinds of MPPT The conventional MPPT is tracking the most power from the SPV and these techniques are green however gradual in convergence, constantly oscillating the electricity. These drawbacks are averted using a smart controller for tracking the maximum power from the SPV. The sensible strategies are nicely monitored and it is used for solving nonlinearity. The SPV modeling, solar irradiance, and temperature are relatively nonlinear and dynamic in nature. The fuzzy logic controllers (FLC), particle swarm optimization (PSO) based MPPT strategies are used for extracting the smoothening strength [6-7]. These artificial strategies are used to extract electricity primarily based on the regulations and the system of the problem-established. These techniques are reducing the oscillation present within the MPP (maximum strength point). However, none of these strategies is absolutely lowering the oscillation presence. The adaptive Neuro-fuzzy information gadget (ANFIS) primarily based MPPT approach is likewise used to harmonics the most electricity from SPV. The ANFIS intelligent controller is easy to expand the model and music the maximum energy from the SPV based totally on the education the statistics. The monitoring performance also improves. The oscillation presence is greatly decreased [8-9]. The dynamic version of solar power is utilized effectively by the use of a battery energystorage system.

The SPV with battery energy storage system coordinates load for addressing the voltage and power. But the dynamic variation in the source and load is not taken into account. It may fail to supply continuously due to day availability and with limited battery state of the charge. This can be overcomeby using the fuel cell as secondary source and it can provide clean power without any harm to the present environment. Fuel cell isintegrated with the DC link through the open loop boost DC-DC converter. The PEMFC alkaline fuel cell, phosphoric acid fuel cell; solid oxide fuel cell, molten carbonate fuel cell; direct methanol fuel cell [19-20]. The proposed SPV with battery storage, Fuel cell integration addresses the DC link voltage, grid voltage and a dynamic condition of the source, and load for single phase distribution system. It stabilizes the DC link voltage and grid voltage under the stochastic nature of the SPV system. Grid synchronization can be achieved with the help of power conditioning unit under dynamic condition of the load.ANFIS controller is added for regulating the voltage at the DC hyperlink by computing the measured DC voltage with the reference DC voltage (Vdc). Similarly, it'll modify the battery charging contemporary and battery kingdom of the rate. It generates the switching pulses to a bi-directional converter based totally on the reference battery country of the rate (SoC).The control circuit operated with phase lock loop dc link voltage, grid voltage is input by using proportional integral controllerthe output variable is the duty cyclewhich is given to PWM generator than PWM generates pulses which are used to control generate gating pulses to the inverter for maintain dc link voltage constant sudden variation of load parameters and volatile changes in grid parameters.

II. Mathematical Model of Solar PV System

The main part of solar system is solar cell. Solar cell absorbs light and converts percentage of energy of absorbed photons to electric current. Solar cell can be thought of diode which separates and collects electrons and holes conducts in a specific direction. Solar cell converts solar energy into electrical energy. Equations ofsolar PV system is given below

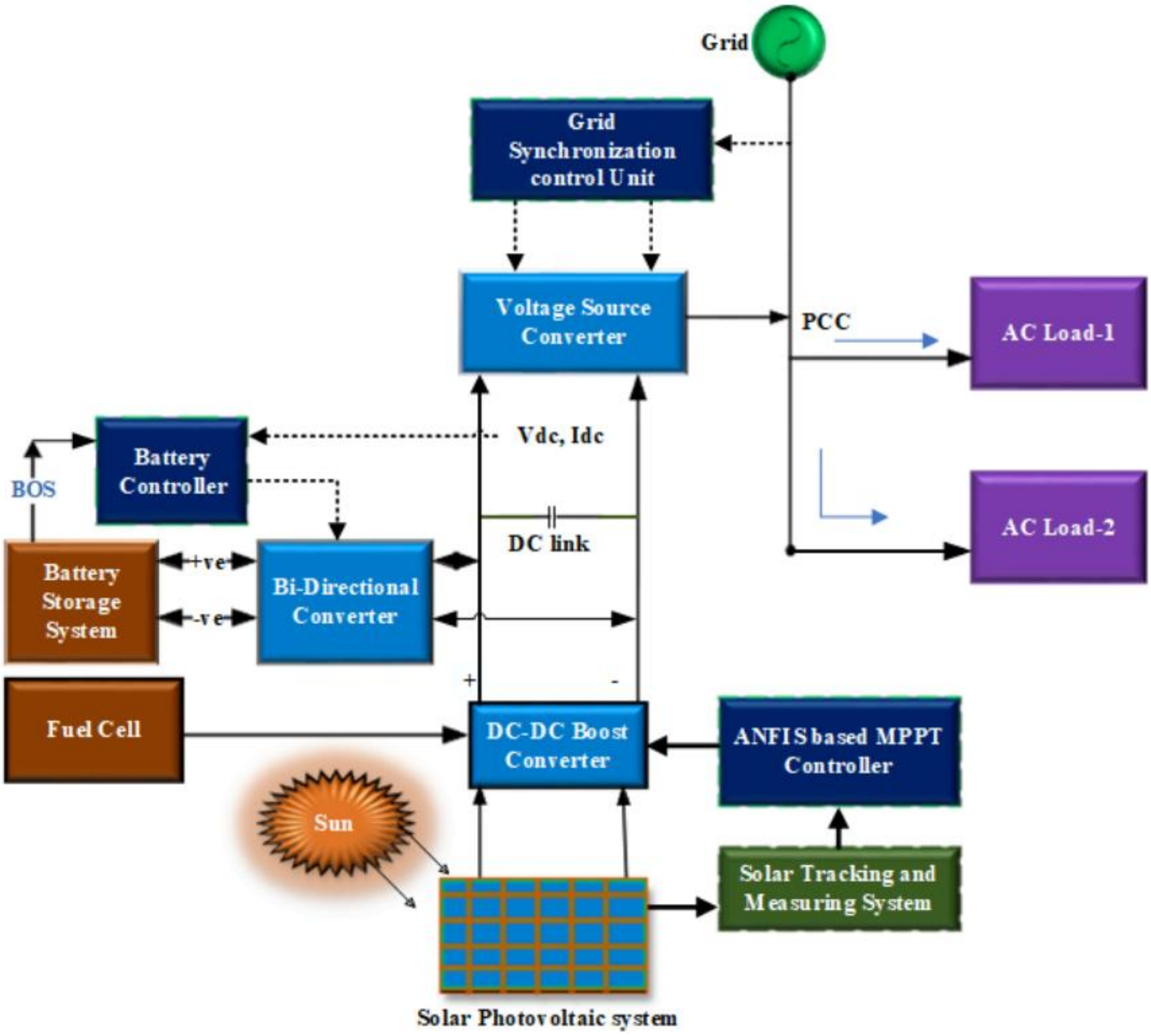

Fig1. Proposed hybrid system

$$I = I_{ph} - I_d \left[e^{\frac{qV}{k_b TA} - 1} \right] \quad (1)$$

$$I_{sh} = \frac{[V+(I*R_s)]}{R_{sh}} (2)$$

$$I_{ph} = I_{rr}\,[I_{sc} + K_i(T_{op} - T_{ref})] \quad (3)$$

$$I_d = I_{rr} \left[\frac{T_{op}}{T_{ref}} \right]^3 e^{\frac{qEg}{kQA} - [\frac{1}{T_{ref}} - \frac{1}{T_{op}}]} \quad (4)$$

where, V = output voltage (V); I = current (A); T = temperature (◦C); ki = short-circuit temperature coefficient; q = electron charge; Rsh = Shunt Resistance; Rs = Series Resistance; Ish = shunt resistance current; k = Boltzmann's constant; and kb = open-circuit voltage temperature coefficient; Irr = saturation current at Tref; Id = diode current; A = ideality factor; Iph = load current; Isc = short-circuit current at reference condition; Q = total electron charge; Tref = reference temperature; Eg = band-gap energy.

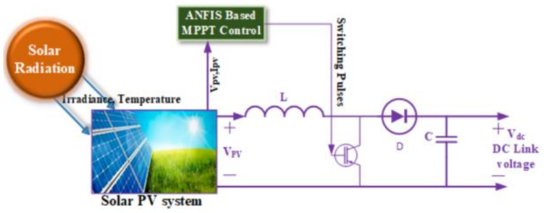

Fig. 2. PV with Boost Converter.

III. FC Mathematical Model

The FCconsists of Proton exchange membrane (PEM), gas channel (GC), gas diffusion layer (GDL), catalyst layer (CL), and current collector (CC) of both the anode and cathode. Fig3. illustrates the PEMFC.

A. Model Equations of FC

FC's essential model consists of mass, thermal electricity, momentum, organisms, and rate. This FC model is based totally on five equations. These equations are used to form an electrochemical method to specific reaction kinetics and electro-osmotic drag for the duration of the polymer electrolyte manner. Equations (5)–(10) constitute the (5)equ for this FC version in vector shape.

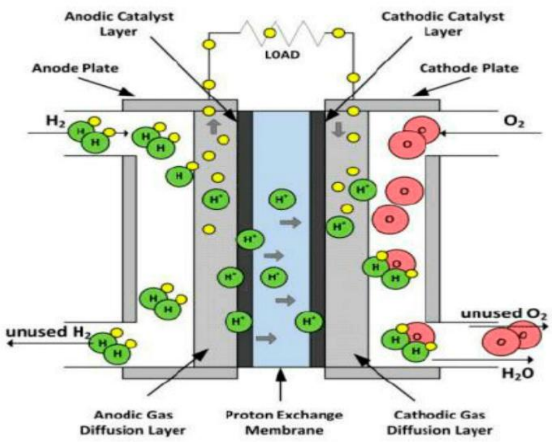

figure 3. Schematic illustration of proton exchange membrane fuel cell (PEMFC).

Continuity Equation The electrodes present within the FC is made from carbon fiber or carbon fabric. The reactant gases are spread over the catalyst layer, and the electrodes are constrained as a porous medium everywhere. The continuity equation for the porosity with the assist of electrodes (ε) has given in Equ (5)

$$\left(\frac{\partial \varepsilon\rho}{\partial t}\right) + \nabla x(\varepsilon\rho U) = 0 \qquad (5)$$

where ∇ = differential operator of a vector, ρ = liquid density, ε = porosity, U = floating speed vector and t = time.

B. Momentum Conservation

Navier–Stokes equation has given in Equation (6) and designed for a Newtonian fluid.

$$\frac{\partial(\varepsilon\rho U)}{\partial t} + \nabla.(\varepsilon\rho U^2) = -\varepsilon\nabla p + \varepsilon F + \nabla.(\varepsilon\tau) - \frac{\varepsilon^2\mu U}{k} \qquad (6)$$

where ρ = pressure; τ = stress tensor; F = floating mass vector; μ = liquid viscidity degree; k = permeate ratio of the liquid by porous medium.

C. Conversion of Charge Equation

PEMFC has been utilizedinthe behaviourof electrochemical reactions. Theequations are an integral part of the FC, and this equation includes two equations: electron removal above conductive solid section and proton transference above the membrane. The oxygen diffusion flux (ODF) at the catalyst surface is used to calculate the current density (CD) that circulates in conjunction with CL. The CL's two-dimensional Poisson's equation is as follows:

$$\nabla.i = 0 \qquad (7)$$

The sum of phase currents of solid (is) and membrane (im) during CL is equal to the total Current (i) phase currents of solid (is) and membrane.

$$i = i_s + i_m \qquad (8)$$

Using Ohm's law, the transfer current density (Jt) with solid surface tension is given by

$$j_t = -\nabla.-(\sigma_s\nabla\varphi_s) = \nabla.-(\sigma_m\nabla\varphi_m) \qquad (9)$$

where Jt = transfer current density at time t, σs = solid phase surface tension, σm = membrane phase surface tension, ϕs = solid phase flux, ϕm = membrane phase flux.

D. Electrochemical Reaction Dynamics equation

The current density at the time (Jt) is a classification of electrochemical reaction velocity, the concentration of species, and potential among the phase of the membrane and solid. The expression for Butler–Volmer (B–V) has expressed below.

$$j_t = j_o\left\{exp\left[\frac{\alpha_a F}{RT}(\Phi_s - \Phi_m)\right] - exp\left[\frac{\alpha_c F}{RT}(\Phi_s - \Phi_m)\right]\right\}\prod_{j=1}^{N}[\Lambda]^{\alpha j} \qquad (10)$$

where, Λ = mol concentration of the reactant, R = electrical resistance, F = Faraday's constant, J0 = exchange current density, αa and αc = transfer coefficient, αj = charge transfer coefficients of cathode and anode.

IV. Battery storage System

The layout of battery storage and controller is proven in Fig.4. The battery storage is included with the DC-link through the bi-directional converter for stabilizing the DC link voltages at 720V.

LetE_{batt} be how many kWh of energy the battery needs each day to stay charged. It is judged by how much power it has left over at the end.deficit$P_{diff}(t)$ calculated as below$P_{dem}(t)$where is the power that is to be dispatched over a time periodΔt . Let's show the number of days in the simulation. Consider.

$$P_{diff}(t) = p_{gen}(t) - P_{dem}(t) \qquad (11)$$

$$E_{batt}(kWh) = max\{\sum_{i=1}^{N} P_{diff}\ x\ \Delta t\} \qquad (12)$$

Battery power limit constraints is $P_{b,min} \leq P_b(t) \leq P_{b,max}$. (13)

BatterySOCconstraints$SOC_{min} \leq SOC(t) \leq SOC_{max}$ (14)

Where$SOC(t) = SOC(t-1) + P_b(t)x(\frac{\Delta t}{E_{bess}})$ (15)

Battery energy limit constraints is$E_{b,min} \leq E_b(t) \leq E_{b,max}$

For discharging,

$$E_b(t) = max\{E_b(t-1) + (\Delta t \; x \; P_b(t))/\eta_{dis}), E_{b,min}\} \quad (16)$$

For charging,

$$E_b(t) = min\{E_b(t-1) + (\Delta t \; x \; P_b(t))/\eta_{chg}), E_{b,max}\} \quad (17)$$

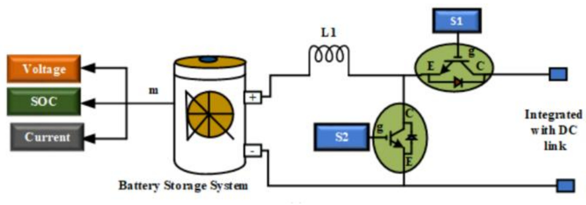

Fig.4. Battery storage systems (a) Battery with bi-directional converter

ANFIS controller is added for regulating the voltage at the DC hyperlink by computing the measured DC voltage with the reference DC voltage (Vdc). Similarly, it'll modify the battery charging contemporary and battery kingdom of the rate. It generates the switching pulses to a bi-directional converter based totally on the reference battery country of the rate (SoC).

V. SYSTEM MODEL

The VSC primarily based PLL and THD control machinelinks to the offshore platforms presenting strength from the dc link.VSC is adopted with the AC voltage control approach so that it will provide uninterrupted and balanced AC voltage at the terminal.The following equations are acquired in the d-q synchronous frame.

A. Voltage control

$$V_{sd} - V_{cd} = L\frac{di_d}{dt} + Ri_d + \omega Li_q \quad (18)$$

$$V_{sq} - V_{cq} = L\frac{di_q}{dt} + Ri_q - \omega Li_d \quad (19)$$

Where i_d and i_q are line currents, V_{sd} and V_{sq} are source voltages, V_{cd} and V_{cq} are converter input voltages.

Since V_{sd} is constant, it is clear that the active power will be controlled by i_d, whole the reactive power will be controlled by i_q. On the DC side of the converter, DC current and DC power are;

$$i_{dc} = C\frac{dv_{dc}}{dt} + i_c \quad (20)$$

The control circuit of VSC includes an outer manage loop and an internal current manipulate loop. The outer controller includes active, reactive energy management, dc voltage manipulate, and an AC voltage controller. The preference among those controllers will rely upon the software. The outer controller will calculate the reference values of the converter cuttingedge.It's far clear that each converter can manage its energetic and reactive power independently. A combination of an open-loop and PI controller is used to maintain the lively electricity to its preferred fee, given through the equation:

$$i_{sd\_ref} = \frac{P_{ref}}{V_{sd}} + (K_p + \frac{K_i}{s})(P_{ref} - P) \quad (21)$$

Similarly, reactive energy can also be managed as in the preceding case through combining the PI controllers as shown below.

$$i_{sd\_ref} = \frac{Q_{ref}}{V_{sq}} + (K_p + \frac{K_i}{s})(Q_{ref} - Q) \qquad (22)$$

In fashionable, the AC voltage controller is chosen at an inverter station positioned on an offshore oil platform with the intention to gain an uninterrupted and balanced AC voltage from the AC voltage controller, the d-axis present-day reference may be acquired the use of the equation

$$i_{d\_ref} = (K_p + \frac{K_i}{s})(V_{s\_ref} - V_s) \qquad (23)$$

With

$$V_s = \sqrt{(V_{sd}^2 + V_{si}^2)} = V_{sd} \qquad (24)$$

$$i_{d\_ref} = (K_p + \frac{K_i}{s})(V_{s\_ref} - V_{sd}) \qquad (25)$$

AC grid and on this way without any energy storage device, VSC acts asthe strength buffer via encountering the switching losses and transmission losses. When a PI controller is used, the dc modern reference of VSC can be written as

$$i_{d\_ref} = (K_p + \frac{K_i}{s})(V_{dc\_ref} - V_{dc}) \qquad (26)$$

All these outer loop ANFIS regulators calculate the reference value of the converter current vector, which is the input to the inner modern-day loop.

VI. ANFIS based Coordinated Controller

A. Proposed MPPT Method By ANFIS.

Designing of ANFIS combines the advantages of neural networks and fuzzy logic and hence deals efficiently with a nonlinear behavior of solar PV modules based MPPT scheme which is interfaced with a boost converter. Maximum power transfer between load and solar PV module is also carried out for designing of an open-loop DC-DC boost converter. In this paper, an ANFIS-based MPPT method is proposed to achieve tracking the maximum power of the PV module. The proposed system is two input variables those are temperature and irradiation. The output variable is the duty cyclewhich is given to PWM generator while PWM generates pulses which areused to control the dc-dc isolated boost converter to obtain maximum power. Since the modeling of the conventional FLC is based on trial and error, the probability of obtaining theoptimal performance is low. Therefore, obtaining membership functions and fuzzy rules can be done through the ANFIS using Sugeno block. The input training data to the ANFIS are the membership function of the PV voltage (Vpv), Currents (Ipv).

B. ANFIS VSC Controller.

More than converters for the same DC bus make the VSC Structure more difficult. As a result, it's critical to keep the DC link voltage within acceptable limits so that the DC grid's active energy can reach the AC grid/load. An ANFIS based managementtechnique is presented in this research to ensure the stability and dependability of the VSC device. ANFIS is an adaptive network that functions like a fuzzy inference machine, in which the output is derived by utilizing fuzzy rules to analyze inputs. In Fig. 3, an ANFIS structure with two inputs and one output is depicted. There are two inputs, x1 (errors), which are converted into x2 (change in errors), and the output is a controlled DC link voltage by using sugeno block. Linguistic variables can be found for each input and output variable: NL, NS, ZERO, PS, and PM. Because of this, a total of 25 linguistic variables for the output are used in the proposed ANFIS controller.

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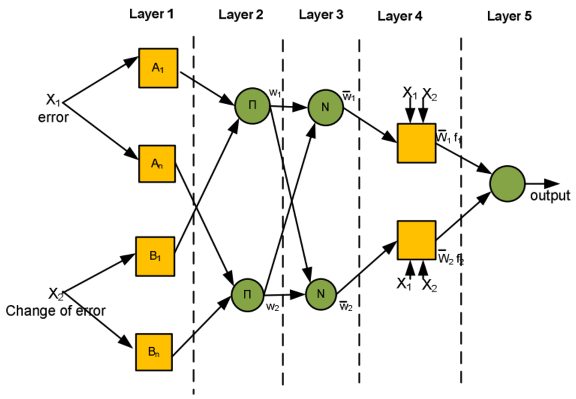

Fig5. An ANFIS structure.

In the proposed ANFIS architecture, there are hidden layers of nodes, each of which has a circle or rectangular shape and a constant or adaptive shape. The node parameters are independent of the other nodes. There is a linguistic variable for each neuron in the first layer and an output for each one.his linguistic variable's club function is equal to 1. To depict a rule's firing electricity, nodes in the second layer multiply incoming signals and send the resulting signal out.The final layer sums up all of the incoming alerts to provide the final output. A triangle club feature in the MATLAB/ANFIS editor toolbox is used to verify the suggested controller since it produces some training errors. This contribution uses a hybrid mastering technique because the backpropagation algorithm is infamous for its slowness and tendency to get stuck in local minima. The parameters may be identified quickly and accurately using this set of rules.In this inference system output of each rule is linear combination of input variables added in a constant term. The final output is weighted average of each rule's output.The inverter mainly depends upon the modulation approaches which controls the inverter. In this design, PWM technique has been tailored to control the inverter. In this technique,the switching state can be determined as follows When Vref> Vdc, upper switches are on and Vref< Vdc, lowerswitches are on this is interlinked with control circuit.
The control circuit operated with phase lock loop dc link voltage, grid voltage are inputs by using proportional integral controllerthe output variable is the duty cyclewhich is given to PWM generator than PWM generates pulses which are used to control generate gating pulses to inverter formaintaindc link voltage constant sudden variation of load parameters and volatile changes in grid parameters.Measured grid side voltage (Vabc) is fed to a PLL to get instantaneous angle measurement which is later fed into abc/dq0 converter. Measured grid side voltage (Vabc) and current (Iabc) are passed through abc/dq0 converter to get corresponding d and q axis components i.e. Vd, Vq, Id, and Iq.

VII. SIMULATION AND RESULTS

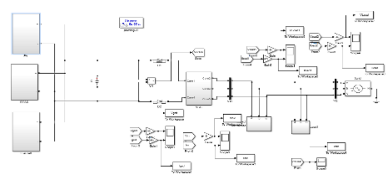

Fig6. Simulation Diagram of the Proposed System.

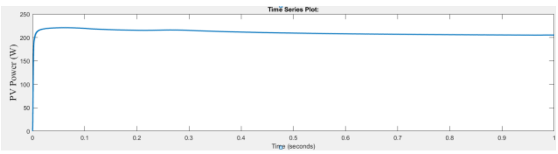

Fig 7. (a) PV power

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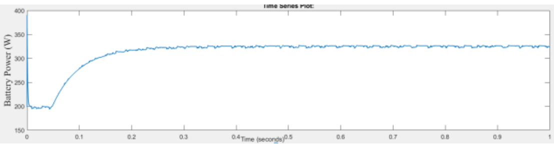

Fig 7. (b)) Battery Power

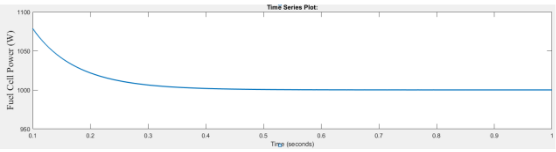

Fig 7. (c) Fuel Cell power.

Different source powers are shown in fig 7 like PV, Battery, and Fuel Cell with 230W, 320W, and 1000W.

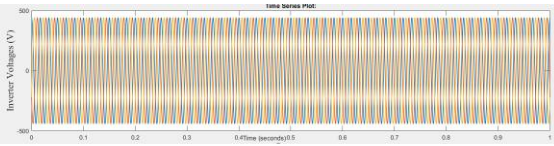

Fig8. Inverter (a) Voltages

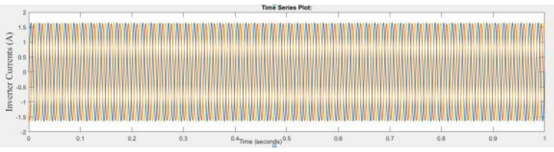

Fig8. Inverter (b) Currents

In the Above fig8. The VSC voltages of 440V and Currents of 1.6A are shown, which are controlled by the ANFIS controller.

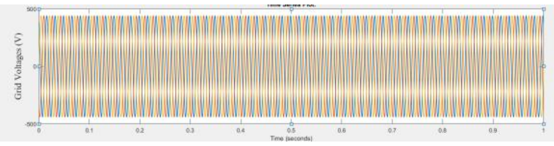

Fig9. Grid (a)Voltages

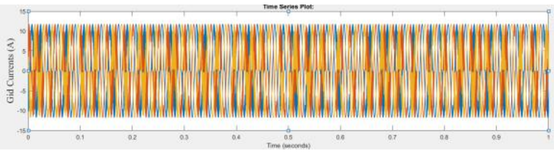

Fig9. Grid (b)Currents.

Fig 9. This shows that the voltages 440V and currents 11A of the grid with the disturbance in the Currents.

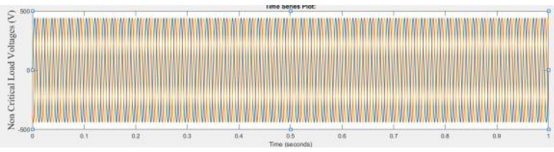

Fig 10. Load1 (a) Voltages

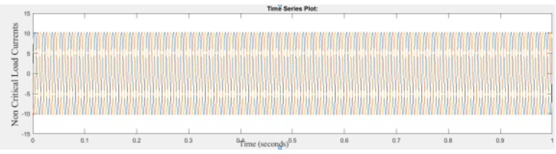

Fig 10. Load1(b)Currents

Fig 10. This shows that the voltages 440V and currents 2.2A of the non-critical load.

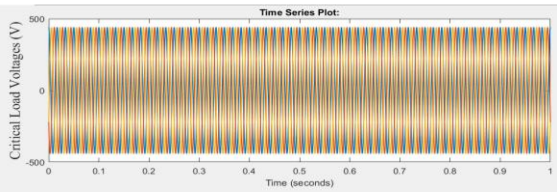

Fig11. Load2 (a) Voltages

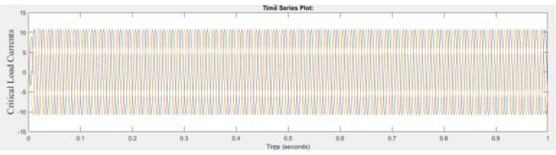

Fig11. Load2 (b) Currents

Fig 11. This shows that the voltages 440V and currents 2.2A of the non-critical load.

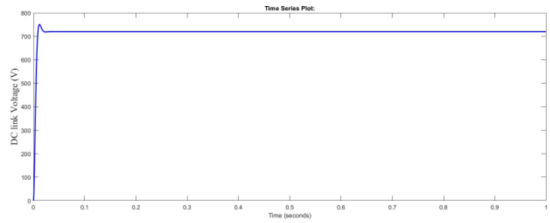

Fig12. DC link Voltage

DC link voltage 7200V after the sources of PV, battery, and fuel cell at the inverter.

FFT ANALYSIS

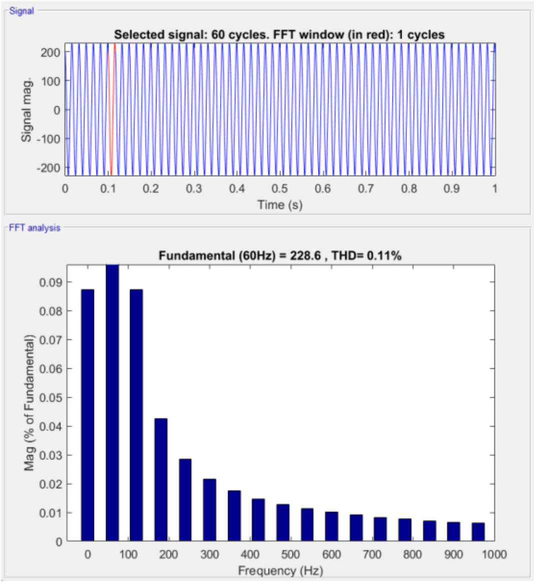

Fig11. Grid(a) Voltages

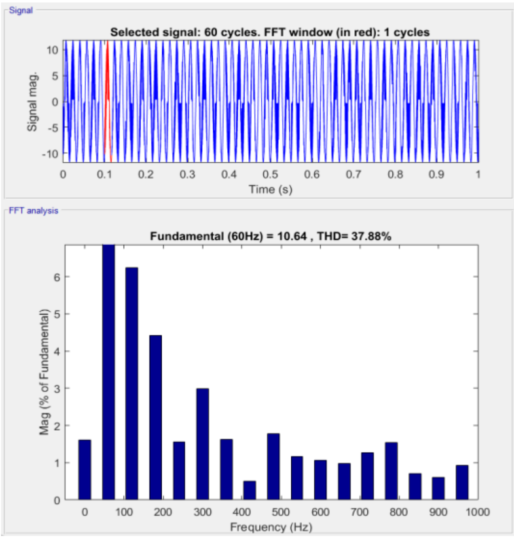

Fig11. (b)Grid Currents THD 37.88%

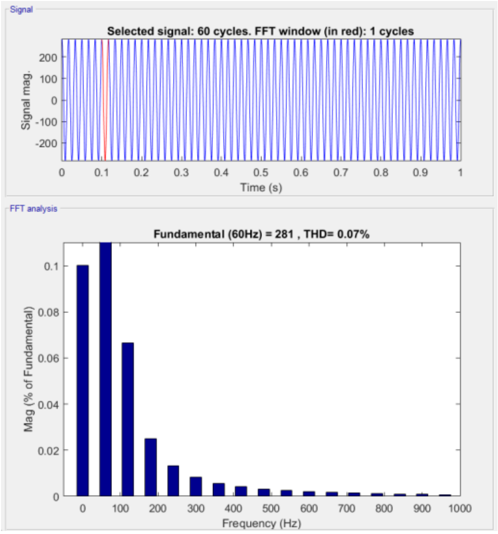

Fig14. (a) Inverter Voltage THD of 0.07%

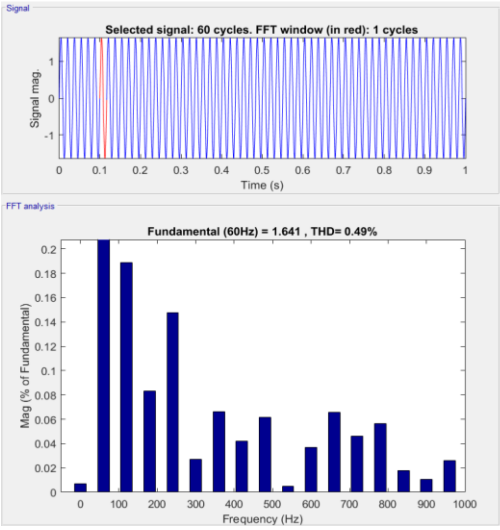

Fig14. (b) Inverter Current THD of 0.49%

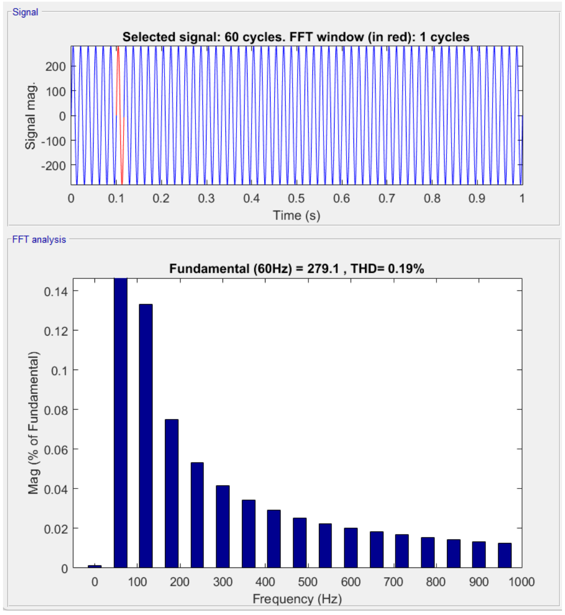

Fig15. (a) Non-critical load Voltage THD of 0.19%

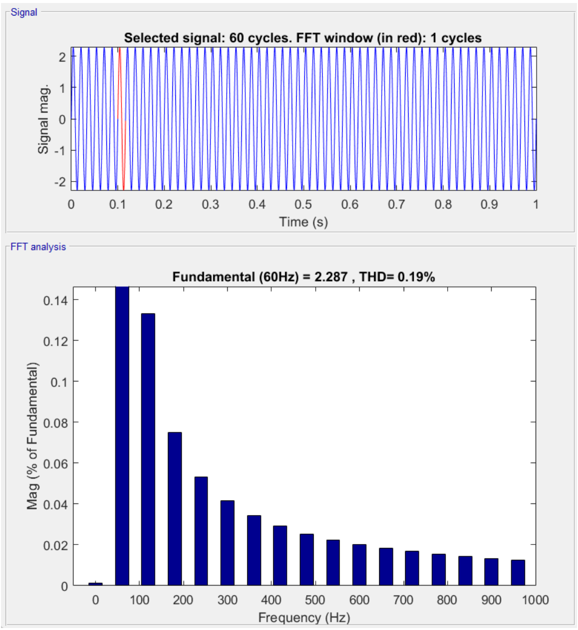

Fig15. (b) Non-critical load Currents THD of 0.19%

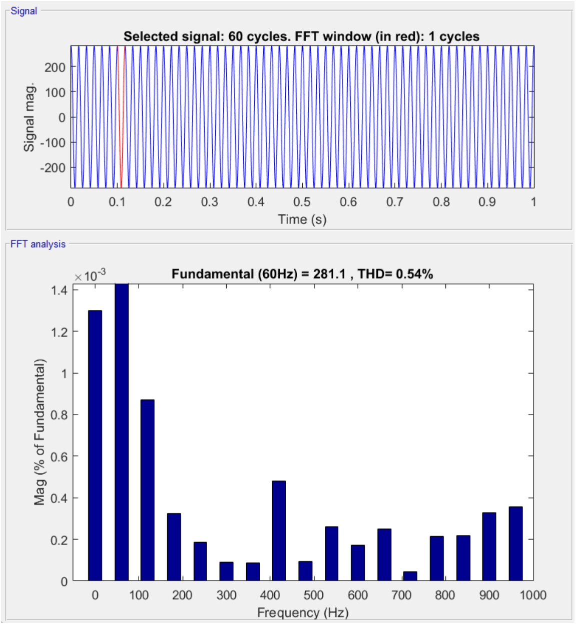

Fig 16. Critical load (a) Voltage THD of 0.54%

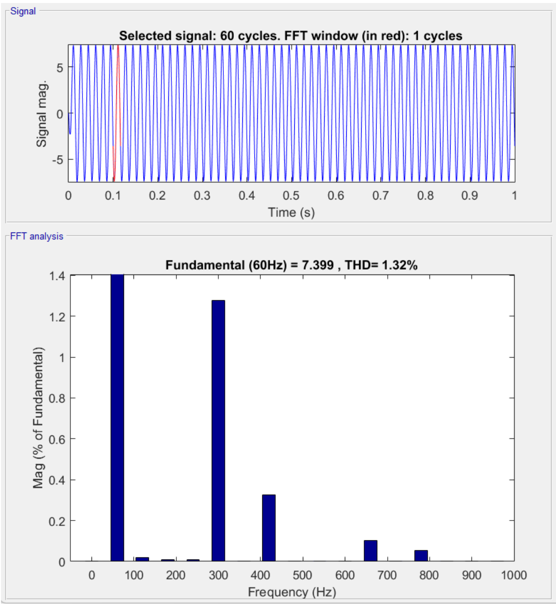

Fig 16. Critical load(b) Currents THD of 1.32%

CONCLUSION

In this paper, ANFIS based coordinated control approach has been used for the MPPT of the PV system and voltage source converter. To maintain constant voltage atdc link hybridsystem is an integrated solar photovoltaic system, fuel cell with battery energy storage system. Battery energy storage system with bidirectional controller maintaining dc link voltage constant through dc-dc converter. To achieve smoothen power ANFIS based MPPT control technique was used with help of a boost converter under dynamic variation of temperature and irradiation. Dc link is an integrated with the grid through a Three-phase voltage source converter. A three-phase voltage source converter adaptive Neuro-fuzzy information system (ANFIS) is used to control volatile changes in grid parameters rising by its variable demand with critical and non- critical loads.ANFIS controller in voltage source converter gives THD within 5% stipulated limit at different loads under volatile changes in grid parameters is analyzed.

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