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POWER CONTROLLING OF SOLAR PHOTOVOLTAIC WITH BATTERY STORAGE FUEL CELL BY THE ANN-BASED INTEGRATION

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Abstract : Providing clean electricity and reaching the electricity demand is the biggest problems inside the contemporary power state of affairs. These troubles may be alleviated with the combination of renewable energy resources (RES) which include solar, wind and many others. The solar photovoltaic source (SPV) became more outstanding within the application device. The SPV stochastic nature may be overcome with the combination of sustainable assets in the utility machine. The day availability and stochastic nature of sun photovoltaic may be used successfully with the integration of DC hyperlink structures. In this paintings, the hybrid generation with DC hyperlink integration is split into components. In the first element the DC hyperlink is incorporated with the SPV, Fuel mobile and battery storage system. These hybrid assets are used to preserve constant DC hyperlink voltage. The stochastic nature of the SPV supply electricity is extracted the usage of an adaptive Neuro-fuzzy records device (ANFIS) based maximum electricity point tracking technique (MPPT). The battery garage gadget is used through the bi-directional converter and it's operated based totally at the battery state of the charge. The battery country of the rate is monitored with the bi-directional controller. In the second one element, the DC hyperlink integration is made with the application grid and loaded thru the Three-phase voltage supply Inverter. The grid synchronization can obtain with the grid synchronization unit even below dynamics in the load and resources. The strength conditioning of the proposed system continues the DC hyperlink voltage and grid synchronization voltage through the DC link medium. This can be executed with the usage of hybrid resources with the aid of maintaining the constant voltage at the DC link of the voltage supply inverter. The dynamic variation inside the load and the utility grid-linked hybrid machine performance is simulated beneath one of a kind supply situations the use of MATLAB/Simulink software program.

IndexTerms **- Battery storage system, DC-DC converter, Fuel cell; Maximum power point tracking (MPPT), Power conditioning; Solar photovoltaic (PV), Voltage Source Converter.**

I. INTRODUCTION

The necessity of strength has been increasing due to fast development in generation, populace increase, as well as improvement in industries. Providing clean energy and assembly the burden demand are the large issues inside the contemporary situation [1]. Still, India is struggling a scarcity of 929MW to fulfil the height demand. This may be alleviated with the discovery of renewable assets along with solar, wind and tidal, etc. These renewable resources are intermittent in nature and their drawback can be overcome with the combination of or greater assets inside the application gadget. The integration of those assets is presenting flexible strength and satisfies the essential height call for for a longer time. The integration of or more strength sources is defined as a hybrid generation. This hybrid era imparts a prime role in the distribution device to satisfy the weight call for [2]. Solar, wind sources are gambling critical position in isolated and grid-related systems. Among these, the SPV integration is gambling a critical position inside the distribution device. The SPV have become popular in the application grid-connected machine a number of the other renewable sources. The intermittent sun power is extracted the usage of unique kinds of MPPT techniques [3, 4] consisting of perturb and statement, incremental conductance (INC) method, and so on. The predictive version manipulates based totally MPPT is used to music the maximum electricity from solar PV and the stability of the device [5]. The conventional MPPT is tracking the most power from the SPV and these techniques are green however gradual in convergence pace, constantly oscillating the electricity. These drawbacks are averted using an smart controller for tracking the maximum power from the SPV. The sensible strategies are nicely monitored and it is used for solving in nonlinearity, nature of the time-various hassle. The SPV modelling, 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 the electricity primarily based on the regulations and the system of the problem-established. These shrewd techniques are reducing the oscillation present within the MPP (maximum strength point) underneath steady-kingdom. However, none of these strategies is absolutely lowering the oscillation presence. Researchers are working for purchasing the smoothening power effectively. The adaptive Neuro-fuzzy information gadget (ANFIS) primarily based MPPT approach is likewise used to song 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]. In this paper, the ANFIS based totally MPPT is used to music the smoothening energy from the SPV using a lift converter. The day availability and intermittent nature of SPV may be applied efficiently with the combination of the DC link gadget thru the enhance converter. But the PV strength isn't always presenting a non-stop energy deliver due to its intermittent nature. The inconsistent solar energy results in affect the sensitive load in addition to the impact on the grid when its miles included with the grid. The dynamic version of solar power is utilized effectively the use of a battery garage system. The impact of the inherent nature of PV is averted using a battery garage machine. Effective usage is made with the battery garage device. The authors have addressed the voltage sag and swell with the integration of SPV with a battery storage machine [10-11].

They do no longer have any reactive power and complicated frequency troubles. DC/DC converters are vital for the integration of disbursed era in DC microgrids [3]. Buck converters, boost converters, and greenback-raise converters [4] are the three varieties of DC/DC converters typically used. Buck converter produces a controlled output voltage, that's lesser than the enter voltage; for a lift converter, the controlled output voltage is more than the enter voltage; in addition, for a greenback-improve converter, the managed output voltage is lesser or greater than the enter voltage. Compared to an AC micro-grid, connecting RESs to a common DC bus has many advantages, together with more overall performance and accuracy and the elimination of frequency and phase manage necessities [5,6]. Similarly, bi-directional DC/DC converters are used in this dc microgrid to maintain excessive reliability and cargo power deliver [7]. The ultra-capacitor is preferred with battery combinations due to low energy density battery cannot reimburse for fast power fluctuation [8,9]. In the FC, an electrolyze produces hydrogen gas by way of the procedure known as electrolysis. The fuel tanks and metallic hydride tanks are used to shop the hydrogen fuel in the FC. Compared to gas tanks, steel hydride is extra steeply-priced and larger in length, however the safety against accidents is high, and that’s why it is essential for self-governing structures mounted in remote areas [11]. In this paper, the most energy point monitoring (MPPT) of solar PV and FC are performed. To song the most energy, specific types of MPPT strategies are used, particularly perturb and examine (P and O), incremental conductance (INC), FLC, ANN, and particle swarm optimization (PSO) set of rules. In these distinct MPPT strategies, the P and O MPPT approach is maximum frequently used, and it is proposed for both PV and FC structures [12,13]. In this paper, exceptional types of MPPT [14–16] techniques (FLC, ANN and PSO) are used for accomplishing the maximum strength of PV and FC systems and embracing all hybrid electricity (PV-FC) with battery and extremely-capacitor strength at DC hyperlink. Figure 1 indicates the allotted RES, ESS, DC load with grid-linked voltage supply converter. DC microgrids have more benefits together with excessive efficiency, reliability, and low environmental pollutants than AC microgrids and do not have frequency, reactive strength problems. Hence, it is easy to hyperlink with DC micro sources. A have a look at of different controllers together with FLC, NN, and PSO algorithm for hybrid DC microgrid has been made on this paper. With the assistance of various controllers, the settling time of strength is discovered. It is decided that fuzzy provides the simplest MPPT machine as compared to different control strategies. The smart techniques are well monitored and it is used for solving nonlinearity, nature of the time-varying hassle. The SPV modelling, sun irradiance and temperature are tremendously nonlinear and dynamic in nature. The fuzzy logic controllers (FLC), particle swarm optimization (PSO) based MPPT strategies are used for extracting the smoothening electricity [6-7]. These artificial strategies are used to extract the power based on the guidelines and the formula of the problem-dependent. These sensible techniques are reducing the oscillation gift within the MPP (most power point) below constant-country. However, none of these techniques is completely decreasing the oscillation presence. Researchers are operating for purchasing the smoothening energy correctly. The adaptive Neuro-fuzzy records device (ANFIS) based totally MPPT technique is also used to song the maximum energy from SPV. The ANFIS sensible controller is straightforward to broaden the version and track the maximum electricity from the SPV based on the training the records. The monitoring performance additionally improves. The oscillation presence is substantially decreased [8-9]. In this paper, the ANFIS based totally MPPT is used to song the smoothening energy from the SPV the usage of a boost converter.

II. Mathematical Model of Solar PV and Fuel Cell

The mathematical equations are modelled and designed using MATLAB/Simulink for PV and FC, which is illuminated as follows: 2.1. Modelling of Solar PV cells is electrical devices that transform sun electricity into power the usage of semiconducting devices that display the photovoltaic effect. The photovoltaic mobile is used to explain electrical variables along with cutting-edge, voltage, and resistance as they change in reaction to sunlight. The equivalent circuit of a solar mobile is proven in Figure 2. When an electron collides with any other electron in its certain country, electron conduction occurs, and those electrons are energized through the bottom power provided by means of the semiconductor’s bandgap. The equivalent circuit of the PV [20] module carries a diode, light-created source, and resistance-related in parallel. Figure three suggests the P-V and I-V traits [21–23] of the solar cells, that is conditioned and screened for diverse irradiances at T = 25 ◦C. The following Equations (1)–(4) constitute the mathematical equations for modelling sun cells.

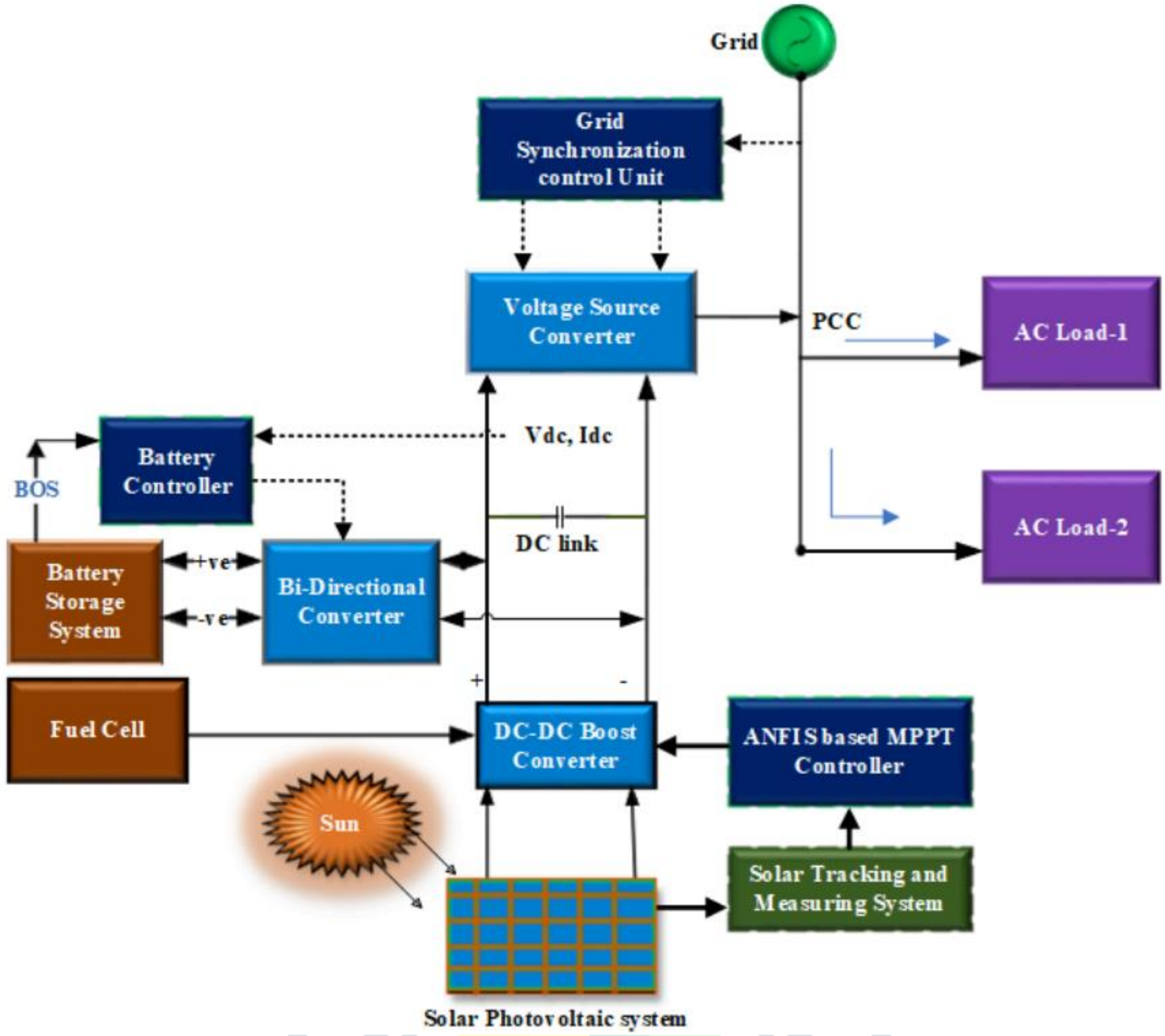


Fig1. Proposed hybrid system

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

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

$$I_{ph} = I_{rr}\left[I_{sc} + k_i\left(T_{op} - T_{ref}\right)\right]$$

$$I_d = I_{rr}\left[\frac{T_{op}}{T_{ref}}\right]^3 \exp\left(\frac{qE_g}{kQA}\left[\frac{1}{T_{ref}} - \frac{1}{T_{op}}\right]\right)$$

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.

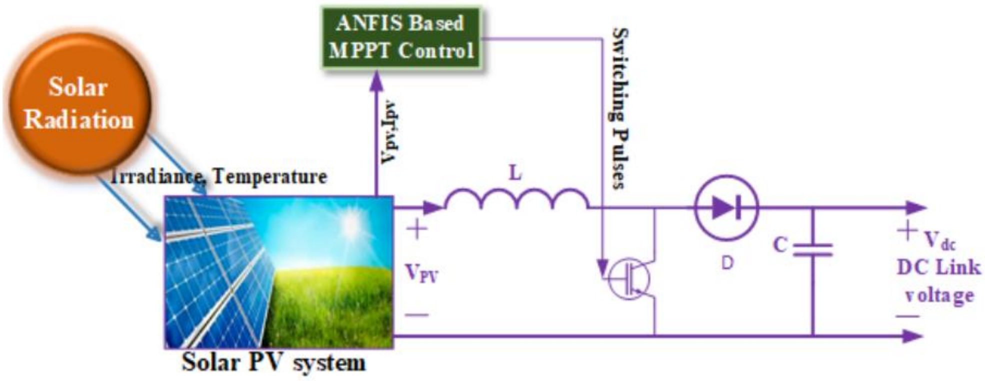


Fig. 2. PV with Boost Converter.

III. FC Mathematical Model

The FC consists 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 blended to form an electrochemical method to specific reaction kinetics and electro-osmotic drag for the duration of the polymer electrolyte manner. Equations (five)–(10) constitute the 5 equations for this FC version in vector shape.

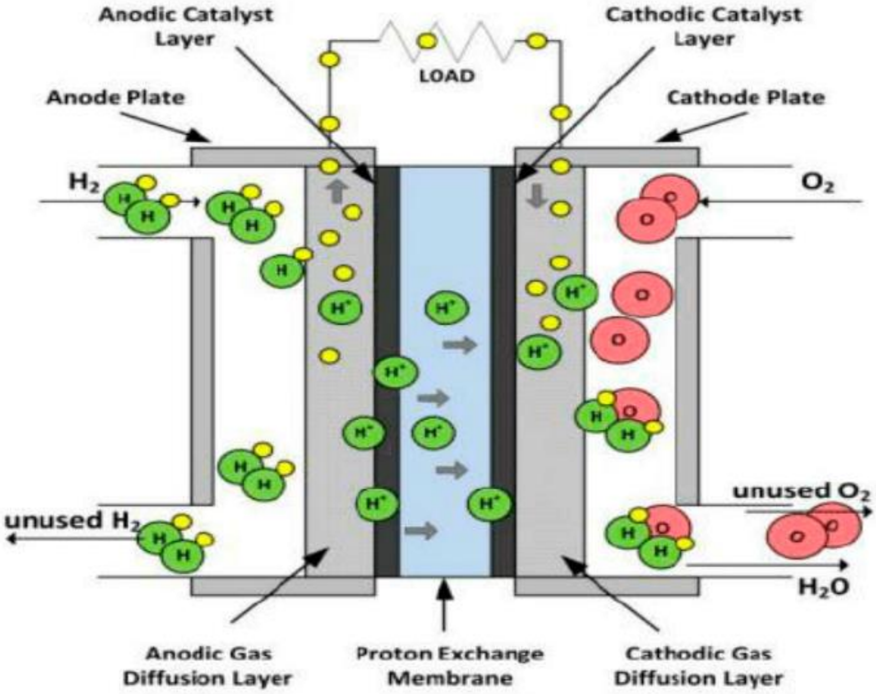


figure 3. Schematic illustration of proton exchange membrane fuel cell (PEMFC).

Continuity Equation The electrodes present within the FC is made from carbon fibre or carbon fabric. The reactant gases are spread over the CL, 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)

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

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.

$$\left(\frac{\partial(\varepsilon\rho U)}{\partial t}\right) + \nabla\cdot\left(\varepsilon\rho U^2\right) = -\varepsilon\nabla p + \varepsilon F + \nabla\cdot(\varepsilon\tau) - \frac{\varepsilon^2\mu U}{k}$$

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 utilized in CL to behaviour electrochemical reactions. The fee equations 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:

$$\nabla\cdot i = 0$$

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

$$i = i_s + i_m$$

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

$$J_t = -\nabla\cdot - (\sigma_s \nabla\varphi_s) = \nabla\cdot(-\sigma_m \nabla\varphi_m)$$

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 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

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

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 battery garage is a backup strength supply. It stores the charge throughout the immoderate energy generated from the supply and can deliver lower back through the bi-directional converter at some stage in the load demand. 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. The bi-directional controller keeps the DC hyperlink voltage primarily based on the state of the fee. The switching pulses of the bidirectional converter function via the bi-directional controller. The battery state of the charge in the variety of 30% to eighty% is taken into consideration to perform the battery state of the price.

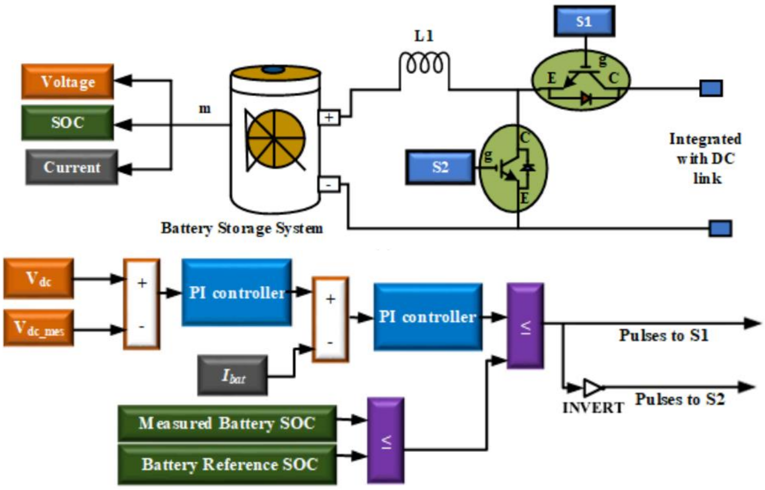


Fig.4. Battery storage systems (a) Battery with bi-directional converter, (b) Bi-directional controller

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 at the reference battery country of the rate (SoC).

V. SYSTEM MODEL

The VSC primarily based PLL and THD control machine is tested in this paper is proven in Fig.5. It includes three terminals, one terminal (VSC) is connected to the conventional electricity flora like PV Fuel Cell and Battery structures to a robust AC grid located at masses Dc hyperlinks Light transmission machine, links to the offshore platforms presenting strength from the dc link.

AC voltage, using strength impartial control structures. Finally, the converter linked to VSC is adopted with the AC voltage control approach so that it will provide uninterrupted and balanced AC voltage at the terminal. Each VSC of the gadget is coupled with an AC network thru DC capacitor C is in parallel to the DC bus from the station as proven in Fig.1. The following equations are acquired in the d-q synchronous frame.

A. Voltage control

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

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

Where id and iq are line currents, Vsd and Vsq are source voltages, Vcd and Vcq are converter input voltages.

Since Vsd is constant, from (5) and (6) it is clear that the active power will be controlled by id, whole the reactive power will be controlled by iq. On the DC side of the converter, DC current and DC power are;

$$i_{dc} = C\frac{dv_{dc}}{dt} + i_c$$

Outer Controllers In widespread, continuously energetic, reactive power manipulate or regular AC/DC voltage manipulate method can be followed for nearby manipulate at every VSC in the MTDC device. The control circuit of VSC is proven in Fig.2 includes an outer manage loop and internal current manipulate loop. The outer controller includes active, reactive energy manage, 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 cutting-edge. From equations (five) and (6), 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:

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

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

$$i_{sq\_ref} = \frac{Q_{ref}}{v_{sq}} + (K_p + \frac{K_i}{s})(Q_{ref} - Q)$$

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

$$i_{d\_ref}=(K_p+\frac{K_i}{s})(v_{s\_ref}-v_s)$$

With

$$v_s=\sqrt{(v_{sd}^2+v_{si}^2)}=v_{sd}$$

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

AC grid and on this way without any energy storage device, VSC acts as an 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

$$i_{dc\_ref}=(K_p+\frac{K_i}{s})(v_{dc\_ref}-v_{dc})$$

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

VSC Structure is extra complicated because of the interconnection of greater than converters for the same DC bus. So it is important to govern the DC link voltage inside applicable limits to guarantee that all lively energy at the DC grid is transmitted into the AC grid/load. In order to make sure the stability and reliability of the VSC gadget, ANFIS based coordinated management strategy is brought in this paper. ANFIS is an adaptive network that is functionally equivalent to a fuzzy inference machine, wherein the output has been obtained by using the usage of fuzzy rules on inputs. Fig. 3 depicts a two - input one - output ANFIS structure [14]. The two inputs are x1 (errors) which become obtained as x2 (change of blunders) and the output is a managed DC hyperlink voltage. Each enters and output variable has 5 linguistic variables, i.E., Negative huge (NL), Negative small (NS), Zero (Z), Positive small (PS) and Positive massive (PL). Hence, in this proposed ANFIS controller total of 25 linguistic variables for the output are employed.

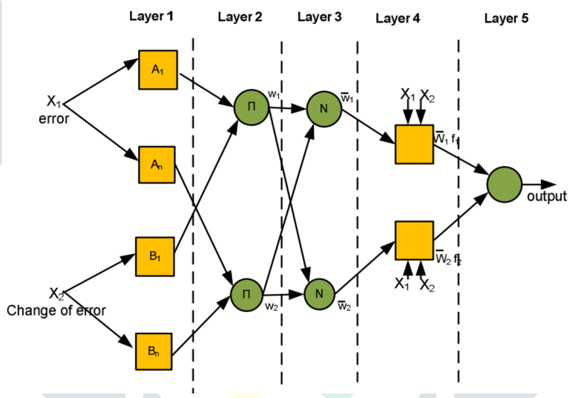


Fig 5. An ANFIS structure

The proposed ANFIS architecture consists of 5 layers wherein circle-shaped nodes are known as constant nodes, which means that the node parameters are impartial of the other nodes and rectangular-shaped nodes are known as adaptive nodes, whose node parameters rely upon the opposite nodes. Each neuron in the first layer corresponds to a linguistic variable whilst the output.

Equals the club function of this linguistic variable. In the second one layer, each node multiplies the incoming signals and sends out the product that represents the firing electricity of a rule. Each node inside the 0.33 layer estimates the ratio of the rule of thumb firing electricity to a number of the firing strength of all guidelines. In the fourth layer, the output is the made from the formerly determined relative firing electricity of the ith rule. The very last layer computes the general output as the summation of the incoming alerts. The proposed controller is checked in MATLAB/ANFIS editor toolbox with a triangular club feature because it gives minimal schooling errors. Since the backpropagation algorithm is notorious for its slowness and tendency to grow to be trapped in neighbourhood minima, a hybrid mastering algorithm is used in this contribution. This set of rules is speedy and accurate in identifying the parameters.

VII. SIMULATION AND RESULTS

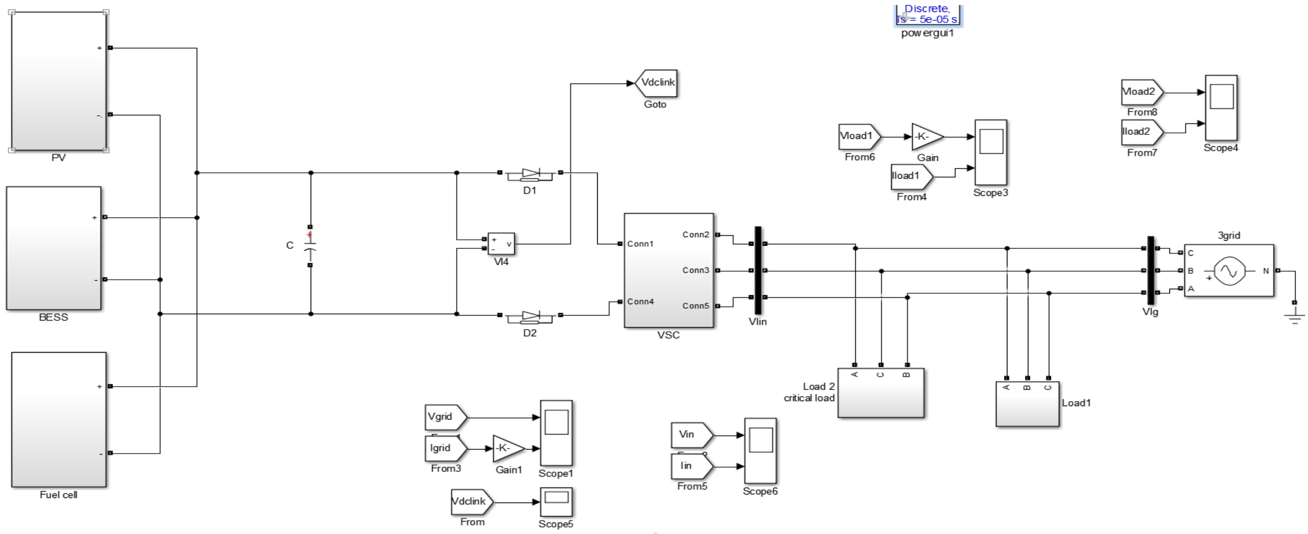
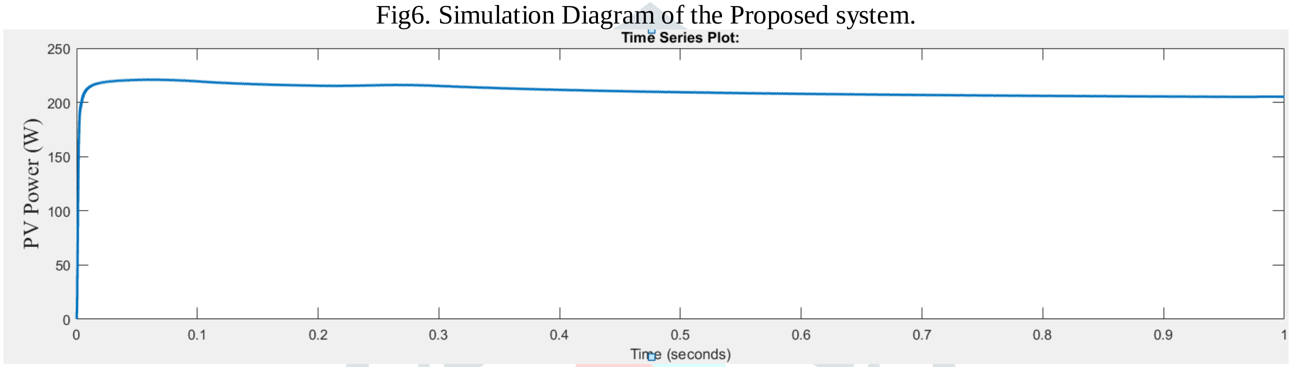
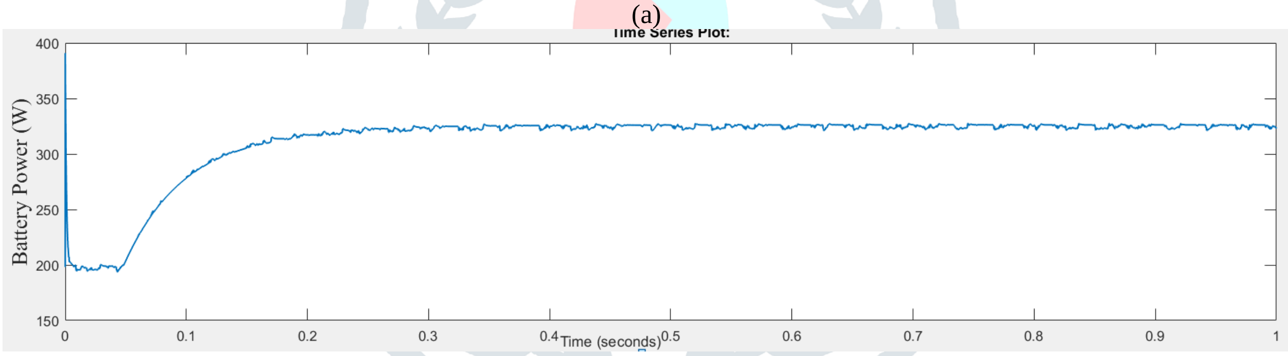


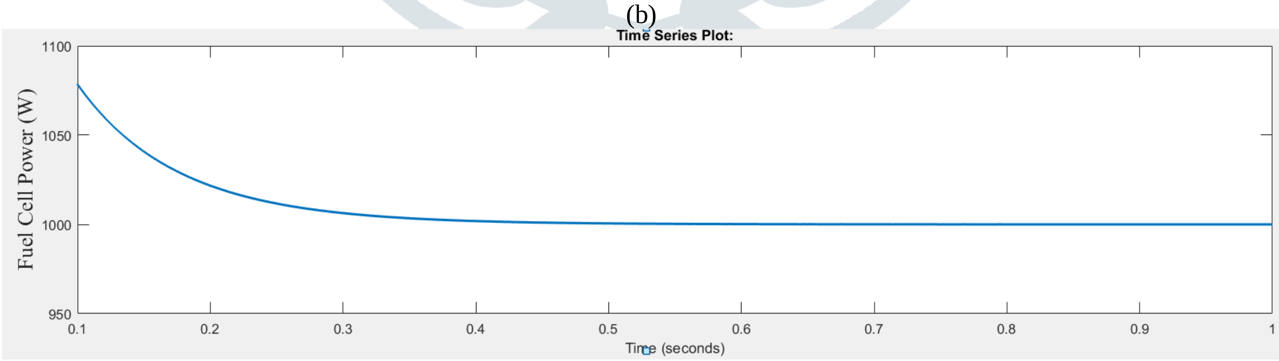
Fig6. Simulation Diagram of the Proposed system.



(a)



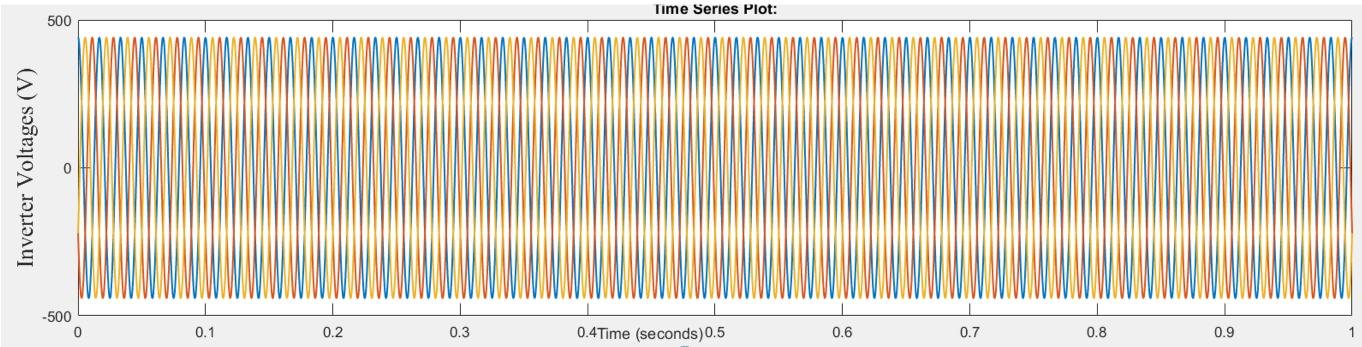
(b)



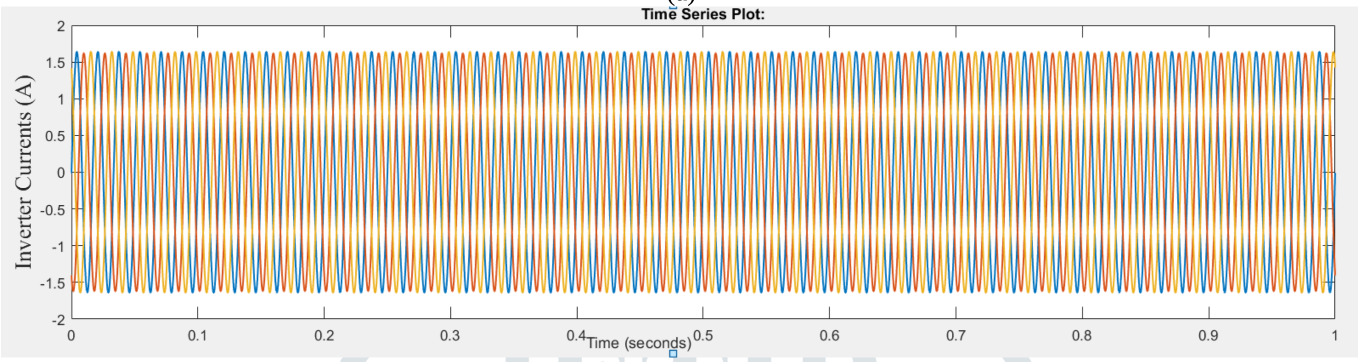
(c)

Fig 7. (a) PV power (b) Battery Power (c) Fuel Cell power.

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



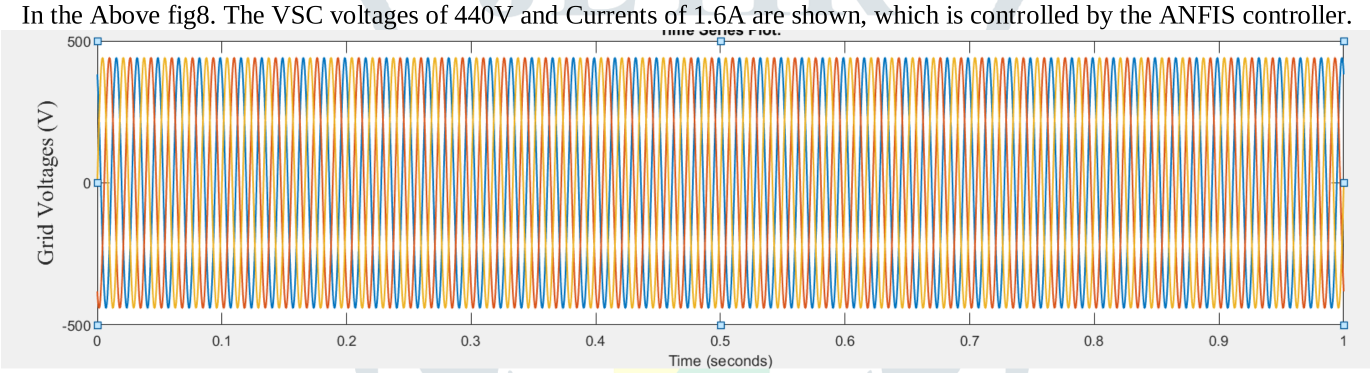
(a)



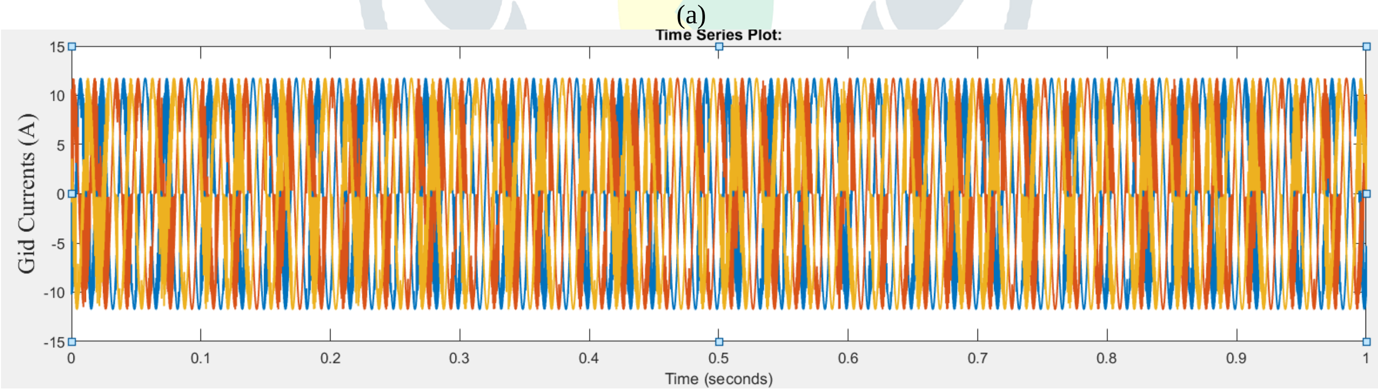
(b)

Fig8. Inverter (a) Voltages and (b) Currents

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



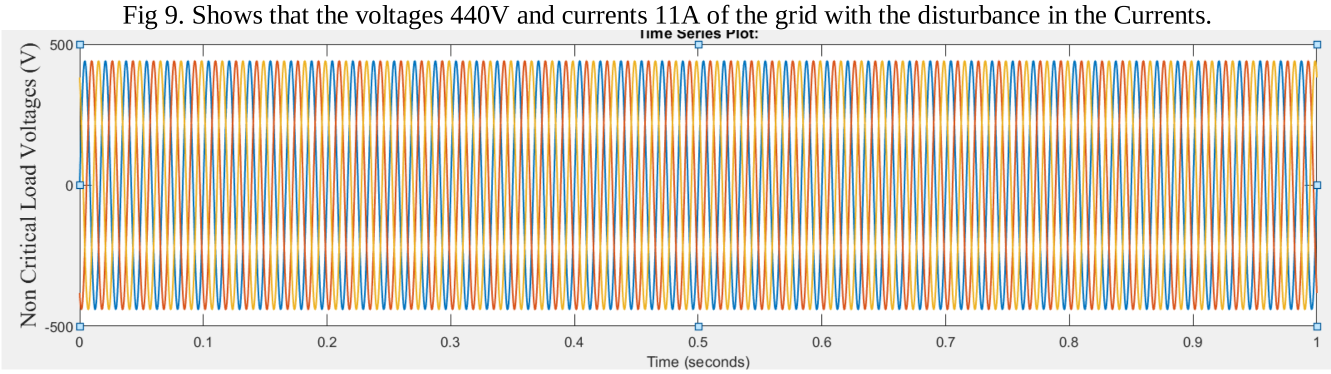
(a)



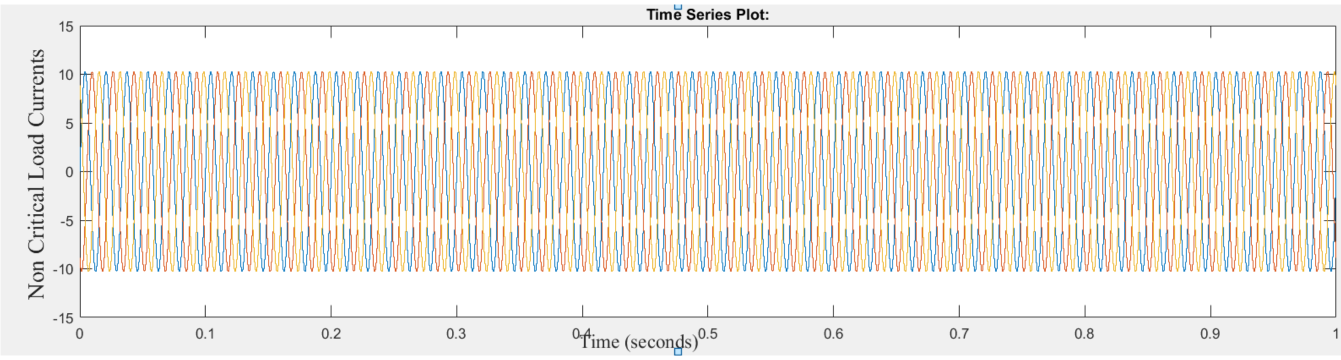
(b)

Fig9. Grid (a)Voltages and (b)Currents.

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



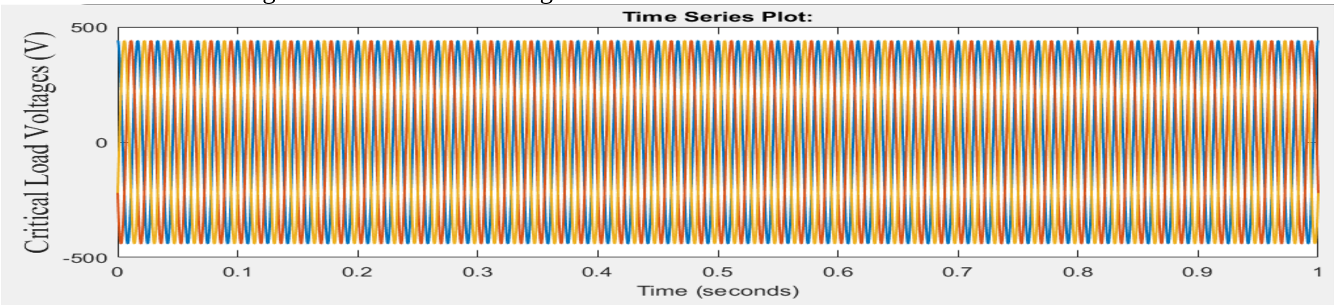
(a)



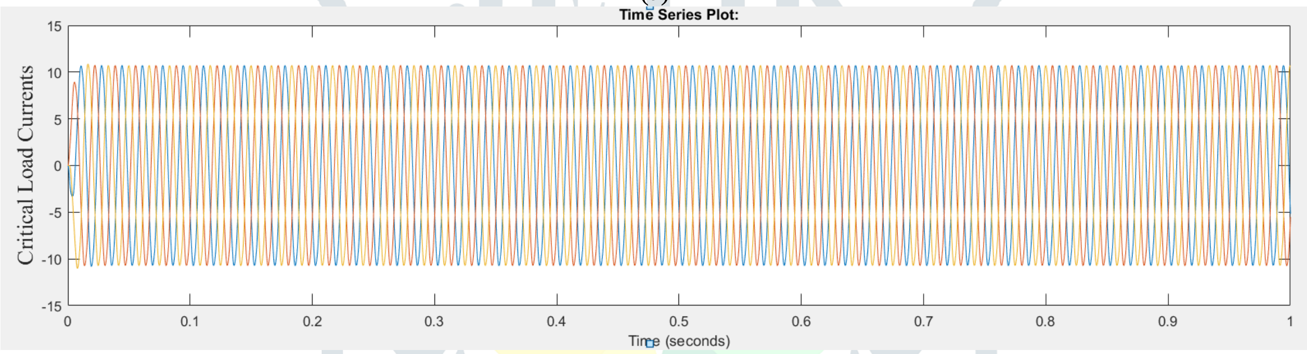
(b)

Fig 10. Load1 (a) Voltages and (b) Currents

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



(a)



(b)

Fig11. Load2 (a) Voltages and (b) Currents

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

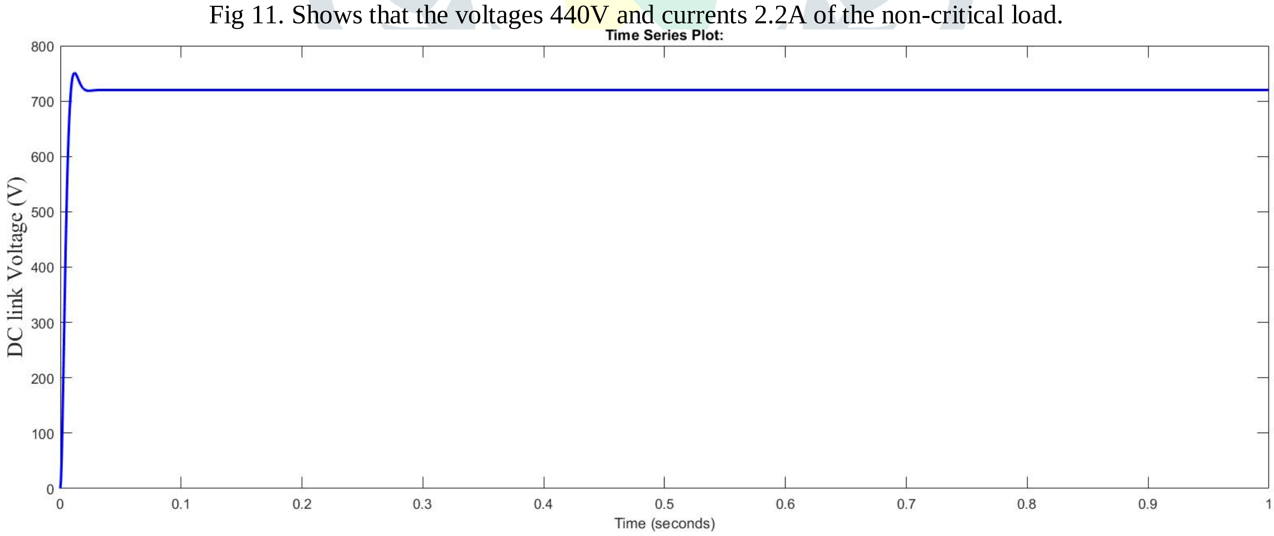
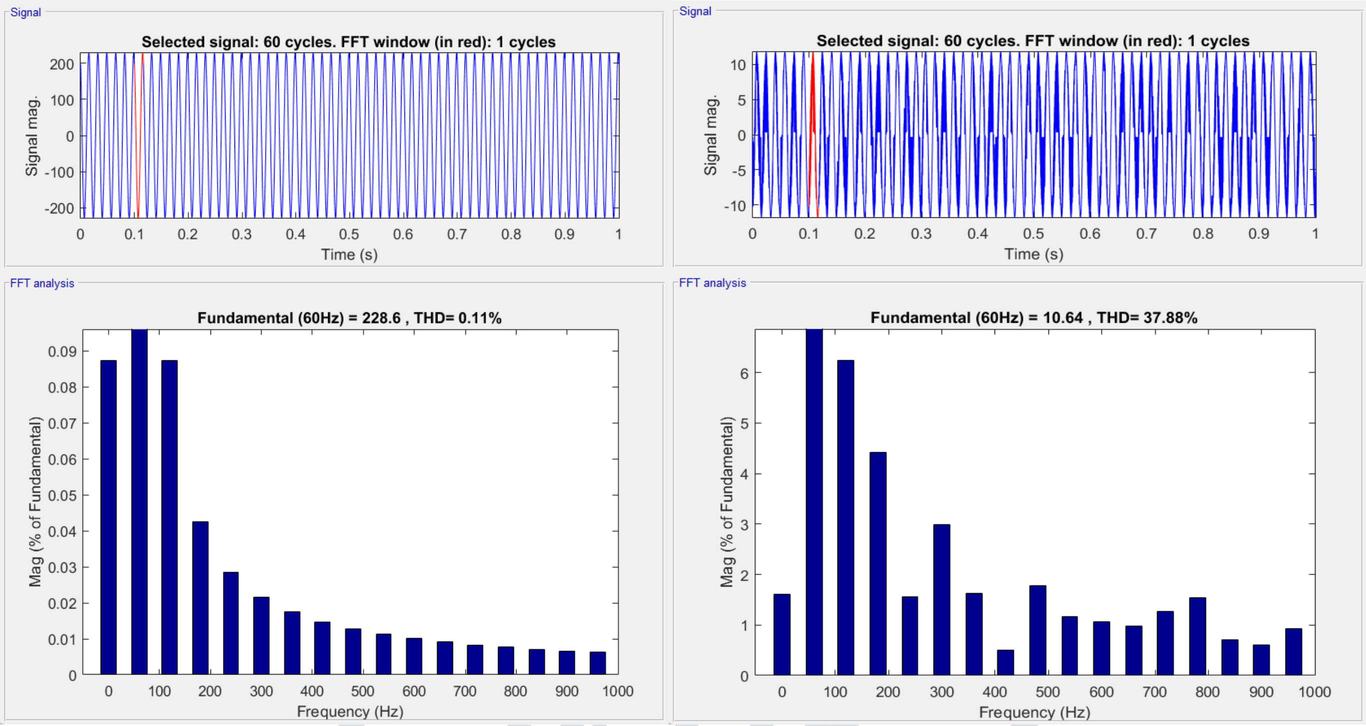


Fig12. DC link Voltage

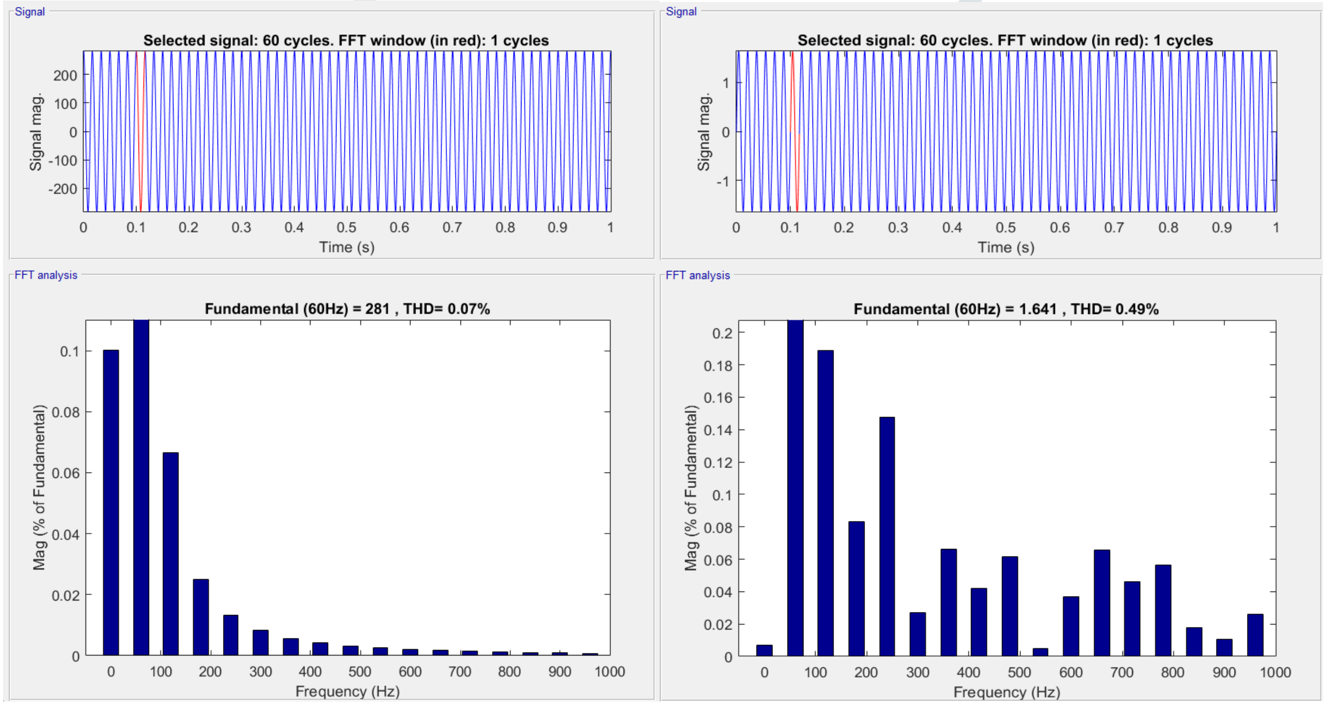
DC link voltage 700V after the sources of PV, battery and fuel cell at the inverter.

FFT ANALYSIS



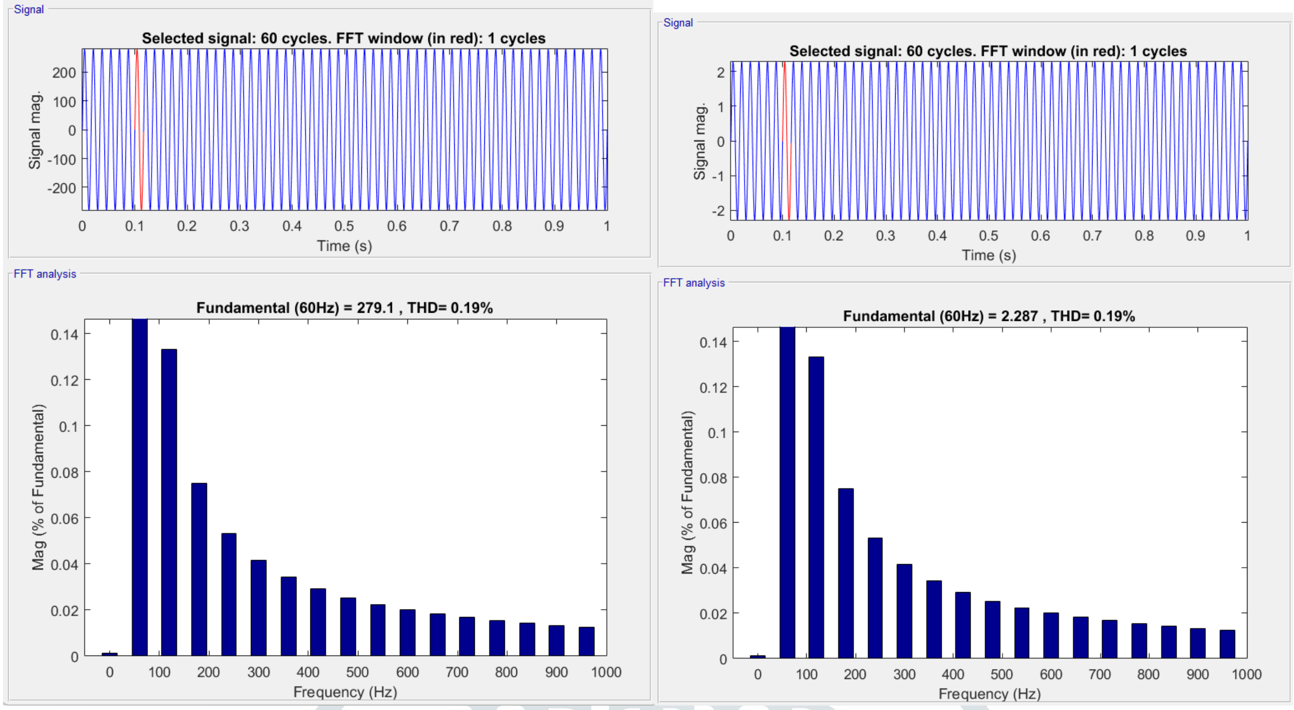
(a) (b)

Fig 13. (a) Grid Voltage THD 0.11% (b) Grid Currents THD 37.88%



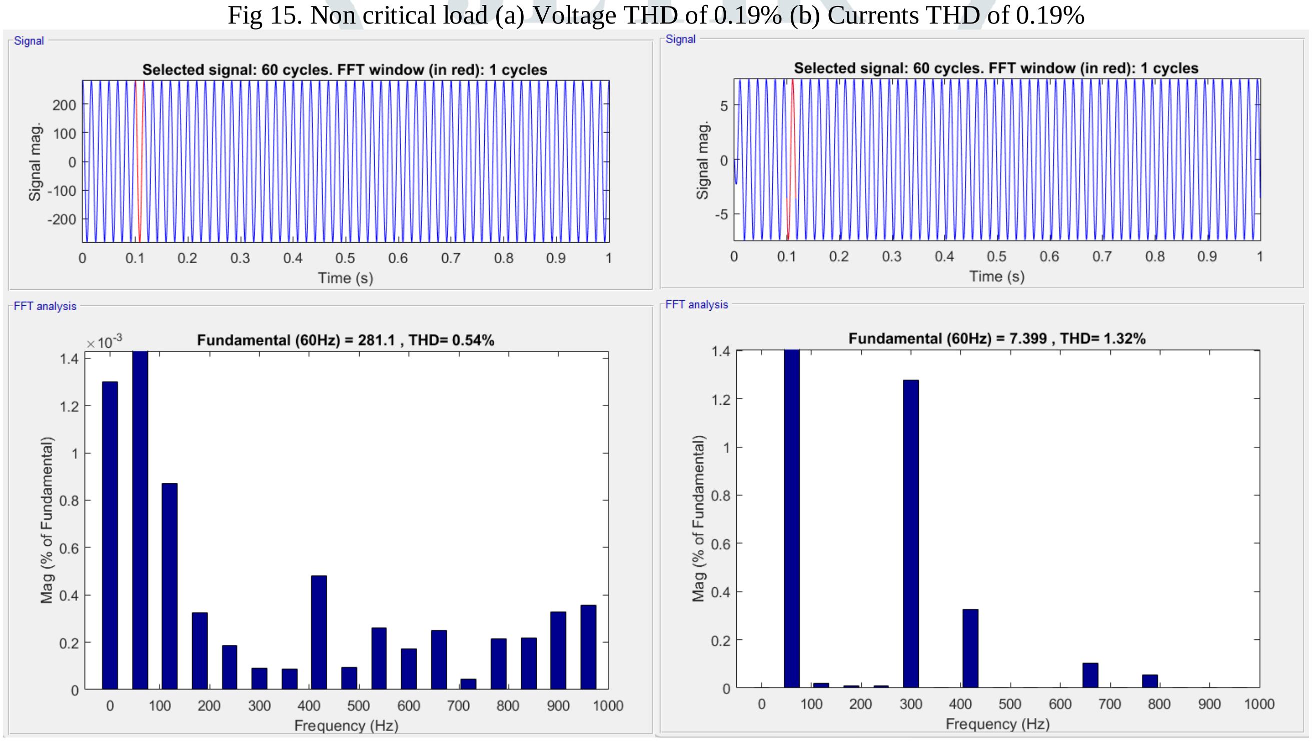
(b) (b)

Fig14. (a) Inverter Voltage THD of 0.07% (b) Inverter Current THD of 0.49%



(a) (b)

Fig 15. Non critical load (a) Voltage THD of 0.19% (b) Currents THD of 0.19%



(c) (b)

Fig 16. Critical load (a) Voltage THD of 0.54% (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 VSC device at different manipulate techniques with ANFIS controller. The simulation effects under everyday circumstances indicate that the coordinated manipulate strategy keeps AC voltage RMS regular, transmits the strength from PV, Fuel Cell and Battery to AC grid through DC line. By the ANFIS based MPPT for the PV system, it extracts the maximum power. Similarly, for large at an AC grid/ offshore platform, the ANFIS device responds quickly after which every managed output returns to its predefined cost at once. In this paper, the Voltage law and the THD of the Loads are analysed. Here the ANFIS controller gives the most correct values in comparison to the PI controller.

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