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Power Quality Improvement for Microgrid with Multiple Energy Sources

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Abstract: The hybrid micro gird is growing due to the potential benefits in providing safe, reliable and sustainable electricity from renewable energy sources. In this paper, we are discussing the multiple energy sources i.e. PV/Fuel cell and wind based hybrid microgrid with help of simulation approach to improve the power quality in microgrid with ANN control. The artificial neural network control is used for dc/ac conversion with PWM and DVR control to improve the power quality. A small hybrid microgrid has been modeled and simulated using the simulink in the MATLAB. The simulation results are comparing with Pi control.

Keywords: microgrid, hybrid, renewable energy sources, PV, Fuel cells, wind, Power quality, ANN control, Simulation, Pi control.

I. INTRODUCTION

In recent years the microgrid has been growing due to its several potential and economic advantages like, the mircogrid has small investment, which reduces capital exposure and risk by closely matching capacity increases to growth in demand. It is also reduced transmission and distribution cost. The micro-grid has less energy losses and higher overall energy efficiency [1].

The progressive decrease of fossil fuels like coal, diesel and increase the environmental problem associated to their combustion force to search the alternative sources of electrical energy to meet the load demand [2]. The micro-grid is designed based on the renewable energy sources near by the Load. The fuel cells, PV cell technology and wind power is mainly used in the microgrid to full-fill the load demand with hybrid technology. In hybrid micro-grid the power quality problem is the measures aspect, which is affecting the load demand. The main cause of power quality problem is power electronic components, which required in microgrid to convert dc to ac. The output of the inverter in microgrid should be compatible in voltage and frequency with load [3].

In ac micro-grid dc power from photovoltaic panels and fuel cells has been converted into ac using dc/dc boosters and dc/ac inverter in order to connect the ac load. Due to static devices in converter results are harmonics injection and lower power factor to electric power system [6]. The load equipments of the modern generation are more sensitive. Due to harmonics can initiate production loss, economic loss and environmental effect [10]. In this paper, we are discussing the dc/ac inverter based on the ANN control to improve the performance of PWM inverter. To minimize the harmonics in the microgrid the ANN based DVR control is proposed.

II. CONTROLS IN MICROGRID

In the microgrid the major source of electricity are Photovoltaic cells and Fuel cells. These sources are generating the dc output. The load connected to the grid is ac load. The conversion devices have main role in the microgrid.

a) Conversion control: The Photovoltaic cells and fuel cells are connected to the dc bus through a boost DC/DC converter in order to generate the maximum power from PV cells and fuel cells.. After boost the dc the load is connected to the grid. The PWM based inverter is used to convert the dc to ac. To operate or control the boost converter and inverter different gate control are used for accurate output and to minimize the power losses . The major problem with control devices are harmonic generation[3].

b) Power quality control: The power electronics devices are used for interface the renewable sources to microgrid or interconnected with other sources like renewable and non-renewable generators, storage systems and load in microgrid. The microgrid is different from the main grid, where the large and sudden changes in the load may results in voltage transient of large magnitudes in ac bus. The non-linear loads and switching power converters are decreasing the power quality in microgrid [5]. To overcome the power quality problem in distribution the DVR control is proposed.

III. DYNAMIC VOLTAGE RESTORES

In electrical power system the power quality problems occurs when the alternating voltage power sources sine wave is distorted. The dynamic voltage restores are becoming more established to reduces the voltage drop in the power system. The basic principal operation of DVR is to inject a dynamically controlled voltage in series with the supply through booster transformer, which will help to eliminate detriment effects of a bus fault to the load voltage. It is also used for harmonic compensation and power factor correction [14].

There are three methods to inject DVR compensating voltage.

a.) Pre-Dip compensation (PDC): It compensate the load voltage during fault to pre-fault condition. In this method, the load voltage can be restored ideally, but the injected active power cannot controlled. The lack of the negative sequence detection the PDC method leads to the phase-oscillation in case of single line faults shown in fig-1[14]

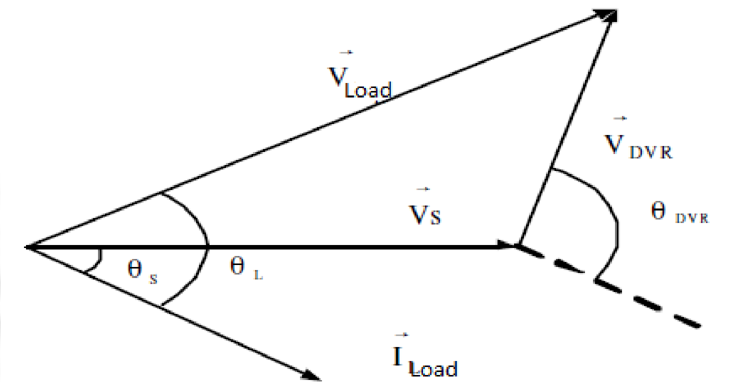

Fig:-1: Single Phase Vector diagram of PDC[14]

From fig-1,
Apparent Power of DVR is

$$S_{DVR} = I_{Load}\, V_{DVR} = I_{Load}\sqrt{V_{Load}^2 + V_s^2 - 2V_{Load}V_s\cos(\theta_L - \theta_s)} \quad (1)$$

Active Power

$$P_{DVR} = I_L(V_{Load}\cos\theta_L - V_S\cos\theta_s) \quad (2)$$

The magnitude and phase angle of DVR voltage

$$V_{DVR} = \sqrt{V_{Load}^2 + V_s^2 - 2V_{Load}V_s\cos(\theta_L - \theta_s)} \quad (3)$$

$$\theta_{DVR} = \tan^{-1}\left(\frac{V_{Load}\sin\theta_L - V_S\sin\theta_S}{V_{Load}\cos\theta_L - V_S\cos\theta_S}\right) \quad (4)$$

b) In-phase compensation (IPC): This is mostly used method to inject the DVR voltage in phase with supply voltage as shown in Fig-2. The IPC method required large amounts of real power to mitigate the voltage sag, which means a large storage device[14].

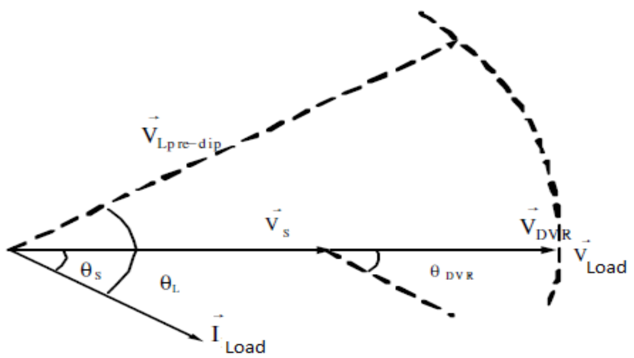

Fig-2: single phase vector diagram of IPC method[14]

The apparent Power

$\boldsymbol{S_{DVR} = I_{Load}V_{DVR} = I_{Load}(V_{Load} - V_s)}$ **(5)**

Active Power

$\boldsymbol{P_{DVR} = I_{Load}V_{DVR}cos\theta_s = I_{Load}(V_{Load} - V_s)cos\theta_s}$ **(6)**

The magnitude and angle of DVR voltage

$\boldsymbol{V_{DVR} = V_{Load} - V_S}$ **(7)**

$\boldsymbol{\theta_{DVR} = \theta_s}$ **(8)**

c) In-Phase Advanced compensation (IPAC): This method is controlling injection energy, in phase advance compensation method was proposed. The injection of active power is made zero by means the injection voltage phasor perpendicular to the load current phasor. This method reduce the energy stored in DC link by injecting reactive power [14].

IV. ANN CONTROL FOR MICROGRID

To improve the performance of the gate control circuit for PWM inverter and DVR control in PV/Fuel cell based microgrid, a multilayer back propagation type artificial neural network controller is used. The back propagation algorithm is used to train the network. The Gradient decent method is used to find the local minimum of a given function. The GD method is the first order optimization algorithm and it is robust when it start far of the final minimum. The Levenberg Marquardt back propagation algorithm is the second order optimization and it is more robust & finds a solution even if it does begin far from the final optimum. The Levenberg Marquardt algorithm is interpolates between the Gauss Newton algorithm and gradient decent method and it is best comparing to Gauss Newton and gradient decent method.[10].

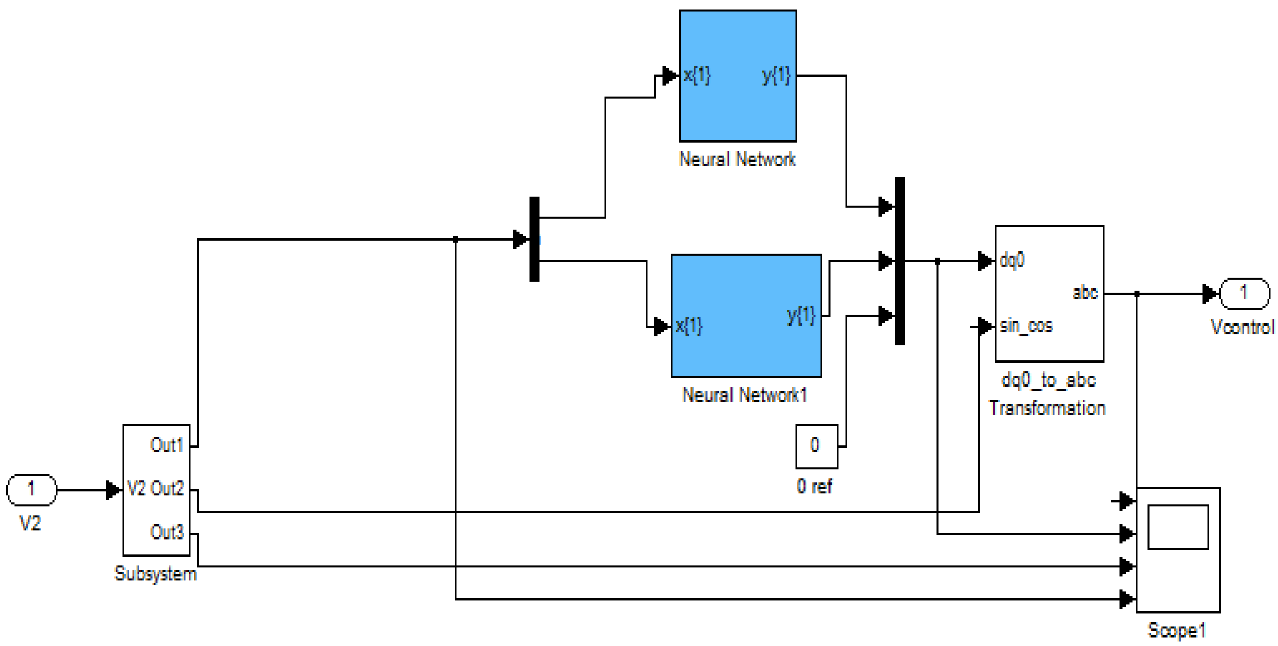

Fig:-3: ANN control circuit for Inverter control

In fig-3 shown the artificial neural network control simulation circuit in MATLAB simulation for DVR control and PWM inverter control in the microgrid with Levenberg Marquardt back propagation algorithm. All the input are used to train the ANN from conventional controller. As shown Fig-4 the artificial neural network contain the three layer composed of two input layers and one output layer. Here Input1 and a(1) are the input layers and a(2) are the output layer of the network. Each input layer have the input with weights W_{11} with adder function to compute the weighted sum and input of the layer. It is also containing a Linear transfer function as activation function and bias **b**.

Output= activation function (weighted sum of inputs + bias) (9)

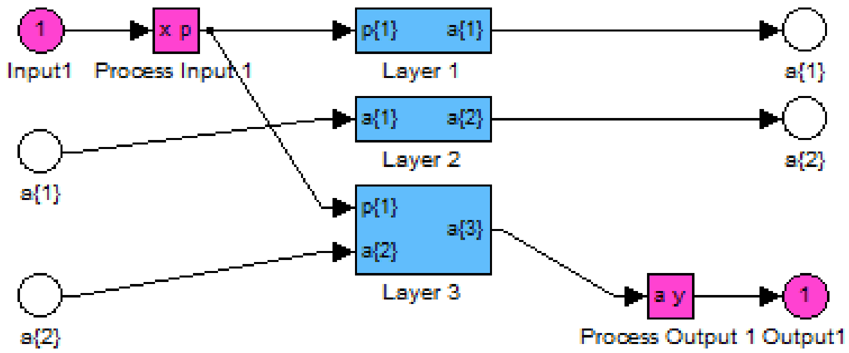

Fig-4: Multilayer ANN network for control circuit

The Output layer have the process input from input1 and a(2) with the delay and input weight as shown the Fig-5. The output is given by :

netsum = (p(1)w{3,1})+(a(2)W{3,2})------ (10)
output (a{3}) = AF(netsum + b{3}-------- (11)

Here,
netsum = An adder function
p(1)and a(2)= Input of the neuron
w{3,1} and {3,2} = weight of input neuron
AF= activation function (Linear transfer function)
b{3}= bias input

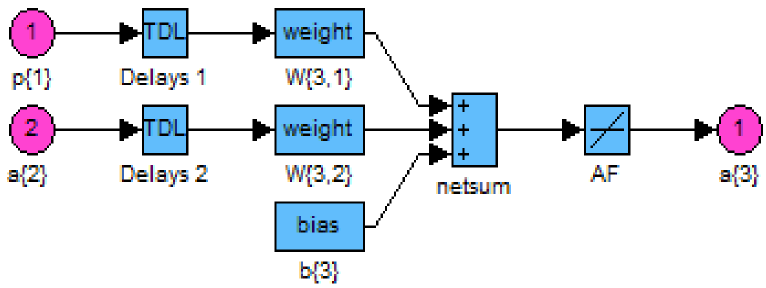

Fig: 5: Output Layer for ANN

The input of the artificial neural network with error, So, the error signals are not fed directly to the artificial neural network. First the error signals from input and phase signal from PLL is converted from abc to dqo. The abc to dqo transformation will done on three phase signal and it computes the direct axis V_d ,quadratic axis V_q and zero sequence V_o quantifies two axis rotatively reference frame.

$$V_d = 2/3[v_a \sin(\omega t) + v_b \sin\left(\omega t - \frac{2\pi}{3}\right) + v_c \sin\left(\omega t + \frac{2\pi}{3}\right)] \ldots \quad (12)$$

$$V_q = 2/3[v_a \cos(\omega t) + v_b \cos\left(\omega t - \frac{2\pi}{3}\right) + v_c \cos\left(\omega t + \frac{2\pi}{3}\right) \ldots \quad (13)$$

$$V_o = 1/3[v_a + v_b + v_c] \ldots \quad (14)$$

Where ω is the rotation speed(rad/sec)

The neural network will minimize the error in both d and q coordinates with the help of training algorithm. After minimizing the error signal the dqo convert in abc components again as follows.

$$V_a = v_d \sin(\omega t) + v_q \cos(\omega t) + v_o \ldots \quad (15)$$

$$V_b = v_d \sin\left(\omega t - \frac{2\pi}{3}\right) + v_q \cos\left(\omega t - \frac{2\pi}{3}\right) + v \ (16)$$

$$V_c = v_d \sin\left(\omega t + \frac{2\pi}{3}\right) + v_q \cos\left(\omega t + \frac{2\pi}{3}\right) + v_o \ (17)$$

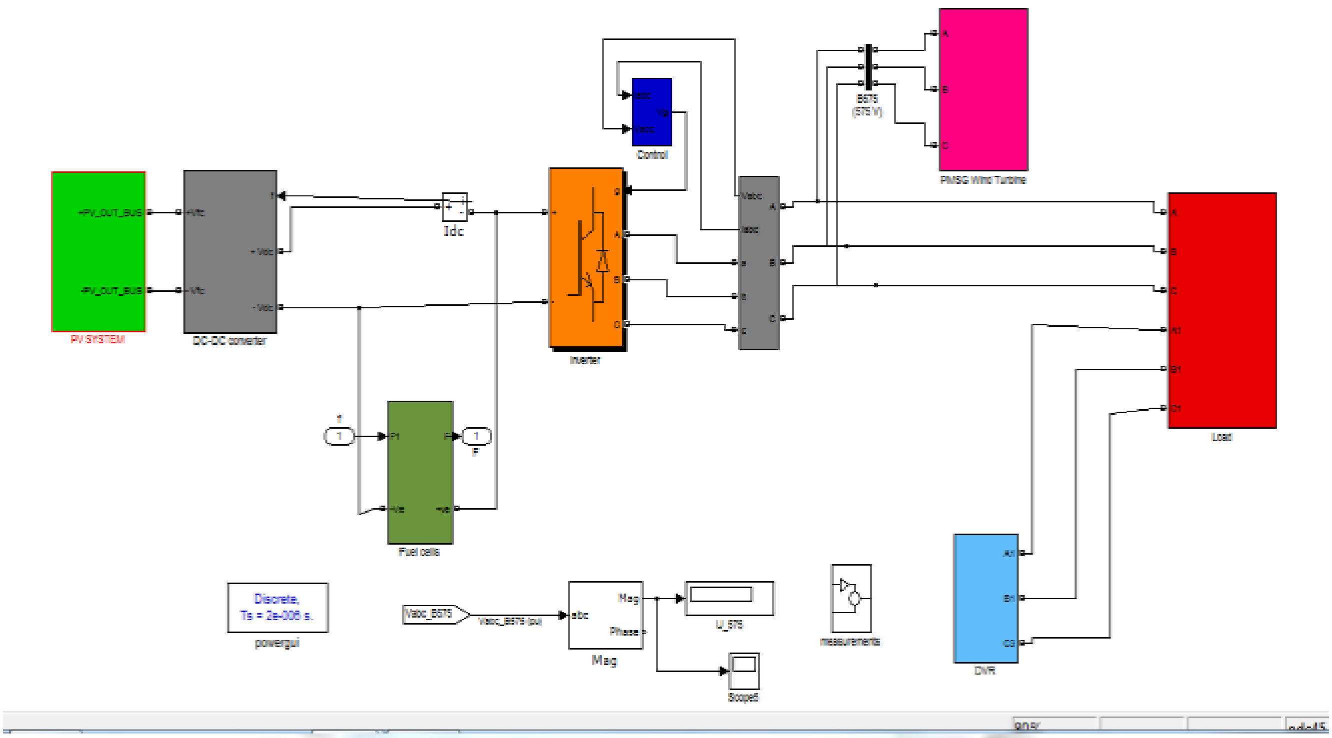

Fig: 6: ANN control for microgid with multiple sources

As shown in Fig-7 Input voltage for control circuit feeding from the load end to control circuit. The input signal will contain the high value of harmonic as shown in Fig-8. As per the FFT analysis the harmonics value is 41.49%.

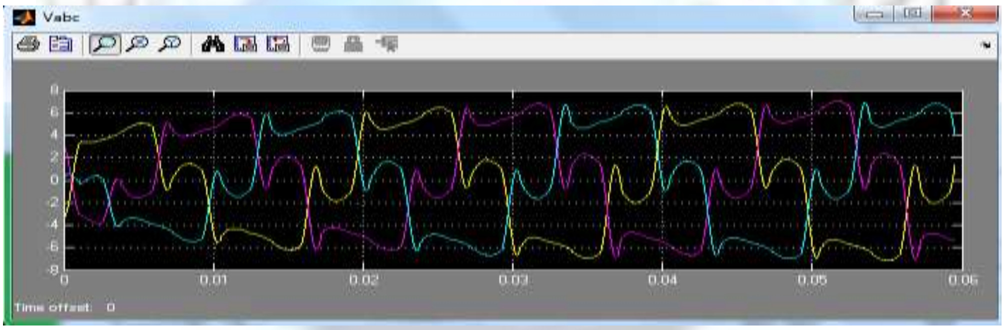

Fig. 7: Input voltage to control circuit

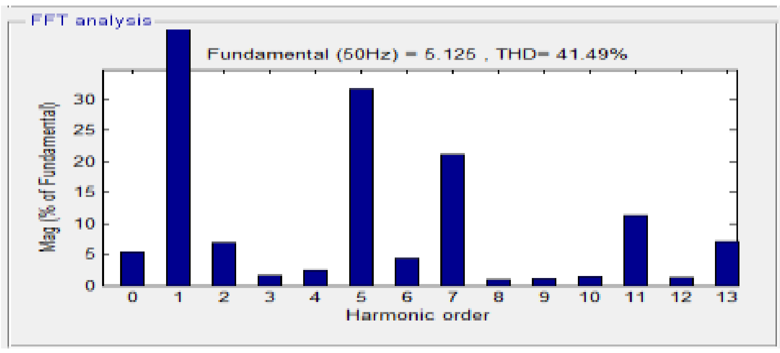

Fig. 8: FFT analysis for Input signal of the control circuit

The control signal will feed to the PWM generator to generate the gate pulses for controlling PV inverter in microgrid.

V. Results analysis

As shown in Fig-6 the PV & Fuel Cell Plant are connected to the inverter for conversion of dc to ac. After conversion, the ac is fed to the microgrid. To control the inverter the ANN control circuit is used, which will generate the gate pulses. After transmit the power on DVR with ANN control is used to minimize the harmonics. As we discuss above section IV the ANN will convert the error signal to smooth signal for gate control for PWM inverter and DVR.

The input signal will converter from abc to dqo transformation because input signal will contain the errors in input. As Fig-9 shown the dq input signal to Neural network.

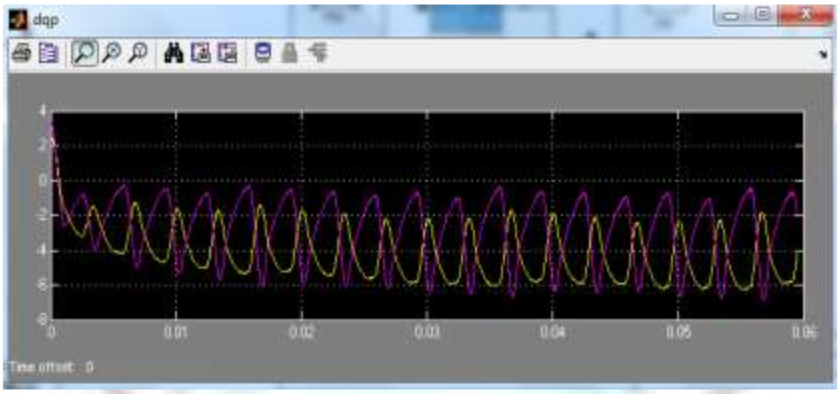

Fig:-9 abc to dq transformation for input signal

The neural network will minimize the error signal in dq signal with the help of training algorithm is discussing in section-IV and generate the error free signal. The error free signal dqo to abc transformation. The dqo to abc trnasomarion signal is shown in Fig:-10 and the signal is error free pure sine wave.

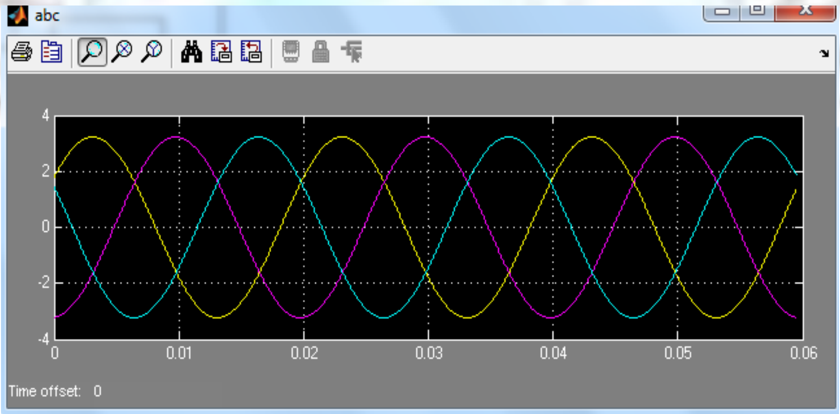

Fig:-10: dqo to abc transformation for error free signal

The Vcontrol signal is given to PWM pulse generator to generate the gate pulses and Vcontrol shown in Fig-11 and the FFT analysis is shown in Fig-12. The gate pulses are shown in Fig:-13 from ANN control.

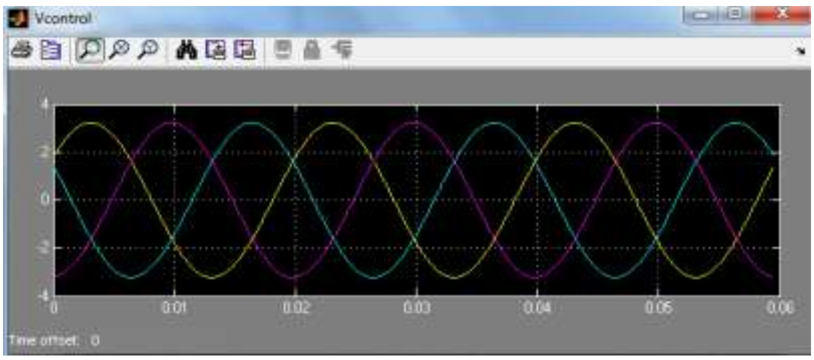

Fig:-11: Vcontrol signal to pulse generator

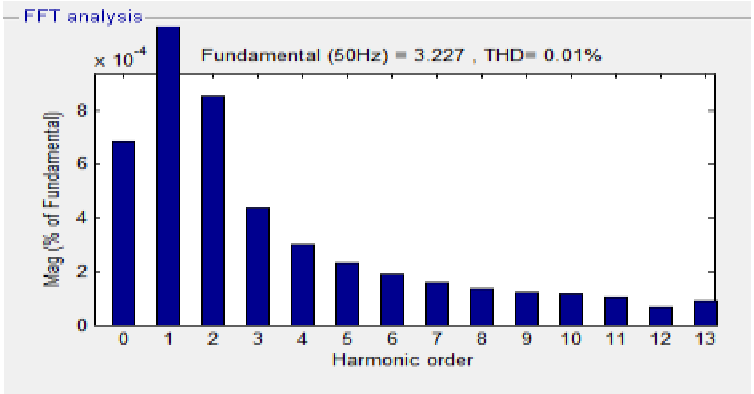

Fig:- 12: FFT analysis for Vcontrol signal

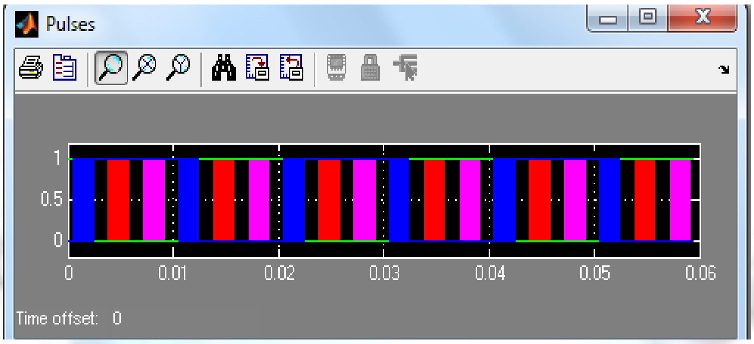

Fig:-13: Gate pulses for gate control

The voltage and current wave form are shown in the Fig-14 and Fig:-15 for PV & Fuel Cell based microgrid. The FFT analysis for voltage and current with ANN DVR control shown in Fig:-16 and Fig-17 and voltage & current waveform with Pi control are shown in Fig:18 and Fig 20.The FFT analysis for current and voltage with Pi control shown in Fig 19 and Fig-21.

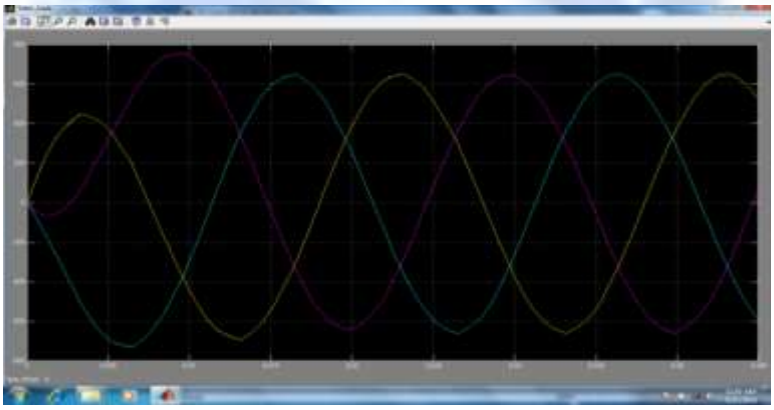

Fig:-14: Load voltage with ANN based DVR control

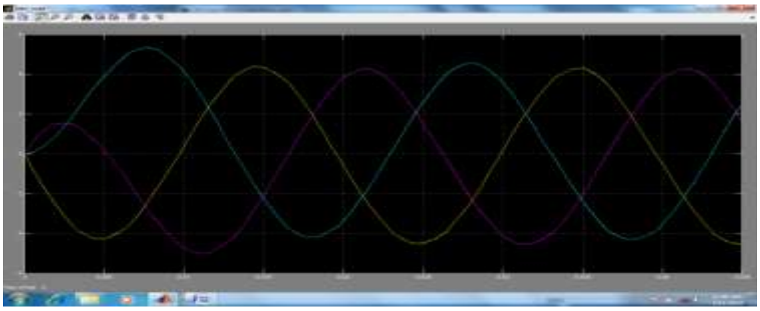

Fig:-15: Load current with ANN based DVR control

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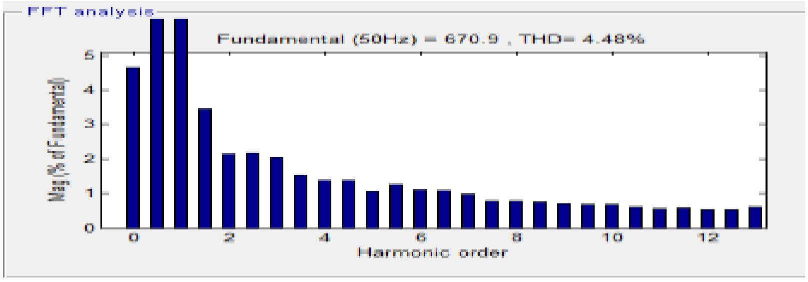

Fig:-16: FFT analysis for Load voltage with ANN based DVR control

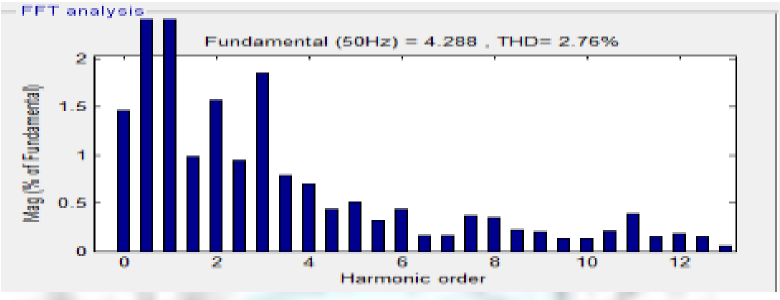

Fig:-17: FFT analysis for Load current with ANN based DVR control

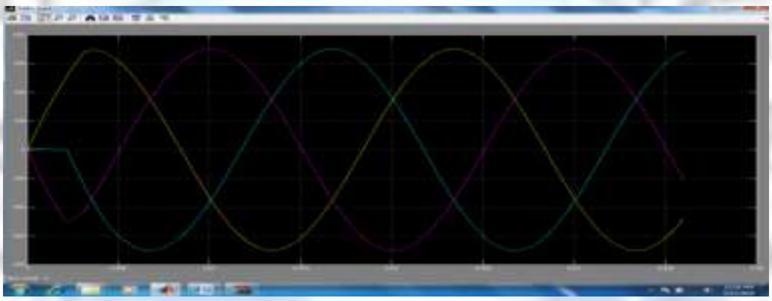

Fig: 18: Load voltage with Pi control based DVR control

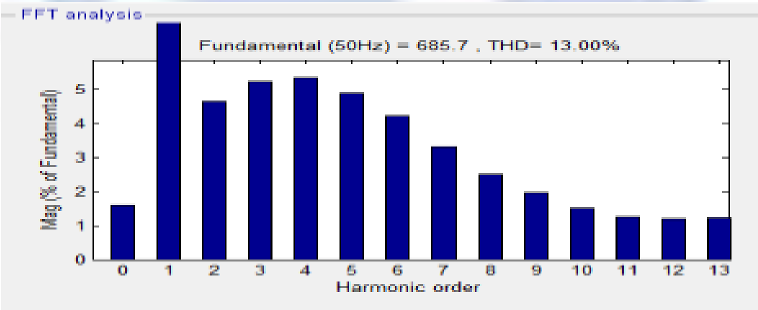

Fig:19 Load voltage with Pi control based DVR control

Fig:20 Load current with Pi control based DVR control

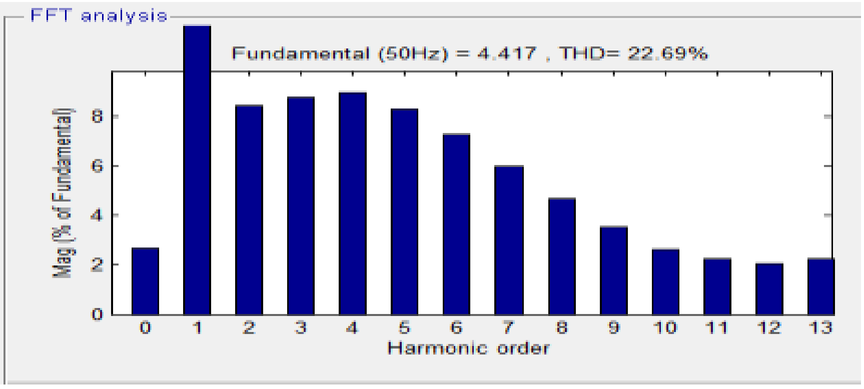

Fig: 21: Load current with Pi control based DVR control

VI. Conclusion

The paper present PV inverter & DVR control with artificial neural network and Pi control to convert the dc to ac in PV & Fuel Cell based microgrid. The artificial neural control used the reference voltage to generate PWM switching signals. The ANN control will remove the error from reference signal and improve the switching signals. The ANN control, training algorithm and principal operation for inverter control were analyzed in details. The DVR control are improving the power quality in microgrid. Experimental results indicate that the THD with ANN control signals and Pi control signals for PWM inverter and DVR. From the result analysis ANN control signals THD value is much less than that of conventional method.

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