Performance analysis of solar PV powered DC micro grid with ANN controllers with PI controllers for Sustainable rural electrification

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Abstract: In recent year the DC microgrids came to the picture because of availability of DES and increase in the number local DC loads. In some of the rural areas where main grid not available micro grids playing key role to serve the electrical energy need of the people. As the penetration of DER in the grid increases the load sharing problems comes into the picture. For effective load sharing the proper operation of converter provides the optimum power extraction of power from source. the grid needs a stable voltage to maintain stability. This can be achieved only when the dynamic control of converters obtained in coordination with load and generation changes. In this paper the performance of the DCMG with classical PI controllers with ANN and FLC controllers have compared.

Keywords: *Distributed energy resources (DER), Renewable energy sources (RES), DC micro grid (DCMG), Proportional integral (PI), Artificial neural network (ANN), Fuzzy logic controllers (FLC), Digital logic controllers (DDC)*

1. Introduction

Most of the people who are living in rural/remote locations suffering from severe power outages, weak infrastructure, Poor operating and maintenance performance, high distribution and transmission cost or completely no electrical energy supply. The socio-economic development of any country depends on status of Health services, Education facilities, financial aids and social wellbeing of its people. As the electricity necessary element of the human daily life, it requires more attention to create more stable and reliable electrical energy facilities. Electrification through fossil fuels involves the difficulties in installations, environmental impacts, emission of greenhouse gases and disturb the living surroundings of the human life with pollution. One possible way to get sustainability in the rural electrification is involvement of naturally available resources to generate electricity.

The RESs are providing green energy and the cluster of all micro sources like solar PV, WES, fuel cell, microturbines and gas turbines and loads together operated and controlled to energize local area called as microgrid (MG). DC micro grids are optimum solution to sustainability of rural electrification due to reliability, lower transmission and conversion losses and higher efficiency [2]. DC microgrids with distribution generation (DG) is the perfect combination for reliable, affordable, and cost-effective solution for supplying demand nearby its installation. Most of DERs generate DC power and main grid operation in AC mode. To interface DERs to grid DC/AC conversion required which reduces the quality of power and increases switching harmonics. In addition to that most of loads like computers, mobile phones and most of the electronic gadgets operates with DC and further AC/DC conversion required [3].

To avoid multiple DC/AC/DC conversion and to provide quality power to loads, DC MG are the suitable solution.The RESs are providing green energy and the cluster of all micro sources like solar PV, WES, fuel cell, microturbines and gas turbines and loads together operated and controlled to energize local area called as microgrid (MG). DC micro grids are optimum solution to sustainability of rural electrification due to reliability, lower transmission and conversion losses and higher efficiency [2]. DC microgrids with distribution generation (DG) is the perfect combination for reliable, affordable, and cost-effective solution for supplying demand nearby its installation. Most of DERs generate DC power and main grid operation in AC mode. To interface DERs to grid DC/AC conversion required which reduces the quality of power and increases switching harmonics. In addition to that most of loads like computers, mobile phones and most of the electronic gadgets operates with DC and further AC/DC conversion required [3]. To avoid multiple DC/AC/DC conversion and to provide quality power to loads, DC MG are the suitable solution.

2. DC Microgrid for Sustainability of Rural electrification

Micro grids may be thought of as a simplified form of a traditional power grid, consisting of a collection of loads and microgenerators, perhaps with the addition of an energy storage system (ESS) and other control devices. Normally, in our daily life we see so many low powered DC loads like cell phones, wireless phones, computers, laptops, data centres, DVD players, battery-powered vacuum cleaner, and Internet routers, etc. These days, DC microgrids are widely deployed as reliable and efficient power distribution networks in the maritime, automotive, and industrial sectors [4]. To meet our future power demand and to have flexible and reliable power flow in the low voltage distribution networks, the DC-MGs are emerging in present day power scenario and becoming more attractive in the DC-MG architecture shown in Fig.1. The concept of local power generation, power sharing and controlling in the effective way is the basic idea of DC-MG. The DC bus is linked to the various sources of power; those that provide DC power use a DC-DC converter, while those that produce AC power use an AC-DC converter.

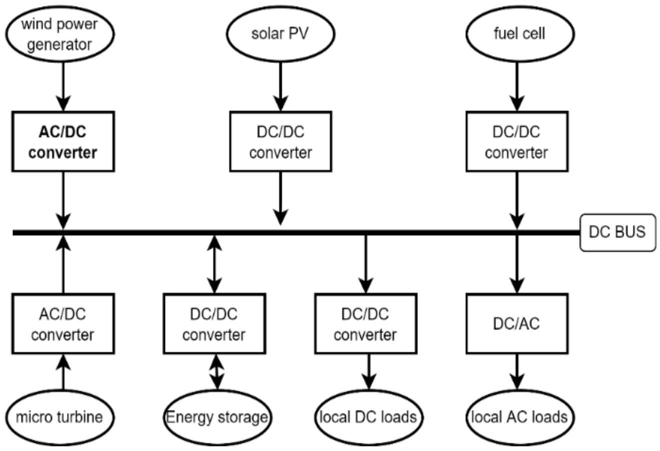


Fig 1: DC-MG architecture

The inverter is very important part of micro grid architecture, which is connected between DG units, loads and main grid. To maximise the reliability of the system during fault conditions, the parallel operation of inverter may also be recommended. As per figure 1 the DC bus is the main supporting system which is connected to all the components of the MG. It takes care of allocation of power generated from distributed energy sources to loads connected to it. Solar PV, wind power generator, fuel cell and micro turbine are the power generating sources. Energy storage is the supporting system during power fluctuations. Local AC & DC loads are energy receive points from energy sources and battery storage through their respective converters. Various converters are used to bring the voltage to the required levels. Controllers like PI and ANN are used to maintain the frequency to the required levels while feeding AC loads.

Even though the environmental effects are relieved by RESs, but they have some technical challenges and limitations. Because of variable power generation of RES, they create new challenges when they are integrated. More importantly DC output generation, variable frequency and dependency on environmental conditions are the challenges and limitations of RES. Optimum utilisation of distributed energy resources (DER)s possible only when MGs installed in both grid connected and islanded modes, especially in remote and rural areas. Both modes of operation can be obtained as AC, DC, or AC – DC hybrid microgrid. When the MG suffers from deficit of power, it will get required power from main grid. If the MG generating more than its requirement, there is a controlled power flow from MG to main grid. All the controlling actions are taken care by control system under different layers of MG. In islanded mode of operation MG itself deals with stability and energy management issues. Under low power generation, loads are supplied based on their priority.

3. Design of solar PV powered DC Microgrid

The efficiency of DC loads with DC microgrids is observed as very high, which in turn creates large scale market for DC microgrids. This situation favours the sustainable development of rural electrification. Since the solar PV technology provides clean, green and eco-friendly energy generation, solar PV powered DC microgrid performance analysis done in this paper. Solar photovoltaic panels and a control system make up the planned DC microgrid. If we plug time t into equation (1) [5], we can calculate the system's overall output at that instant. Where Npv is the Number of PV panels, Apv is the area of PV module, Ipv is the solar irradiation incident on the PV system (kWh/m^2), η_{pv} is the efficiency of the PV system. The total PV power generated is P_{pv}.

$$P_{pv}(t) = Npv * Apv * Ipv * \eta_{pv} \quad \text{-----------} \ (1)$$

Each of the 86 parallel strings in the PV array consists of 7 SunPower SPR-415E modules wired in series. The grid is based on a prototypical North American configuration. It had two 25 kV feeders, loads, and a 120 kM transmission system's worth of power. Input irradiance to the PV array model is set at 1000W/m2 and temperature is set at 450C. When the solar PV system has achieved steady state, the output is 481 V at 236 kW. In response to the quick decrease in solar irradiance from 1000 W/m2 to 200 W/m2 that occurs because of maximum power point tracking (MPPT) operation, the control system drops the output voltage to 464 V at t = 0.3 sec, as specified by the MPPT algorithm. The above given specifications are considered for MATLAB simulation of Solar powered DC microgrid. The main objective of this work is to compare the performance analysis of DC microgrid for rural electrification with different controllers and their individual performances are given in the further sessions.

4. DC-DC converters

Power electronic converters acts as interfacing between DES and DC grid. Many researchers developed this integration techniques for high voltage conversion of generated low voltage DC to High voltage dc and vice versa. Boost converter, Bidirectional DC-DC converters and multilevel inverters are simultaneously operating optimized usage of storage energy and maintaining DC bus voltage within limits.
The boost converter has an inductor, capacitor, metal-oxide-semiconductor field-effect transistor, and diode in its circuit diagram. When the MOSFET is activated, an

inductor may make a direct connection to the power supply, allowing it to rapidly charge to a dangerously high voltage. The capacitor charges to its maximum capacity by absorbing stored energy from inductor when MOSFET is in off condition. The diode which is placed in between capacitor and source to prevent backword power flow. The converter supplies current to grid within required limits, so that it can maintain constant voltage. The output voltage also depends on the duty cycle of the converter. The mathematical expression for duty cycle of boost converter is given by equations 2 & 3. [6]

Duty cycle max Dmax $= 1 - \frac{Vinmin * \eta}{Vout}$ ----------- (2)

Duty cycle min Dmin $= 1 - \frac{Vinmax * \eta}{Voutmin}$ ------------- (3)

Similarly, the size of the inductor and inductor current are calculated by using following equations 4 & 5

The inductor value can be calculated by using the relation

$$L = \frac{Vin*(Vout-Vin)}{\Delta IL*Fs*Vout} \text{ ----------- (4)}$$

$$\Delta IL = (0.2 \text{ to } 0.4) * Ioutmax * \frac{Vout}{Vin} \text{ ----------(5)}$$

The current flowing through the inductor can be calculated by using the relation given in equation

5. MATLAB/SIMULINK model of DC microgrid with PI controller

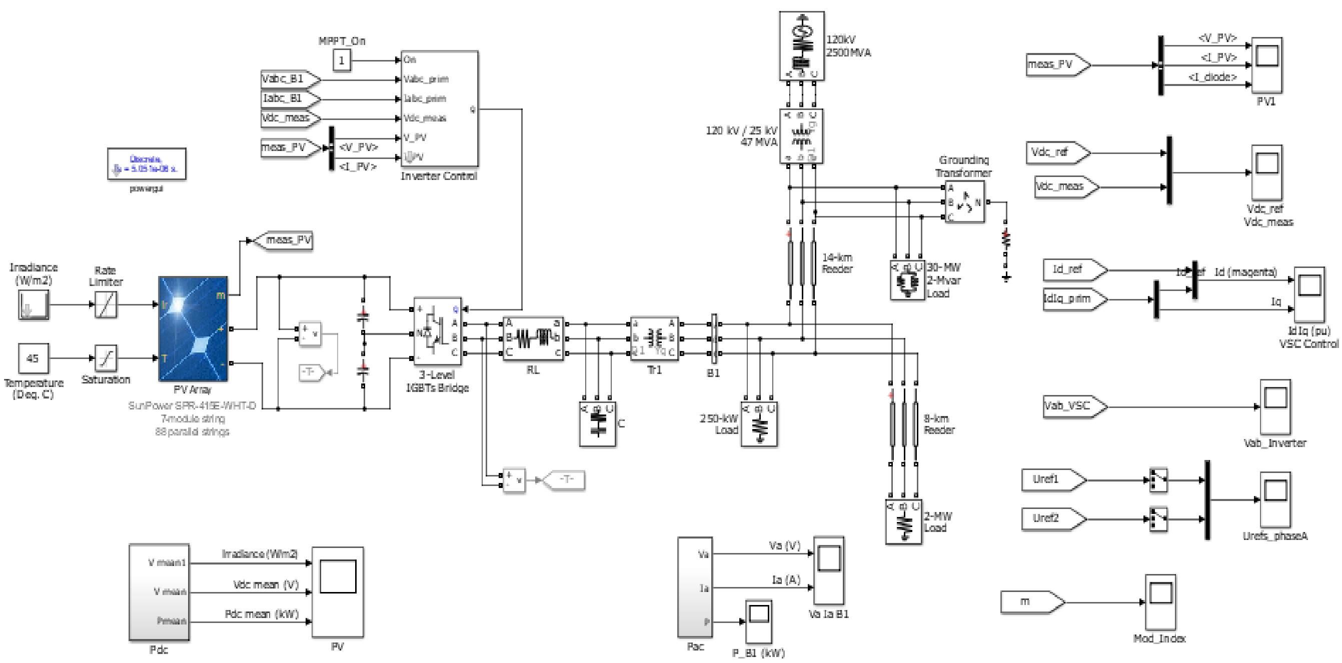


Fig 2: MATLAB/Simulink model with PI controller

The Proportional integral control (PI) operation depends on the error signal which is generated by difference of output signal and reference signal. The PI controllers can track the changes in the output of converter and tries to adjust gains to reduce error. The process of determination of PI constants called tuning, w.r.t to dynamic response of the plant. The error signal will be adjusted to produce control signal for converter [7]. The mathematical expression for error signal is given by equation 6. The boost converter with PI control MATLAB simulation model of DCMG with PI controller is shown in figure 2

$$U(s) = Kp\,(1 + K_p\,(1+\frac{1}{tis}) \text{ ----------- (6)}$$

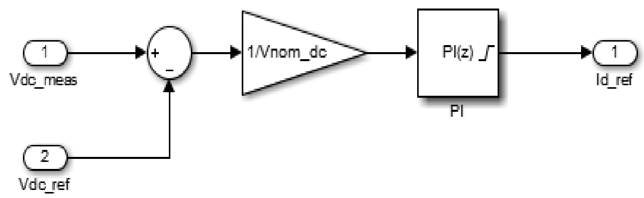


Fig 3: Subsystem of PI Controller

391

The subsystem of PI controller shown in figure 3, which compares the Vdc reference with Vdc measured. The design parameters of PI controller are show in figure 4. The output of PI controller is connected to relational operator. It compares the PI controller output with repeating sequence to generate control signal.

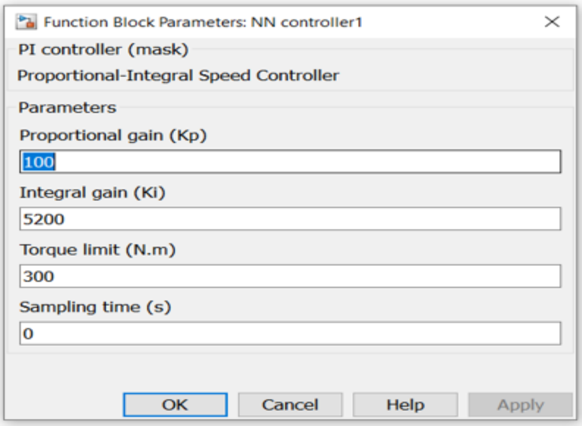


Fig 4: Parameters of PI Controller

6. Artificial neural network controller for DC Microgrid

A neural network is a kind of artificial neural network consisting of a large, linked group of simple processors, or neurons. These neurons are involved in the human brain's nonlinear mapping approach of information processing. After testing number of models, it has been Identified that the Neural Network with 2 hidden layers having 10 and 20 neurons. Fig.4 shows the proposed ANN model. In the proposed architecture there are 2 neurons in input layer and the normalized values of differential current of each phase was given to each neuron as input sample. For the purposes of training the NN, input samples are provided at 1/8th of a cycle's frequency. Input side data may be reduced according to input parameters when analysis is performed on 1/8th cycle data. With only a single neuron dedicated to producing an output value, this model simply returns 1 if the input value being measured deviates from the reference value. It is during training that the model's generalizability for the task at hand is optimised by adjusting the weights associated with the linkages. Adaptive learning, parallel processing, and distributed storage capacity are just a few of the unique characteristics of artificial neural networks [8], in addition to their fault tolerance and problem diagnostic capabilities.

The suggested technique employs a two-hidden-layer version of the multi-layer perceptron (MLP) artificial neural network model. The Fig.5 shows the subsystem model of ANN. The error and the integral of the error will the inputs of the input layer. The traditional PI controllers are takes same inputs and adjust the gains to get perfect gain signal but in case of ANN the weights of the connections are going to be adjusted to get better control signal [9]. Each neuron present in the hidden layer uses hyperbolic tangent as activation function. The weighted sum is greater than the threshold then the corresponding output will be generated and passed to the next layer.

The ANN is cable of learn from its surroundings. Learning is required to update the weights and architecture based on the inputs and output requirements. ANN must be trained to get efficient and appropriate control signal for converter with set of training vectors. Incremental changes implemented in weights and in bias of s network as needed after presentation of each individual vector. In the literature several number of training algorithms have given [10].

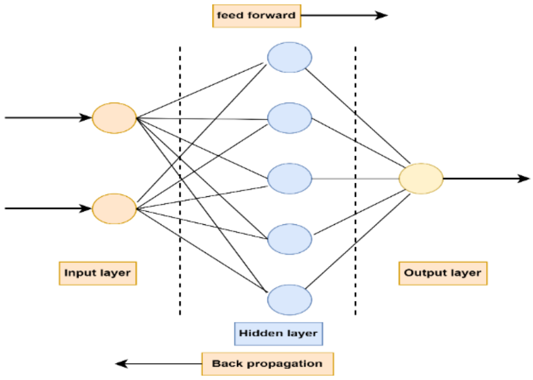


Fig 5: Architecture of ANN

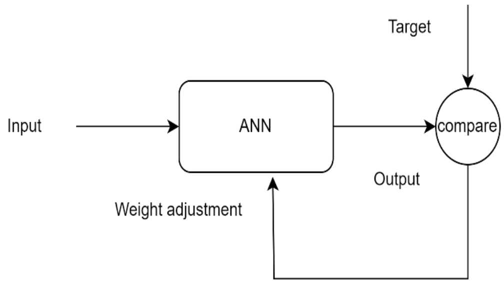


Fig. 6 Block diagram of Neural Network

The backpropagation algorithm is supervised learning method, which uses a desired response as the reference signal to generate error signal. In order for ANN to learn from training data, the method begins with randomly generated weights and seeks to decrease the error. The BPA makes use of a method called a "gradient decent," in which the network weights are modified in accordance with the inverse gradient of the performance action. The combination of weights that we receive after training of the network is considered as solution of the control signal. The linear and nonlinear relation between input and output variables can be established with help of connection between hidden layers. The error can be reduced by increasing number of training iterations. Properly trained BP network will give perfect control signal for DC-DC converters.

```
Load n
Kl=max(I');
K2=max(ol');
P=1'/k1;
T=o1'/k2;
n=157128;
net = newff(minmax(p), [5 a], ( 'tansig'
'purelin'));
net.trainParam.epochs = 200;
net = train(net, P, I);
Y = sinn(net, P);
Plot (P, T, P, Y, 'O')
 Genism (net, -1)
```

The M-fie program for NN controller with BP algorithm given above. The above given used to train the ANN with BP algorithm. The desired voltage output of the controller will be feed to ANN as desired response. The measured value of the output voltage of converter compared with the desired response and error signal will be generated and that signal feed to ANN as input. The ANN which is already trained with BP algorithm will generate the control signal so that the switching of the converter switches controlled. The output voltage of the converter adjusted to required level and it will a continuous process to maintain the grid voltage at required levels.

Subsystem of the ANN controller with the block parameters given in the figure 7. The measured voltage and reference voltage signals are given to comparator to generate error signal. The error signal will be given to ANN for generation of switching signal for control. The Subsystem of ANN controller with hidden layers given in the figure 8.

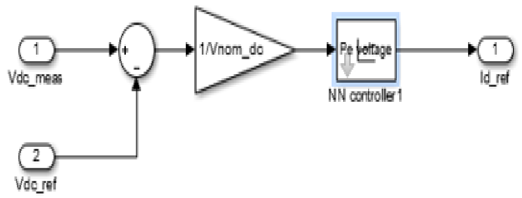


Fig. 7: Subsystem of ANN controller

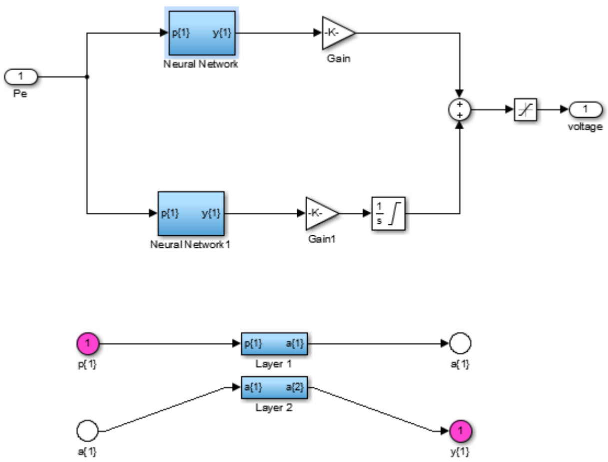
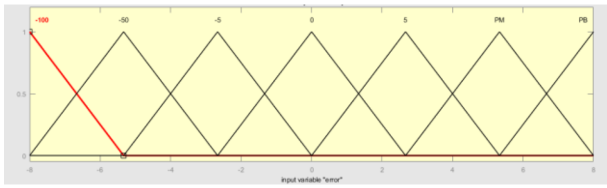


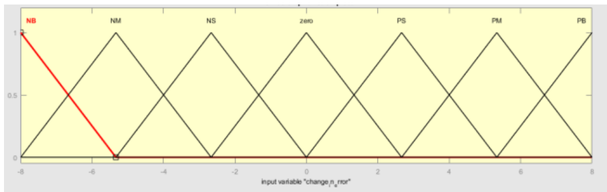
Fig 8: Subsystem of NN controller with hidden layers

6. Fuzzy logic controller for DC microgrid

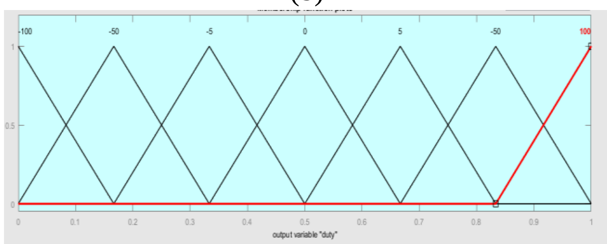
The primary goal of fuzzy logic control (FLC) systems is the regulation of complicated procedures by means of expert knowledge. The controller adjusts the input variables of the process and tries to reach desired state. The input variable is always different from output variables, and they are identical. The closed loop controller designed to compare the desired and measured values. The control signal which is generated from FLC try to adjust the switching of the power electronic devices in the controller to get desired output voltage. Fuzzy logic controllers are a kind of DDC that make use of rules to establish a relationship between input and output variables in terms of language variables [11]. Linguistic regulations are knowledge-based conditional statements. Nonlinear functions of 'n' independent variables are systems in which a value for a single dependent variable may be estimated to any degree of accuracy [12]. Other side ANNs trained on the numerical data and some performance criteria. They can give only 0 or 1 as output.



(a)



(b)



(c)

Fig. 9 (a) Membership function for error, **(b)** Membership function for rate of change of error, **(c)** Membership function of Duty cycle

The rate or derivative of the output (e') and the output error (e) are often used as control inputs. 9 (a) and (b) are membership functions of error and derivative of error signal. The output of the FLC is the duty cycle and the membership function for the duty cycle is shown in figure 9(c). The output of converter sensed by measuring sensors and that is sent to fuzzification after normalization. The rules are fed to inference system based on which the control signal will be generated and defuzzied later. The knowledge-based rules play very important role in this to generate appropriate control signal for converter [13]. In order to construct an FLC, it is necessary to take into account a number of factors, including the identification of control variables, the selection of membership functions, the formulation of rules, the specification of an inference engine, and the selection of fuzzification and defuzzification procedures. The controller's input should be selected based on the converter's dynamic performance. The efficiency of the FLC will depend on the appropriate gains and signal. Subsystem of FLC Controller shown in the figure 10.

Table 1: Rules for FLC

e/e'	PB	PM	PS	Z	NS	NM	NB
NB	0	-5	-50	-100	-100	-100	100
NM	5	0	-5	-50	-100	-100	-100
NS	50	5	0	-5	-50	-100	-100
Z	100	50	5	0	-5	-50	-100
PS	100	100	50	5	0	-5	-50
PM	100	100	100	50	5	0	-5
PB	100	100	100	100	50	5	0

Table 1 shows fuzzy logic rules for fuzzy logic controller to generate Duty cycle to operate DC-DC converter. There are 49 rules formed out of all combinations.

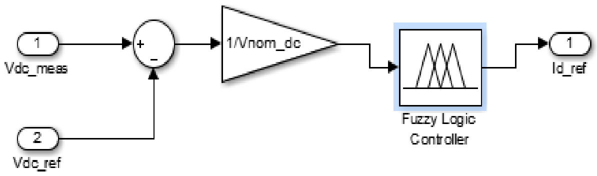
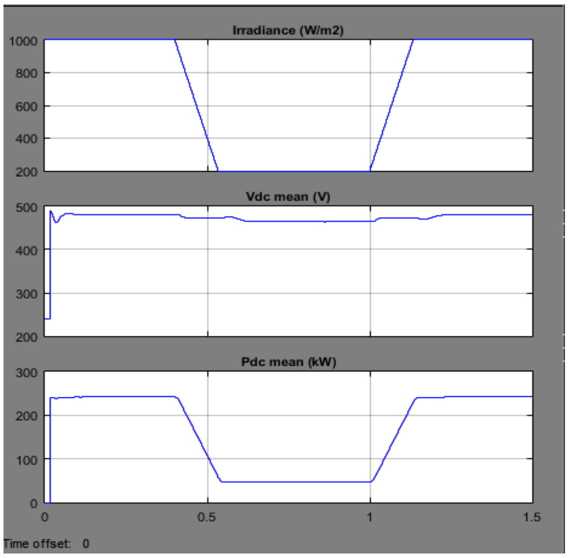


Fig 10: Subsystem of FLC Controller

7. Results and discussion

The DCMG output power and voltage for PI controller is shown in 11.a and 11. b. The output voltage shows peak overshoot and disturbance when irradiance is ramp down at 0.3sec. 0.35% THD observed after 0.3sec.

In The PI controllers the disturbance observed in the voltage levels during irradiance changes. The DCMG output power and voltage for ANN controller is given in the figure shown 12.a and the FFT analysis shown in the 12.b. from 12.b observations, the peak overshoot in the voltage absent and we can observe less disturbance in the power when irradiance reduced. The THD valve with ANN controller is 0.07%. Figure 13.a and 13.b shows the output of the converter with FLC. The peak overshoot not observed but there is great reduction the output power observed. And THD value for FLC is 0.12 shown. The comparison of THD values of PI, ANN and FLC controllers are given table 2.



394

Fig. 11. (a) DCMG power and voltage output with PI controller

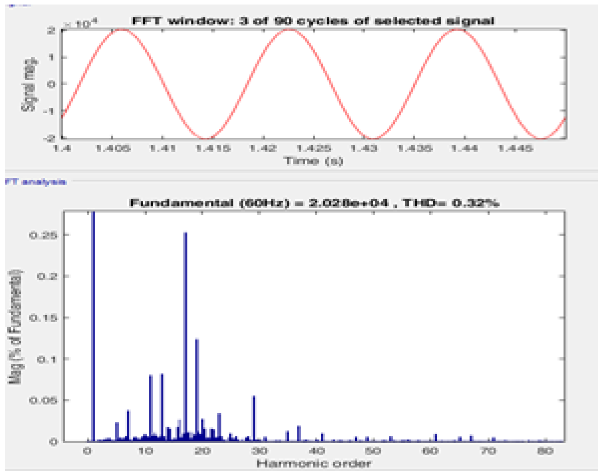


Fig. 11. (b) FFT of DCMG wit PI controller

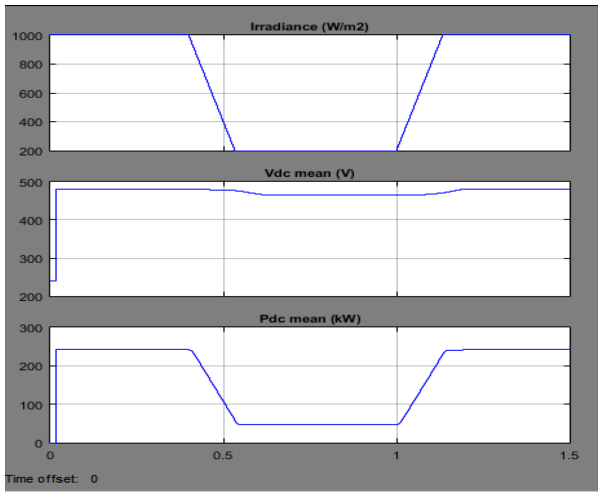


Fig. 12. a. DCMG power and voltage output with ANN controller

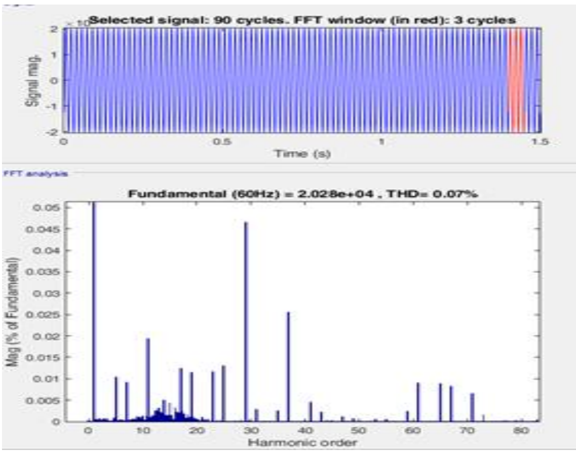


Fig. 12. b. FFT of DCMG with ANN controller

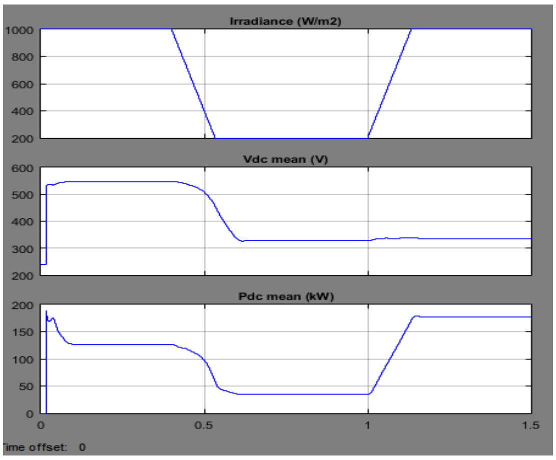


Fig. 13. a. DCMG power and voltage output with FLC

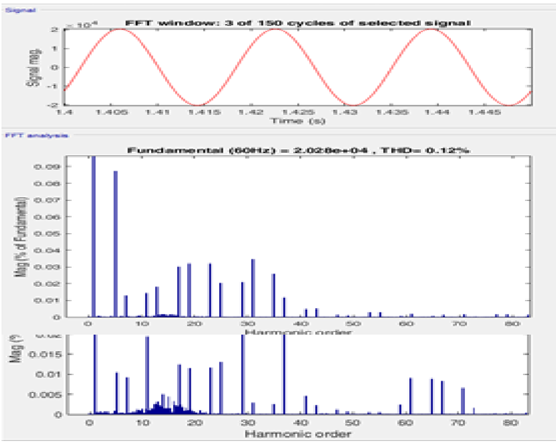


Fig. 13. b. FFT of DCMG with FLC controller

Table 1: Comparison of THD values of PI, ANN & FLC controllers

Controller/THD	PI Controller	ANN Controller	FLC Controller
Grid Voltage THD (%)	0.32	0.07	0.12 S

8. Conclusion:

The literature proves that DCMG is suitable to serve for remote areas and rural areas where main grid is the accessible. The simulation results of PI, ANN and FLC controllers have compared. The PI controller shows the fast transient response and comparatively the THD is also more. The FLC controllers give less THD than PI but not good in power and voltage profiles. The results obtained with ANN controller shows better performance in terms of power and voltage profiles and in the THD values.

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