Renewable Hybrid Battery Energy Management System Using ANN Controller

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ABSTRACT

Renewable energy sources are major focus in power system areas for new researchers. Recently many power plants are being established based on these sources. Integration of solar and wind energy-based power plants are common. In this paper variable DC motor load connected with wind and solar power-based hybrid power system is described. To enhance the utilization of these energy sources as per demand load, battery bank-based energy storage system is used to handle the excess power generation. The switching control is required to route the power through battery bank in the condition of excess power generation. Many researchers have proposed the control strategy based on PI control, fuzzy control etc. for switching control in this case. Adaptive Control system with added intelligence is proposed in this paper for controlling the excessive power control. With the time, multiple battery bank and more sources can be connected to the power system. The adaptability in control system helps to reconfiguration itself based on the training from the desired signals. Artificial Neural Network based controller has been proposed here. The training results and results of the handling the excessive power during simulation are described in the result section of the paper.

Keywords:

Power system, Renewable energy, Solar system, Wind power, ANN controller etc.

NOMENCLATURE DESCRIPTION

Nomenclature	Description	Nomenclature	Description
Iph	Photocurrent	Pmax	Maximum output power of a PV cell
V_t	Thermal voltage of the array	Gn	Reference irradiation
T_j	Temperature for PN junction	Is	Reverse saturation current
Q	Electron charge of 1.602X10-19 Coulomb	Ns	Cells connected in series
G	Solar irradiation	k	Boltzmann constant of 1.38x10-23 J/K
Isr	Reference reverse saturation current	a	Permittivity of the diode
Eg	Band gap energy	Ki	Temperature coefficient mA/0C
Vpv	Photovoltaic voltage	Ipv	Photovoltaic current
Tn	Reference temperature	△T	Temperature deviation from reference value
Isc	PV short-circuit current	Rs	Intrinsic series resistances
BS	Battery System	Rsh	Intrinsic shunt resistances
SC	State of charge	IB	Battery current
CB	Nominal current	$\sigma(t)$	Hourly self dis-charge rate
VW	Total of wind velocity	VWB	Base wind velocity
VWG	Gust wind component	VWR	Ramp wind component
PV	Photovoltaic cell		

1. INTRODUCTION

During the period of 1970s, there were crises in the oil-based energy sources and this energy source was the prime source of power generation at that time. This time many researchers had started their researcher in the field of the power generation based on the coal, nuclear power, natural gas etc. Due to finite avaibility of this fossil fuel, these power plants have limited production of energy source. This problem is well recognized by the researchers of power system. During the period of last few years, many researches have been recorded in the field of power generation using renewable energy sources like solar, wind etc. as it has infinite avaibility of energy. The figure1 shows the various renewable sources.

Figure 1. Various renewable energy sources available on Earth [1]

Recently much enhancement has been observed in the solar and wind-based power system. The integration of solar and wind hybrid power system has solar photovoltaic (PV) arrays, wind turbine generator, controller with Neural Network, batteries for excess power storage and a DC motor load. The reliability of the power system is ensured by battery for all climatic change condition.

1.1 Photovoltaic cell model

The solar power is converted into electrical energy through the solar cell. Solar cell is made by many semiconductor materials like Si, GaAs, AlGaAs, MIS junctions etc. [2]. Number of solar cell modules forms a PV array to generate sufficient voltage for use. In principle, solar cell is considered as a current source. The current output is proportional to the solar irradiation on it. The electrical equivalent of PV array is shown in figure 2.

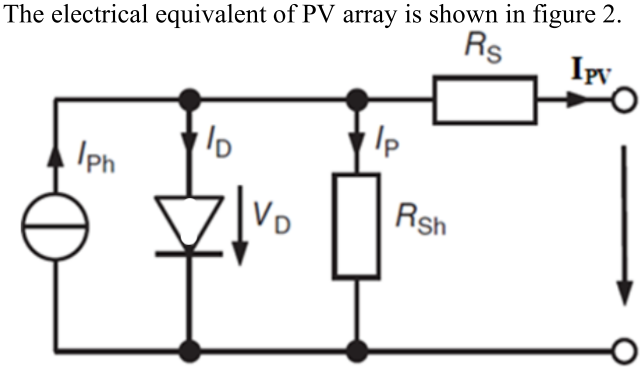


Figure 2. Electrical equivalent of PVarray [3]

Solar cell is represented using a current source (Iph) with shunt and series resistance of Rsh and Rs respectively. The value of Rsh is much larger compared to Rs. For simplification of the model, Rs and Rsh may be neglected. The photovoltaic (PV) cells are connected in series and parallel combination called PV modules. For Ns series and Np parallel configuration of PV modules, the mathematical expression for panel output current is given as follows.

$$I_{PV} = I_{Ph} - I_s\left[exp\left(\frac{V_{PV}+R_s\times I_{PV}}{V_t+a}\right)-1\right]-\frac{V_{PV}+R_s\times I_{PV}}{R_{sh}} \quad (1)$$

$$where, V_t = \frac{N_s k T_j}{q} \quad (2)$$

Modelling photo-current expressed as;

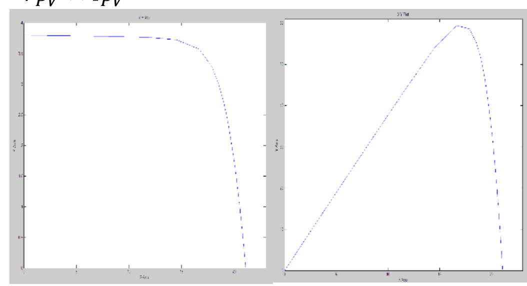
$$(I_{SC}K_i \times \Delta T)\times G/G_n \quad (3)$$

The reverse saturation currentI_s of module varies with the no. of cells which is given by

$$I_s = I_{rs}\left[\frac{T_n}{j}\right]^3 exp\left[\frac{q\times E_g}{ak}\left\{\frac{1}{T_n}-\frac{1}{T_j}\right\}\right] \quad (4)$$

Maximum output power of PV cell is as

$$P_{max} = V_{PV}\times I_{PV} \quad (5)$$



I-V Characteristic Curve PV Characteristic Curve

Figure 3. Solar cell characteristics curve

A lot of solar power-based power system is established in many parts of the world. Apart from this renewable energy source one main important source of energy is wind power. The integration of solar and wind power system is much common [4]. The details regarding and mathematical equations regarding wind energy system is described as follows.

1.2 Wind Energy

Wind turbines produce kinetic energy through the rotations of turbines which are installed on the top of the tower and convert it to the electrical energy. Wind turbines are manufactured on the basis of its wide range of vertical and horizontal axis types [5-6]. They are becoming an increasingly important source of intermittent renewable energy. The model of the wind should be able to simulate the variations of the wind velocity, wind base, and wind gust, which consists of gusts and rapid wind speed changes.

The fitting equation of the output characteristic of wind generator can be expressed as:

$$V_W = V_{WB} + V_{WG} + V_{WR} \quad (6)$$

$V_{WB} = C_1; C_1$ Constant, VWG is gust wind speed and VWR is rapid wind speed.

$$V_{WG} = \begin{cases} 0 & t < T_1 \\ C_2\left\{1-cos\left[\pi\frac{t-T_1}{T_2-T_1}\right]\right\} & T_1 \le t \le T_2 \\ 0 & t \ge T_2 \end{cases} \quad (7)$$

Where C2 is the maximum value of the gust while T1 and T2 are the start and stop times of the gust component, respectively.

The Wind speed change is represented by a ramp function.

$$V_{wR} = \begin{cases} 0 & t < T_3 \\ C_3\left[\frac{t-T_3}{T_4-T_3}\right] & T_3 \le t \le T_4 \\ 0 & t \ge T_4 \end{cases} \quad (8)$$

The excess energy available from solar and wind power will charge the battery and will discharge on lack of power to meet the load demand. This needs a battery management system, which is described below.

1.3 Battery Management System

The battery management system is important with renewable energy sources for observation, safe and optimal operation of individual battery pack and performance measurement of full system. The batteries power is dynamically changing with time, and constantly operating outside of equilibrium state during the charging cycle. The situation becomes most awful for intercalation-based storage systems in which the batteries operate in a closed scheme having very few measurable variables [7-9]. This makes it difficult to properly monitor battery state and maintain it for the safe operation. In this paper battery charges and discharging process given below:

Battery charging process

$$S_c(t+1) = S_c(t)[1-\sigma(t)] + [I_B(t)\Delta t.\eta_C(t)/C_B] \quad (9)$$

Battery dis-charging process

$$S_c(t+1) = S_c(t)[1-\sigma(t)] - [I_B(t)\Delta t.\eta_C(t)/C_B] \quad (10)$$

2. System Description

The analysis of the time varying condition is simulated in this work. The model of hybrid power system with common DC bus connected renewable energy sources (PV and wind) has been implemented with changing DC motor load. The battery bank system has been introduced in the proposed model with AI based charge control circuit. The block diagram of the model has been given in figure 4.

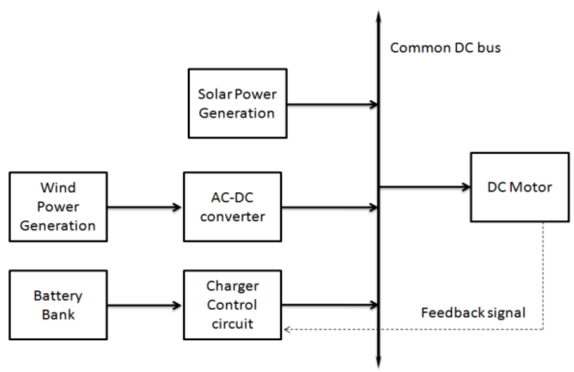


Figure 4. Block diagram of the power system model

The ANN based charger control circuit has been implemented in this model. In this paper ANN based charger control techniques has been explained and modelled. A simplest neuron model which is widely used in ANN based controller is given as:

$$a = \left(\sum_{j=1}^{n} w_j u_j\right) + \Phi \quad (11)$$

For ANN controller modelling feed forward back propagations neural network with two hidden layers is used to control the switching of power signals of battery bank. The scheme of ANN controller is shown in the figure 6.

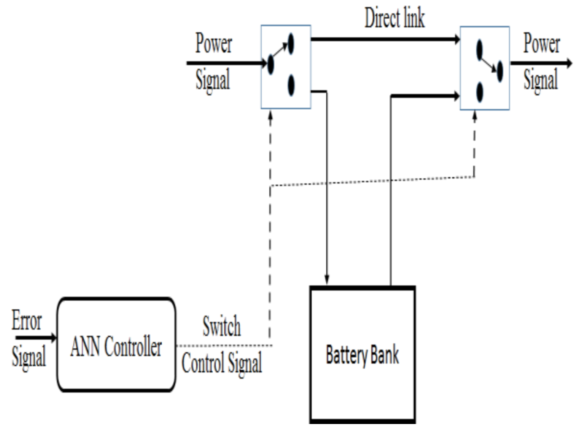


Figure 5. ANN controller for power system management

To train the ANN controller a PI based charger control system has been modeled and simulated to record the necessary signals. This signal is used for training.

2.1 System model and its modules

To develop the renewable energy system above, MatLab Simulink using solar and wind toolbox is used. This toolbox has all components of renewable energy technique which are PV cell, wind turbine, induction machine, drive train, and voltage source as generator and P&Q measurement. After simulating the model, the output power and waveform has been seen through the scope block. Figure 8 shows the wind energy system circuit.

The different sub module has been developed in the simulation model. Solar and wind source has been modelled.

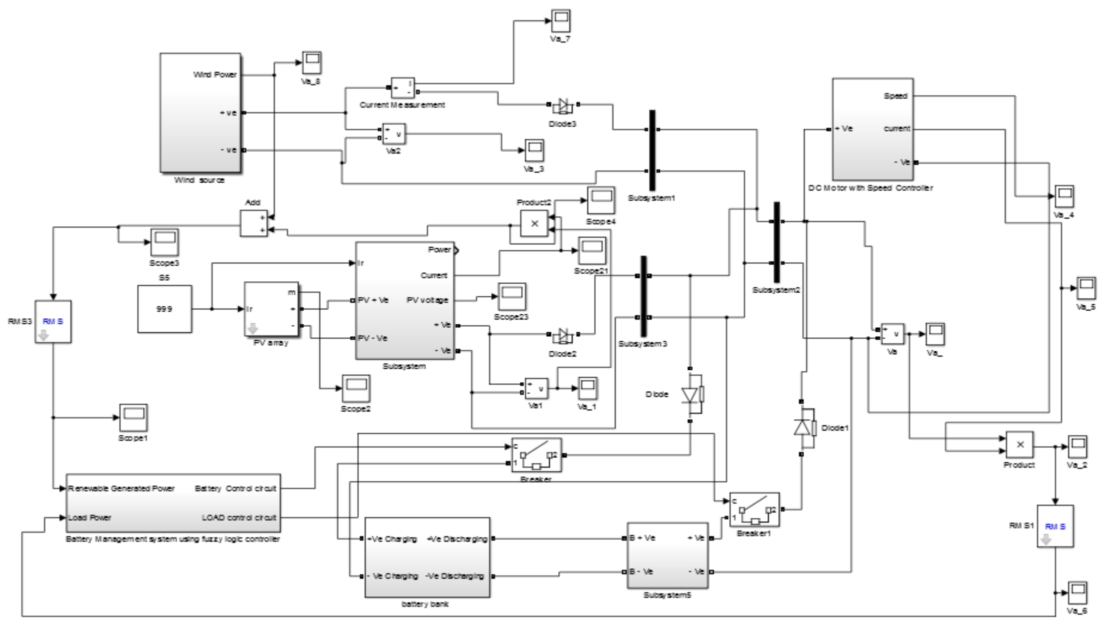


Figure 6. Hybrid Wind and solar simulation Module

The detailed model of solar model and their parameters are as follows.

2.2 Solar panel module

The solar module used in simulation has following parameter.

TABLE 1. Simulation parameter of solar power system

Sr. No.	Specification	Value
1	Solar radiation	1000 W/m2
2	No. of cell	72
3	Power output	1 kW
4	Voc	44.4999 V
5	Isc	8.19978 A
6	Solar cell material	Monocrystalline silicon

The detail of this module is shown in figure 7.

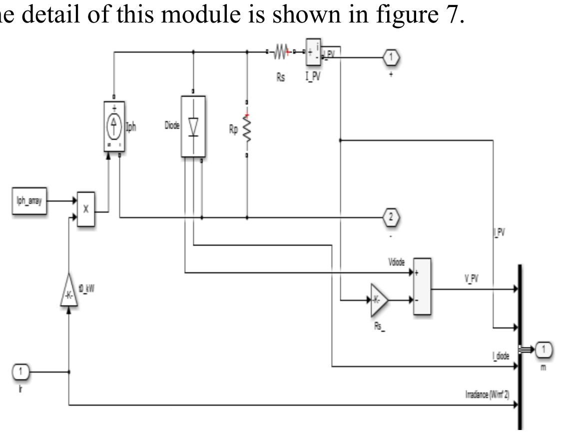


Figure 7. Solar power model based on the equation

2.3 Wind energy Simulink module

The wind energy module used in simulation has following parameter.

TABLE 2.: Simulation parameter of wind energy

Sr. No.	Specification	Value
1	Nominal output power	5000 W
2	Base power	190/.9 VA
3	Base wind speed	12 m/s
4	Base rotational speed	1.2 p.u. of base generator speed

The detail of this module is shown in figure 8.

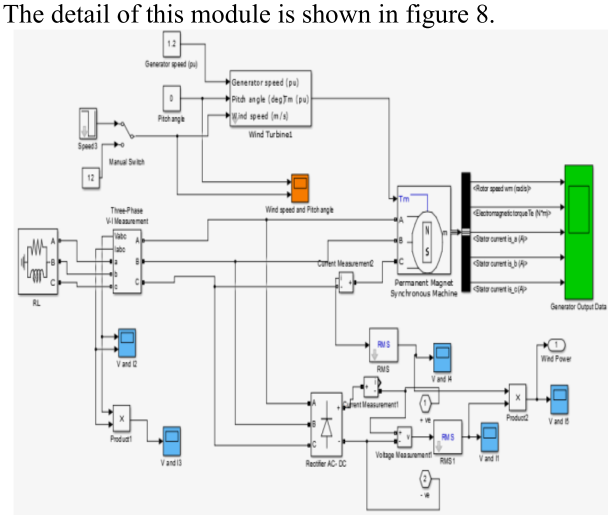


Figure 8. Wind Energy Generator Subsystem

2.4 DC Load

The DC load used in simulation has following parameter.

TABLE 3. Simulation parameter of DC motor

S. No.	Specification	Value
1	Armature resistance and inductance	0.78 Ω, 0.016 H
2	Field resistance and inductance	150 Ω, 112.5 H
3	Field-armature mutual inductance	1.234 H
4	Total inertia	0.05 J
5	Initial speed	1 rad/sec

2.5 Battery System

The battery management system used in simulation has following parameters.

TABLE 4. Simulation parameter of battery system

S. No.	Specification	Value
1	Nominal voltage	43 V
2	Rated capacity	100 Ah
3	Initial state of charge	100 %
4	Max capacity	60 Ah
5	Fully charged voltage	230 V
6	Discharge current	20 A
7	Internal resistance	0.0043 ohm

2.6 ANN Training

Two hidden layers with 11and 8 nodes has been using ANN controller. Only one input and one output neurons are used in the controller architecture. The purpose of using two hidden layers is to provide the flexibility for more complex input and output training and make it equivalent to PID controller structure. The architecture and training of ANN controller is shown in figure 9.

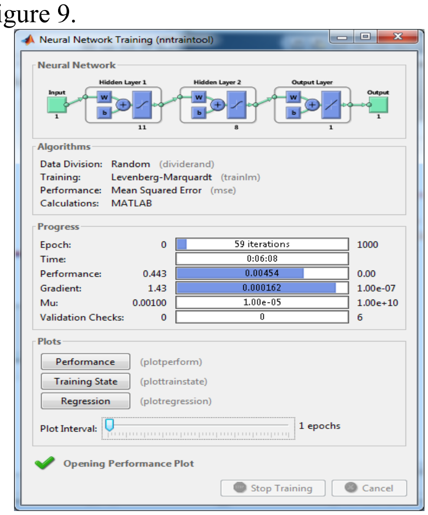


Figure 9. Neural Network Training

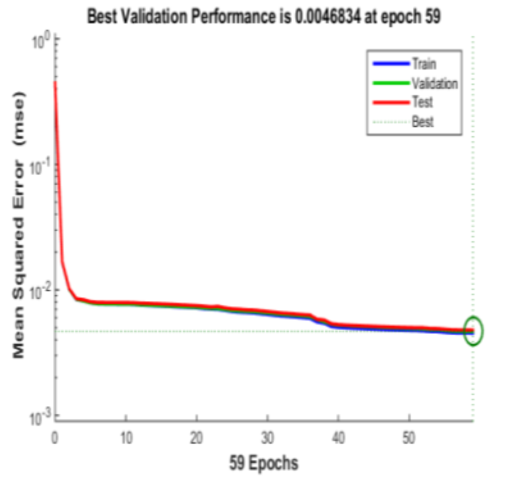


Figure 10. Performance of iterations Vs MSE

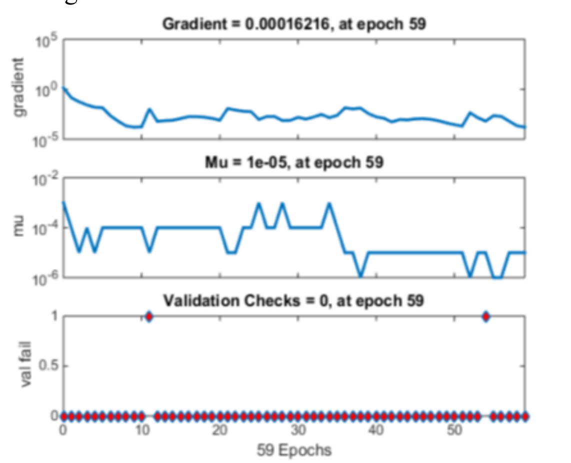


Figure 11. Neural network Training

After successfully training of the ANN the ANN controller has been designed with the trained coefficients (weights and biases) for battery charging control. The figure 12 shows the layered architecture of the ANN controller module.

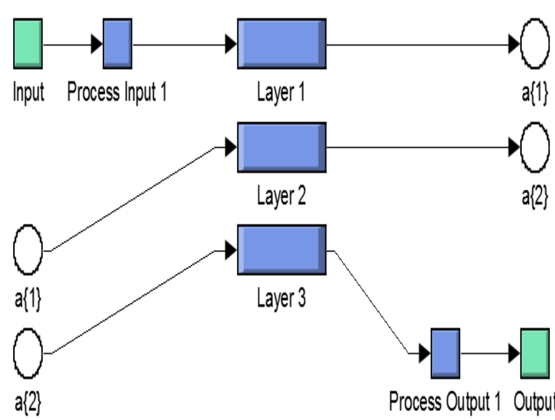


Figure 12. ANN controller module

With above development the simulation has been carried out and finds the results for different parameters. The result has been described in the next section.

3. Results

The solar and wind power is used as a renewable energy source and battery bank recharging has been controlled using ANN controller. The total renewable energy is intensely changed with time by change of the wind velocity. The total renewable energy with respect to time is shown in the figure 13 below.

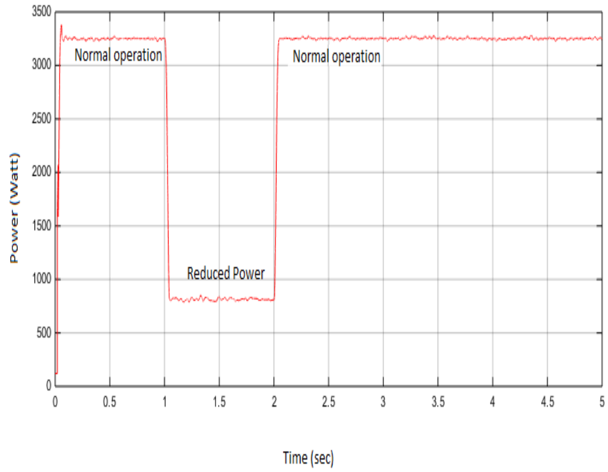


Figure 13. Performance of time Vs total renewable power during simulation

From the above figure 13 it is seen that the renewable power is switched at one second of simulation time. This condition has been handled by switching the battery into ON condition and power is drawn from battery. Again, at two second of simulation time the renewable power is restored and batteries are switched to the charging mode.

The transients of the renewable sources of solar and wind power are depicted in the figure 14 below

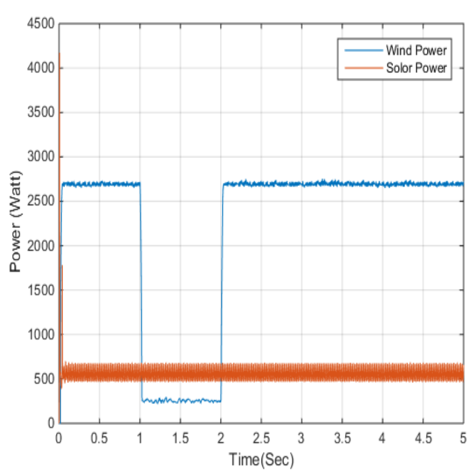


Figure 14. Transient of Solar and Wind power

Initially during the simulation, load power is high as compared to renewable power, hence the battery power will be consumed by load and then accordingly the controller will switch the power.

The load power variation across the DC motor is recorded and variation is depicted in the figure 15 below

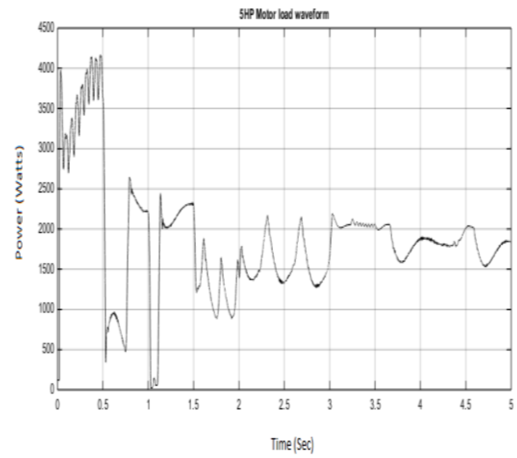


Figure 15. Simulation graph of Load power

Initially the load power is higher compared to the rating of renewable power and then it is reduced to certain level which is less than the rating.

In this simulation environment, the battery management controller waveform is depicted in the figure 16 below.

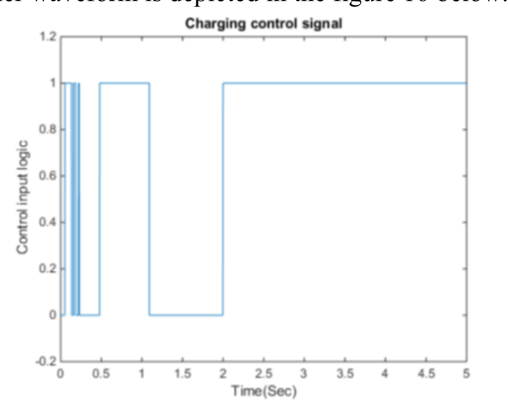


Figure 16. Performance of time Vs controller output logic value for switching input

The DC motor with speed control has used as a load. The reference speed and actual speed is shown in the figure 17 below.

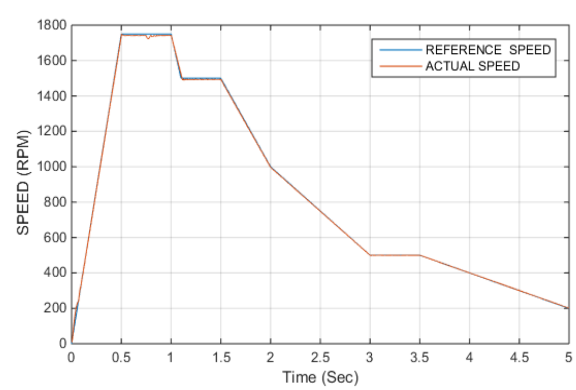


Figure 17. Performance of time Vs Speed control of the DC motor

From the above figure 17 it is seen that the actual speed attained by the DC motor is same as that of reference speed.

4. Conclusion

The system has been simulated and working successfully. The switching transients of renewable sources and battery does not affect the speed of the DC motor (Load) and hence constant output power as per requirement is available. The adaptability of ANN makes the system to be tested in different scenario. The controller has the ability to be trained itself for any change in the signal. The training accuracy is found to be 94%.

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