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Small Scale Hydropower Generator Electrical System Modelling Based on Real-Measurements

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ABSTRACT

It has been realized that using renewable resources will be better for the world in the future. The advantage of the hydro turbine is using renewable energy to provide electricity because the water is released back into the source from which the water came. This small scale hydroelectric system can provide cheap electricity without producing greenhouse gases and polluting the atmosphere. The proposed system can generate electricity at a constant rate as long as there is a source of water flowing downward. Also if there is no demand for electricity, the generator can be turned off to conserve electricity for later needs. This paper proposes design and modelling of a small scale micro-hydro power electrical system capable of supplying a house near flowing water with sustainable power. A small scale hydropower turbine system and a larger system using a DC power supply generator are built. Real small hydro-generator associated with electric generator is used with a simple load, rectifier, and dc-dc converter. Larger system will use programmable power supply attached with rectifier to act as the larger hydro-turbine system is used. DC to DC converter is used to regulate the voltage level. Instead of using a battery to store energy, supercapacitors and static capacitors are used to store the energy. Smart dc load equipment is used to act as the compatible dc loads for smart homes. Artificial Neural Network (ANN) is used with feed forward back-propagation technique to implement Charging and discharging ANN models for load range up to 150 W. These models are checked and verified by comparing actual and predicted ANN values, with good error values and excellent regression factors (0.997: 1) to imply accuracy. Finally, the Simulink models are generated and deduced to use them without training the neural units each time. The discharging ANN models are introduced with Time and Resistance ranges as inputs and Voltage, Current and Power ranges as outputs for both the static capacitor and supercapacitor associated with our system. Also, charging Models are proposed using the same technique with Time and Voltage as inputs and Energy and Current as outputs.

Key words: Hydropower, Modelling, Storage devices, Neural Network, Renewable Energy

INTRODUCTION

Energy is the ability to do work and it is one of the most essential elements of our lives. In recent years, problems linked to the energy crisis have sparked many discussions and questions. According to the World Energy Council, about 80 percent of the world's energy comes from fossil fuels and about 66 percent of the world's electricity is generated from those fossil fuels [1]. Fossil fuel can be classified into three main groups, coal, oil and natural gas. Coal is formed from the combination of carbon, hydrogen, oxygen, nitrogen and sulfur. The use of coal dates back to 3 thousand years ago, it was used by the Chinese for smelting of copper. Today coal a major key for generating electricity. The next form of fossil fuel is oil, also known as petroleum can be found beneath the earth in folds of rocks. The last fossil fuel type is natural gas. Natural gas is a combination of hydrocarbons and is found in reservoir underground. Natural gas is used mainly in industrial and electrical production. Out of the three classification of fossil fuel natural gas is the cleanest burning fossil fuel, but yet it is still harmful to the environment. Not only is burning fossil fuel for energy is harmful for the environment, but also extracting it can harm a wide range of species from bacteria to animals. Many people believe the fossil fuel age will be over in a few decades and the world will run out of energy [2]. In today's society the search for alternative energy sources are at an all-time high. Renewable energy provides only about 1.5 percent of the world's energy and about 5 percent of the world's electricity. The advantage of using renewable energy sources rather than burning fossil fuel for energy is that there is no environmental pollution. Hydro-electric power is a form of renewable energy source.

It is very efficient and inexpensive compared to other energy sources. Today's hydro turbines can convert as much as 90 percent of available energy into electricity, while the best fossil fuels plants are only 50 percent efficient [3]. Hydropower provides more than 97 percent of all electricity generated by renewable sources worldwide, making it the leading source of renewable energy [3]. In 1831, the first electric generator was invented by Michael Faraday. The world's first hydropower plant began operating in 1882 in Appleton, Wisconsin, and it generated a capacity of about 12.5 kW of power [4]. A few years later, the number of hydroelectric power plants in the U.S. had reach 200. In 1936, the Hoover Dam Hydroelectric Power Plant was opened, and generated a capacity of about 1345 megawatts of power. This made it the largest hydroelectric power plant then. The largest hydroelectric power plant today is the Three Gorges Dam in China; it generates a capacity of 22,500 megawatts of power. Although hydroelectric power doesn't pollute the Earth' atmosphere, the concern dealing with hydropower is mainly focused on flooding. This concern is sparked by cities with a large hydropower plant near it. This would cause loss of power, loss of drinking water, destruction to irrigation systems, and many people could die [5].

EXPERIMENTAL SYSTEM DESIGN & IMPLEMENTATION

The proposed hydro turbine system's turbine will capture the kinetic energy from the water and convert it into mechanical energy. The generator connected to the turbine will then convert the mechanical energy into electrical energy, which then creates electricity. A full wave bridge rectifier will convert the alternating current into a direct current. A DC to DC converter will be used to regulate the voltage level. Instead of using a battery to store energy, a supercapacitor will be used to store the energy. As for the system using the DC power supply, the DC power supply will supply 12 volts to the DC-DC converter, which will step up the voltage to 16 volts. The 16 volts will go to the static capacitor and supercapacitor. The static capacitor will supply voltage to a DC load, and the supercapacitor will supply voltage to a power inverter so that we can supply voltage to an AC load. A supercapacitor and static capacitor will be used because they store energy in an electric field, and can distribute energy more quickly than batteries which use chemical reactions to store energy. This means some of the energy can be lost when using batteries. Supercapacitors can tolerate shocks, vibrations, and temperature changes better than batteries can. Supercapacitors can also be recharged hundreds of thousands of times before they wear out.

The Fig. 1shows the initial block diagram for the hydro turbine system. The block diagram helped us determine how each component in the systems would work together. The system contains the hydro generator, full-wave bridge rectifier, DC-DC converter, static capacitor, supercapacitor, and the load which is a DC smart load.

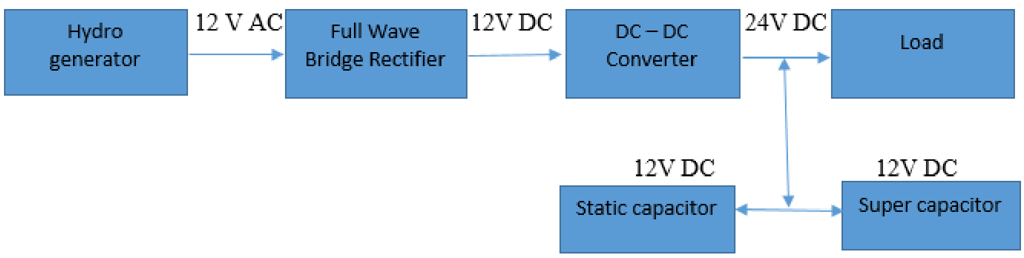

Fig. 1 Proposed block diagram for hydro turbine system

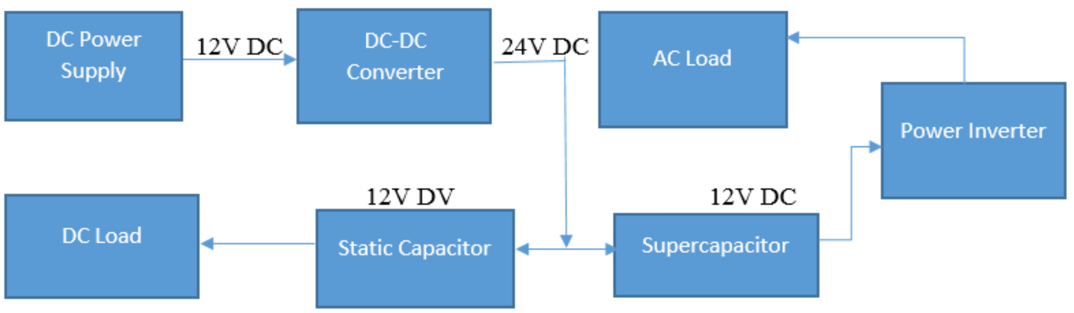

Fig. 2 Proposed block diagram for the DC power supply system

There were two problems with this block diagram, with the first being the output of 24 volts DC from the DC-DC converter was too much for the capacitors. Both of the capacitors had a maximum voltage of 16 volts. The second problem was trying to spit the voltage between the two capacitors. The capacitors had two different farads value and one of the capacitors was drawing all of the current while the other didn't really draw any current. Also with the capacitors in series, they were acting like a short circuit for DC current. Because of these problems, we decide to lower the output voltage of the DC-DC converter to 16 volts, and just use the super capacitor to store the energy.

As for the system using the DC power supply, the Fig. below shows the block diagram for the system. We chose a DC power supply to perform a hydro generator's duty. Since the DC power supply will output a DC voltage, there was no need for us to use a rectifier in the design.

The problems with this design are the same problems we had with the hydro turbine system. The DC-DC converter was outputting 24 volts, so we decided to lower the output voltage to 16 volts. Instead of having the capacitors in series, we decided to put them in parallel to share the 16 volts and supply their respective load. The two real experimental systems small-scale one and large-scale one are shown in Fig. 3. These systems are used to get the training data for the neural networks models.

Fig. 3 The Experimental Systems

A set of 3 D Figs samples are presented as inputs and outputs samples to cover the most probable situations at various circumstances. These surface faces relations will be considered as the learning or training data for the general neural network simulation. Samples for the inputs and outputs for supercapacitor and static capacitor discharging models are shown: [4-9]

These Figures present each output as a function of the two inputs (Resistance Loads and Time). The next part of the work presents a simple but efficient modeling trials ANN toolbox in MATLAB. The result shows a good matching with the real data. These neural network units are implemented, using the back propagation (BP) learning algorithm due to its benefits to have the ability to predict values in – between learning values, also make interpolation between learning curves data. That is the main reason of using ANN. This is done with suitable number of network layers and neurons at minimum error and precise manner.

Static Capacitor Samples (Note: These Figures aren't for the whole load range but only samples):

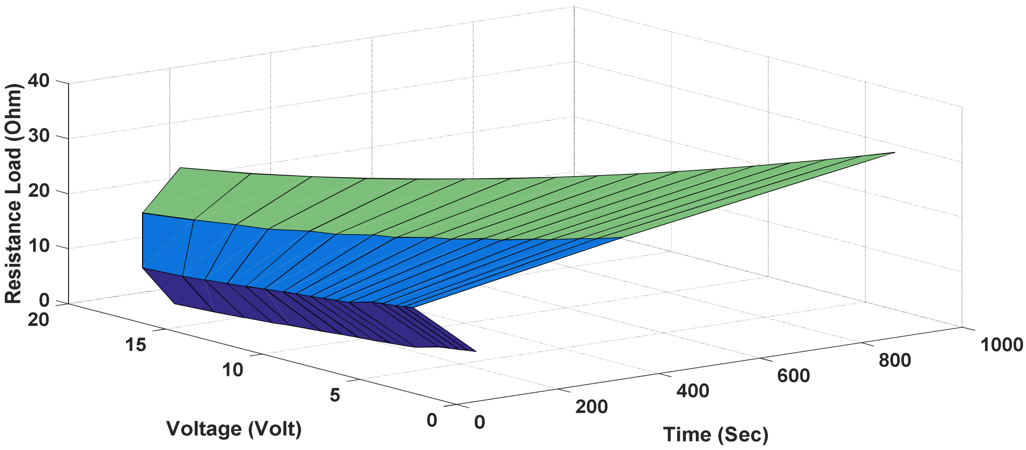

Fig. 4 3 D Relation for Resistance, Voltage and Time

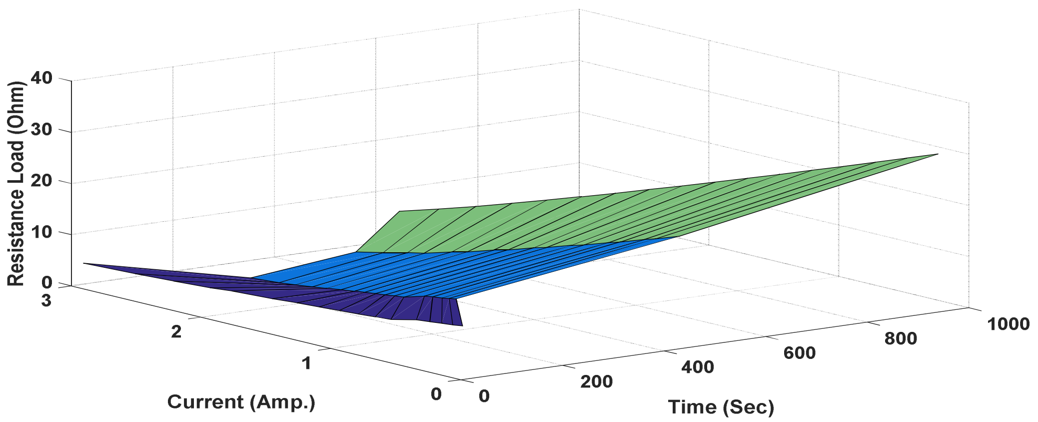

Fig. 5 3 D Relation for Resistance, Current and Time

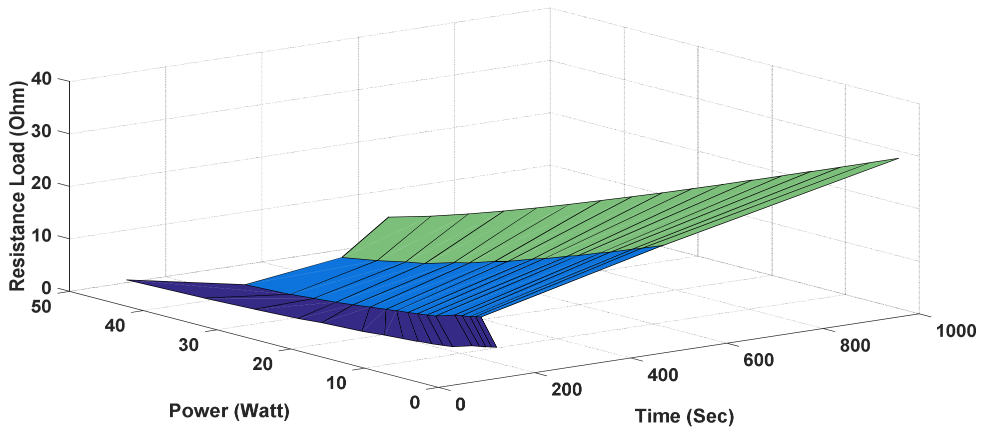

Fig. 6 3 D Relation for Resistance, Power and Time

Supercapacitor Samples (Note: These Figures aren't for the whole load range but only samples):

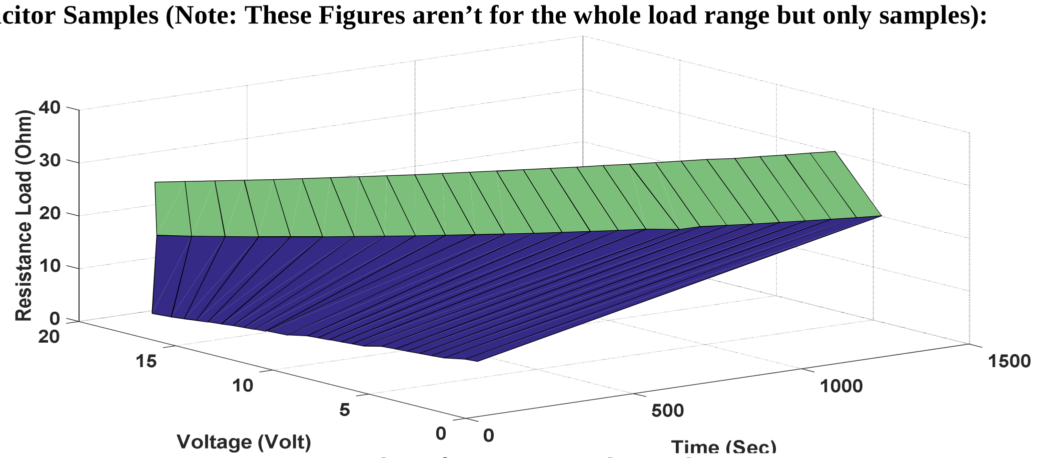

Fig. 7 3 D Relation for Resistance, Voltage and Time

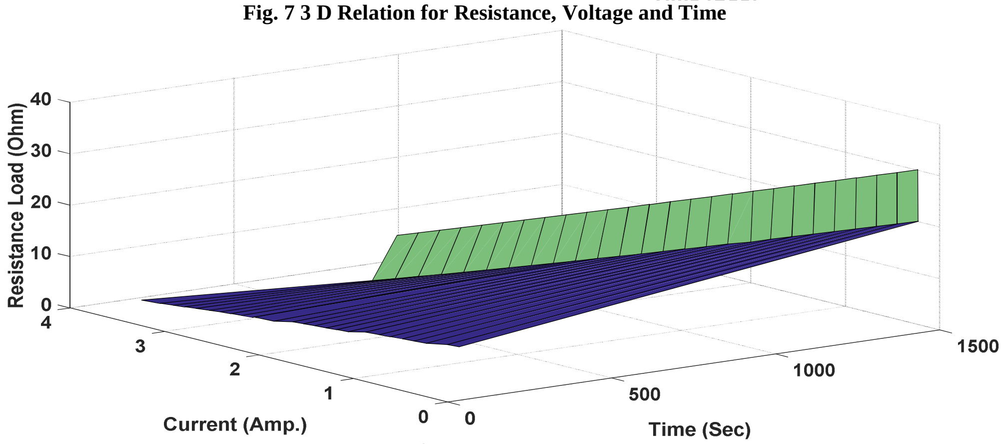

Fig. 8 3 D Relation for Resistance, Current and Time

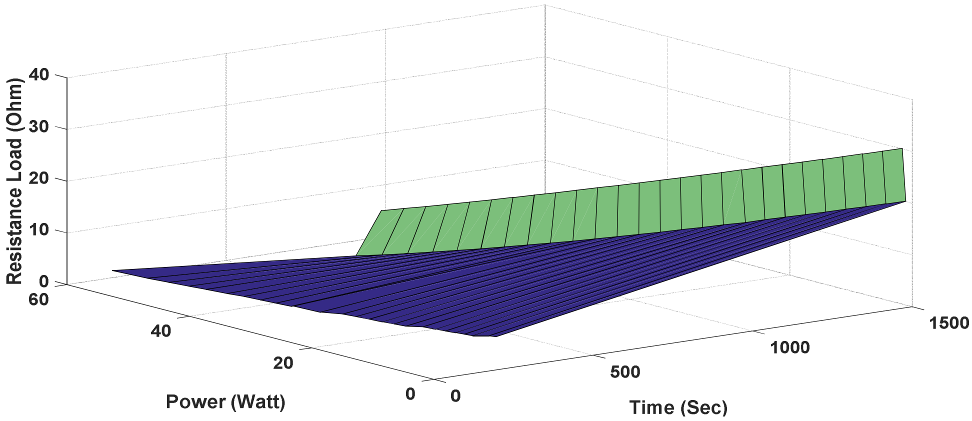

Fig. 9 3 D Relation for Resistance, Power and Time

ARTIFICIAL NEURAK NETWORKS (ANN) MODELS & RESULTS

Artificial Neural Networks are networks used [6-10] to estimate functions depending on many number of inputs. These networks can simulate a problem to any accuracy. The back-propagation method is the most popular artificial neural network used for engineering, and used for this project. The network consists of interconnected processors called neurons. The neurons are connected to each other by weighted links where signals can pass. Each neuron receives multiple inputs from each other to produce outputs. ANNs are carried out in two steps; the first step is to train the network without data, and the second step is to test the network with the collected data. The collected data should be in the form of a data set, and the input data will be used to produce outputs. If there is a difference between the training process and the testing process, the weights are changed so that the error will decrease. When the network is done with the input patterns, if there is an error bigger than the maximum designed tolerance, the ANN will run through the inputs repeatedly until the errors are within an acceptable tolerance. The Artificial Neural Network has two layers, an input layer which is a hidden layer, and an output layer. The hidden layer has the log-sigmoid function inside of it, and the output layer has the pure-line function inside of it. The input layer sends the collected data to the hidden layer where the processing and computation takes place. The hidden layer then send the output of the network to the output layer. The number inputs and outputs is based off the collected data, and how one wants the network to act. There is no theoretical reason to use networks with more than two hidden layers, because these networks can represent functions with any kind of shape [6-10].

1st Model for Static Capacitor Charging

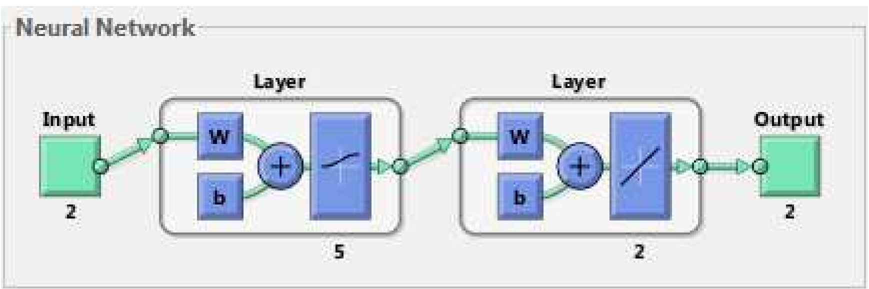

Fig. 10 Static capacitor ANN model (5 neurons at hidden layer and 2 neurons at output layer)

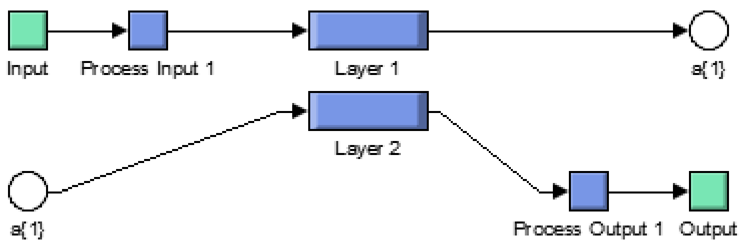

Fig. 11 Static capacitor ANN two layer construction

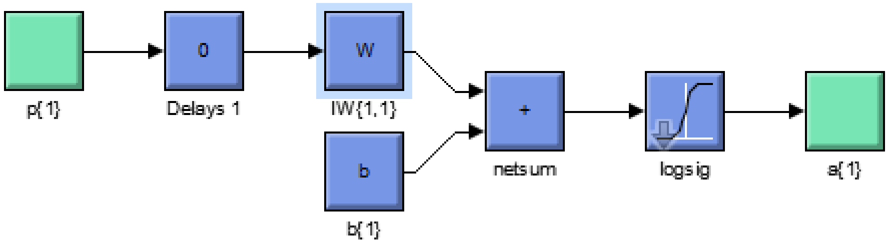

Fig. 12 Static capacitor ANN hidden layer with log-sigmoid function

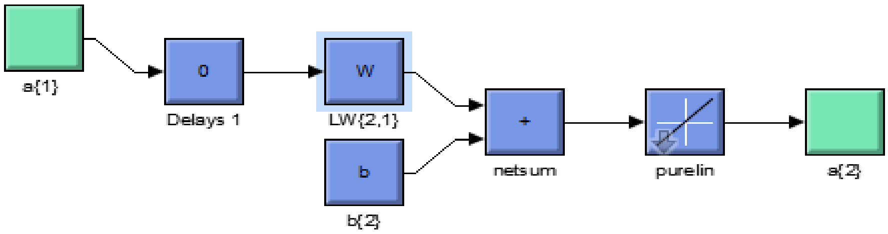

Fig. 13 Static capacitor ANN output layer with pure-line function

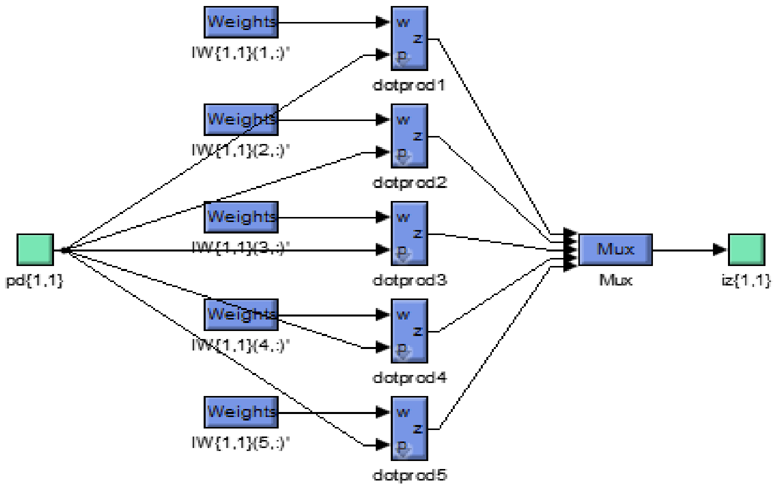

Fig. 14 Static capacitor ANN first layer weights for the two neurons

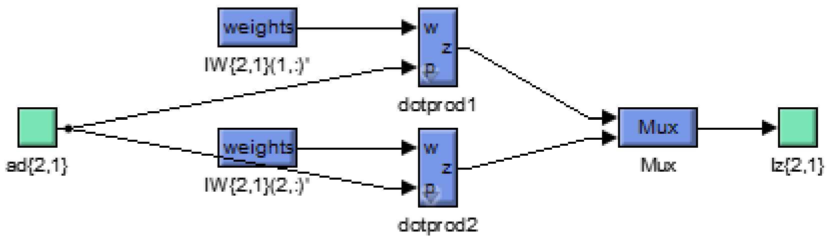

Fig. 15 Static capacitor ANN second layer weights for the three neurons

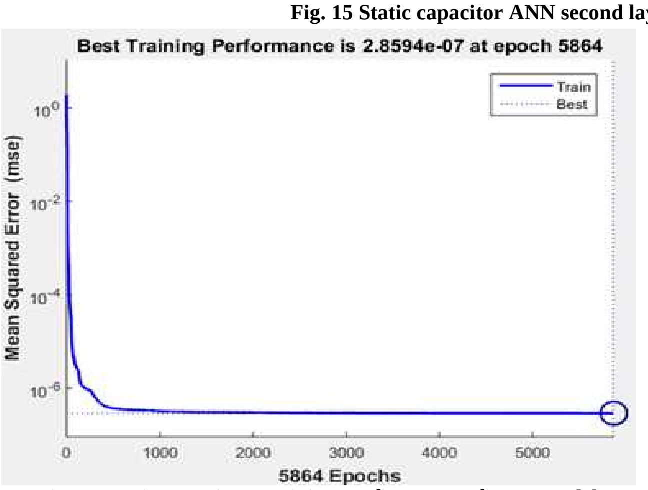

Fig. 16 Static capacitor Training performance of ANN model

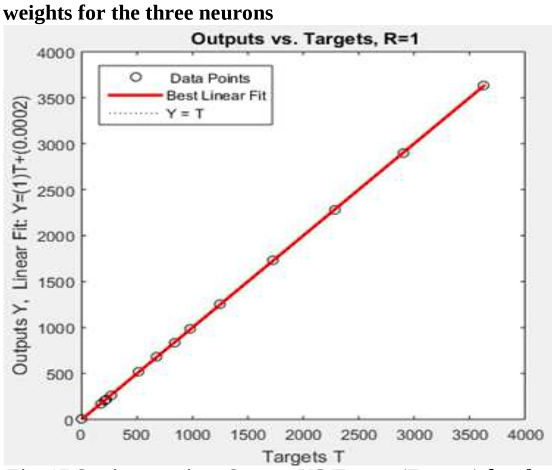

Fig. 17 Static capacitor Output VS Target (Energy) for the ANN Model Accuracy (Regression = 1)

2nd Model for Static Capacitor Discharging; Load Resistances range (5:30 ohms)

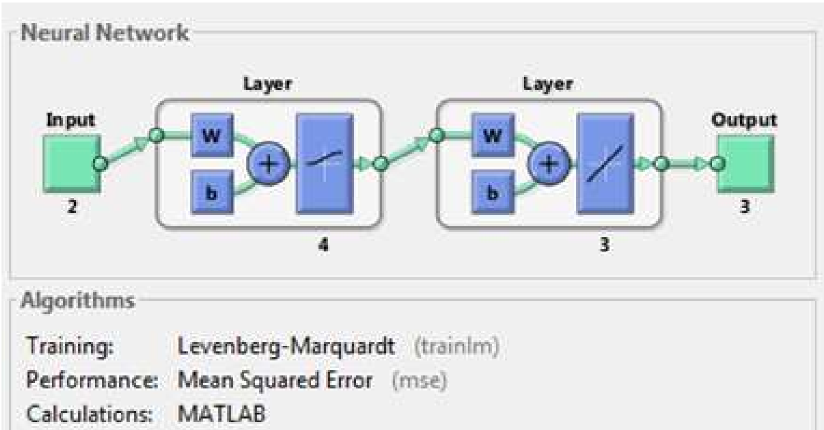

Fig. 18 Static capacitor discharging ANN model (4 neurons at hidden layer, 3 neurons at output layer)

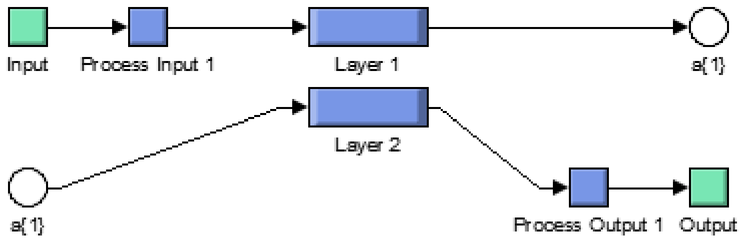

Fig. 19 Static capacitor ANN two layer construction

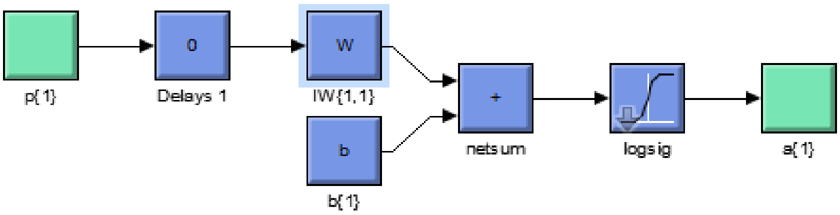

Fig. 20 Static capacitor ANN hidden layer with log-sigmoid function

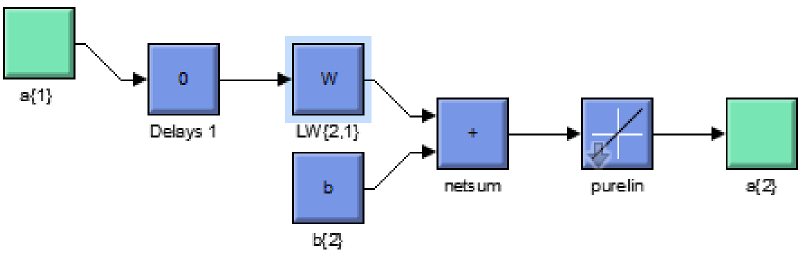

Fig. 21 Static capacitor ANN output layer with pure-line function

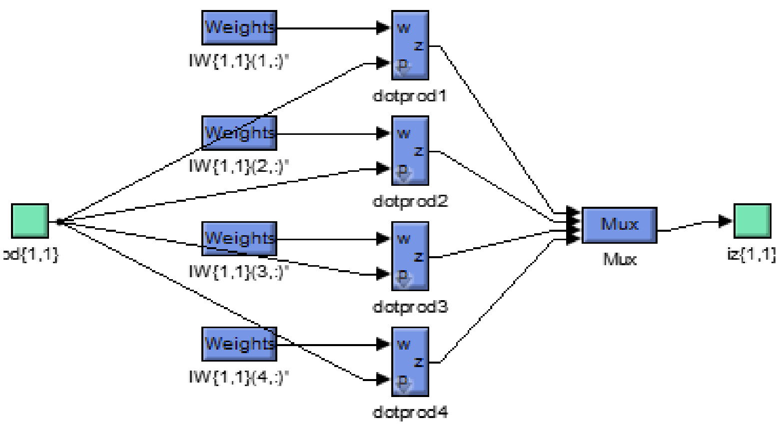

Fig. 22 Static capacitor ANN first layer weights for the four neurons

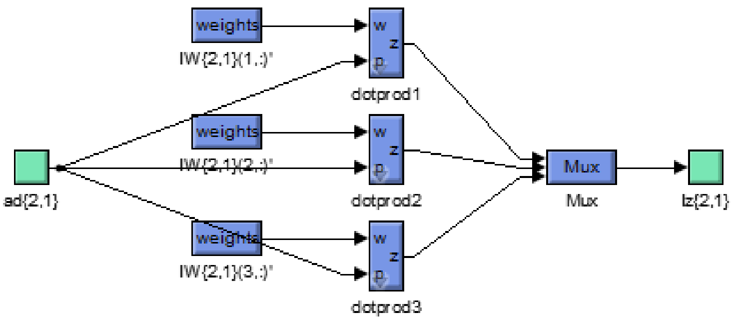

Fig. 23 Static capacitor ANN second layer weights for the three neurons

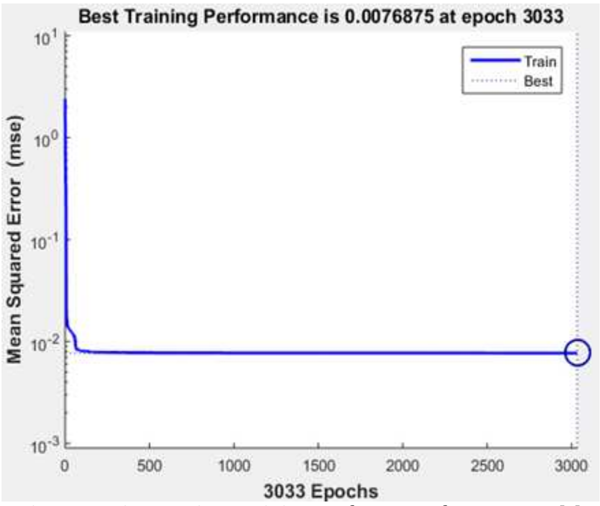

Fig. 24 Static capacitor training performance for ANN model

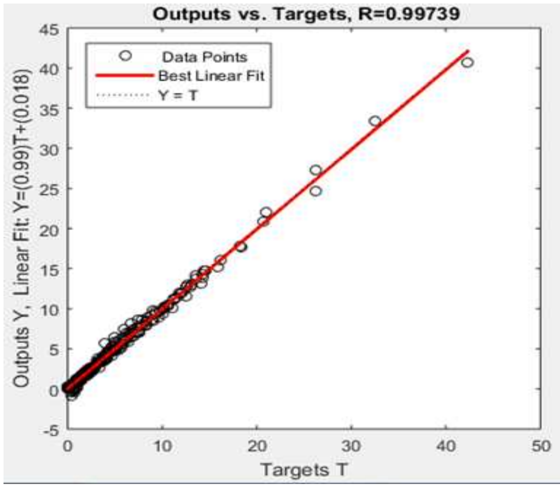

Fig. 25 Static capacitor output vs target (Power) for the ANN Model Accuracy (Regression = 0.99739)

3rd Model for Supercapacitor Charging

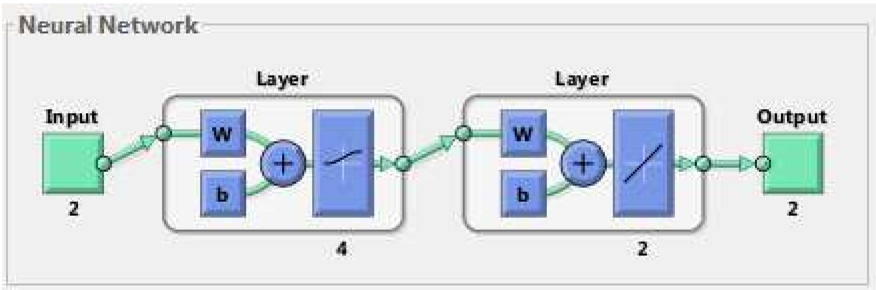

Fig. 26 Supercapcitor ANN model (4 neurons at hidden layer and 2 neurons at output layer)

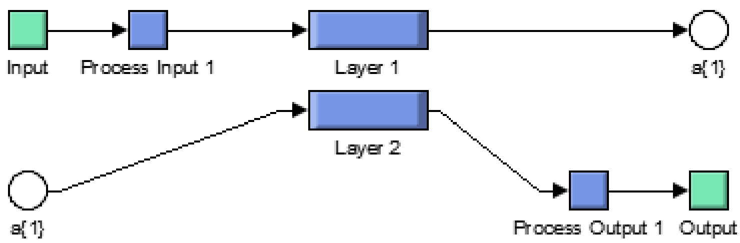

Fig. 27 Supercapcitor ANN two layer construction

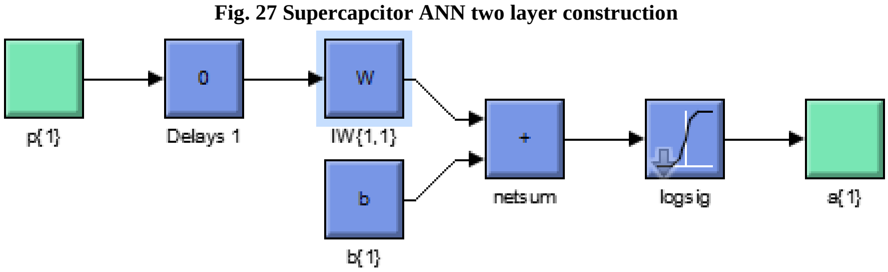

Fig. 28 Supercapcitor ANN hidden layer with log-sigmoid function

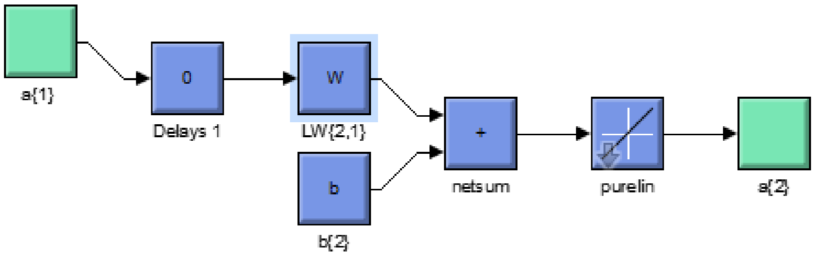

Fig. 29 Supercapacitor ANN output layer with pure-line function

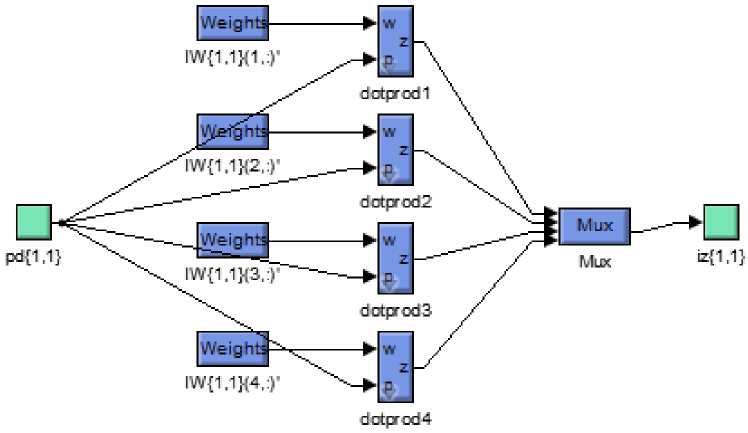

Fig. 30 Supercapacitor ANN first layer weights for the fours neurons

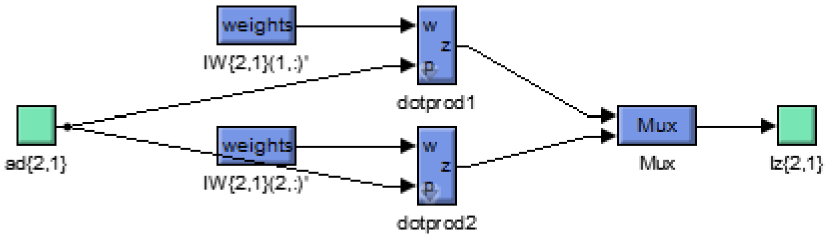

Fig. 31 Supercapacitor ANN second layer weights for the two neurons

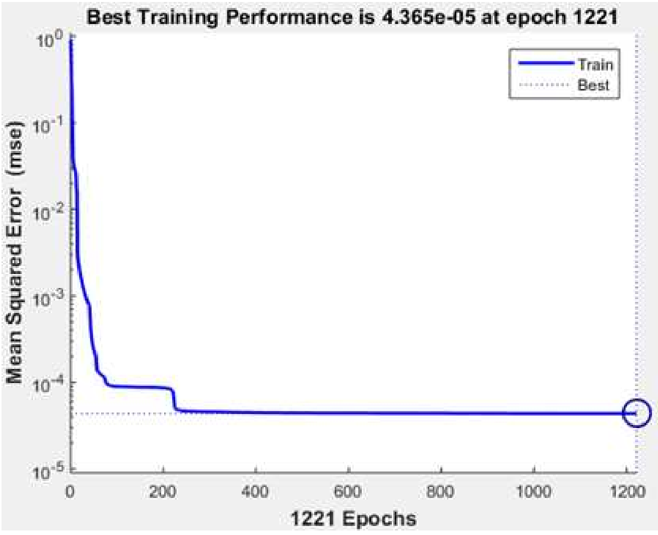

Fig. 32 Supercapacitor training performance for the ANN model

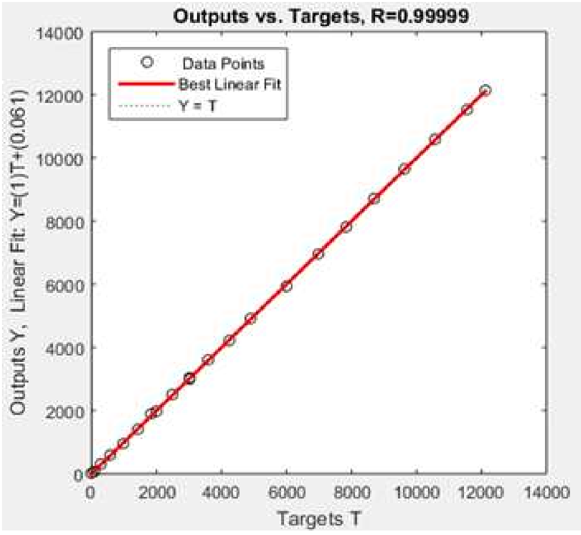

Fig. 33 Supercapacitor output vs target (Energy) for the ANN Model Accuracy (Regression = 0.99999)

4th Model for Supercapacitor Discharging; Load Resistances range = (5:30 ohms)

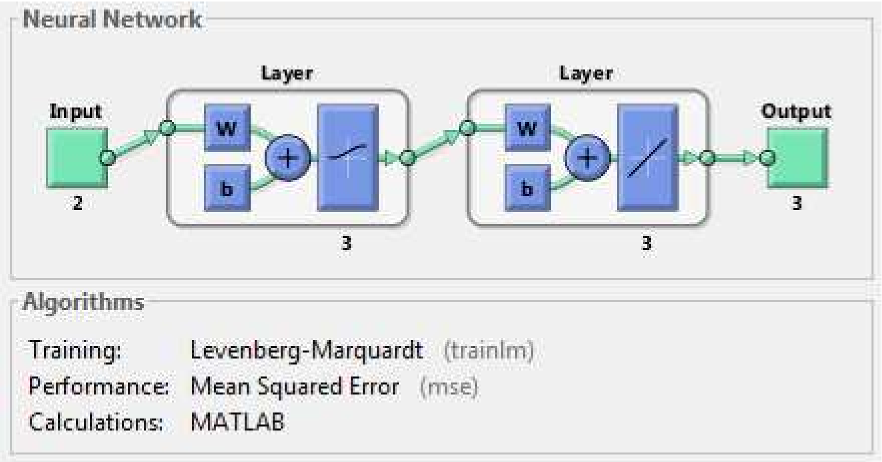

Fig. 34 Supercapacitor ANN model (3 neurons at hidden layer, 3 neurons at output layer)

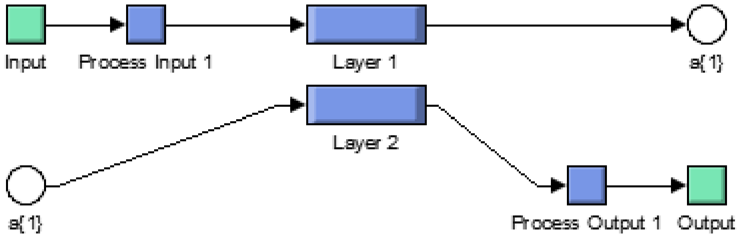

Fig. 35 Supercapacitor ANN two layer construction

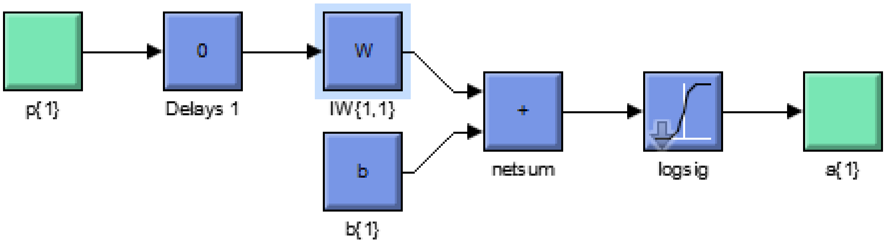

Fig. 36 Supercapacitor ANN hidden layer with log-sigmoid functionn

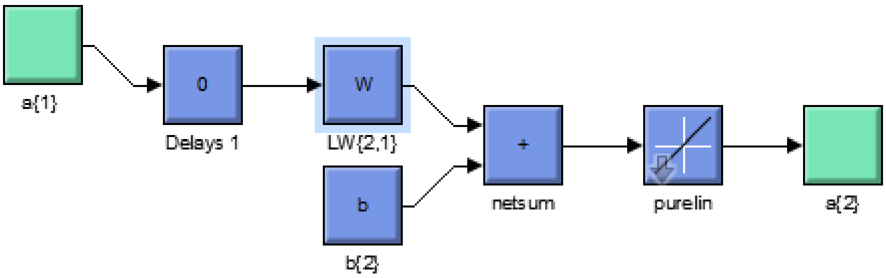

Fig. 37 Supercapacitor ANN output layer with pure-line function

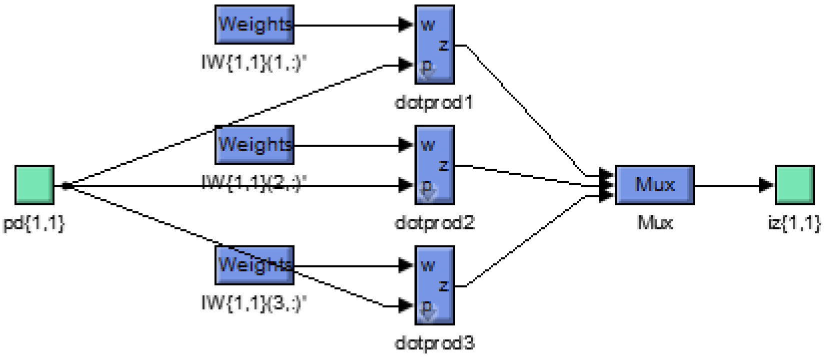

Fig. 38 Supercapacitor ANN first layers weights for the three neurons

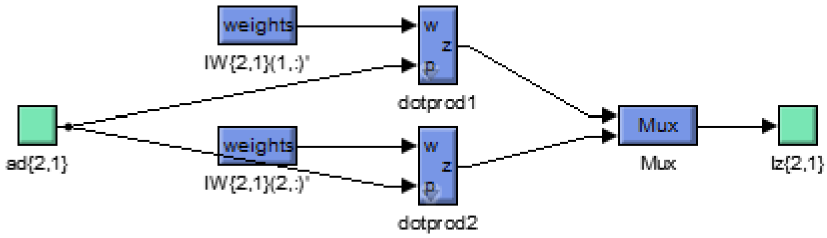

Fig. 39 Supercapacitor ANN second layer weights for the three neurons

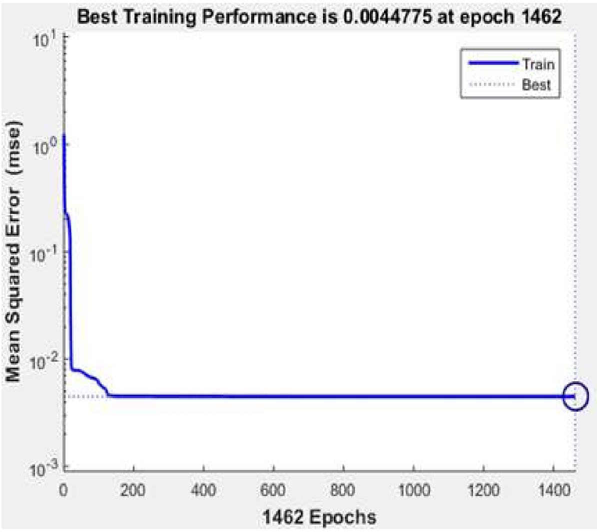

Fig. 40 Supercapacitor training performance for ANN model

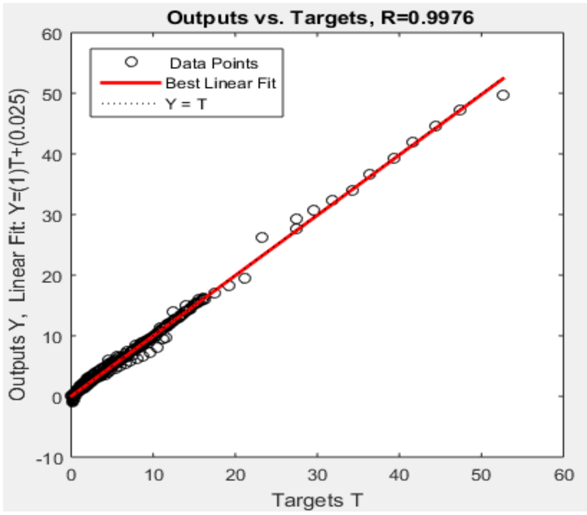

Fig. 41 Supercapacitor output vs target (Power) for the ANN Model Accuracy (Regression = 0.9976)

CONCLUSION

The proposed hydro generator system used a small hydro turbine and generator, a full-wave bridge rectifier to convert the alternating current supplied by the hydro generator and converted it into a direct current. A DC-DC converter was used to step up 12V DC to 16 V, and a supercapacitor was used to store the energy. The stored energy was then supplied to the load, which was a DC smart load. The proposed DC power supply system used a DC power supply, a DC-DC converter to step up 12V DC to 16 V, and a static capacitor and supercapacitor was used to store the energy. The stored energy was then supplied to the AC load. We used Artificial Neural Networks to show the charging and discharging characteristics of the static capacitor and supercapacitor. Overall we believe our system will be user friendly and efficient enough to generate electricity and satisfy the customer needs now that we have fixed the problems with the rectifier and power inverter. Artificial Neural Network (ANN) is used with feed forward back-propagation technique to implement Charging and discharging ANN models for load range up to 150 W. These models are checked and verified by comparing actual and predicted ANN values, with good error values and excellent regression factors (0.997: 1) to imply accuracy. Finally, the Simulink models are generated and deduced to use them without training the neural units each time. The discharging ANN models are introduced with Time and Resistance ranges as inputs and Voltage, Current and Power ranges as outputs for both the static capacitor and the supercapacitor associated with our system. Also, charging Models are proposed using the same technique with Time and Voltage as inputs and Energy and Current as outputs. These Fig.s present each output as a function of the two inputs (Resistance Loads and Time). The next part of the work presents a simple but efficient modeling trials ANN toolbox in MATLAB. The result shows a good matching with the real data. These neural network units are implemented, using the back propagation (BP) learning algorithm due to its benefits to have the ability to predict values in – between learning values, also make interpolation between learning curves data. That is the main reason of using ANN. This is done with suitable number of network layers and neurons at minimum error and precise manner.

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