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Artificial Neural network-based Controller for PEMFC based Distributed generation

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Abstract- An artificial neural network (ANN) based maximum power point tracking (MPPT) technique for proton exchange membrane fuel cell (PEMFC) is analyzed and proposed in this paper. The proposed ANN technique employs Radial basis function network (RBFN) based MPPT strategy to extract the maximum available power from fuel cell in different operating condition. In order to achieve high voltage rating, a novel high step-up DC/DC converter is incorporated in the proposed configuration. To validate the performance of the proposed configuration, the result is compared with different DC/DC converter and MPPT control strategy. The proposed system is simulated in MATLAB/Simulink platform to analyze the performance of the system.

***Index Terms*-** Fuel cell, Quadratic boost converter, MPPT technique, Neural network.

I. Introduction

Constant depletion in the fossil fuel reserve, has drawn the focus of the automobile sector towards fuel cell based electric vehicles. Solar and wind- based renewable energy sources are most preferred among power producers to generate a clean power [1-3]. However, these powers are intermittent in nature. The power generated from PV and wind systems are highly dependent on availability of solar irradiance and wind velocity respectively [4]. Hence, in order to obtain constant power supply, efficient storage components such as Supercapacitors, Batteries and Fuel Cell (FC) are used. Among these, fuel cell-based power generation are best suitable for this efficiency and high-power density. FC is a static electric power source that converts the fuel chemical energy into electrical energy. The main advantages of FC-based power generation are high power density, enhanced efficiency and flexible modular structure. Fuel cells are generally categorized based on the electrolyte used such as include alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), solid oxide fuel cell (SOFC), proton exchange membrane fuel cell (PEMFC) and molten carbonate fuel cell (MCFC) [5]. PEMFC based FC generation is widely preferred for electrical applications for its high-power density and compact design. The details of Fuel cell applications from materials component have been comprehensively explained in Refs. [6-10]. Fuel cells are the best preferred option for reliable and continuous power generation. But they fail to response to the electrical load transients instantly due to slow internal electrochemical characteristics. The performance of the fuel cell depends entirely upon interfacing devices that include power electronic converters. The output voltage of a single FC is very minimal which is not feasible for grid integration. Thus, to overcome this, many fuel cells are connected in series and parallel to obtain high DC voltage. But, increase in the number of fuel cells, results in deterioration of the efficiency of the FC. There is also an increase in the cost of the system. Power electronic converter such as DC-DC converters is implemented for overcoming this problem and providing a boost to the low voltage from a single cell to high voltage rating as per the load demand [11-12]. The boost converter is a typical converter which is used to increase the output voltage with high firing angle. However, the functioning of the converters with high firing pulse reduces the overall efficiency. Thus, an efficient converter which has a large voltage gain with low duty ratio is preferred for fuel cell application [13]. An interleaved converter for medium and large scale has been implemented in Ref. [14]. In Ref. [15], the author implements a buck-boost type converter for fuel cell-based application. A soft switched based boost converter is implemented in Ref. [16]. The authors in Ref. [17,18] also presented a novel DC/DC converter for fuel cell application. In all the above literature, the proposed methodology fails to achieve a suitable voltage gain which can be integrated with the MPPT technique. In this article, an ANN based MPPT controller is implemented for FC application in order to achieve maximum power under varying operating conditions. The RBFN based ANN controller is employed for extracting maximum power.

CONSTRUCTS

1) Abstract
2) Introduction
3) Fuel cell configuration
4) Design Specification
5) MATLAB Modelling

Application of PEMFC

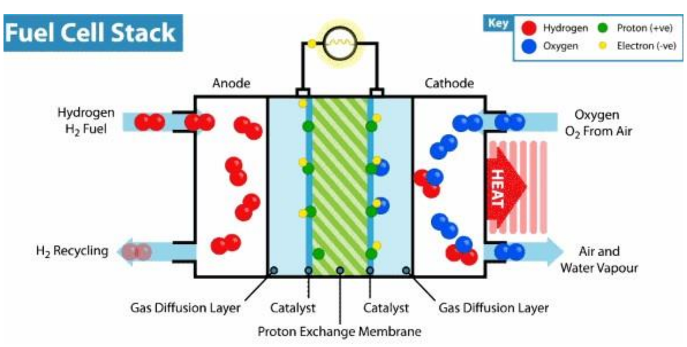
Fuel cells can be used in a wide range of applications, including transportation, material handling, stationary, portable, and emergency backup power applications. Fuel cells have several benefits over conventional combustion-based technologies currently used in many power plants and passenger vehicles. The major application of PEM fuel cells focuses on transportation primarily because of their potential impact on the environment, e.g., the control of emission of the greenhouse gases (GHG). Other applications include distributed/stationary and portable power generation.

PROBLEM STATEMENT

Constant depletion in the fossil fuel reserve has drawn the focus of the automobile sector towards fuel cell based electric vehicles. Solar and wind- based renewable energy sources are most preferred among power producers to generate a clean power. However, these powers are intermittent in nature. The power generated from PV and wind systems are highly dependent on availability of solar irradiance and wind velocity respectively. Hence in order to obtain constant power supply, efficient storage components such as Supercapacitors, Batteries and Fuel Cell (FC) are used. Among these, fuel cell- based power generation are best suitable for efficiency and high-power density. The performance of the fuel cell depends entirely upon interfacing devices that include power electronic converters. Increase in the number of fuel cells, results in deterioration of the efficiency of the FC and there is also an increase in the cost of the system. Power electronic converter such as DC-DC converter is implemented for overcoming this problem and providing a boost to the low voltage from a single cell to high voltage rating as per the load demand.

II. FUEL CELL CONFIGURATION

A fuel cell is a static electrochemical device, which converters chemical energy stored in a molecular device into electrical energy. By arranging the anode, electrolyte and cathode, with the help of anode and cathode catalyst in series or parallel, a fuel cell is constructed to produce electrical energy through chemical reaction between hydrogen and oxygen [12,13].



where,

H: hydrogen
e: electron.
O: oxygen.
Ecell: generated voltage.
E_O: standard potential voltage
R: gas constant (universal)
T: temperature (absolute)
F: Faraday's constant.
PH_2: partial pressure of water.
PH_2O: partial pressure of oxygen

III. MPPT TECHNIQUE

The proton membrane exchange fuel cell (PEMFC) constitutes a desired maximum power point (MPP) where it can extract the maximum power at any given operating condition. Thus, MPPT control strategy is employed in the proposed topology for the extraction of the maximum power. In this paper, the DC-link voltage is used for tracking the maximum power point and generation of the appropriate firing pulse for the switch in the DC/DC converter. The MPPT algorithms implemented in this paper are described below.

PERTURB AND OBSERVE

The Perturb and observe (P&O) algorithm is the conventional MPPT strategy which is used widely for its simplicity and low cost. Fig. 1 is the flowchart of P&O control system. The P&O control strategy works on the direction of perturbation and also the step size of perturbation. The change in the input-controlled variables determines the direction of the perturbation. The step size of the perturbation also plays a major role in the determination of the convergence speed of the strategy. Fixed step size P&O algorithms are not yet implemented in the recent system for improving its performance of the system [19]. The convergence speed is basically determined using the perturbation size. When the large perturbation size is employed, the convergence speed of the P&O is rapid, but the efficiency of the system is low. The smaller step size is implemented to improvise the system efficiency but the convergence speed is to track the MPP is low. Hence, an adaptive P&O method is implemented in the proposed strategy for overcoming this problem. With the implementation of adaptive step size, P&O algorithm can achieve faster convergence speed and high efficiency. With rapid chance in the fuel cell operating point, the P&O method fails to track the maximum power [20].

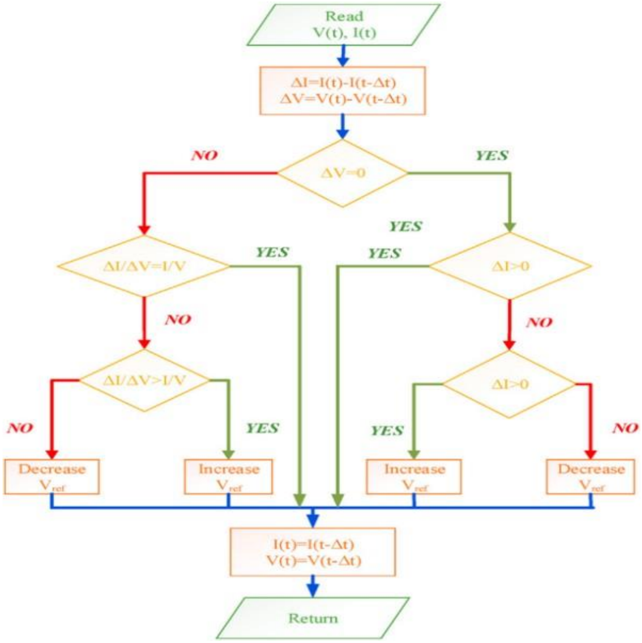


Fig.1 Flowchart of P&O based MPPT controlstrategy

RADIAL BASIS FUNCTION NETWORK

RBFN controller uses a radial basis network as activation network which uses a feed forward type neural strategy [24]. The RBFN is configured with both supervised and unsupervised learning phases. The RBF network is constructed using the distance between the input and the prototype vector. The training of neurons is performed using two different divisions. In first period, the unsupervised training- based method is executed where the parameter is administrated by the radial basis function. In the second period, the supervised based process is engaged to train the weights [25]. The supervised training method is same as back propagation algorithm [26]. In this research, proposed ANN technique is employed for the generation of the duty cycle for the converter. Generated voltage and current were fed to the input neurons of the RBFN which were used in the computation of the duty cycle as the output neuron. The nodes of RBFN are categorized as input layer, a hidden layer and outer layer as shown in Fig. 3 [27]. The inputs of the two neurons in this layer were transmitted directly to the consecutive layer.

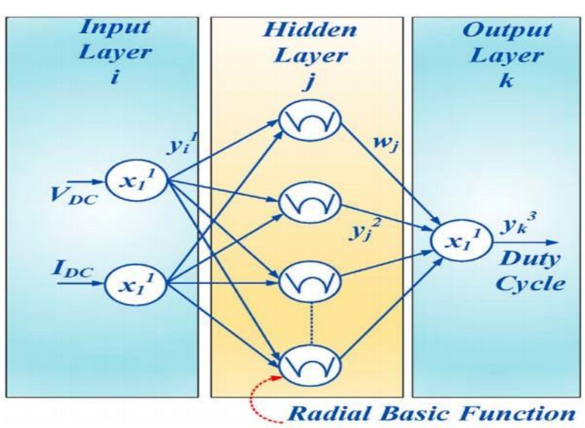


Fig.2 Proposed radial basis function network forfuel cell application

Fig 3 Training states of RBFN

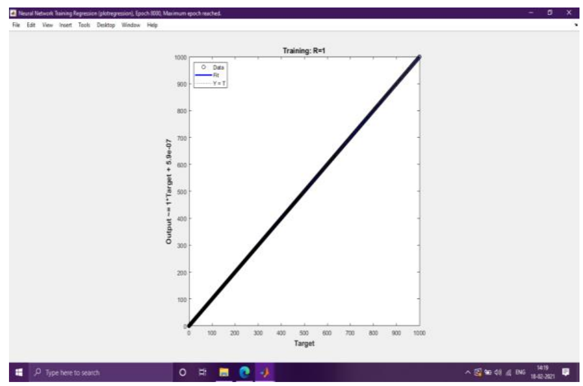
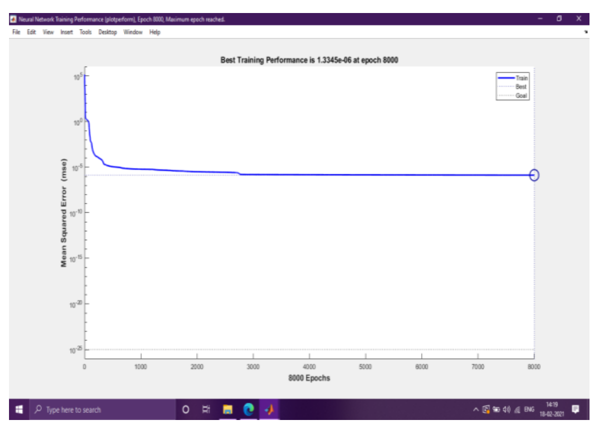


Fig 4 Training error plot



DC/DC CONVERTER

The converter in fuel cell topology is employed forobtaining a high voltage output for the desired application. The DC/DC converter implemented inthis paper is converter from 24 V generator voltages to 230 V which is the standard voltage for an AC microgrid. In this paper, boost converter, Quadraticboost converter have been designed.

Quadratic boost converter

Quadratic refers to a combination of two series converters and the elimination of the need for a second switch. The QBC is similar to a cascaded boost converter (CBC) which is used for obtaining a high voltage conversion ratio. The CBC requires a dual a control strategy to control dual switch

Whereas QBC

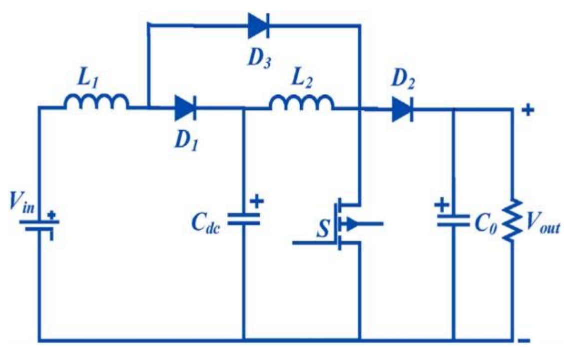


Fig.6 Configuration of Quadratic boost converter

requires only a single control strategy since it has only one switch, thus eliminating the need of additional driver circuit and also switching losses [30]. QBC requires two inductors, three diodes, twocapacitors and a single switch as shown in Fig. 5. The QBC operates like boost converter and themodes of operation is depicted in Ref. [26].

FUTURE SCOPE

Future development and implementation of fuel cell technology would depend on upward trend in global oil price, depletion of oil wells, fall in oil well discovery and the improvement of hydrogen energy infrastructure. Hence the PEMFC based distributed generation provide better Efficiency and less emission with constant output voltage.

Table 1 Fuel cell specification

FUELCELL PARAMETERS	VALUES
Stack power:	
Nominal	**1259.96 W**
Maximal	**2000 W**
Fuel cell Resistance	**0.061871 Ω**
Nearest voltage of one cell (En)	**1.115 V**
Nominal Utilization:	
Hydrogen (H_2)	**99.92%**
Oxidant (0_2)	**1.18%**
Nominal Consumption:	
Fuel	**15.22slpm**
Air	**36.22slpm**
Exchange current (IO)	**0.027318 A**
Exchange Coefficient	**0.308**

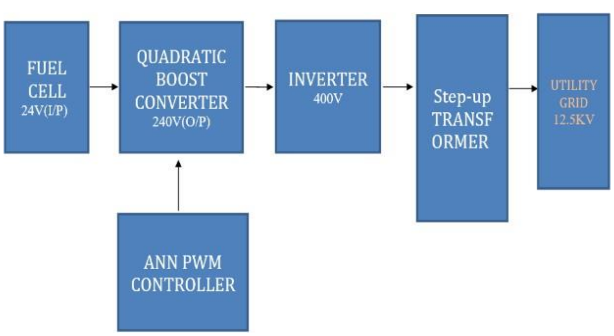
IV. DESIGN SPECIFICATION

Specifications	Ratings
Input voltage, (Vin)	24 V
Output voltage, (Vo)	230 V
Power, (Po)	
Switching frequency	1.26 kW
Inductors	120 kHz
Capacitors	L_1 = 4.69mH L_2 = 4.69mH C_1 = 1.87mF C_2 = 3.75mF

Table 4.1 Parameters of Quadratic boost converter

The above table is presented along with appropriate design values considered for modelling of Quadratic boost converter in MATLAB. The above listed parameters are utilized with its values for modeling MATLAB based simulation environment.

V. BLOCK DIAGRAM



Block 5.1 Proposed block diagram

The above block diagram represents the closed loop model in which the output voltage 240V isconverted into 400V (DC/AC converter) and high voltage is obtained at the secondary side of the transformer which is fed to an AC micro grid.

VI. MATLAB MODELING

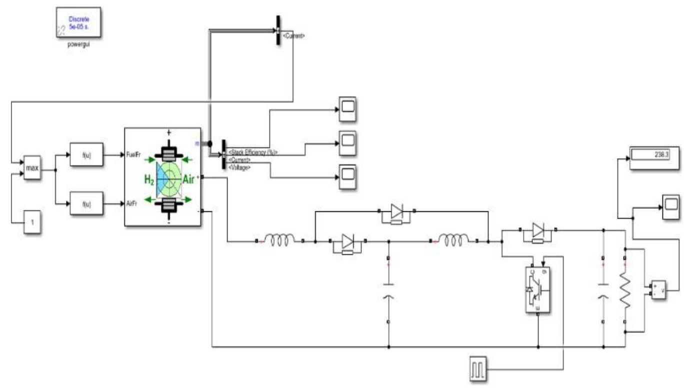


Fig 6.1 Fuel cell with converter

The above Simulink shows how the 24V(DC) is converted into 240V(DC) output by using a switching device (IGBT) and the current is limited through an output resistance.

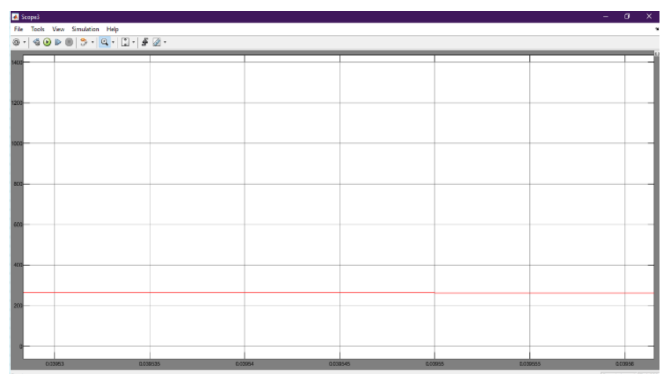


Fig 6.2 Output voltage waveform

This simulated waveform is obtained from the fig 6.1 which shows the output of the fuel cell- converter.

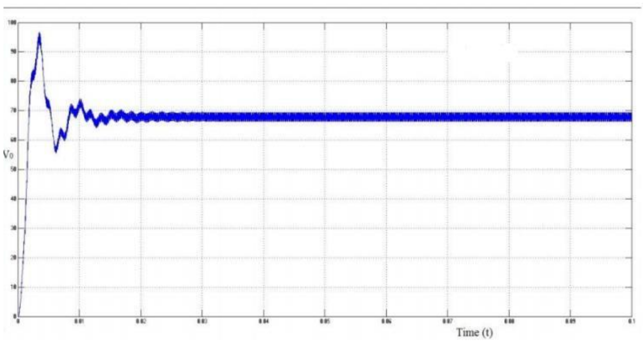


Fig 6.3 Max.voltage from fuel cell

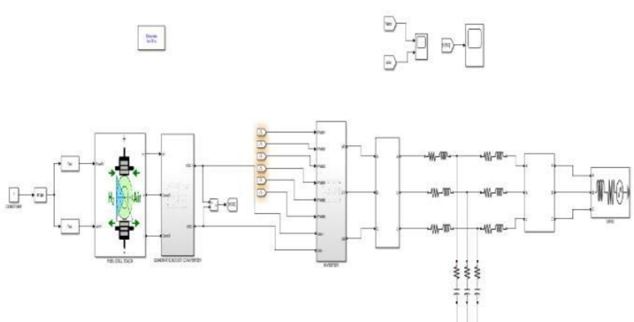


Fig 6.4 closed loop model

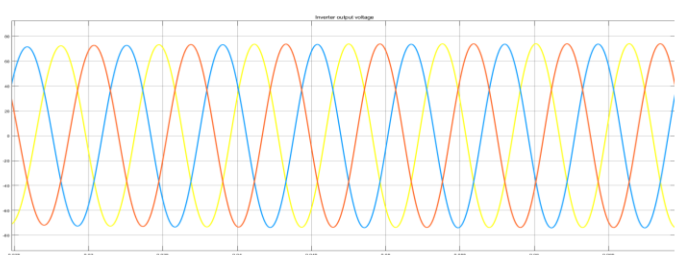


Fig.6.5 Inverter output voltage

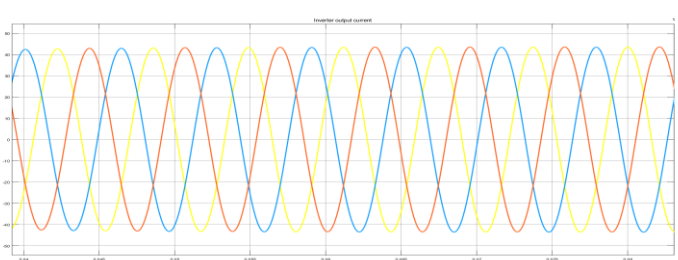


Fig.6.6 Inverter output current

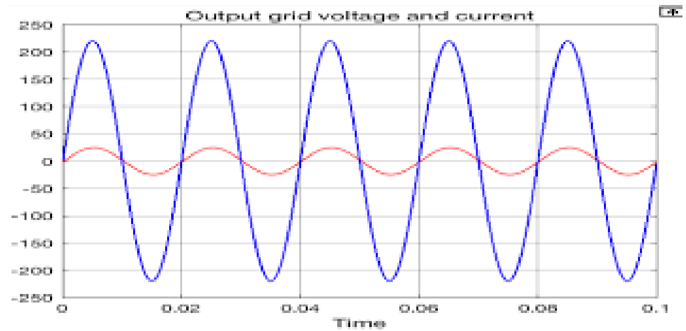


Fig 6.7 Uncontrolled grid output

VII. CONCLUSION

In this work, a novel configuration of a Quadratic boost converter is proposed along with RBFN based MPPT control strategy for fuel cell-based energy conversion system. Various MPPT strategies, namely, P&O and fuzzy logic with different DC/DC converters that includes a Boost and Quadratic Boost converter have been discussed in detail. The main objective of the MPPT control technique is to maximize the output power and optimize power to an optimum value of fuel cell in different operating conditions. Quadratic boost converter which can provide high voltage gain is employed to enable the operation of WECS at a higher voltage and also the achievement of a high performance. The proposed topology has been compared with the Boost and Quadratic boost converter-based configuration in order to validate their performance. MATLAB/ Simulink software was employed for testing the design and validating the results. The conclusion from the analysis is that RBFN based MPPT controller with Quadratic boost converter provides effective results better than P&O and FLC based method in terms of maximum power extraction. The major advantage of RBFN controller is the smaller settling time compared to P&O and FLC controller, with fewer oscillations during the sudden gust in the input system. The RBFN technique requires a precise calculation of the input and target variables.

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