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Design, Modeling And Simulation Of Anfis Borne Mppt Controller For Fuel Cell Electric Vehicle Utilization

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Abstract: Owing to the strong and powerful directives on the release of carbon gas into the atmosphere and limited reserves of fossil fuels, Fuel Cell Electric Vehicles (FCEVs) has become a promising solution in the automobile industry. In this article, a neural-fuzzy framework bound MPPT controller is represented on 1.26kW PEM fuel cell prototype that is widely accustomed in electric vehicle usages. So as to draw the optimal power, we require a high voltage gain step-up converter that acts as an interface linking the PEM fuel cell model following Brushless DC motor. The power cycle of the propounded converter can be regulated with the neural fuzzy reference model, and hereby the optimal power then supplied to Brushless DC motor. And the behavior of the suggested controller is trailed to extending trivial running constraints in conjunction with abrupt shifts in the transposition of the fuel cell. Besides this, to inspect the efficacy and trailing behavior of the propounded controller, the outcomes were collated with those prevailed with the Radial Basis Function Network backed MPP Tracking controller in MATLAB/Simulink Platform.

Indexterms:Adaptive Neuro-fuzzy Interface System (ANFIS), Fuel Cell Electric Vehicles (FCEV), High Voltage Gain Interlaced Boost Converter, MPPT, PEMFC.

I. INTRODUCTION

With the continual increase in the usage of natural resources alike fossil fuels, that creates large amounts of pollution when exploited, most of the automobile industries are working on auxiliary sources of energies such as batteries, fuel cells, and super capacitors for the electric vehicle actuation[1]. The fleeting advancements in fuel cell technologies and power electronics had made the remarkable spread in fuel cell borne electric vehicles. Fuel Cells had many edges correspondent to clean power generation, high irradiance, and high efficacy. Fuel cells are listed relying on the sort of electrolytic material resembling PEMFC, AFC, and SOFC. Amongst these, PEM Fuel Cells are the most dominant owing to their low running temperature and high irradiance capability.

The voltage at the outturn of the PEM Fuel Cell relies on the cell temperature, partial weights ofoxygenand layered water content [4]. However fuel cell attributes are disparate from the traditional chemical borne

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battery, as they have random V-I attributes, thereis hardly one eccentric operating point accessible with optimal output voltage and power. Hence to draw the optimal power from the PEM fuel cell MPP Tracking controller is necessary. Many MPPT controllers are developed in the literature [2]. Such approaches alike P&O and INC are the commonly used techniques yet they generate fluctuations at steady state that reduces the economy of the model [2].

As mentioned prior to this, PEMFC framework has random V-I attributes. Since, the Artificial Intelligence approaches give superior solutions for such networks; these are predominantly arranged into Artificial Neural Networks (ANN) and also Fuzzy Logic Controller (FLC). FLC had many edges of Quick Response, besides the statistical replica of the framework is not necessitated exactly. Major downside is that it requires more memory. Contrast to this ANNs had the proficiency to trace random correlation amidst unconventional and dependent variables. The major disability is that, this controller requires enormous figures of training data that supplements the dimensions of the controller.

In this report, an ANFIS bound MPPT controller for the PEM fuel cell system is proposed.

ANFIS is generally a neural-fuzzy approach where the integration is made between the neuro network and the fuzzy inference network [7]. Since the fuzzy logic regards erroneous and unreliability of the system which is being modeled, while the neural network provides it an understanding of flexibility. The input variables are voltage and current while the outturn is the power cycle.

The rest of the report is structured as conformed: PEM Fuel Cell Modeling, Three Phase High Voltage Gain IBC, conferred in suggested system, MPP Tracking and Brushless DC motor control are enfolded in Designing of controller, Simulations and results analysis and Conclusions.

II. PROPOSED CONFIGURATION

Fig. 1 depicts the power train framework of the FC Electric vehicles composed with 1.26 kW PEM fuel cell, a 3-phase voltage gain Interlaced Boost Converter (IBC), Voltage Source Inverter (VSI) and an electronically commutated motor. ANFIS borne MPP Tracking controller is outlined to draw the optimal power against the PEM fuel cell framework. The details of the framework are described as follows:

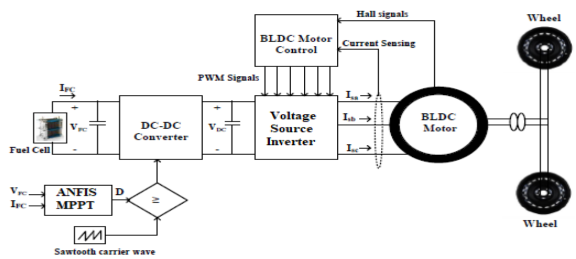

Fig. 1 Configuration of propounded FCEV system relating to ANFIS bound MPP Tracking controller.

III. PEM FUEL CELL MODELING

A PEM fuel cell is a phytochemical energy variation device which transfigures the chemical energy of a hydrogen fuel into electrical power. The input variables on to the PEM fuel cell are air along with fuel and are thereby translated to water as well as electric energy all through the chemical reactions [4]. The conventional outline of the PEM fuel cell is as depicted below in fig. 2. It is comprised of two electrodes and an electrolyte.

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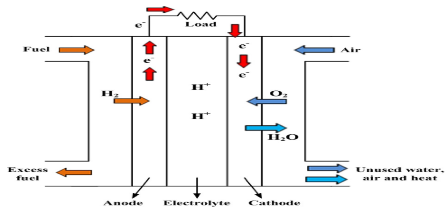

Fig. 2 PEM fuel cell representation

The voltage of PEM fuel cell is as presented below;

$$V_{FC} = E_{nernst} - V_{act} - V_{ohm} - V_{conc}$$

$$E_{nernst} = 1.23(8.50*10^{-4})(T_{FC}-298.150) + (4.36*10^{-5}T_{FC}) \ln (P_{H2}) + 0.50 \ln (P_{O2})$$

$$V_{act} = \zeta_1 + \zeta_2 T_{FC} + \zeta_3 . T_{FC} \ln(C_{O2}) + \zeta_4 . T_{FC} \ln(I_{FC})$$

$$V_{ohm} = (R_M + R_C) I_{FC}$$

Where V_{FC} is the voltage of fuel cell, E_{nernst} is the thermodynamic circuit voltage T_{FC} is PEMFC temperature, P_{H2}, P_{O2} are the vapor pressures correspondent to hydrogen and oxygen experimental coefficient of the respective cell, C_{O2} is oxygen gas concentration, I_{FC} is current of Fuel Cell, R_M is fuel cell resistance of the membrane, R_C is resistance of the proton, b is loss constant concentration and Imax is maximum current. The parameter peculiars of PEM Fuel Cell are enlisted in below Table.1

Table. IFor 1.26 kW PEMFC parameter particulars

Parameter Particulars	Ratings
Optimal Power(P_{max})	1.26 kW
Optimal Current(I_{max})	52 A
Optimal Voltage(V_{max})	24.23 V
Operating Temperature	55°C
No of cells	42

IV. 3-PHASE VOLTAGE GAIN IBC

The circuit layout is dwelled into three switches viz., S_1,S_2,S_3, three diodes viz., D_1,D_2,D_3 along with filtering inductors of phase-1,2,3 respectively. V_{FC} is the voltage input, V_o is the voltage output, R is the load resistance. The inferences are made for the perusal of voltage gain IBC as furnished below [3].

1. Filtering inductances are treated to be ideal.
2. Filter capacitors are considered same.
3. The converter consistently performs in CCM

The three switches are turned on with the aid of two gate pulses that are phase transposed by 180 degrees. Fig.3 below explains the operating modes of 3-phase voltage gain interlaced step-up converter.

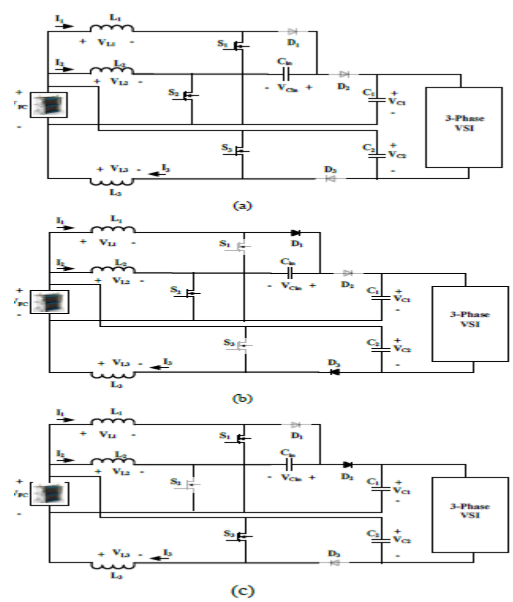

Fig. 3 operating modes of 3-Phase voltage gain IBC

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Mode-1: During first mode, all the available three switches are turned on and the corresponding diodes are thereby reverse biased. The voltage input source charges the inductors and the current through these filtering inductors are linearly increased. The capacitor input is disconnected from loads and the supply. The capacitors at the output provide energy to the resistor load.

Mode-2: In this operating mode, the S_2 switch is ON while the rest are OFF. The respective diodes D_1, D_3 are forward biased and the D_2 is further reverse biased.

Mode-3: This mode of operation is analogous to first mode. However, the available three switches are turned ON and each of the corresponding three diodes is turned OFF.

Mode-4: In this operating mode, S_2 switch is OFF and correspondent to switches S_1, S_3 are turned ON. The diodes D_1, D_3 are thereby reverse biased and further the D_2 diode conducts as depicted in fig. 3

V. CONTROLLER DESIGN

Two strategies of control were defined for the proposed converter configuration. One is for trailing optimal power from the PEM fuel cell network and the other is for brushless DC motor to operate.

A. ANFIS bound MPPT controller

MPP Tracking controller is essential for PEM fuel cell framework to draw the optimal power against it at various operating circumstances. In this report, a neural-fuzzy backed MPPT controller is outlined for the PEM fuel cell and a correlation is made with RBFN controller.

ANFIS is generally a member of Adaptive Networks in which integration is made in between Artificial Neural Networks and Fuzzy Inference System. This Fuzzy Logic estimates the lack of exactness and flexibility and indetermination, while the ANNs deliver a sense of flexibility [7]. However, it provides the merits of both FIS and training proficiency of Neural Networks.Fig.4 depicts the trivial ANFIS framework of Takagi-Sugeno fuzzy model.

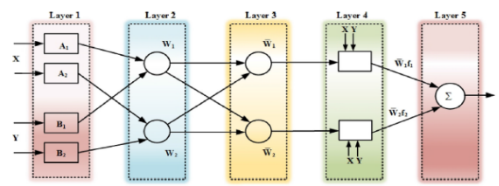

Fig. 4 ANFIS Architecture

In the above fig; the squares represent the adaptive node while the circle represents permanent node. The intent of each layer illustrates the following;

Layer 1: It has input variables representing the membership functions

Layer 2: layer 2 is to verify the weights of each MF's and acquire the results from the previous layer.

Layer 3: So called the rule layer which is used to evaluate the activation function of each rule.

Layer 4: To acquire the defuzzified output.

Layer 5: So called the output layer is to acquire the addition output of all the outputs

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advancing from previous layer that result in a stimulating value.

B. ANFIS training:

With the help of MATLAB/Simulink prototypical of PEM Fuel Cell entity, the transposition of the fuel cell system is changed for attaining the training sets of data of ANFIS and the corresponding current and voltage of respective data training is observed. By utilizing the input/output sets of data the ANFIS initiates to a fuzzy inference system (FIS) in which membership functions (MFs) aspects can be trained with the help of hybrid optimization methods.

Fig.6 below depicts ANFIS output and training data.

Fig.7 below depicts ANFIS typical developed in MATLAB, with double inputs (current and voltage), single outturn and three Membership Functions (MFs) for the respective excitation.

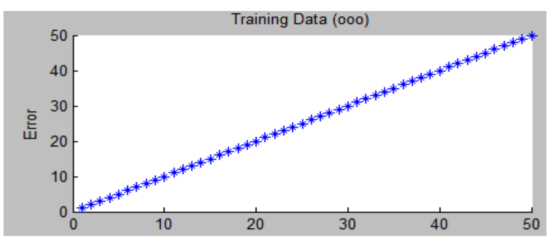

Fig. 5 Training Error in ANFIS and its Epochs

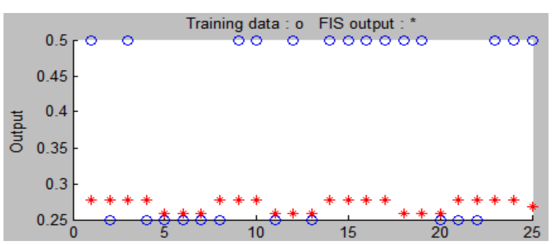

Fig. 6 ANFIS data training and output

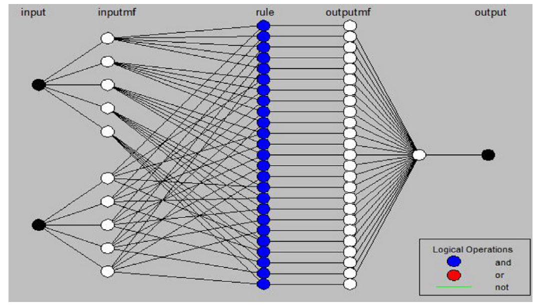

Fig .7 ANFIS structure generated in MATLAB

C. Brushless DC Motor Control:

Brushless DC motors has begun to be a promising solution in automobile industries because of its large force to current ratio, high irradiance ability and high power factor. The construction of stator in BLDC motor is almost homogeneous to that of rotating transformer while rotor coil is composed of fixed magnets. Thereby, the rotor in position is a requisite to control the motor speed. Three hall sensors are used against the stator yoke with 120 deg to notice the orientation of the rotor. Such sensors produce hall signals subjected to the rotor orientation which are then transfigured to shifting states to VSI with a decoder network. Table below represents the shifting positions of VSI for electronic commutation

Table.II Electronic commutation of EC motor and its Switching States

Θ (deg)	Hall Signals			Switching States					
	H_1	H_2	H_3	S_4	S_5	S_6	S_7	S_8	S_9
NA	0	0	0	0	0	0	0	0	0
0-60	1	0	1	1	0	0	1	0	0
60-120	1	0	0	1	0	0	0	0	1
120-180	1	1	0	0	0	1	0	0	1
180-240	0	1	0	0	1	1	0	0	0
240-300	0	1	1	0	1	0	0	1	0
300-360	0	0	1	0	0	0	1	1	0
NA	1	1	1	0	0	0	0	0	0

VI. SIMULATION AND RESULT ANALYSIS

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To carry out the exactness and execution of derived MPP Tracking controller simulations are made using MATLAB/Simulink at different operating circumstances. The performance characteristics of Brushless DC motor driven FCEV system are also distinguished.

During abrupt changes in temperatures of fuel cell:

To inspect the vigorous output of propounded controller, the abrupt shifts in fuel cell system temperature are as follows at T=320K, 340K, 330K for a duration of 0-0.3sec, 0.3-0.6sec, 0.6-0.9 sec respectively.

Fig.8 depicts the temperature variations in the propounded PEM fuel cell.

The voltage and power at the dc link of the propounded configuration with ANFIS borne MPPT controller is shown in which the fuel cell voltage output is regulated to 248.8 V to 1379 W against dc link using proposed ANFIS, however the power and voltage at the dc link are correlated; it is found that the propounded ANFIS bound MPPT controller has trailed the MPP quicker. The performance attributes of the Brushless DC motor like counter emf, Tem and the speed are depicted in figures below for both the controllers.

It can be seen that in comparison to RBFN based MPPT controller, the propounded ANFIS controller elevates the average power at the DC link by 1.16%

Table.III Correlation of DC link specifications

Parameter	1.26 kW PEM fuel cell with RBFN based MPPT			1.26 KW PEM fuel cell with ANFIS based MPPT		
Period(sec)	0 to 0.3	0.3 to 0.6	0.6 to 0.9	0 to 0.3	0.3 to 0.6	0.6 to 0.9
Fuel Cell temperature (K)	320	340	330	320	340	330
DC link voltage (V)	222.3	273.4	247.5	224.2	276.8	248.8
DC link current (A)	4.949	6.1	5.506	4.983	6.145	5.543
DC link power (W)	1100	1668	1363	1117	1701	1379

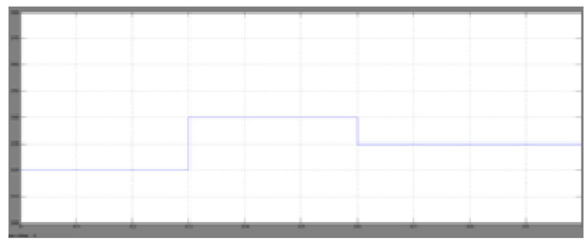

Fig. 8 Variations in temperature for considered PEMFC.

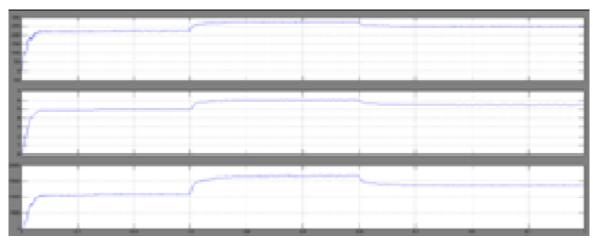

Fig.9 voltage, current and output power at DC link with RBFN

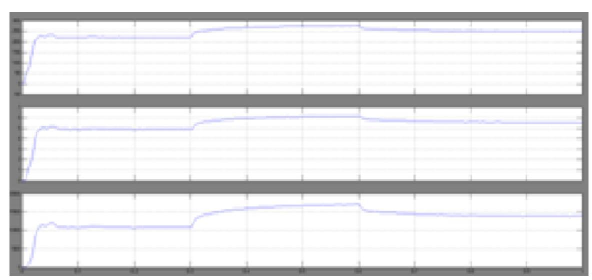

Fig.10 voltage, current and corresponding power at DC link with ANFIS

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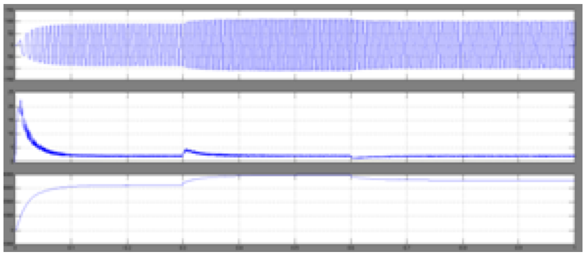

Fig.11 BLDC motor characteristics with RBFN

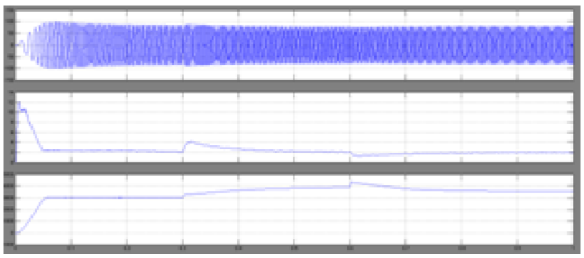

Fig.12 BLDC motor characteristics with ANFIS controller

VII. CONCLUSION

In this paper, a neural-fuzzy borne MPP Tracking controller is presented as well as a high voltage gain IBC is outlined for 1.26kw PEM fuel cell system for the utilization in electric vehicles. The propounded ANFIS bound MPP Tracking controller is depicted at different temperature circumstances of the model. The outcomes for the ANFIS centered controller is collated to that of RBFN based MPPT controller. From simulation outcomes, it is clear that the ANFIS based MPPT controller intensifies the power at the DC link in comparison to RBFN backed MPPT controller. Likewise, various performance aspects of the Electronically Commutated motor are examined at various operating temperatures of fuel cell framework.

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