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A new RBFN based MPPT controller for grid-connected PEMFC system with high step-up three-phase IBC

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ABSTRACT

Extraction of maximum power from a proton exchange membrane fuel cell (PEMFC) power source is necessary for its economical and optimal utilization. In this paper, a neural network based maximum power point tracking (MPPT) controller is proposed for the grid-connected PEMFC system. Radial basis function network (RBFN) algorithm is implemented in the neural network controller to extract the maximum power from PEMFC. A high step-up three-phase interleaved boost converter (IBC) is also designed in order to reduce the current ripples coming out from the PEMFC. Interleaving technique provides high power capability and reduces the voltage stress on the power semiconductor devices. The performance analysis of the proposed RBFN MPPT controller is analyzed in MATLAB/Simulink platform for both standalone as well as for the grid-connected PEMFC system.

Introduction

In recent years, the fuel cells are grown as an alternative green energy source to the solar and wind power sources in power system applications due to its high efficiency, low emission and low noise. The abrupt advances in power electronics and fuel cell technologies have empowered the significant development in fuel cell power generation [1–3]. Fuel cells are categorized into different types based on the characteristics of the electrolyte. Various types of fuel cells include solid oxide fuel cells (SOFC), proton exchange membrane fuel cells (PEMFC), alkaline fuel cells (AFC), phosphoric acid fuel cells (PAFC), zinc-air fuel cells (ZAFC), photonic ceramic fuel cells (PCFC), molten carbonate fuel cell (MCFC) and direct methanol fuel cell (DMFC). Among all these types, PEMFC is dominantly using in automobile industries and distribution systems due to its low operating temperature, high power density, quick startup, low corrosion, simple construction and small size [4].

The output power of PEMFC is not constant and varies greatly with respect to cell temperature, membrane water content, hydrogen and oxygen gas partial pressures. The V–I characteristics of the PEMFC are non-linear, and there exists a single specific operating point is available for PEMFC with the maximum output voltage and power [5]. Hence, a maximum power point tracking (MPPT) algorithm is required for the PEMFC system to increase the efficiency. In the literature, researchers have presented various MPPT techniques for fuel cell systems.

Perturb and observe (P&O) method is most popular conventional MPPT technique used in fuel cells [6]. This algorithm is based on the trial and error process in tracking and finding

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Nomenclature

Symbols

V_{FC}	PEMFC voltage
I_{FC}	PEMFC current
T_{FC}	cell temperature
V_{ohm}	ohmic over voltage
V_{con}	concentration over voltage
V_{act}	activation over voltage
E_{nernst}	open circuit thermodynamic voltage
R_M	equivalent resistance electron flow
R_C	proton resistance
ρ_m	specific resistivity of membrane
A	area of membrane
P_{H_2}	hydrogen partial pressure
P_{O_2}	oxygen partial pressure
W	membrane water content
J	current density
ξ_{1-4}	empirical coefficients of each cell
C_{O_2}	oxygen concentration
P_a	anode inlet pressure
P_c	cathode inlet pressure
R	universal gas constant
F	Faraday's constant
Q	thickness of membrane
K	duty cycle
G	voltage gain
f_S	switching frequency
ΔI	input current ripple
ΔV	output voltage ripple

Acronyms

MPPT	maximum power point tracking
PEMFC	proton exchange membrane fuel cell
SOFC	solid oxide fuel cell
PAFC	phosphoric acid fuel cell
AFC	alkaline fuel cell
ZAFC	zinc air fuel cell
PCFC	photonic ceramic fuel cell
MCFC	molten carbonate fuel cell
DMFC	direct methanol fuel cell
P&O	perturb & observation
FLC	fuzzy logic controller
IC	incremental conductance
SMC	sliding mode controller
PSO	particle swarm optimization
RBFN	radial basis function network
IBC	interleaved boost converter

the maximum power point. At every point, the tracking controllers or sensors measures the PEMFC voltage and current and calculates the actual power, then perturbs the operating point by monitoring change in power and sweeping the operating voltage. If the change in power is positive, the next perturbation of the operating voltage must be in same direction [7]. Otherwise, the operating voltage is perturbed in reverse direction. The advantage of the P&O method is that it is easy to execute. However, this method suffers from several drawbacks such as slow tracking speed and produces more oscillations at steady state [8,9].

In Refs. [10,11], conventional incremental conductance (IC) based MPPT controller is designed for PEMFC. In this controller the PEMFC voltage gets changed based on the instantaneous and incremental conductance value of the PEMFC system. As the tracking of control variable is done continuously, this method overcomes the disadvantages of P&O method which is failed to track the control variable under dynamic varying conditions of the PEMFC temperature and membrane water content. This method utilizes the slope of the PEMFC power characteristics to track the MPP. The slope of the PEMFC curve is zero at the MPP, positive for output power smaller than MPP and negative for output power greater than MPP. The size of the increment or decrement or decrement decides how fast the MPP is tracked. Fat tracking may be attained by using larger increments, but the PEMFC cannot operate at the MPP and produces oscillations around MPP. The major drawback of this method is it requires complex control circuitry [12].

To overcome the disadvantages of conventional MPPT controllers, in Refs. [8,13,14] the authors proposed fuzzy logic controller (FLC) based MPPT technique for PEMFC system. Fuzzy controllers do not require an accurate mathematical model of the system. The other main advantage of this controller is that the controller parameters can be changed rapidly with respect to changes in system dynamics without parameter estimation. In general, FLC consists of three stages: fuzzification, decision making and defuzzification [15,16]. In the fuzzification stage, the crisp numerical input variables are converted into linguistic variables based on the membership functions. In the second stage, the linguistic variables are manipulated by using a set of IF-THEN rules. During the defuzzification stage, the linguistic variables are converted back into numerical variable. The fuzzy based MPPT controller works well under varying PEMFC temperature and varying membrane water content conditions. But, its effectiveness depends on the type of membership function chosen and number of fuzzy rules considered. The memory requirement also causes limitations in its execution [17].

In Refs. [18,19], the authors proposed sliding mode controller (SMC) based MPPT technique for the PEMFC system. SMC is a non-linear controller which is robust in the presence of parameter uncertainties and disruptions. The SMC technique has two modes: sliding mode and extension mode. The sliding mode is used to track the MPP and the extension mode is used to calculate the controller gain value. Even though, the controller has the advantages of fast tracking speed, the performance of the controller is highly depends on the sliding surface. The selection of sliding surface is a difficult task in SMC [20].

In Ref. [21], the authors proposed particle swarm optimization (PSO) algorithm based MPPT in order to extract the maximum power from PEMFC.PSO algorithm acquires its searching capability from the behavior of swarms and insects [22]. The idea behind this algorithm is that the inceptive particles are selected randomly within the boundary limits. These duty cycles/particles are made to move in search space. The most appropriate movement in the inceptive values is known as P_{best} and the overall best in the next iteration is known as

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