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How fuzzy logic can improve PEM fuel cell MPPT performances?

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ABSTRACT

This paper addresses the development of new variable step size fuzzy based MPPT controller. In this study, the fuzzy logic approach is firstly used to auto-scale the variable step size of the Incremental Conductance (IC) MPPT controller. Secondly, the proposed variable step size fuzzy based MPPT controller is used to track the output power of the PEM fuel cell system composed of 7 kW fuel cell supplying a 50Ω resistive load via a DC-DC boost converter controlled using the proposed MPPT. The proposed variable step size fuzzy-based MPPT controller is compared to the conventional fixed step size IC, the variable step size IC and the fuzzy scaled variable step size IC MPPTs using the implemented Matlab/Simulink PEM Fuel Cell power system model. Comparative simulation results between the four studied MPPTs show better performances for the proposed fuzzy based variable step size MPPT in term of: response time reduction between 3.6% and 82.35%; overshoot reduction between 34.55% and 100%; and ripple reduction between 70.93% and 100%, improving as consequence the fuel cell lifetime affected by high current ripple.

Introduction

Global warming is a result of the greenhouse effect induced by the presence of carbon dioxide in the atmosphere, resulting in many ecological and natural disasters that affect human populations. Natural disasters command our attention more than ecological disasters because of the amplitude of the damages they cause. Global warming is believed to have induced meteorological phenomena such as El Nino, which disturbs the south pacific region and regularly causes tornadoes, inundations, and dryness. The melting of the polar icecaps, another major result of global warming, raises the sea level and can cause the permanent inundation of coastal regions and sometimes of entire countries. More and more stringent emissions and fuel consumption regulations are stimulating an interest in the development of safe and clean energy [1].

Clean energy technology includes an astounding variety of ideas for nonfossil fuel, nonpolluting power supplies. These technologies currently have an encouraging amount of support from government agencies, leaders, and universities. Not every technology will prove to be realistic due to high costs or difficult technical challenges, but certainly a number of new-clean energy technologies are possible and on the horizon [2].

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Nomenclature

Acronyms

FC	fuel cell
MPP	maximum power point
MPPT	maximum power point tracking
P&O	perturb and observe
IC	incremental conductance
ESC	extremum seeking control
HC	hill climbing
FO	fractional order filter
SMC	sliding mode control
FLC	fuzzy logic controller
PSO	particle swarm optimization
ES	eagle strategy
WCA	water cycle algorithm
UTA	unified tracker algorithm
PEMFC	polymer exchange membrane fuel cell
MSE	mean squared error
FS	fixed step size
VS	variable step size
NN	neural network

Symbols

V_{FC}	fuel cell voltage
E_{nernst}	the reversible open circuit voltage
V_{act}	activation voltage
V_{ohmic}	ohmic voltage
V_{con}	concentration voltage
T	temperature
P_{H2}	hydrogen pressure
P_{O2}	oxygen pressure
ξ_i	($i = 1$ to 4) parametric coefficient
C_{O2}	oxygen's concentration
R_M	membrane resistance
R_C	contact resistance
B	concentration loss constant
i_{FC}	fuel cell current
A	active cell surface
I_{max}	maximum current density
dP	power variation
dV	voltage variation
dI	current variation
D	duty cycle
SF	scaling factor
ΔD	fixed step size
P	power
I	current
E	error
ΔE	change in error

Subscripts

nernst	Nernst
act	activation
ohmic	Ohmic
con	concentration
H_2	hydrogen
O_2	oxygen
i	1–4
M	membrane
C	contact
FC	fuel cell
max	maximum
k	sample k
k−1	sample k−1

Fuel Cells (FC) are one of the devices promoted as a potential technological contributor to the clear green energy economy. Fuel cell systems offer clean and efficient energy production and are currently under intensive development by several manufacturers for both stationary and mobile applications. The viability, efficiency, and robustness of the fuel cell technology depend on understanding, predicting, monitoring, and controlling the fuel cell system under a variety of environmental conditions and a wide operating range [3].

Among the many different fuel cell technologies, Proton Exchange Membrane (PEM) fuel cells are extensively used for mobile and portable applications. This is due to their compactness, low weight, high power density and clean, pollutant free operation. From the operational point of view, a relevant aspect is their low temperature of operation (typically 60–80 °C), which allows fast starting times. In a PEM Fuel Cell, a hydrogen-rich fuel is injected by the anode, and an oxidant (usually pure oxygen or air) is fed through the cathode. Both electrodes are separated by a solid electrolyte that allows ionic conduction and avoids electrons circulation. Catalytic oxidation of H_2 and catalytic reduction of O_2 take place in the negative and positive electrodes, respectively. The output of a PEM Fuel Cell is electric energy, with water and heat as the only by-products. Efficiency can be high, as previously said, due to the absence of a Carnot cycle [4].

The output power of the PEM fuel cell is not regulated, and its stability is a relevant issue. The small voltage of each individual cell is heavily influenced by changes in electric current, partial gas pressures, reactants humidity level, gas speed and stoichiometry, temperature and membrane water content. Due to this nonlinear, multi-variable dependent behavior, precisely controlled conditions must be ensured for proper operation. Therefore, the operation of a fuel cell in applications with varying load demands without power electronics is impossible. The power electronics are also needed to adjust the point on the I/V curve corresponding to the actual power demand [4,5].

The last decade has seen a huge development of the maximum power point tracking (MPPT) controller for fuel cell power systems [6–8]. The improvement of the MPPT tracking efficiency using new control strategies is the easiest and the inexpensive way compared to the effort due to the improvement of the efficiency of the converter or the conversion ratio of the PEM fuel cells. This finding pushes scientific community to a massive development of MPPT algorithms. Among which we can cite: Perturb and Observation (P&O) [9–11], Incremental Conductance (IC) [12–14], Sliding Mode Controller (SMC) [15–17], Fractional Order filter Controller (FOC) [18], Hysteresis Controller (HC) [19], Extremum Seeking Control (ESC) [20,21], Fuzzy Logic Controller (FLC) [22–24], Particle Swarm Optimization Controller (PSOC) [25], Water Cycle

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