HYBRID PREDICTIVE- NEURAL NETWORK BASED ON PROTON EXCHANGE MEMBRANE FUEL CELL MAXIMUM POWER POINT TRACKING

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PhD ☐

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ABSTRACT

Renewable energy is the most efficient and dependable energy source that can be utilised in a variety of sectors, particularly in daily and commercial applications, and can reduce the continuous consumption of fossil fuel. Due to its various benefits, such as being environmentally friendly, highly efficient, noiseless, and safe to run, fuel cell power generation technology is gaining popularity in the present global energy generation, distribution, and consumer demand scene. In this study, PEMFC is chosen due to its promising characteristics, which can be widely applied in daily life and aid in all aspects with the expectation of larger results. Non-linear and greatly impacted by these parameters, the output of this fuel cell is extremely sensitive to cell temperature, oxygen partial pressure, and membrane water content. Each input has a unique operational output that maximises output, and it is best to determine the voltage or current that maximises the fuel cell's efficiency. MPPT methods, including SMC, P&O, INC, and PSO are introduced to achieve maximum production. This project's objective is to simulate a fully functional PEMFC system that is based on mathematical models and combines them with an artificial neural network. This is to improve accuracy and reduce the high computational. This project will implement a PEMFC system coupled with an ANN system. In this project, specific features such as model predictive control (MPC) are being added to provide reliable dataset, and DC-DC boost converters are being utilised to manage the output voltage of fuel cells to extract the maximum output power, with the switches being controlled by MPC. This project's primary objective is to demonstrate that ANN may achieve maximum power output when parameters are emphasised, whereas PEMFC systems will become more efficient in a shorter amount of time. Since the proposed method and other existing MPPT algorithms are compared, the performance of PEMFC is determined., and an additional ANN feature is introduced to support system efficiency. As a result, the ANN system will display rapid MPP locus tracking with exceptional precision and robustness.

KEYWORD: ANN, DC-DC Boost Converter, MPPT, MPC, PEMFC.

ABSTRAK

Tenaga boleh diperbaharui ialah sumber tenaga yang paling cekap dan boleh dipercayai yang boleh digunakan dalam pelbagai sektor, terutamanya dalam aplikasi harian dan komersil, dan boleh mengurangkan penggunaan berterusan bahan api fosil. Disebabkan oleh pelbagai faedahnya, seperti mesra alam, sangat cekap, tanpa bunyi dan selamat untuk dijalankan, teknologi penjanaan kuasa sel bahan api semakin popular dalam penjanaan tenaga global, pengedaran dan suasana permintaan pengguna. Dalam kajian ini, PEMFC dipilih kerana ciri-cirinya yang menjanjikan, yang boleh digunakan secara meluas dalam kehidupan seharian dan membantu dalam semua aspek dengan jangkaan hasil yang lebih besar. Tidak linear dan sangat dipengaruhi oleh parameter ini, output sel bahan api ini sangat sensitif terhadap suhu sel, tekanan separa oksigen dan kandungan air membran. Setiap input mempunyai output operasi unik yang memaksimumkan output, dan yang terbaik adalah untuk menentukan voltan atau arus yang memaksimumkan kecekapan sel bahan api. Kaedah MPPT, termasuk SMC, P&O, INC, dan PSO, diperkenalkan untuk mencapai pengeluaran maksimum. Objektif projek ini adalah untuk mensimulasikan sistem PEMFC berfungsi sepenuhnya yang berdasarkan model matematik dan menggabungkannya dengan rangkaian saraf tiruan. Ini adalah untuk meningkatkan ketepatan dan mengurangkan pengiraan yang tinggi. Projek ini akan melaksanakan sistem PEMFC ditambah dengan sistem ANN. Dalam projek ini, ciri khusus seperti kawalan ramalan model (MPC) sedang ditambah untuk menyediakan set data yang boleh dipercayai, dan penukar rangsangan DC-DC sedang digunakan untuk menguruskan voltan keluaran sel bahan api untuk mengekstrak kuasa output maksimum, dengan suis sedang dikawal oleh MPC. Objektif utama projek ini adalah untuk menunjukkan bahawa ANN boleh mencapai output kuasa maksimum apabila parameter ditekankan, manakala sistem PEMFC akan menjadi lebih cekap dalam masa yang lebih singkat. Memandangkan kaedah yang dicadangkan dan algoritma MPPT sedia ada lain dibandingkan, prestasi PEMFC ditentukan., dan ciri ANN tambahan diperkenalkan untuk menyokong kecekapan sistem. Hasilnya, sistem ANN akan memaparkan penjejakan lokus MPP pantas dengan ketepatan dan keteguhan yang luar biasa.

Kata Kunci:ANN,MPPT,MPC,PEMFC,Penukar Ransangan DC – DC.

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LIST OF SYMBOLS

ΔD	–	Fuzzy controller output
ΔG	–	Specific entropy
$\Delta G°$	–	Gibbs free energy
Δi_L	–	Change in inductor current
ΔI_{FC}	–	Change/ripple in fuel cell current
Δi_L	–	Change/ripple in inductor current
ΔP_{FC}	–	Change/ripple in fuel cell power
ΔV_{FC}	–	Change/ripple in fuel cell voltage
α	–	Parameter randomization
τ_{H_2}	–	Hydrogen time constant
τ_{O_2}	–	Oxygen time constant
φ_h	–	Activation function
ξ_{1-4}	–	Parametric coefficients
E_{Nernst}	–	Thermodynamic potential
I_{FC}	–	Fuel cell current
I_{pv}	–	Current at PV system
k_{H_2}	–	Hydrogen valve molar constant
k_{O_2}	–	Oxygen valve molar constant
k_r	–	Modeling constant
P_{FC}	–	Fuel cell power
P_{H_2}	–	Partial pressure of hydrogen
P_{O_2}	–	Partial pressure of hydrogen
q_{H_2}	–	Molar flow of hydrogen
q_{O_2}	–	Molar flow of oxygen
r_m	–	Membrane specific resistivity
T_{ref}	–	Standard temperature
T_s	–	Sampling time
t_m	–	Membrane thickness

V_{FC}	–	Fuel cell voltage
V_L	–	Inductor voltage
V_{act}	–	Activation voltage
V_{cell}	–	Cell voltage
V_{con}	–	Concentration voltage
V_{ohm}	–	Ohmic voltage
V_o	–	Voltage output
V_b	–	Voltage at boost converter
V_{pv}	–	Voltage at PV system
h	–	Radial Basis Function units
k	–	Number of discrete sampling steps
n	–	Number of electrons
R	–	Universal gas constant
r	–	Distance of two fireflies
T	–	Operational temperature
t	–	Time
γ	–	Fixed light absorption coefficient

LIST OF ABBREVIATIONS

AFC	–	Alkaline Fuel Cell
ANN	–	Artificial Neural Network
DC	–	Direct Current
FA	–	Firefly Algorithm
FLC	–	Fuzzy Logic Controller
HC	–	Hill Climbing
HFA	–	Hybrid Firefly Algorithm
IGBT	–	Insulated Gate Bipolar Transistor
INC	–	Incremental Conductance
LMA	–	Levenberg-Marquardt
MATLAB	–	Matrix Laboratory
MF	–	Membership Function
MCFC	–	Molten Carbonate Fuel Cell
MPC	–	Model Predictive Control
MPP	–	Maximum Power Point
MPPT	–	Maximum Power Point Tracking
NS	–	Small Negative
NL	–	Large Negative
NN	–	Neural Network
NNC	–	Neural Network Control
P&O	–	Perturb and Observe
PAFC	–	Phosphoric Acid Fuel Cell
PB	–	Big Positive
PEMFC	–	Proton Exchange Membrane Fuel Cell
PID	–	Proportional Integral Derivative
PS	–	Small Positive
PSO	–	Particle Swamp Optimisation
P-I	–	Power-Current
PV	–	Photovoltaic
PWM	–	Pulse Width Modulation

RBFN	–	Radial Basis Function Network
SOFC	–	Solid Oxide Fuel Cell
V-I	–	Voltage-Current

CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy sources have played a crucial role in the energy production industry to minimize greenhouse gas emissions over the past decade. Renewable energy production has supplied all categories of energy consumers with energy. The combustion of fossil fuels such as coal, oil, and natural gas has had a substantial effect on the environment. Contribution to severe environmental harm and the greenhouse effect are among the most prominent consequences. The greenhouse effect is a natural phenomenon that regulates the Earth's temperature. Carbon dioxide and other greenhouse gases are released into the atmosphere in significant quantities when fossil fuels are burned. This rise in greenhouse gases traps more solar heat, resulting in global warming. This phenomenon is known as global warming, and it has been linked to several detrimental environmental effects, including rising sea levels, more frequent and severe heat waves, and altered precipitation patterns. In addition to contributing to global warming, the combustion of fossil fuels has serious environmental consequences. The extraction and transport of fossil fuels can result in the loss of natural habitats and the relocation of local inhabitants. For instance, coal mining can result in the destruction of forests and poisoning of water sources. Consumption of fossil fuels also adds to air pollution, which can have severe health consequences for residents of impacted areas. Coal combustion, for instance, discharges particulate matter and Sulphur dioxide into the atmosphere, which can lead to respiratory difficulties and cardiovascular illness.

The tremendous increase in energy demand has necessitated the development of cost-effective renewable energy-based technologies to replace fossil-fuel-powered equipment in a variety of applications. Recent interest in fuel cell systems has increased, as fuel cells are clean and efficient producers of electricity and have numerous automotive uses [1].This is because fossil fuels still meet a significant part of the energy demand. Carbon dioxide emissions from the combustion of fossil fuels are the primary cause of environmental problems including global warming and air pollution. These issues represent a threat to health complications and diminish life expectancy.

Renewable energy has exploded in popularity over the past century, and it continues to grow at a considerably quicker rate than conventional energy sources such as oil and coal [2].Consequently, it is imperative to seek out sufficient and sustainable energy sources. Fuel cells are regarded as one of the most advantageous renewable energy sources that can be utilized. Due to its low environmental effect, fuel cells have gained interest as a promising renewable energy source recently [3]. In a PEMFC, hydrogen gas is fed to the anode side of the cell and oxygen (or air) is fed to the cathode side. At the anode, hydrogen is separated into protons and electrons. The protons pass through the proton-conducting membrane to the cathode, while the electrons are forced to flow through an external circuit, generating electricity. At the cathode, the protons, electrons, and oxygen combine to form water, which is the only by-product of the reaction [4].The non-emission of harmful gases during their operation, great energy efficiency, and low noise levels make fuel cell is the optimal answer for a variety of applications, particularly for co-generation of heat and electricity in combined cycles [5]. In a fuel cell system, the unit cell is the central component responsible for electrochemical energy conversion. It consists of an electrolyte in contact with anode and cathode electrodes, respectively [6]. According to Table 1.1 fuel cells can be categorized into five major types based on the electrolyte used [7].

Table 1.1:Type of Fuel Cell [6], [8]

Characteristic	Polymer Electrolyte	Alkaline	Phosphoric Acid	Molten Carbonate	Solid Oxide
Temperature (°C)	40-80	65-220	205	650	600-1000
Electrolyte	Hydrated Polymeric ion	Potassium Hydroxide	Liquid Phosphoric Acid	Liquid Molten Carbonate	Perovskites
Electrode	Carbon	Platinum	Carbon	Nickel	Perovskite Metal Cermet
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskite
Charge Carrier	H+	OH-	H+	CO3+	O-
Efficiency (%)	40-60	60-70	55	65	60-65

PEMFC is the highlight because these fuel cells have a high-power density, compact, operate at low temperatures due to the employment of catalysts, and allow for a rapid start-up. They work at temperatures between 80°C and 90°C, resulting in minimal heat loss to the surrounding environment. However, they have a low tolerance for carbon monoxide: platinum catalysts can be poisoned by quantities of carbon monoxide exceeding 10 ppm. High-temperature proton exchange membrane fuel cells are another form of PEMFC. The difference between the two types is the composition of the anode and cathode proton exchange membranes. In the high temperature cell, the membrane is comprised of polybenzimidazole (PBI) doped with phosphoric acid, which serves as the H+ ion conductor, resulting in an operating temperature of approximately 200°C [5]. This characteristic assists the cell by increasing its tolerance to carbon monoxide and the usage of heat produced in combined heat and power cycles, as well as the utilization of natural gas for hydrogen generation. In addition, the high-temperature

PEMFC membrane does not require an external water source. The anode and cathode of this cell are composed of platinum-ruthenium supported on carbon.

Among these fuel cell types, PEMFC, also known as polymer electrolyte membrane [9], is regarded as a promising power source contender due to its remarkable characteristics, which include high efficiency, clean utilization, lightweight, fast start-up, low operating temperature, and high-power density [10]. In addition, as stated in [11], PEMFC is the most prominent fuel cell employed in a variety of applications. Other than that, as suggested in [6], Kyoto Protocol has proposed that to reduce carbon dioxide emission is by using renewable energy sources, carbon dioxide sequestration and producing high efficiency technologies and advanced low-carbon dioxide emission energy system.

To consistently extract the maximum amount of power from a fuel cell, it is required to establish a technique that allows the fuel cell to circumvent the MPP under any operating conditions which is Maximum Power Point Tracking (MPPT). However, this method has significant limitations, such as steady-state fluctuations and tracking error when operating circumstances vary rapidly [12]. On the other hand, algorithms based on Artificial Neural Networks (ANNs) may represent complicated non-linear systems without precise mathematical correlations between the input and output system variables.

1.2 Problem Statement

Nowadays, renewable energy has become one of the energy sources especially on fuel cell application. Because of the fuel cell system is too complex [13],thus making it is quite high cost [14], Because of its extensive use and particular advantages, researchers are now compelled to create an exact model of the PEMFC. As a result, modelling of PEMFC systems has become critically important for better understanding and development of high efficiency PEMFC systems [15]. Despite this, nonlinearity, multivariate, and strongly coupled features of PEMFC, mathematical modelling based on empirical equations has been widely used. As a result of the shortage of data, the modelling complexity, and the huge number of unknown parameters, the employment of optimization methods is essential [16].

In addition, the output power of PEMFC is highly dependent on parameters such as temperature, membrane water content, oxygen partial pressure, and hydrogen partial pressure, resulting in a nonlinear output characteristic of the fuel cell [17].Regarding to this matter, many variable need to be consider so this is where Artificial Intelligence is being put in the