CHAPTER 1

INTRODUCTION

Nowadays, most of energy demand in this global relies on fossil fuels such as petroleum, coal and natural gas, which are begin run out rapidly. More importantly, one of their combustion products, carbon dioxide, is the major cause of the serious problem of global warming, which are posing great hazard for the entire life on the world. To solve this problem, renewable energy sources, such as solar, wind and fuel cell are considered as alternative energy sources to conventional fossil fuel energy due to environment pollution and global warming problems. Moreover, the combination of two or more energy sources can improve higher power efficiency of the system called hybrid system. One of energy source presently famous use as hybrid power source is proton exchange membrane (PEMFC). It is an electrochemical energy converter. Fuel cell converts chemical energy of fuel, typically hydrogen, directly into electrical energy. Fuel cell generates zero emissions. Many of researchers have been studied the behavior and performance of fuel cells, especially PEM fuel cell (P. R Pathapati et al, 2005), (Alejandro et al, 2007), (M. T. Outeiro et al, 2008), (Sophie et al, 2008), (Zhuqian et al, 2010), (M. M. Hussain et al, 2005), (O. Shamardina et al, 2010), (M. Tohidi et al, 2010). The applications of fuel cell are also studied by many researches, such as the application of hybrid power system (M. Hatti et al, 2011), (O. C. Onar, 2006), (Lijun et al, 2004), (Zhenhua et al, 2004), (M. T. Iqbal, 2003), (Rajesh et al, 2005), (M. J. Khan et al, 2005), (Yong et al, 2011). From advantages and many application of fuel cell, the PEM fuel cell is the interesting power source to study and the hybrid system also give high performance of power and reduce energy. So, both of fuel cell and hybrid system are very interesting to investigate in this study.

1.1 Statement and Significance of the Problem

Hybrid system is a technology which consists of two or more energy sources to generate energy source to power electricity devices or power train vehicles. Advantage of hybrid systems gives high power and reduces energy consumption (Rajesh et al, 2005). Moreover, one of the technologies that can solve oil crisis is fuel cell technology. So, hybrid and fuel cell technologies are introduced for higher performance oil usage and low emission. Fuel cell technology is an electrochemical energy conversion device that converts chemical energy of hydrogen and oxygen into electricity and heat by electrochemical reactions at the anode and the cathode of the cell, respectively, that produces water as the only by-product. There are various existing fuel cell systems and one of the most popular types of fuel cell is a proton exchange membrane fuel cell (PEMFC). It can be used for transportation and power generation for electrical devices. Fuel cell system overall efficiency can reach about 50% (Fei Gao et al, 2009). The operating temperature of a fuel cell is quite low (60℃ to 80℃), which lead to a fast start up, the fuel cell is environment friendly primary energy sources, and fuel cell stack system can be very compact when compared to other sources of energy. The hybrid power source system gives high power, high performance and high reliability. The hybrid power source system can improve the performance, reduce the energy consumption and produce low air pollutions. The combination of two power sources can be classified by power source and power transmission. Combination of two power sources are, for example, engine-battery (Karen et al. 1999, Liu et al. 2005, Thounthong et al. 2008, Lee et al. 2008), solar-engine (Tadokoro et al. 1994), fuel cell-battery (Nadal et al. 1995, Gokdere et al. 2002, Jiang et al. 2003, Mauldin et al. 2006), solar-fuel cell (Iqbal, 2003, Wei et al. 2007, Alejandro et al. 2007) and wind-fuel cell (Khan et al. 2004). Combination of three power sources are engine-wind-solar (McGowan et al. 1996, the PREGA National Technical Experts, 2005), and wind-solar-fuel cell (Das et al. 2005, El-Shatter et al. 2005, Sathyan et al. 2005) and solar-fuel cell-battery (Jemei et al. 2006). All of above researches aimed for electronic devices. The combination of two power source that use for power transmission can be divided into three types. First is series type that the power source is connected in series (Rahman et al. 1999). Second is parallel type that the power source is connected in parallel (Rahman et al. 1999), and the last is series-parallel type that combined of two types together (Liu et al. 2005). The performance analysis and operation strategies of the hybrid system are also necessary, in order to achieve the optimization of the system. Recent researches show that a hybrid system gives high performance and improve reliability. Many of the researches are focus on improving performance, operation in various strategies, modeling, experimental, and designing the hybrid system as mention above. There is a gap that should have fulfilled and there is no published research in a small hybrid system between proton exchange membrane fuel cell and internal combustion engine generator. The advantage of the hybrid system between proton exchange membrane fuel cell and internal combustion engine generator will give low emission because the system uses hydrogen as a fuel to PEM fuel cell with no combustion in the process to generate electric energy. Proton exchange membrane fuel cell can be operated as a based power or add-on to supply the electric device and the electric generator also can be worked as main or add-on power. The study of a hybrid system between proton exchange membrane fuel cell and internal combustion engine generator is interesting and it will be the main area of to study in order to find out the performance and operating strategies of the hybrid system. The challenge of this work is to study affect of parameters on operation condition of the hybrid system. This research will focus on a small unit of hybrid power source of PEMFC and electric generator in both of modeling and experimental for power to a small electricity device in order to identify the appropriate operation of the hybrid system.

The objective of this research is to simulate and investigate the operation of PEM fuel cell and engine generator hybrid power source system. The numerical results will provide fundamentals knowledge on hybrid system behavior and can be used to develop the operation procedure for such a system in the future.

1.2 Literature Review

The thesis aims to analyze the parametric and performance of the combination of proton exchange membrane fuel cell (PEMFC) and internal combustion engine generator. Some of previous work which are related to this thesis can be mentioned as follows.

1.2.1 Fuel cell modeling

The modeling of proton exchange membrane fuel cells has been widely developed in many areas in order study the behavior and characteristics of fuel cell. Technology and application of hybrid system will be reviewed. The modeling of proton exchange membrane fuel cell and hybrid system can be classified based on interested parameter and control strategies which affect the characteristic of the system as following:

1.2.1.1 The effect of operating temperature to polarization of PEM fuel cell

Wang et al. (2003) developed numerical model in order to support the experimental of the effect different operation on the performance of PEMFC using pure hydrogen on the anode side and air on the cathode side. Numerical model and experiments tested with different fuel cell operating temperature, different cathode and anode humidification temperature, different operating pressure, and various combinations of these parameters have been carried out. The results of both model and experiment are presented in the terms of polarization curves, which show the effects of the various operating parameters on the performance of the PEMFC. The performance of the PEMFC improves with the increase of operation temperature when provided enough humidification. Hui et al. (2007), Leonard et al. (2005), and O. Shamardina et al. (2010) developed mathematical model of PEM fuel cell in order to study the polarization losses of PEM fuel cell at 120℃ (at high temperature for PEM fuel cell). The result shows that at high operating temperature cause reducing of relative humidity and it affects to increase the polarization losses. S. Shimpalee et al. (2000) have been developed 3-D model of fuel cell in order to investigate the temperature distribution inside a straight channel proton exchange membrane fuel cell and the effect of heat produced by the electrochemical reactions on fuel cell performance. The results show that the temperature distribution in all directions of the insulated top surface boundary of both the anode and cathode side is higher than both sides of fixed with a constant temperature. Yuyao et al. (2005) developed a dynamic model of PEM fuel cell in order to study the effects of electric loads on temperature, voltage and efficiency. Ronard et al. (2005) have been test the fuel cell at low pressure operating and high temperature (>70°C). At the system work, huge amounts of water have to be evaporated in the humidifier, requiring large amounts of heat. Zhihao et al. (2006) introduced a semi-empirical dynamic model of PEM based on the measurement from a Nexa^{TM} PEM fuel cell power module under different load conditions. The results of the experiments have indicated that both the stack temperature and the equivalent internal resistance change dramatically with the change in the load currents.

1.2.1.2 The effect of other parameter to polarization of PEM fuel cell

Zhang et al (2010) investigated transient behavior of a PEM fuel cell under different operating conditions such as, operating temperature, pressure, inlet reactants humidity and gas stoichiometric ratio (Shuguo et al, 2008). The increasing of operating pressure will cause increasing of the cell voltage but it's not the major influence to PEM's performance. The increasing of relative humidity at both the cathode or anode side will cause water flooding and effected to PEM performance. Yuan et al (2010) developed the model to predict the effects of operating parameters on proton exchange membrane fuel cell performance. The three-dimensional multi-phase fuel cell model is developed by using commercial CFD software package Fluent. The model shows that the operating pressure and temperature have an influence on PEM performance. Hussain et al (2005) developed the thermodynamics modeling of a polymer electrolyte membrane fuel cell power system for transportation applications based on energy and exergy analysis in order to improve the PEM's performance by changing some parameters such as, temperature, pressure and air stoichiometry. The model shows that the system exergy efficiency of the PMFC increased with increasing operating temperature and pressure. P.C. Sui et al. (2006) investigated the coupled electrical conduction and mass diffusion in the cathodic GDL of a PEMFC by using 2D simulations. The result shows that current density distribution at the GDL/catalyst interface can be dictated by either electron transport or mass transport in the GDL depending on parameters including channel geometry (land versus channel width), oxygen concentration in the gas channel, transport properties (conductivity and diffusively), membrane resistance. Fang et al. (2005) presented the 3D mathematical model of PEMFC in order to predict and analysis fuel cell species concentration and current density distributions in different flow field patterns and operating conditions. The results show that the cell performance increases as the temperature increases due to the high membrane conductivity. Joon-Ho et al. (2003) studied the overall pressure variation and flow distribution in different gas flow patterns. The results show that the pressure variation in fuel cell stack manifolds is influenced not only by manifold size but also by manifold geometry. The results show that the pressure loss by wall friction is negligible compared with the pressure recovery in inlet manifolds or loss in outlet manifolds due to mass dividing or combining flow at manifold cell junctions. Sampath et al. (2003) have developed mathematical models of polymer electrolyte membrane fuel cell (PEMFC) to study the dynamic behavior and performance of PEMFC systems by using MatLab/Simulink. The PEMFC model's result was compared with the experimental result of 1.5 kW PEMFC. The model's result shows that the voltage response is similar to the experiment result and the model can illustrate the effects of inverter load current changes on the fuel cell system. The output power efficiency of the fuel cell system mainly depends on the required current, stack temperature, air excess ratio, hydrogen excess ratio, and inlet air humidity. Dongji et al. (2009) studied the optimal operating points of PEM fuel cell model with those parameters by using response surface methodology. M. Ceraolo et al. (2003) and Fabio et al. (2011) implemented the MATLAB/SIMULINK to model the fuel cell in both static and dynamic conditions based on physical and chemical equation. Lin et al, (2003) studied experimentally the effects of different operating parameters on the performance of proton exchange membrane fuel cell by using pure hydrogen on the anode side and air on the cathode side. The results show that the effects of the various operating parameters, such as different operating temperature, humidification temperatures and pressure, the performance of the PEM fuel cell improves with the increase of operation temperature and when the operating temperature is higher than the gas stream humidification temperature, the performance of the fuel cell decreased. Alejandro et al. (2007) developed the dynamic model of a 1.2 kW polymer electrolyte membrane fuel cell and validated with 1.2 kW PEM Ballard stack. The research methodology used equations which combined the experimental relations in order to adapt the thermal equations for an air cooled stack and modeling of the flooding event. M. Tohidi, (2010) presented one dimensional, steady-state and isothermal model for a proton exchange membrane fuel cell in order to investigate the effects of various parameters, such as the molar fraction of nitrogen gas, relative humidity, temperature, pressure, membrane thickness, anode and cathode stoichiometric flow ratio and the distribution of oxygen in the cathode catalyst while water transfer in membranes is produced by diffusion, pressure gradient and electro-osmotic drag. The results show that the membrane ionic conductivity and the cell performance increase by increasing the cell temperature. The increasing the relative humidity of inlet gases, the water content of membrane increases and membrane resistance decreases due to increasing the output voltage. Zhuqian et al. (2010), P. Srinivasa et al. (2010) and Ahmad et al. (2010) investigated transient behaviors of a proton exchange membrane fuel cell under different operating conditions by developing a transient model. The sub-model of mass transport and an equivalent circuit are created by MATLAB-simulink environment. The results show that the dynamic response of a single cell was influenced by the diffusion and balance speeds of reactant gases inside the fuel cell and at high operating temperature, the fuel cell performance improved. We i et al. (2010) developed 3D model of a proton exchange membrane fuel cell by using a commercial Computational Fluid Dynamics (CFD) software package Fluent in order to predict the effect of operating parameters on PEM fuel cell. The results show that the performance of a PEM fuel cell increases with the increase of operating pressure and operating temperature. Guo-Bin et al. (2008) tested proton exchange membrane fuel cell for sub-kilowatt mobile applications with ambient force-feed-air supply at the cathode side. The results show that the humidity of cathode inlet gas had a significant effect on fuel cell performance at the air relative humidity was higher than 55%, the stack operation resulted in more stable and higher performance. Yongping et al. (2010) studied the effect of the characteristics of dynamic output voltage under current step change. The results show that the voltage overshoots and undershoots have different characteristics, and the current levels also have an effect on output voltage of PEM fuel cell.

1.2.2 Technology and Applications of Hybrid System

C. Bernay et al. (2002) investigated the different fuel cell technologies for vehicle applications. The conclusions of this study show that the proton exchange membrane fuel cell is providing short starting and response times at the stack level and suitable technology for drive application. Nadal et al. (1995) developed a hybrid fuel cell / battery powered electric vehicle. 10 batteries with 12 voltages each are used in the experimental. The battery system supplies power to vehicle during periods of peak power demand such as vehicle acceleration or traveling at a high constant speed. The fuel cell contains 180 cells with 21 kW maximum outputs. The 26 kW DC motor was used to drive the vehicle. The vehicle has been successfully driven over several hundred kilometers on fuel cell power during the initial test period and vehicle speed can reach top speed 96 km/h. It can be shown that the hybrid system seems to improve the efficiency of the system. Zhenhua et al. (2004) designed and tested the control strategies of hybrid fuel cell and battery power sources by using MATLAB/Simulink. The experimentally tests were performed under a pulse current load condition. Three strategies were conceived. The first is an adaptive strategy which aimed to maintain a relatively constant battery voltage by switching between Strategies 1and 2. Lijun et al. (2004) presented the experimental of fuel cell/battery hybrid by introducing DC/DC power converter to actively control the power flow between the fuel cell and battery to achieve both high power and high energy densities. The results show that both the hybrid power sources using a six cell battery and an eight cell battery are effective, but the latter yields higher peak power capability. The hybrid system of fuel cell/battery can reduce the number of battery which used in the system (Andreas et al, 2005). To improve the performance of the hybrid system and widely use in many area of fuel cell/battery hybrid system, the hybrid system which combined a 2 kW air-blowing proton exchange membrane fuel cell stack and lead-acid battery pack is introduced (Yong et al., 2011). In order to meet the energy demands of the hybrid system with varying load conditions, wind/fuel cell/ultra-capacitor was introduced (O. C. Onar, 2006, T. Yalcinoz, 2008). Butler et al. (1999) studied a methodology for designing the vehicle drive trains using a program called Versatile-Electrically Peaking Hybrid Vehicle Simulator (V-Elph). The vehicle model consists of four major types of components such as electric motor, internal combustion engine, batteries and support components. The parallel hybrid electric drive train design was based on a typical midsized family sedan with a gross mass of 1838 Kg. Two parallel HEV drive trains were designed using different control strategies (control strategy 1 operates such that the ICE runs at a constant fuel throttle angle and the electric machine makes up the difference between the torque requested by the driver and the torque produced by the ICE and control strategy 2 operates such that the ICE runs over its entire speed range and makes the ICE throttle angle a function of speed to meet the steady-state road load.). The result of electric motor torque and ICE torque with drive cycle first one applied to the parallel vehicle using control strategy 1 shows that the electric motor torque increases with the increase in vehicle speed. When the vehicle reaches cruising speed, the electric motor torque reduces to a slightly negative constant value while the ICE torque maintains a constant value. During the deceleration phase of the drive cycle, the ICE torque is at its idling torque while the electric motor torque is providing a negative torque. The comparison results of the fuel consumption show that the fuel consumption for the parallel HEV and series HEV were lower when compared to the conventional vehicle. The energy consumption of the HEV using control strategy 1 is almost as much as the motor in the SHEV. Rahman et al. (1999) designed a series and parallel hybrid heavy-duty transit bus using V-Elph 2.01 computer simulation package developed in Texas A&M University. The main design parameters of this hybrid are the selection and sizing of the electric motor and auxiliary power unit (APU). The sizing of the propulsion motor determined from vehicle dynamic equation. The battery pack is determined by the power requirement of the motor and the sizing of the APU calculated from the energy capacity requirement of the vehicle. Wei et al. (2007) and M. Hatti et al. 2011 developed modeling of a solar photovoltaic fuel cell hybrid generation (PVFC) system using MATLAB/Simulink program. The model consists of a photovoltaic (PV) generator, a proton exchange membrane fuel cell, an electrolyser, a supercapacitor, a storage gas tank and power condition unit. In the hybrid power system, the fuel cell is used to produce power if the load power exceeds that produced from the PV generator. It can also function as an emergency generator, if the PV generator system fails. J. J. Hwang et al. (2009) developed the mathematical model a stand-alone of Photovoltaic-Fuel Cell (PVFC) hybrid system. PV generator generates the electrical power meets the user loads when there is sufficient solar radiation and the excess power from the PV generator is then used for water electrolysis to produce hydrogen. FC generator works as a backup generator to supplement the load demands when the PV energy is deficient during a period of low solar radiation.

Reviewing of literatures shows that many researchers are focusing on improving the performance, operation in various strategies, modeling, experimental, and designing the hybrid system between internal combustion engine and battery, fuel cell and battery, and solar and fuel cell. From that point, there is an alternative system that should be investigated in order to study the behavior, performance and control strategy, especially, in a small hybrid power source system, which can stand alone and use in remote area to generate the electric power to supply to an electronic device. PEM fuel cell and electric generator hybrid power source system is interested in order to understand the behavior, performance of the system and to find the appropriate control strategy of the system. Moreover, this hybrid system designs not to use battery in order to reduce the equipment, area, and cost of the system.

1.3 Objectives of Study

1. To model the operation of the proton exchange membrane fuel cell and internal combustion engine generator hybrid power sources system under various load conditions.
2. To experiment the operation of the proton exchange membrane fuel cell and internal combustion engine generator hybrid power source system under various load conditions.
3. To determine operation strategy for optimal performance of the proton exchange membrane fuel cell and internal combustion engine generator hybrid system under various load conditions.

1.4 Scopes of Study

1. The numerical modeling of hybrid power source system consists of two power source models which are proton exchange membrane fuel cell model and internal combustion engine generator model.
2. The experimental of proton exchange membrane fuel cell and internal combustion engine hybrid power source system is a parallel type only.

3. In the experimental of proton exchange membrane fuel cell and internal combustion engine hybrid power system, the maximum rate power of proton exchange membrane fuel cell is not higher than 1 kW and the power of internal combustion engine generator is not more than 5 kW.

1.5. Expected Benefits

1. To observe performance and any related parametric results given from the current load changed.
2. To know the realistic option control strategy of the proton exchange membrane fuel cell and internal combustion engine hybrid system.
3. The mathematical model that can predict the performance and behavior of the proton exchange membrane fuel cell and internal combustion engine hybrid system.