Power Management of Hybrid Power System Using Proportional Integral Control Strategy

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Abstract- This paper present an Proportional Integral (PI) control strategy for power management of a hybrid power system consists of fuel cells, lithium-ion batteries and super-capacitors along with associated dc/dc and dc/ac converters. This strategy is based on the control of battery state of charge (SOC) as main performance parameters using PI controllers. The load power is distributed in such a way to allow the fuel-cell system to provide the steady-state load demand. The proposed control system is implemented in MATLAB Simpower software and tested for various load conditions. Results are presented and discussed.

Index Terms- Battery State of Charge, Proportional Integral, Energy Management Strategy, Fuel Cell, Supercapacitors

1. INTRODUCTION

Hybrid power systems (HPS) are the system which brings two or more sources of energy together. HPS can run as sustainable stand-alone or back up power solution with the grid. These system harness energy from multiple sources and also provide storage capabilities. This solution proves to be not only cost effective and efficient alternative but also improve the entire system capacity, security and reliability [1]. It has been proven that small to medium size hybrid power generation system based on renewable sources may electrify villages, powering lamps and small appliances, small industries, health clinics, school and community centers.

Multi-source hybrid power generation system with proper control has a higher potential for providing better quality and more reliable power to utilities than a system based on a single resource. Because of this feature, hybrid energy systems have caught worldwide research attention. In general, hybrid systems convert all the resources into one form (typically electrical) and/or store the energy into some form (chemical, compressed air, thermal, mechanical flywheel, etc.), and the aggregated output is used to supply a variety of loads [2]. Different generation sources may also help each other to achieve higher total energy efficiency and/or improved performance. The outputs from various generation sources of a hybrid energy system need to be coordinated and controlled to realize their full benefits. Since power management, operation and control of hybrid power system are more complicated than those of an individual ac or dc grid, appropriate control strategies are needed for power dispatch from the energy sources to make the entire system sustainable and efficient to the maximum extent. The development of high-efficiency control strategies for hybrid power generation system is not merely an area of research from the control design point of view, but also and principally a field of technological R&D activity of high interest for environmental, economical and strategic reasons.

Hybrid power system discussed in this paper consists of fuel cell, battery and supercapacitor. Fuel cell provides electrical power with high efficiency, less noise, and near zero emissions compared with conventional internal combustion engines. But fuel cell has slow dynamic characteristics, so hybridization of fuel cell with battery and supercapacitors is required to improve the dynamics and power density. This hybridization allows the fuel-cell system to be optimized to achieve better fuel economy and performance as part of the load is provided by the batteries/super-capacitors. This optimization is accomplished through an energy management strategy (EMS), which distributes the load power among the energy sources. The design of such an EMS should be made in such a way to increase the overall efficiency or to achieve an optimal fuel economy while ensuring that each energy source operates within its limits. In addition, the EMS impact on the life cycle of the whole hybrid power system as well as individual sources should be limited as possible.

Different energy management strategies for fuel-cell hybrid power systems have been reported in the literature. This paper presents a Proportional Integral (PI) control strategy for a fuel cell hybrid system. This strategy is based on the control of the main performance parameters, such as the battery state of charge (SOC), the supercapacitor voltage, or dc-bus voltage using PI controllers.

The PI control strategy is implemented in MATLAB Simpower software and tested for varying load conditions. Results are presented and discussed.

2. HYBRID POWER SYSTEM COMPONENT MODELLINGS

To develop an overall power management strategy for the system and to investigate the system performance, dynamic models for the main components have been developed using MATLAB/SIMULINK. The proposed hybrid system consists of fuel cell, battery and super-capacitor. In this section, the modelings of the above system components are discussed.

2.1. *Fuel Cell Model*

The model used in the paper is based on the dynamic proton exchange membrane fuel cell model (PEMFC) discussed in [3] and [4].
This model is based on a relationship between the Nernst voltage and the average magnitude of the fuel cell stack voltage [6]

$$V_{fc} = N_o E - V_{loss} \tag{1}$$

Where V_{fc} is the fuel cell voltage, N_o is the number of fuel cell connected in series, E is the Nernst voltage, and V_{loss} is the irreversible voltage losses.

The output voltage of a fuel cell at normal operating conditions is determined by the irreversible voltage loss ((V_{loss}) , which can be classified into three types: the activation voltage loss, ohmic voltage loss , and concentration voltage loss [7].
The output power of a fuel cell is determined as follows:

$$P_{fc} = V_{fc} I_{fc} \tag{2}$$

where I_{fc} is fuel cell output current.

2.2. *Battery Storage System Modelling*

The batteries considered for this paper are of type Li-ion as they have proven to exhibit high energy density and efficiency compared with other battery types (such as lead-acid, NiCd or NiMH) [5], [6].
The generic Li–ion battery model is used [10]. The battery state of charge (SOC) is an indication of the energy reserve and is expressed as follows [7]:

$$SOC = 100\left(1 - \frac{\int i_b dt}{Q}\right)\% \tag{3}$$

Where i_b is the battery current, and Q is the battery capacity.
The battery controller is a bidirectional dc–dc converter that stabilizes the dc link voltage during sudden load change.

2.3. *Supercapacitor Model*

Supercapacitors, which are also known as electric double layer capacitors (EDLCs) are similar to conventional electrostatic or electrolytic capacitors, with the advantage that they can store or release more energy due to their high capacitance [8].
The supercapacitor model is based on the Stern model, which combines the Helmholtz and Gouy–Chapman models [9]. The capacitance of an EDLC cell is expressed as

$$C = \left[\frac{1}{C_H} + \frac{1}{C_{GC}}\right]^{-1} \tag{4}$$

where C_H and C_{GC} are the Helmholtz and Gouy–Chapman capacitance (in farads), respectively.
For a supercapacitor module of *Ns* cells in series and *Np* cells in parallel, the total capacitance is given by

$$C_T = \frac{N_p}{N_s} C \tag{5}$$

The supercapacitor output voltage is expressed considering resistive losses as

$$V_{SC} = \frac{Q_T}{C_T} - R_{SC} i_{SC} \tag{6}$$

with

$$Q_T = N_P Q_c = \int i_{SC} dt \tag{7}$$

where Q_T is the total electric charge (in coulombs), R_{SC} is the supercapacitor module resistance and i_{SC} is the supercapacitor module current.

3. Energy Management Strategy

The energy management system is required to ensure the low hydrogen consumption, high overall system efficiency, narrow scope of the battery/supercapacitor, long life cycle.
This is achieved by controlling the power response of each energy source with load demand through their associated converters, using a given energy management strategy (EMS).
Strategy used in this paper is based on the control of the main performance parameters, such as the battery state of charge (SOC), the supercapacitor voltage, or dc-bus voltage using proportional–integral (PI) controllers. The knowledge of an expert is not necessary with such type of strategy, and the PI controllers can be easily tuned online for better tracking. The load power is distributed in such a way to allow the fuel-cell system to provide the steady-state load demand.
This scheme controls the battery SOC using a PI regulator [10], [11] as shown in Fig. 1. The output of the PI regulator is the battery power, which is afterward removed from the load power to obtain the fuel-cell reference power. When the battery SOC is above the reference, the fuel-cell power is low, and the battery provides its full power. When the SOC is

below the reference, the fuel cell provides almost the load power. This scheme is easier to implement compared with previous strategies, and the PI gains are tuned online for a better response.

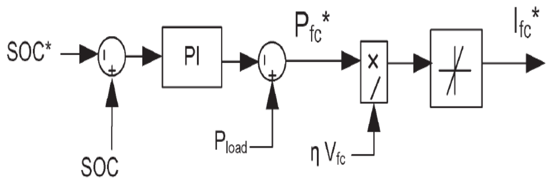

Fig. 1 Energy Management using PI Control Strategy

4. Simulation Results

Simulation model for PI control strategy has been built in MATLAB/Simulink using Simpower system block-set. The performance of the energy management strategy was tested under varying load conditions to investigate its power management and load-following capabilities. Sample simulation results for the control of power under fast varying load condition are given here.
The Fig. 2 shows the variation in battery SOC during the simulation period.

Combined power outputs with load power are shown in Fig. 3 and Fig. 4 shows the load power demand and power shared by individual hybrid power system components.
In the case of PI control strategy, battery SOC value plays an important role in deciding the power sharing among hybrid power system components. Reference value of SOC is taken 60% in this simulation.
Fig. 2 and Fig. 4(c) shows that initially battery SOC is above the reference value, so the battery discharges faster to get the SOC reference and major part of the load power is supplied by the battery and fuel cell power output in such condition is low (Fig 4 (b)). When the SOC is below the reference (at t=120 sec) the fuel cell provides almost the load power.
Supercapacitor delivers the power during sudden change in load power to help the battery and fuel cell, also to maintain the transient stability Fig. 4 (d).
When, the load power decrease below the fuel cell power, because of slow dynamic of fuel cell it takes some time to follow the reference power, in such case excess power is used to charge the battery

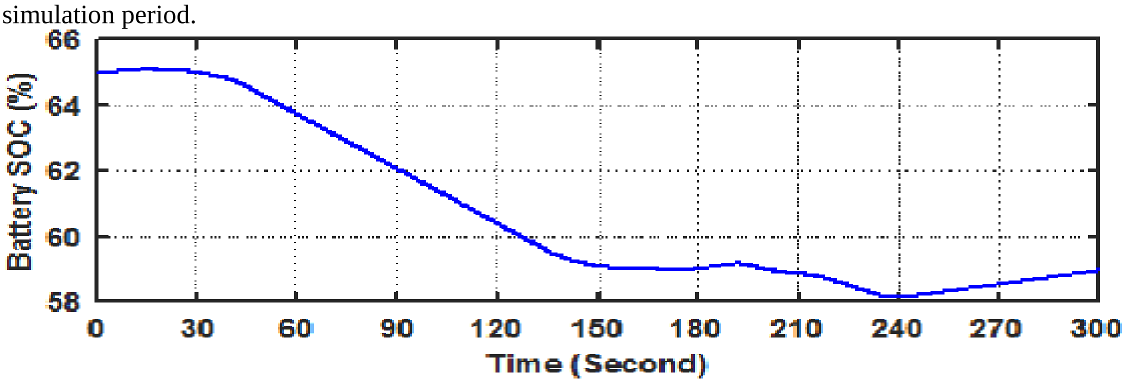

Fig. 2 Battery State of Charge (SOC)

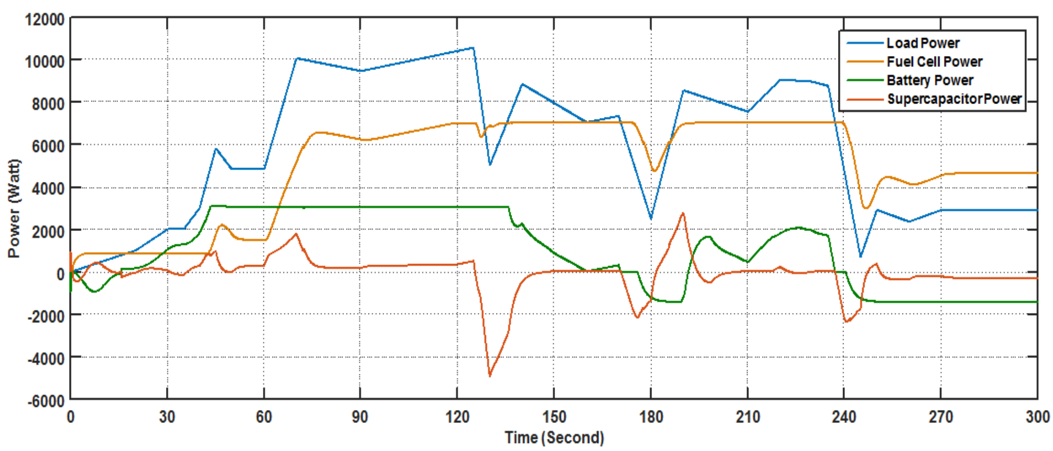

Fig. 3 Combined Power Output

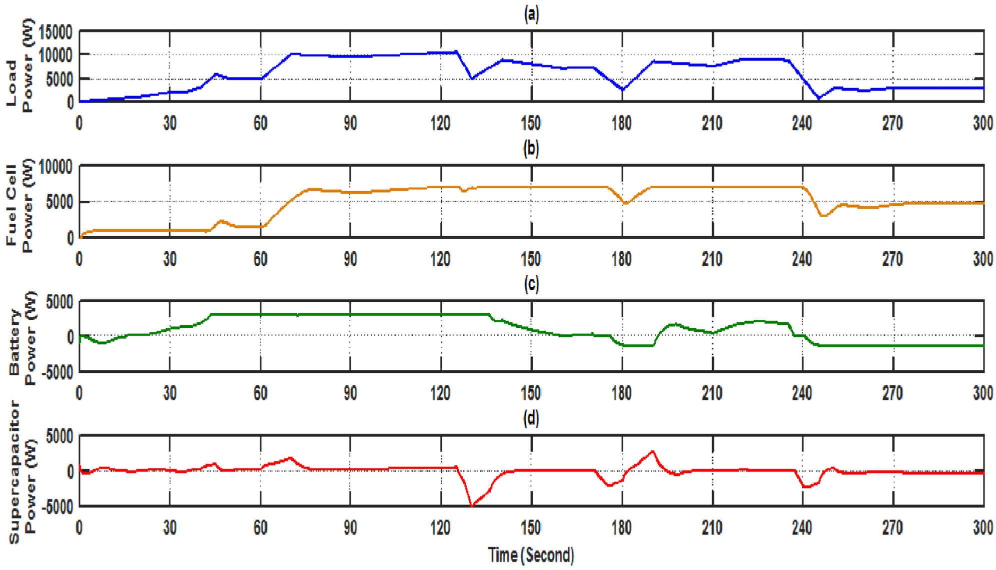

Fig. 4 **Power Sharing (a) Load Power (b) Fuel Cell Power Output (c) Battery Power Output (d) Super-capacitor Power Output**

5. CONCLUSION

A classical PI control strategy for a fuel cell hybrid power system is presented. The performance of the presented control strategy is evaluated under fast varying load conditions. From the simulation studies, it is revealed that the fuel cell power output is controlled by battery SOC. When the battery SOC is above the reference, the fuel cell power is low, and the battery provides its full power. When the SOC is below the reference the fuel cell provides almost the load power. So, proper selection of battery SOC reference is of utmost important in such type of strategy.

The overall coordination of the fuel cell, battery supercapacitors and load is done by the PI energy management strategy. The validity of the presented control schemes was verified through simulations

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