Journal of the Korean Institute of Illuminating and Electrical Installation Engineers (2011) 25(8) : 70~81
http://dx.doi.org/10.5207/JIEIE.2011.25.8.070

A Multiagent-Based Hybrid Power Control and Management of Distributed Power Sources

Gi-Gab Yoon* · Won-Pyo Hong · Ki-Hong Lee**

Abstract

In this paper, a multi-agent control system for DC-coupled photovoltaic (PV), fuel cell (FC), ultracapacitor(UC) and battery hybrid power system is studied for commercial buildings & apartment buildings microgrid. In this proposed system, the PV system provides electric energy to the electrolyzer to produce hydrogen for future use and transfer to the load side, if possible. Whenever the PV system cannot completely meet load demands, the FC system provides power to meet the remaining load. A multi-agent system based-power management and control algorithm is proposed for the hybrid power system by taking into account the characteristics of each power source. The main works of this paper are hybridization of alternate energy sources with FC systems using long and short storage strategies to build the multi-agent control system with pragmatic design, and a dynamic model proposed for a PV/FC/UC/battery bank hybrid power generation system. A dynamic simulation model for the hybrid power system has been developed using Matlab/Simulink, SimPowerSystems and Stateflow. Simulation results are also presented to demonstrate the effectiveness of the proposed multi-agent control and management system for building microgrid.

Key Words : Multi-agent system(MAS), Photovoltaic (PV), Fuel Cell (FC), Ultracapacitor bank, DC-Coupled Hybrid Power System, Matlab/Simulink and SimPowerSystems, Matlab/Stateflow

1. Introduction

Energy consumed in-building accounts for 40[%] of energy used worldwide, also 25[%] of the primary energy in Korea. Traditional buildings consume more of the energy resources than necessary, negatively impact the environment, and generate a large amount of waste. Building microgrid for configuring the smart green building and apartment building offers an opportunity to create environmentally-friendly and resource-efficient buildings through using a multi-agent control system approach to design and manage. Among other advantages, they promote resources conservation, minimize environmental and wasted loads, and reduce operation maintenance costs.

* Main author : T & D Institute of KEPRI, KEPCO
** Corresponding author : Land & Housing Institute, Korea Land & Housing Co..
Tel : +82-42-866-8400, Fax : +82-42-866-8449
E-mail : lkh21@lk.or.kr
Date of submit : 2011. 6. 11
First assessment : 2011. 6. 29
Completion of assessment : 2011. 8. 12

National and local programs encouraging green buildings are growing and reporting successes, thus hundreds of demonstration projects and private buildings across the country provide tangible example that green building can also accomplish comport, aesthetics, and energy and resource efficiency. One of the significant components in the concept of building microgrid is using renewable energy. Fuel cell-based distributed generation has been receiving more attention in the last year because of its high efficiency, low aggression to the environment, no moving parts and superior reliability, durability, and the rapid progress in FC technology. However, each of the aforementioned technologies has its own drawbacks. Different energy sources and converters need to be integrated to meet sustained load demands while accommodating various natural conditions. Therefore, distributed energy resources such as PV cells and wind turbines can be co-operated with fuel cells. The power generated by a PV system is highly dependent on weather conditions. To overcome this problem, a PV system can be integrated with other alternate power sources and/or storage systems, such as electrolyzers, hydrogen storage tanks, FC systems or UC/battery banks [1-2]. The combination of an FC system and UC bank is an attractive choice due to their high efficiency, fast load response, and flexible and modular structure for use with other alternative sources such as PV systems or wind turbines.

The commonly available FCs include polymer membrane, alkaline, phosphoric acid, molten carbonate, and solid oxide-based FCs [3-4].

FCs are capable of generating both electrical and thermal energy. Among the various types of FCs, proton exchange membrane FCs (PEMFCs) are particularly attractive for residential use due to their relatively low operating temperature (80[℃]) and good dynamic response [5]. An FC-based power system mainly consists of a fuel-processing unit (reformer), FC stack and power conditioning unit.

An FC power plant uses oxygen and hydrogen to convert chemical energy into electrical energy. Due to the low working temperature and fast start up, PEM fuel cell power plants (FCPPs) are one of the promising candidates for residential and commercial applications [5]. In this study, a PEMFC power plant is preferred because, among the various types of FC systems, PEMFC power plants have been found to be especially suitable for hybrid power systems. However, the FC system has a weak point of slow dynamics because the power slope is limited to prevent fuel starvation problems, improve performance and increase lifetime. The very fast power response and high specific power of an ultracapacitor complements the slow power output of an FC system. Recent progress in technology makes ultracapacitors the best candidates of fast dynamic energy storage devices, especially for smoothing fluctuant energy production in hybrid power systems. Compared to batteries, ultraca-pacitors are capable of very fast charges and discharges with high power density and can achieve a very large number of cycles without degradation, even at 100[%] depth of discharge. Globally, super-capacitors have a better round-trip efficiency than batteries [6]. Without the UC bank, the FC system must supply all power demands, thus increasing the size and cost of the FC power plant. Besides, overloading of fuel cell systems may cause gas starvation, thus decreasing its performance and lifetime. In Ref. [7], a detailed dynamic model, design and simulation of a wind /FC/UC/battery-based hybrid power generation system is described. The paper of Alam [8] used a simplified model of a DC-DC converter, inverter, power controller for simulating a hybrid power system. To control and manage building microgrid as prosumer, a efficient and reliable operation technology is required. In this context, the multi-agent system technology is a suitable and effective approach for autonomous control of multiple components in the hybrid system [9]. The multi-agent system technology has been applied in manufacturing, transportation, power systems, and many other fields [10]. This approach is successful in modeling and control of distributed energy systems[11]. Distributed nature and potential of the solving complex problems motivate the use of MAS for implementing building microgrid techniques. This research will employ the multi-agent system technology to manage the hybrid power controlling among multiple renewable sources in a hybrid power system.

A novel multi-agent control system of DC-coupled photovoltaic (PV), fuel cell (FC) and ultracapacitor hybrid power systems is studied for building microgrid. A multi-agent based power management and control algorithm is proposed for the hybrid power system by taking into account the characteristics of each power source. Agents' behaviors are modeled by Stateflow diagram according to the their roles and responsibilities. The MAS systems with pragmatic design, and a dynamic models are proposed for a PV/FC/UC/battery hybrid power system. A simulation model for the hybrid power system and the MAS based control systems have been developed using Matlab/Simulink, SimPowerSystems and Stateflow. The system performance under the different scenarios has been verified by carrying out simulation studies using a practical load demand profile. The results are presented to verify the

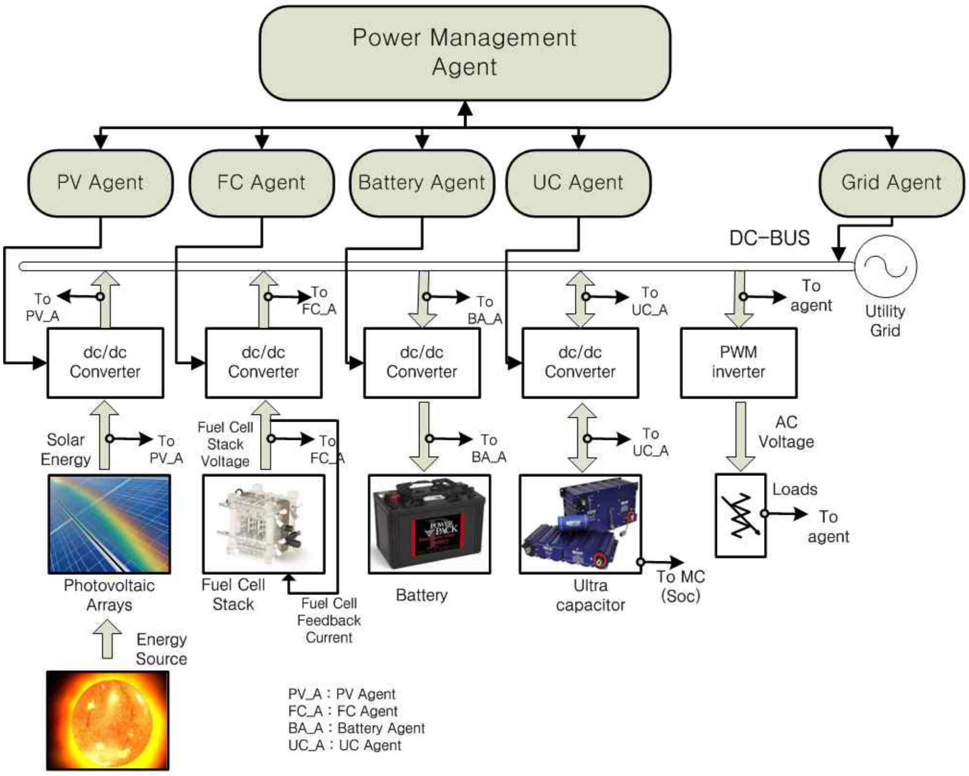

Fig. 1. Overall layout of the simulation model

effectiveness of the proposed MAS based building microgrid under peak power demands or transient conditions.

2. System descriptions in hybrid power systems

2.1 System configuration

A very possible stand-alone solar cell - hydrogen hybrid power system consists of a PV panel with maximum power point trackers (MPPT) for solar energy conversion, a pressurized advanced alkaline electrolyzer with a DC/DC converter for H2 production, a pressurized tank for seasonal H2 storage, fuel cells with a DC-DC converter for H2 utilization, a ultracapacitor bank for a short-time electricity energy buffer, and a DC/AC inverter for the user load [10-11]. A PV panel converts solar irradiations into electricity. For the increase of overall system efficiency, the DC/DC converter with MPPT enables the PV panel to work at the maximum power point in a highly fluctuated environment. The conversion efficiency of most prevalent silicon solar cells is approximately 10-30[%] at ambient temperature 25[°] [12]. Here, to sustain the power demand and solve the energy storage problem, electrical energy can be stored in the form of hydrogen. By using an electrolyzer, hydrogen can be generated and stored for future use.

The hydrogen produced by the electrolyzer using PV power is used in the FC system and acts as an energy buffer. Thus, the effects of reduction and even the absence of the available power from the PV system can easily be tackled. In the integrated system, the necessary measurements are performed, and measurement results are conveyed to the main controller. The main controller evaluates the inputted data and takes the required actions to provide the overall controls. Here, each shown dc/dc converter consists of two cascade dc/dc converters; one for the power tracking and the other for bus voltage regulation. The primary objective of such a solar-hydrogen system is to provide sufficient and reliable electricity to meet the end-use power demand and store the excess energy in the ultracapacitor and hydrogen. For a sustainable stand-alone solar-hydrogen system, all the energy required by user load comes from the solar irradiation via the PV panel. Excluding the partial solar power for meeting a certain load demand, the excess solar power will eventually be stored in both a super capacitor and an H2 tank. In practice, the energy capacity of the H2 tank is usually much higher than that of the battery. Therefore, the final amount of H2 in the storage tank is the key performance index for energy efficiency [13], i.e. the larger the amount of H2 in the storage tank, the higher the energy efficiency. The energy efficiency is significantly determined by the energy management strategy for the stand-alone solar-hydrogen systems. Fig. 1 shows the integrated overall layout of the Simulink model. This figure comprises the PV, ultracapacitor bank and PEMFC system. To control and manage its integration system, the power management, power estimator and controller block are provided.

2.2 Simulation model

2.2.1 PV system characteristics and model

A PV system consists of many cells connected in series and parallel to provide the desired output terminal voltage and current. The PV system can be modelled by various mathematical methods [6-7]. In this paper, the PV system with a 2D-Lookup table and a controlled current source is used for simulation time and computational efficiency. The irradiance data and the I-V characteristic curve of PV array can be used for modeling the PV output power. Fig. 2 shows PV system Matlab/Simulink model using the 2D-Lookup table and the controlled current source. The input data for 2D Look-up table are irradiance data and output voltage of PV system.

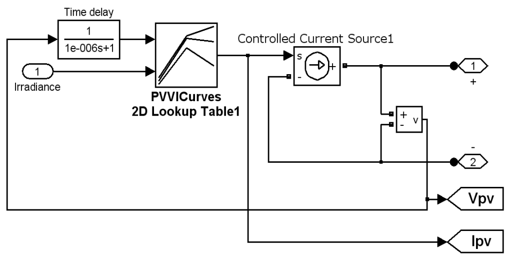

Fig. 2. Matlab/Simulink model for PV array

2.2.2 Direct control of MPPT for PV system

The Perturb & observe (P&Q) algorithm, also known as the "hill climbing" method, is very popular and the most commonly used in practice because of its simplicity in algorithm. However, there are some limitations that it cannot determine when it has actually reached the MPP and oscillates the operating around the MPP. Thus, the modified algorithms for solving this problem have been studied recently. Among different MPPT algorithm, Incremental Conductance (IncCond) method which can solve the problem of the P&Q algorithm is used in this paper. For evaluating the performance of the whole system under the Matlab simulation environment, the IncCond method is developed by Matlab/Stateflow tool as shown in Fig. 3. The IncCond method adjusts PV operating point with small step size and uses average value of 100 samples to avoid the oscillation around the MPP. In this paper, the direct control of MPPT algorithm is adopted for changing the duty cycle of dc-dc converter. A PI controller can be used in general MPPT algorithms, but requires the control loop for regulating the current of MPP calculated by MPPT algorithm. Comparing with the general MPPT algorithms, the direct control of MPPT algorithm shown in Fig.3 is simpler and uses only one control loop which PI controller is excepted because it performs the adjustment of duty cycle within the MPPT algorithm as shown in Fig. 4.

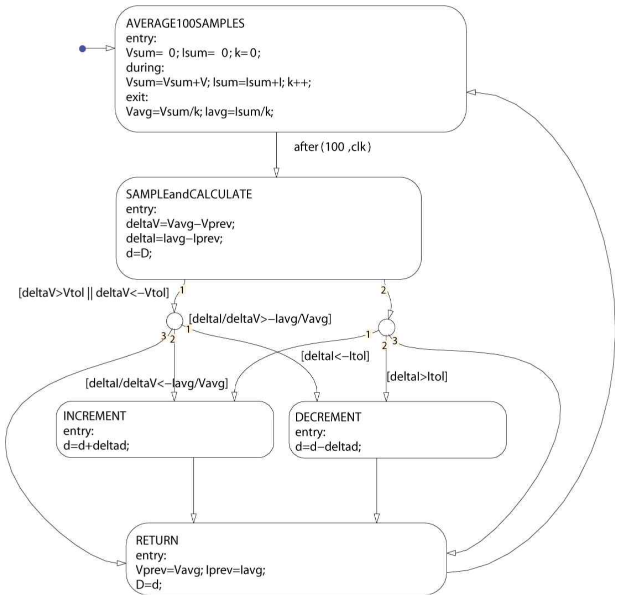

Fig. 3. Matlab/Stateflow chart of Incremental Conductance Algorithm for direct control method

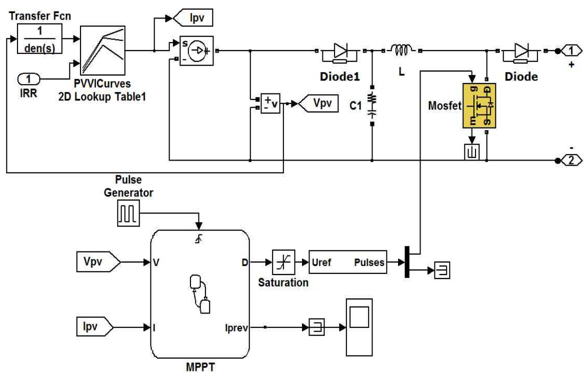

Fig. 4. The direct control model of PV system with dc-dc converter

2.2.3 Battery model

In this paper, electric circuit-based battery model is used for representing state of charge (SOC) estimations of battery packs. The battery can be modelled by using a simple controlled voltage source in series with a constant resistance. This model assumes the same characteristics for the charge and the discharge cycles and the open voltage source that can be calculated with a non-linear equation based on the actual SOC of the battery[13]. Fig. 5 shows the Matlab/SimPowersySystem model for battery. The controlled voltage source is described by the following equation :

$$E = E_0 - K\frac{Q}{Q - \int idt} + A\exp(-B \cdot \int idt)$$

$$V_{batt} = E - Ri$$

E = no-load voltage (V)

E_0 =battery constant voltage (V)

K =polarization voltage (V)

Q =battery capacity (Ah)

$\int idt$ =actual battery charge (Ah)

A =exponential zone amplitude (V)

B =exponential zone time constant inverse $(Ah)^{-1}$

V_{batt} = battery voltage (V)

R = internal resistance (Ω)

i =battery current (A)

2.2.4 Other power source dynamic model

The detailed models of PEMFC, PV system ,ultracapacitor bank(UCB), electrolyzer and hydrogen tank model are developed for analyzing the MAS based control and management of hybrid power system as referred in [4].

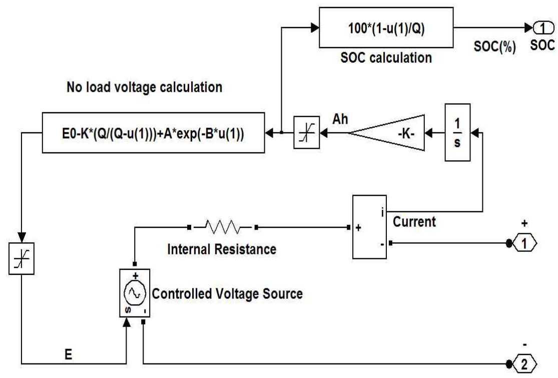

Fig. 5. The SimPowerSystems model of battery

3. Multi-agent system based hybrid power management scheme

3.1 Multi Agent System

MAS is a loosely connected network of intelligent agents working together to achieve a global goal. Fundamental element of MAS is an intelligent agent, which has main characteristics such as autonomy, sociality, reactivity and proactivity. Agents are autonomous, which means that they operate without human intervention. Agents have social abilities in that they interact with other agents via agent communication language. It connotes the ability to negotiate and interact in a cooperative or competitive manner. The agents also perceive and react to their environment. Agents are proactive in that they are able to exhibit goal oriented behaviour by taking initiatives.

In the context of modern power systems like microgrids, MAS is a well suited technology for solving a variety of complex problems such as disturbance diagnosis, microgrid restoration, control and monitoring of microgrids. Currently, some research [12] have started to simulate the operation of microgrids in MAS platform.

In power systems, the current approach of using a central SCADA system together with several smaller distributed SCADA systems is no longer sufficient for the certain control operations. An approach that provides intelligent, fast, and adaptable local control and decision making is required. MAS is one of the suitable technology for implementing such an approach because MAS provides a common communication interface for all elements and has potential to provide autonomous intelligent control and management for modern power systems in distributed manner.

3.2 The choice of Matlab-Simulink-Stateflow

Stateflow extends Simulink with a design environment for developing state machines and flow charts. Stateflow provides the language elements required to describe complex logic in a natural, readable, and understandable form. It is tightly integrated with MATLAB and Simulink, providing an efficient environment for designing embedded systems that contain control, supervisory, and mode logic. Stateflow charts enable the graphical representation of hierarchical and parallel states and the transitions between them. Stateflow augments traditional state charts with flow charts, Embedded MATLAB functions, graphical functions, truth tables, temporal operators, directed-event broadcasting, and support for integrating hand-written C code. C code from Stateflow charts using Stateflow Coder can automatically be generated. Stateflow uses Model Explorer in Simulink to create data, events, and targets and to navigate, search, and configure the attributes of all Stateflow objects.

The behaviour of agents has been modeled by Stateflow diagrams as the ones described in Fig. 6. Simulink features a Stateflow library with which it is possible to encode graphically the behaviour of an agent by drawing his Stateflow diagram.

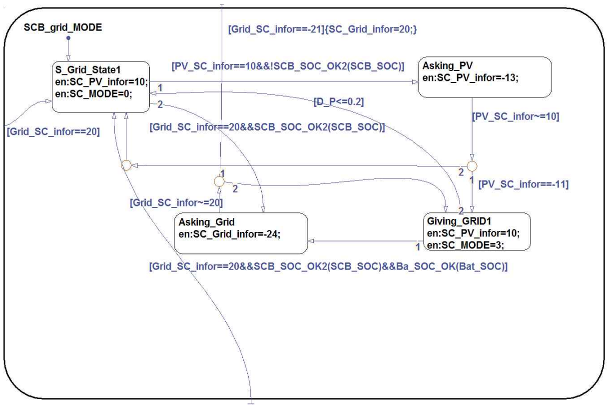

Fig. 6. Simplified Stateflow diagram of SC agent

3.3 Hybrid power management system using MAS

(1) Control architecture

Each converter connected to the DC bus must be controlled current to manage the power of distributed energy systems. This may be achieved by a classic PI controller. Two options are available for the current reference : either the reference comes from voltage-loop or from hybrid power management system(PMS). The converter connecting the battery and the SC bus are a bidirectional current converters. In the grid, the voltage is first rectified by a three-phase diode bridge. Then buck converter controls the power coming from the grid. Finally, the load represented by a current sources is active. In the proposed architecture, The most important characteristics is the control strategy of DC bus voltage by UCB and battery agent. The MAS based PMS plays a role in the efficient power management. it is postulated that each converter on the DC bus can be either voltage-controlled or current-controlled. This selection of control mode is proceeded symbolically by a switch as shown in Fig. 7. Like the reference I_{ref}. the choice of control returns to the PMS. In this way, various sources can control the DC bus voltage, Thus, even if the source that control voltage fails, another sources can replace it. After the introduction of the control structure, PMS will provide at least two pieces of information to the converter's controllers : the control mode and when needed, the current reference.

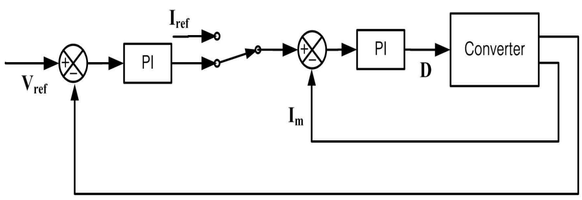

Fig. 7. Control architecture of the converter

(2) A token scheme for DC bus voltage

The battery and UC agent must choose the voltage control or current control mode. At a time, DC bus voltage control of the hybrid power system must be regulated by only one agent to avoid the collision between two agents. The agent who hold a virtual token carries out the voltage control of DC bus. Another agents are operated to the current control mode. After that, the agent may give this token to another one. It loses the voltage control, but it is in charge of the current control. The transfer of token between two agents is done in the case of satisfying the following two phenomena, then the current control mode is operated.

- the agent who hold the token has requested another agent to take it and decide to accept after considering its circumstance of SOC and pressure of hydrogen tank.
- The agent who doesn't hold asked the token and the agent accepted.

For the first case, the transfer of the token can be illustrated in Fig. 8. the first question of SC agent ("Can you take the token") is done by the internal mechanism of this agent. This request could be motivated by an insufficient SC SOC for regulating the DC bus voltage. In the scenario, the battery agent accepts the token.

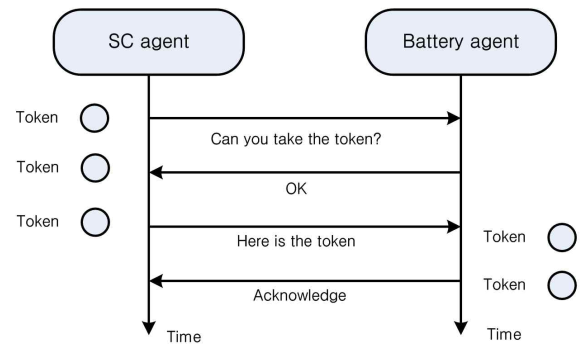

Fig. 8. Communication between two agents during the transfer of the token

However, this acceptance also depends on the internal mechanism of the battery agent. SC agent transfer to the current control mode or the charging mode. in the case of refusal, the SC agent may send its request to another agent.

(3) MAS operational scenario

The proposed MAS based PMS can select the stand-alone mode and grid-connected mode. This proposed building mocrogrid must be capable of meeting the building demand reliably by RES and storage with minimizing the supply power from the grid. Through the behaviour of each agent is developed individually. the agents behave interactively with the communication program imbedded in each agent. Grid agent only receives the token, when RES power and the storage power is under the miminum value. The general behaviour of each agent is described and an example of this behaviour is represented by a Stateflow diagram.

Like all the agents controlling a source connected the DC bus, the SC agent has two fundamental states : with voltage control token or without this token. When it holds the token, it keep it while his SOC is sufficient. In this time, if it receives a message asking to give the token, it will refuseIn addition, SC agent asks battery agent to supply a portion of the current to the DC bus. When the SOC is critical, it will ask other agents if they can take the token. First of all, it asks the battery agent then, if the latter refuses, it will ask the grid agent. If the grid agent refuses the request, SC agent is forced to keep the token. On the contrary, if an agent accept, the SC agent goes into the state "without token". In this state, it must wait until the SC SOC reaches a higher value and then one of the other two agents accepts to give it the token. This behavior is summarized by the Stateflow diagram as presented in Fig. 9. The battery agent operates similarly to the SC agent. If its SOC is sufficient, it accepts the token. Otherwise, it refuse. In addition it communicates with the PV agent asking itself to stop the charge when it is full. Otherwise, it accepts the power generated by the PV panels.

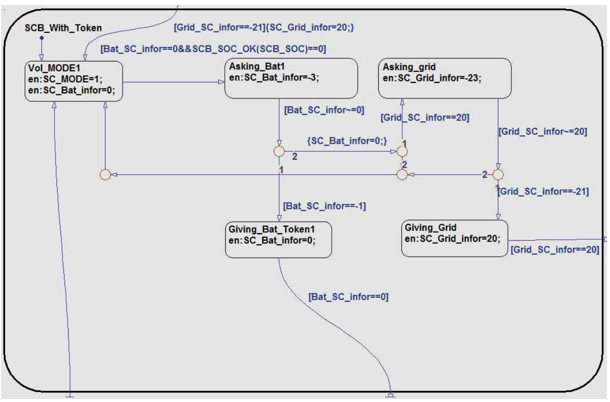

Fig. 9. Stateflow diagram of DC bus voltage control of SC agent

Finally, the operation of the grid agent was designed to minimize the power supplied by the grid. Thus, the grid agent receives a request to take the token, it accepts. It will never try to take the token on its own initiative. Then, the grid agent will give this token the SC agent as a priority including other agents. The SC agent has priority because it allows better control of the DC bus voltage due to the sufficient power supply.

4. Simulation results and analysis

The block diagram of the integrated PV/FC/UC/battery hybrid power system and the MAS based control and management strategy are shown in Figs. 1 and 5, respectively. A dynamic simulation model for the hybrid power system has been developed using Matlab/Simulink, SimPowerSystems and Stateflow. The parameters of the PV system , the PEMFC system and the Maxwell Boostcap BMOD0165-48.6[V] UC unit are given to reference [4]. In order to demonstrate the multi agent energy management system for hybrid system, the demanded load and PV output power given in Fig. 10 are used. With variations in load, the power demand changes from 4.3kW to 7.8kW(at 17:00). The mode transitions of agents are shown in Fig. 11. In the Grid mode transition, '1' and '0' are grid connected mode and stand-alone mode, respectively. Thus, the hybrid system is operated as grid connected mode from 8:00 to about 12:20. After this time, stand-alone mode is maintained by the power management system. In the operation of hybrid system, it is important to control dc-link voltage reliably. Thus, at the beginning, voltage control mode of UCB agent holds the token. In the grid connected mode, UCB and battery can be operated as charge mode to increase the low SOC. In Fig.7, '3' denotes the charge mode of UCB and battery. In the stand-alone mode, UCB and fuel cell can be operated as the voltage control mode and the power mode, respectively. In the power mode, fuel cell system enable to provide 5kW maximum power when H2 tank pressure is stable and the excess power is requested by UCB or battery.

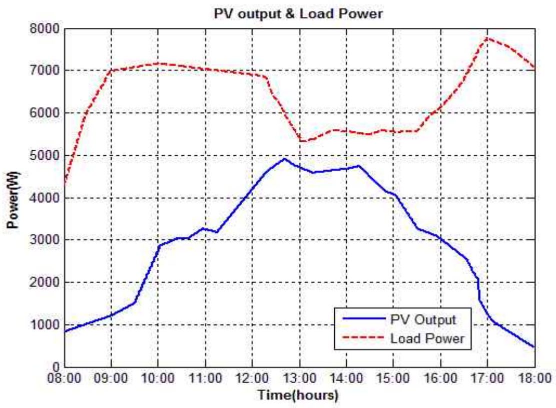

Fig. 10. Demanded load power and PV output power

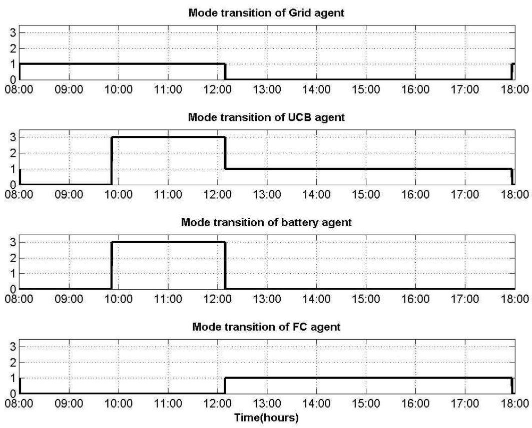

Fig. 11. The mode transitions of agents

Fig. 12 shows the variation power of UC bank power profile switching between negative(charging) and positive(discharging). During the grid connected mode(08:00~12:20), UCB is operated as charge mode due to the predefined SOC. After this period(stand-alone mode), UCB is operated as the voltage control mode to meet the dc-link voltage requirement of the hybrid system.

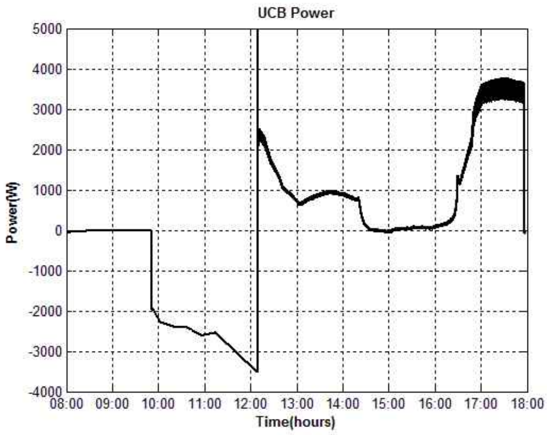

Fig. 12. The charge and discharge power of UCB.

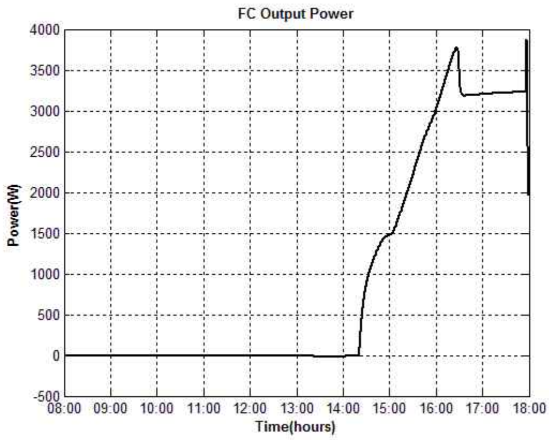

Fig. 13. Power provided by FC system

Fig. 13 shows the power provided by FC for the power mode. In Fig. 11 and 13, although the power mode of FC system starts at 12:20, FC system provide the excess power at about 14:20 according to UCB request. Fig. 14 shows the SOC profile of storage devices and H2 tank pressure. Fig. 15 shows voltage and current of a phase. In the transition from grid mode to stand alone mode, it shows that the voltage and current control is stable.

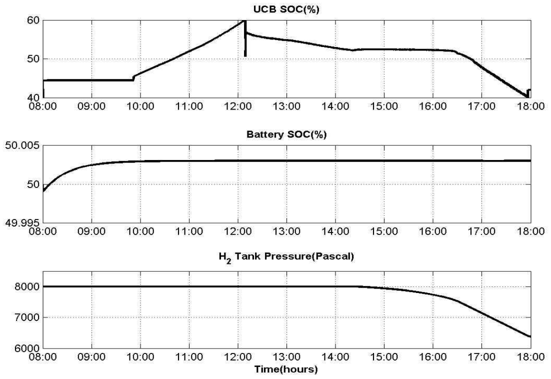

Fig. 14. SOC profile of storage devices and H2 tank pressure

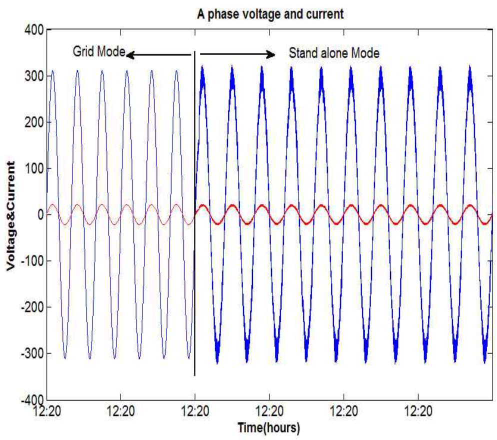

Fig. 15. Voltage and current of a phase

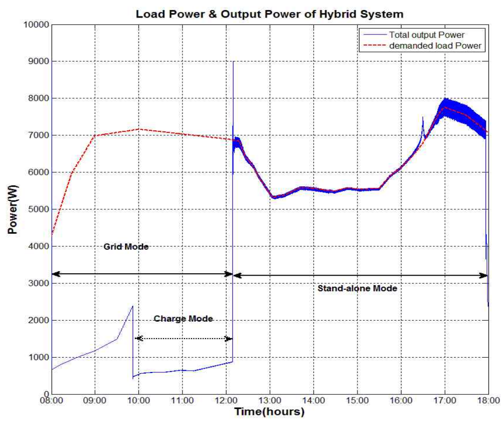

Fig. 16. Total output power of hybrid system and demanded load profile

Fig 16 shows that during periods of grid mode, PV system provides the produced power to load side from 08:00 to 09:40 and UCB and battery charges the power from 09:40 to 12:20. Also, during periods of stand alone mode, the demanded load power is stably supplied by the hybrid system including PV, UCB, battery and FC system.

5. Conclusion

In this paper, a novel multi-agent control system for DC-coupled photovoltaic (PV), fuel cell (FC), ultracapacitor(UC) and battery hybrid power system is studied for commercial building and apartment building microgrid: 1) a photovoltaic with new MPPT methodology by the Matlab/Stateflow chart as a renewable energy generation system, (2) ultra-capacitors and battery as fast-dynamic energy storage system for keeping the stable DC link voltage, and (3) fuel cells with electrolyzers and a hydrogen tank as a long-term energy storage system. (4) MAS based power management system and MAS based sources control system. The hybrid power system is designed and modeled for a grid connected and stand-alone mode with new MAS based power management controllers and power converters of several sources and storages. The proposed hybrid power system and its power management system and control strategies are validated from simulation results with the excellent performance. As the new developed MAS is expendable and reconfigurable, the more complex hybrid energy system could be expended further studies by creating more intelligent agents and implementing additional functions of existing agents.

References

〔1〕 Kyoungsoo R, Rahman S. Two-loop controller for maximizing

performance of a grid-connected photovoltaic-fuel cell hybrid power plant. IEEE Transactions Energy Conversion 1998; 13(3), pp.276-281.
[2] El-Shatter TF, Eskandar MN, El-Hagry MT. Hybrid PV/fuel cell system design and simulation. Renewable Energy 2002; 27(3), pp.479-485.
[3] M. Farooque and H. C. Maru, "Fuel cells-the clean and efficient power generators," Proc. IEEE, vol. 89, no. 12, pp. 1819-1829, Dec. 2001.
[4] W.P. Hong, "Power control strategies of a DC-coupled hybrid power system for a microgrid", English Journal of KIIEE, Vol.25, No.3, pp.41-50, 2011, 3.
[5] J. E. Larmine and A. Dicks, Fuel Cell Systems Explained. Chichester, U.K.: Wiley, 2000.
[6] Burke A. Ultracapacitors: why, how and where is the technology. Journal of Power Sources 2000; 91(1):37-50.
[7] Onar O.C, Uzunoglu M, Alam M.S. Dynamic modeling, design and simulation of a wind/fuel cell/ultra-capacitor based hybrid power generation system. Journal of Power Source 2006; 161(1):707-22.
[8] Uzunoglu M, Onar O.C, Alam M.S. Modeling, control and simulation of a PV/FC/UC based hybrid power generation system for stand-alone application. Renewable Energy; 32(2009), pp. 509-520.
[9] J. Lagorse, "A milti-agent system for energy management of distributed power sources", Renewable Energy, Volume 35, Issue 1, pp. 174-182, 2010.
[10] M. Wooldridge, "MultiAgent Systems", Wiley, 2002.
[11] Zhenhua Jiang, "Agent-based power sharing scheme foractive hybrid power sources", Journal of Power Sources 177, pp. 231 - 238, 2008.
[12] T. Logenthiran, D. Srinivasan and A. M. Khamba, "Multi-agent system for energy resource scheduling of integrated dtributed system," Electric Power Systems Research, Vol. 81, pp. 138-148, 2011.
[13] Ulleberg Ø. "The importance of control strategies in PV-hydrogen systems," Solar Energy 2004, 76, pp. 323-329.

Biography

Gi-Gab Yoon

Gi-Gab Yoon received the B.S., M.S, and Ph.D. degrees in Electrical Engineering from Hanyang University, Seoul, Korea, in 1983, 1988, and 1999. He is presently a senior researcher in distribution power system lab. and advanced distribution system group at KEPRI. His research field includes wind power generation system, distribution generation system, and control of power system.

Won-Pyo Hong

Won-Pyo Hong was born in Daejeon city in the Republic of Korea on May 15, 1956. He received a B.S. degree in Electrical Engineering from Sungsil University, Seoul, Korea, in 1978 and M.Sc. and Ph.D. degrees in Electrical Engineering from Seoul National University, Seoul, Korea, in 1980 and 1989, respectively. From 1980 to 1993, he was senior researcher of the Korea Electric Power Research Institute at the Korea Electric Power Cooperation. He was visiting professor at the UBC, Canada, from 2007 to 2008. He is a professor in the Department of Building Services Engineering of Hanbat National University, where he has taught since 1993. His main research interests are building energy and management systems, green enrgy and buildings, fieldbus based-control and distributed energy resources.

Ki-Hong Lee

Kihong Lee was born in 1962. He received a B.S dergee, M.Sc. and Ph.D degrees in Electrical engineering from Chungnam National University. Dajean. Korea. in 1988, 1990, and in 2001, respectively. he has been serving as a research fellow in Land & Housing Institute from 1992. His main research interests are electrical installations & lightning protection systems in building and a energy management system in city.