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Ghiasi, Mohammad Iman; Hajizadeh, Amin; Aliakbar Golkar,  Masoud ; Marefati, Maryam

# Demand and Supply Side Management Strategies for Zero Energy Buildings

Mohammad Iman Ghiasi

Department of Energy, Research Institute of Petroleum Industry, Tehran, Iran
ghiasimi@ripi.ir

Amin Hajizadeh

Department of Energy Technology, Aalborg University, Esbjerg Denmark

aha@et.aau.dk

Masoud Aliakbar Golkar Department of Electrical and Computer Engineering, K.N.T. University of Technology, Tehran, Iran
Golkar@kntu.ac.ir

Maryam Marefati Department of Computer Engineering, Science and Research Branch of Islamic Azad University (SRBIAU), Tehran, Iran
m.mareftai@gmail.com

*Abstract*— This paper proposes simultaneous Demand Side Management (DSM) and Supply Side Management (SSM) Strategies for smart Zero Energy Building (ZEB). The proposed DSM algorithm based upon game theory determines the optimal reference power of each power units during time interval of 5 min under three operational scenarios. Afterwards, the SSM strategy based on adaptive fuzzy control is proposed to control of power flow between hybrid renewable sources and PEVs of the main building for a short time interval. Moreover, an fuzzy sliding power control strategy for the controlling of battery energy storage is introduced to keep the balance between the requested power from building, PEV and output power of hybrid power generation resources. Simulation and experimental results are presented to validate the capability of the proposed power and energy flow control strategy.

Keywords—Zero Energy Building, DSM (demand side management), SSM (Supply side Management), Renewable Energy, Plug-in Electric Vehicle, Control, Optimization.

## I. INTRODUCTION

Interconnection of distributed power resources and energy storages has created possibility of microgrid, both in AC and DC forms [1]-[2]. Recently, DC energy storages systems such as: plug-in electric vehicles, DC renewable energy sources in residential applications, building integrated-DC power sources are getting more attention. Also, exhausting fossil fuel resources and related environmental issues have rung an alarming bell for developing clean energy technologies. So, because of the smart grid technologies development, implementation of DC microgrid in buildings is becoming more attractive and practicable in the building industry. Generally, smart buildings are expected to utilize both intelligence and sustainability issues by using computer and intelligent technologies to achieve the proper combinations of overall comfort and energy consumption and employing renewable energy to reduce the impact on the natural environment, as well. Furthermore, as the DC connection of renewable energy sources does not need synchronization and reactive power compensation problems relatively to the AC installations, it offers greater controllability [3]–[4]. In addition, the DC interconnection could be fully decoupled from the utility grid by power electronic converters in order to enable the seamless transition between the islanded operation and grid-connected modes. From view point of power management strategy, different power controls have been studied to optimize power flow, [5-6], fuzzy control [7-9], and predictive optimization [10-12].

Moreover, according to the previously published research literatures, the use of renewable energy sources integrated with plug-in electric vehicle as a power supply of the ZEB is a critical issue which should be precisely considered. Furthermore, the simultaneous DSM and SSM for integration of renewable energy sources and PEV with considering of electrical and thermal power demands have not been considered yet. In this case, the role of fuel cell as a power source to generate heat and power is crucial.

Also, the proposed controllers are almost linear which their stability analysis and robustness of the control structures have not been discussed during load power changing, charging and discharging of PEV. Besides, an experimental setup for implementation of DC microgrid for building application has not been presented yet. Hence, in order to mitigate the power intermittency, uncertainty of renewable resources, plug-in electric vehicle, as well as, provide a stable and reliable power supply for both utility and the local customers, it is necessary to design an advanced power control strategy for building integrated-hybrid DC power sources and flexible loads.

In the work presented here, firstly, the economic modeling and DSM strategy of zero energy building are described. The proposed energy management algorithm determines the optimal reference power of each power units during time interval of 5 min under three operational scenarios. Then after, a fuzzy control structure is developed to heat and power management between building, photovoltaic, fuel cell power sources and PEV. Afterwards, to build the hybrid power source combined with plug-in electric vehicles for green buildings, the mathematical models of photovoltaic, fuel cell, battery, power electronic

converters are implemented in Matlab/Simulink environment. Furthermore, an adaptive fuzzy sliding power control strategy for DC-DC converter, connected to battery, is proposed to keep the power balance in DC-link.

Also, to validate the power controller response, an experimental setup has been developed to achieve the energy balance characteristic. Finally, experimental analyses for different case studies are presented.

## II. PROPOSED SYSTEMS FRAMEWORK DESCRIPTION

Figure 1 shows, the overall system which is composed of building system, the power generation resource, battery energy storage and the PEV system. In the presented work, the power generation resources include photovoltaic and fuel cell, which are green energy resources with zero CO2 emission. The PEV system could be considered as a new form of distributed storage. It is combined with the distributed power resources and the controllable loads of the smart building. The detailed mathematical models of fuel cell, photovoltaic, battery energy storage and power electronic converters are available in [13].
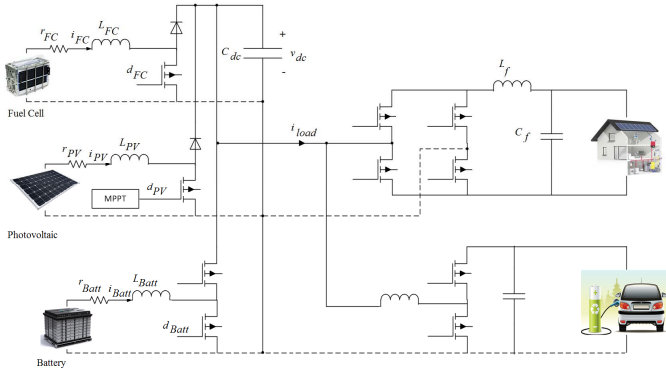


Fig.1. Configuration of Hybrid DC microgrid combined with Plug-in Electric Vehicle

## III. SIMULTANEOUS ENERGY AND POWER MANAGEMENT STRATEGY

The main goal of the energy management system in this paper is to minimize energy cost by scheduling the home appliances usage. The overall architecture of the proposed energy management strategy is demonstrated in Fig. 2.

In this paper, a home energy management scheduling problem with energy sources, electrically and thermally is modeled as a mixed integer linear programming (MILP) problem over a finite horizon of time. The proposed method determines the optimal set point of all suppliers as well as storages in a manner that economically optimized power dispatch while scheduling different appliances. The Hierarchical Controller is the core of energy management system which controls and schedules both electrical and thermal appliances together with controllable DERs such as

combined heat and power (CHP) based fuel cell and plug-in electric vehicle (PEV).
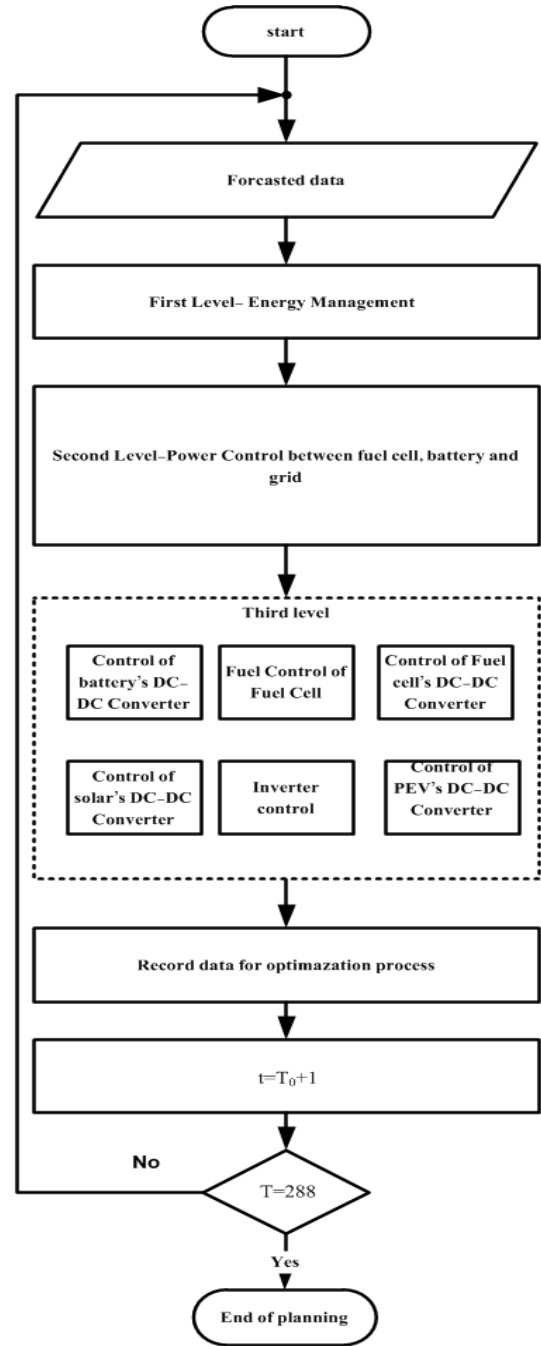


Fig.2. Overall architecture of the proposed energy management strategy

### A. Objective Function

The objective function of the proposed method is the overall cost minimization during the schedule period. The overall cost includes the energy cost transacted with upstream network and the operating costs. The main objective is the cost minimization when the building is

operated. To reach the purpose, it is necessary that the scheduling problem has been done after the first interval, considering into the system parameters in this period, and subsequently, the scheduling problem for the second interval to 288th interval (interval from 00:05 to 24:00) has been done. So the objective function extended by adding a second part can be formulated as:

$$Minimize\, OF = \sum_{t=1}^{T_0-1} \begin{pmatrix} P_{PV}^C(t) \times C_{PV}(t) + P_{FC}^C(t) \times C_{FC}(t) \\ + PD_{Batt}^C(t) \times CD_{Batt}(t) \\ + \sum_{k=1}^{K} \left( PD_{PEV}^C(k,t) \times CD_{PEV}(k,t) \right) \\ + PP_{Grid}^C(t) \times CP_{Grid}(t) - PS_{Grid}^C(t) \times CS_{Grid}(t) \end{pmatrix}$$

$$+ \left[ \sum_{t=T_0}^{288} \begin{bmatrix} P_{PV}(t) \times C_{PV}(t) + P_{FC}(t) \times C_{FC}(t) \\ + PD_{Batt}(t) \times CD_{Batt}(t) \\ + \sum_{k=1}^{K} \left( PD_{PEV}(k,t) \times CD_{PEV}(k,t) \right) \\ + PP_{Grid}(t) \times CP_{Grid}(t) - PS_{Grid}(t) \times CS_{Grid}(t) \end{bmatrix} \right]$$

(1)

Where $OF$ is the objective function in the first stage, $t$ is the time index (each 5 minutes), $P_{PV}(t)$ is the output power in PV arrays (kW), $C_{PV}(t)$ is the cost of PV power generation, $P_{FC}(t)$ is output power in fuel cell, $C_{FC}(t)$ is the cost of fuel cell sales, $PD_{Batt}(t)$ is the battery discharge amount, $CD_{Batt}(t)$ is the battery discharge cost, $PP_{Grid}(t)$ is the purchased power from the upstream network, $CP_{Grid}(t)$ is the cost of purchased power to upstream network, $PS_{Grid}(t)$ is electricity sold to upstream network, $CS_{Grid}(t)$ is the cost of electricity sold to the upstream network, $PD_{PEV}(t)$ is power discharge of battery system at $t$ hour, $CD_{PEV}(t)$ is the generating electricity cost via battery system at $t$ hour, $k$ is $PEV$ index and $C$ index is represented the value have been set by the control system for the last time interval.

The present storage energy is updated between time slices. In case of considering a large number of time slices, operation costs minimization and storage management optimization is possible.

The above-mentioned cost function and constraints is a nonlinear programming problem that can be solved by most optimization methods. In this paper, the commercial General Algebraic Modeling System software package (GAMS [15]) is used to solve the optimization problem using branch and bound algorithm.

### B.    Power Control Strategy

Power control strategy is required to keep power balance at all times between hybrid power sources, PEV, smart building and the power to/from the grid which has to be done while the active and reactive power demanded by the home electrical load are meet. In addition, to satisfy the power required by the load, it is important to consider the

physical limitations of fuel cell and uncontrollable characteristics of photovoltaic power. Hence, in this part, the controller designs for the fuel cell and the energy storage are as follows: Power control strategy for hybrid renewable power sources and PEV to smart building and to/from the grid is required to keep power balance at all times while the active and reactive power demanded by the home electrical load are meet. Moreover, to satisfy the power balance in green building, it is important to consider the physical limitations of fuel cell power and uncontrollable characteristics of photovoltaic power. Hence, in this part the controllers design for fuel cell and battery energy storage are given as follow.

In the proposed hybrid power generation system, fuel cell plays an important role. It has high reliability than other renewable energy sources. In other hand, it has some physical and dynamical limitations that should be considered in the control structure of fuel cell. In this paper, a fuzzy control strategy is proposed for fuel cell power source. In fact, it is modified structure of controller, which has been published in [13-14]. The block diagram of this control strategy is shown in Figure 3.
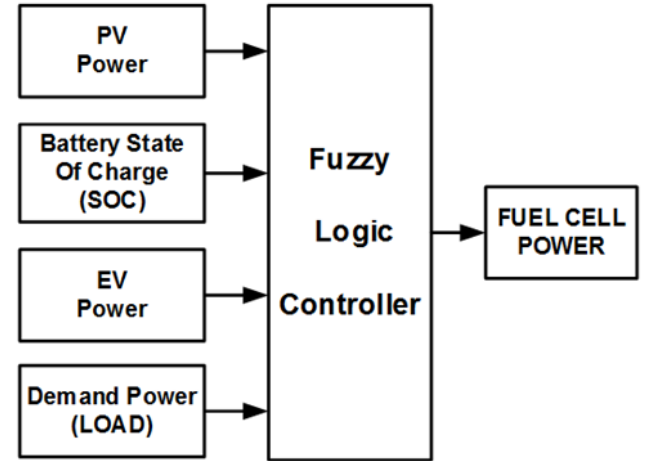


Fig.3. Block diagram of Fuzzy Control Strategy

### IV.  SIMULATION RESULTS

For the application of the methodology we developed a digital program GAMS [15] which has been applied to real case corresponding in Tehran. The considered prices are the following: photovoltaic 0.4 V/kWh; fuel cell 0.9 V/kWh; storage discharging 0.6 V/kWh; storage charging 0.4 V/kWh; undelivered power is 1.5 V/kWh and the excess energy is 0 V/kWh. The simulation considers the technical characteristics have been analyzed for 24 h period sequential time. For this purpose, the profiles have been considered for electrical load, thermal load and PV output power are presented in Figures 4-6. For investigate the response of

proposed energy management, some simulation results for three scenarios are presented. Moreover, In order to show the concurrent operation of proposed energy and power management strategies, the experimental results in the following are presented. For a residential building with solar panels, fuel cell and energy storage, the impact of PEV charging on the performance of proposed fuzzy controller, would depend on the capacity of the PEV battery, PV, fuel cell and energy storage. The battery energy storage in building can be used to partially or fully charge the PEV battery to reduce the peak load. Moreover, to implement the power control strategy, a laboratory scale of zero energy building has been implemented in laboratory. All the simulation and experimental results are presented in [13]
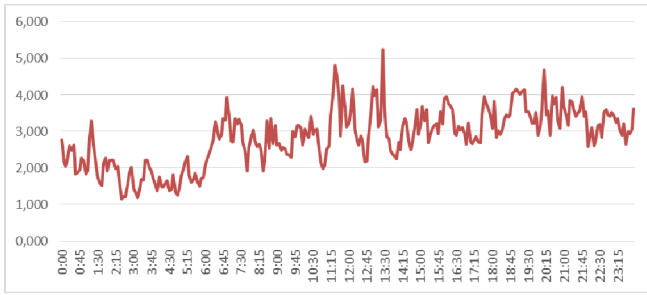
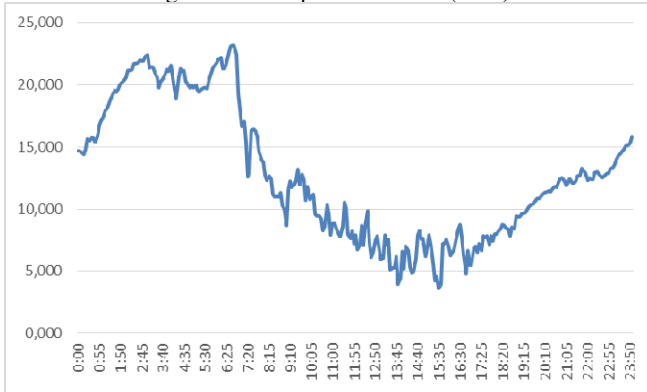

Fig.4 Electrical power demand (Watt)
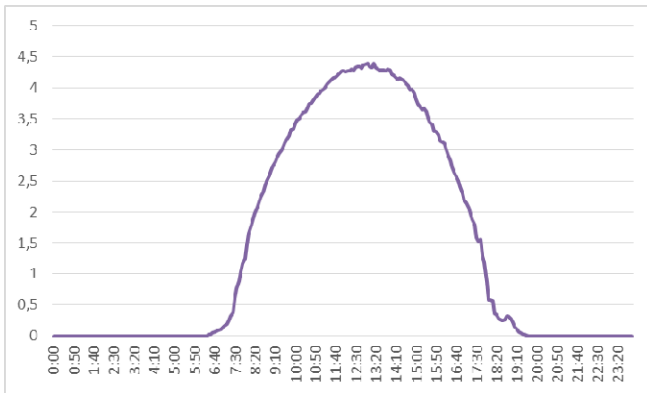


Fig.5 Heat power demand (Watt)



Fig.6. PV power output (kW)

## A. First scenario

The goal of this scenario is planning of power production of solar, battery, and fuel cell vehicles and consumers connected to the building, including controllable and uncontrollable loads. While the building is connected to the upper network and target is the zero cost energy exchange with the network.

Regarding this scenario, the economic definition of zero building has been used, in which, the planning is in such a way, and the cost of energy exchange at the end of the evaluation period is zero.

## B. Second scenario

The aim in this scenario is planning for power production of solar, battery, fuel cell and PEV into zero energy buildings with consideration of three smart controllable loads in grid connected condition mode to achieve zero energy amount of exchanged power to grid. Furthermore, at the end, the energy balance for the second scenario As can be seen in Table I, the cost of purchased power from the upstream to energy sales revenue was equal to it and planning is carried out, aimed at providing scenario.

Table I. Energy balance For Second scenario (kWh)

| Energy Flow | Value(kWh) |
|---|---|
| Energy generated by PV | 30.5 |
| Batteries energy (charge) | 11.2 |
| Batteries energy (discharge) | 11.2 |
| PEV energy (charge) | 22.5 |
| PEV energy (discharge) | 22.5 |
| FC Electrical Energy | 120 |
| FC Thermal Energy | 46.1 |
| non-controllable loads energy | 191.9 |
| 1th controllable loads Energy | 2.25 |
| 2th controllable loads Energy | 2 |
| 3th controllable loads Energy | 0.5 |
| electricity sold to Grid | 118.5 |
| purchased energy from the Grid | 118.5 |
| Energy exchanged with the Grid | 0 |

## C. Third Scenario

In this case study, power planning of each energy sources and PEV with considering of three smart controllable loads during off-grid mode is investigated. The goal is, satisfying of power balance between generated and consumed power. In fact this scenario is power flow control strategy that is implemented for ZEB. The results for this case study are illustrated in next section.

## V. CONCLUSION

In the presented paper, simultaneous Energy and Power management problem for zero energy building

integrated-hybrid green energy sources with PEV is investigated. The overall configuration of the hybrid system including economic and dynamic models of fuel cell, photovoltaic, battery energy storage, PEV and their power electronic interface are briefly described. The economic modeling and energy management strategy of zero energy building have been described, first. The proposed energy management algorithm determines the optimal reference power of each power units during time interval of 5 min under three operational scenarios. Then power management strategy based on fuzzy control is proposed to control of power flow between hybrid renewable sources and PEVs to the main building for a short time interval. Moreover, an adaptive fuzzy sliding power control strategy for the controlling of battery energy storage is introduced to keep the balance between the requested power from building, PEV and output power of hybrid power generation resources. Simulation results are presented to validate the capability of the proposed power and energy flow control strategy.

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