Grid Integration and Optimization through Smart Metering

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***Abstract*— This paper presents a dynamic strategy of optimizing the energy consumption of an electrical system through a smart metering system. A residential energy demand system is used to validate the optimization approach. This method designs an optimal control managing system (OCMS) that communicate with the advanced metering infrastructure (AMI) to enhance the efficiency of the electrical system that brings stratification to both the power consumer and utility. The optimization strategy is designed through a linear programming method, which consists of using fmincon solver. This is implemented through a real-time control strategy that coordinates the power flow on the system. The system objective function aims to reduce the cost of energy from the utility while maximizing the power from the renewable (photovoltaic (PV) system with battery storage). Through the simulation results of the proposed OCMS, the energy saving from the utility grid is about 87.98% of the total energy demand.**

***Index Terms*—Advanced metering infrastructure (AIM), battery storage, Energy management, Photovoltaic, residential load,**

I. INTRODUCTION

Smart grid applications and technology introduce several advantages on the modern electrical grid. The smart grid is a future power system that will enable the achievement of the energy efficient Smart Buildings. By being interconnected and designed in the framework of the intelligent electrical system, any building can present a better efficiency profile to both consumers and suppliers [1]. The Smart Building offers several advantages to the users when it may consolidate in the context of optimizing energy efficiently with the integration of renewable energy [2]. One of the most important factors of Smart Building development is its capacity of introducing advanced technology that gives a novel approach to an energy efficient framework [1]. This strategy could be designed in the conjunction of several scenarios by using a smart grid technology, which introduces a smart meter, data, and signal processing to set the real-time system environment. Smart grid technology may also be considered as a sustainable development goal that can manage the energy demand of the electrical system [3].

A smart meter is a central component of the development of the smart grid environment [4]. Through a smart meter, the electrical system operates in the friendly environment where the energy supplier and consumer get adequate power flow on the system [5]. The smart meters are the new generation of the metering system as they have user-friendly designs that enable customer interactivity and offer novel opportunities to the utilities [6]. A smart meter brings efficiency onto the electrical transmission line and the auto-restoration system of energy after power outages and disturbances. It can also reduce the cost of maintenance and operation from the utility side, decrease the cost of electricity consumption from the end user, and improve the integration of large-scale renewable energy systems as well as the security of the electrical system [5].

Recently several papers have been developed in the framework of the smart metering system combining with specified optimal solver to manage the energy flow on the electrical system. In [7], a hybrid grid connected PV and energy storage is presented by using a model predictive control (MPC) for a business application. The design strategy of this model consists of given an opportunity to the end users to set the cost of power consumption from the utility grid and maximize the use of renewable energy. In [8, 9], the smart metering system is used to coordinate the demand of power optimally through an MPC. In [10], based on the strategy developed in [8, 9], the new generation of the smart meter is introduced. This can allow the user to set an optimal electrical tariff to the device and to reduce the cost of power consumption from the utility grid.

This paper aims to optimize the energy flows on the electrical system for residential application through the technology and use of a smart grid, when the network is connected to PV that must also charge a battery storage. The paper designs a dynamic approach of the power flows in real time strategy that was investigated in [7-10] by using the smart metering environment to coordinate and control the electrical system optimally. Through an objective function, the proposed OCMS approach designs a control strategy that communicates with the smart metering to manage the energy flows on the electrical system. This strategy consists of reducing the energy demand from the utility supply and maximize the use of the energy flows from the renewable energy resources.

The structure of this paper is organized as follows: Section 2 describes the system background and description for an optimal a residential application; the proposed design strategy of the control algorithm is presented in section 3. Section 4 depicts the computed results and describes the analysis and; the paper is concluded in section 5.

II. SYSTEM DESCRIPTION

The smart grid technology is considered as a modernization concept of transmission and distribution of the entire electrical system in the United States. It consists of ensuring the sustainability and the quality of the electricity infrastructure. The primary objective for the smart grid is to meet the peak of future energy demand growth and to achieve all the features of the electrical grid [4]. Figure 1 described a typical smart home, which is supply by the utility grid, PV and battery storage. The smart metering system of Fig. 1 communicates in real time with the OCMS, which manages the power supplies optimally by controlling each Swi switch (with i=1, 2, 3, and 4).

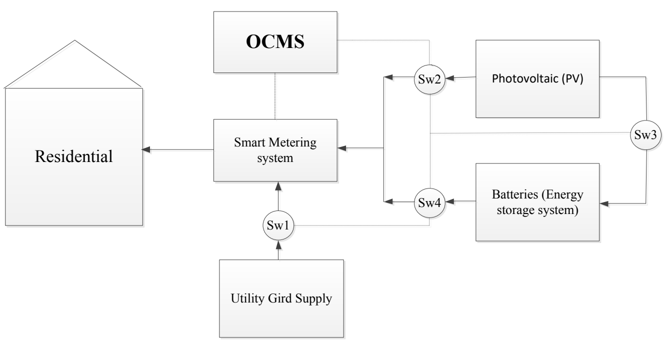

Fig. 1. Optimal control managing system for residential load.

A. Smart Meter

Smart meters introduce additional functionalities and features to the conventional electronic metering system [5]. Some of the features that a smart meter offers for better customer service and reliable supply are data encoding or load profiling, pre-payment and TOU of electricity tariffing, and a remote switching system. These aim to disconnect and reconnect the load, the power outage notification system, and tamper detection [5, 6]. The automatic meter reading (AMR) is a one-way communication, and it can be used in the smart grid environment [11], because of its capacity to relay the communication infrastructure to electronic meters [5]. However, today smart grid technology consists of deploying the Advanced Metering Infrastructure that introduces two-way communication and data management in the electrical system [4-6].

B. Photovoltaic Array

The production and supply of clean energy are the solutions that the world seeks from renewable energy technology. The PV, therefore, is considered as one of the important energy conversion systems to support the global transformation of a clean energy [12]. However, in the market nowadays, the PV modules that are commonly sold depend on the form of silicon in their manufacture. This differs and categorizes the PV modules as three types: amorphous silicon modules, monocrystalline solar cells and polycrystalline solar cells [13]. The PV module is exposed to the possibility of some adverse effects such as shading. Some techniques are used to avoid these effects on the PV module by making it act as load and having less output power due to shading or darkness. This entails connecting the combination of the modules by a by-pass and blocking diodes that protect the modules and avoid the system as acting as a load [13]. The PV module has a lot of advantages concerning the variation of application. Therefore, the PV can be used as Microsystems to large systems that can power the load or the electrical grid directly [14]. This device can be connected or not with the energy storage systems.

III. SYSTEM MODELLING

Equation (1) defines at a given sampling of time (*i*) the power flows of each component in Fig. 1 as follows:

$$P_l(i) = P_{Gr}(i) + P_{PV}(i) \pm P_B(i) \tag{1}$$

where P_l, P_{Gr}, P_{PV}, and P_B are the power flow on the load side, the utility grid, the solar panel, and the battery storage It is important to note that the energy of the battery bank is negative during the discharging process and positive in the charging state. The charging of the battery is only guaranteed by the energy from the solar panel. This is generated by the relation bellows as,

$$+P_B(i) = P_l(i) - P_{PV}(i) \tag{2}$$

The power flow on the battery storage which developed in (2) is a function of the state of charge on the system. The prosed OCMS model uses the state of charge equation that is developed in [10]. The system model of Fig. 1 focus on the minimaxing the cost of energy from the utility grid and maximize the use of energy from the renewable energy system (PV and energy storage). Suppose that the sample of time (*i*) is equaled to the unity value. Therefore, the system objective function can be defined as follows:

$$\min \mathrm{J} = \min \sum_{i=1}^{N} (p_1 P_{Gr} - p_2 P_{PV}) \tag{3}$$

where p_1 is the price of electricity from the utility grid, and p_2 is the price of electricity of renewable energy storage.

Equation (3) is subjected to the system constraints which derives from nonlinear and linear equalities as well as the upper and lower bounds of the proposed system design.

IV. RESULTS AND DISCUSION

A. Simulation Results

Table I presents the daily profile of the system energy demand and the solar irradiance of PV. It is assumed that on the demand side the system of load demand is the maximum in the summer period and the solar irradiance is constituted as the minimum value of daily generation for two axis tracking [15]. Table II describes the simulation parameters for an optimal solution that can minimize the use of utility grid. It is important to note that the value minimal of power flows are set to zero. The results of the simulation are shown in Fig. 2 and 3. The energy storage system is starting at maximal point. The simulation is implemented in on day time horizon with 30 minutes as the sample time of the scheme.

B. Discussion

Figures 2 and 3 present the optimal profiles of the proposed control structure as described in Fig. 1. Figure 2 described the system power flows, and the state of charge of the energy storage is depicted. Figure 2(a) shows that the designed OCMS reduced the energy consumption from the utility grid compared to the given load profile of Table I. Figure 2(b) describes that the energy demand is maximally supplied the PV. As it is assumed that the simulation starts with a significant value in the battery, Fig. 2(d) demonstrates that this has a positive impact on the optimal solution of the system. The coordination of the energy management of the system is assured by the proposed OCMS as expressed through the switching system of Fig. 3. From the utility grid (Fig. 3(a)) to the discharging of the battery (Fig. 3(b)) the improvement of the system design is appreciable. Equation (3) is fulfilled, and the system design is robust. Table III presents the difference between the cost of energy to pay the utility grid without and with the proposed OCMS. This expresses the robustness of the system design and the satisfaction of the performance index. The consumer can pay about 12.02% to the utility grid of the total energy consumption when the OCMS is installed.

Table I. Daily power demand and plane array irradiance

Time hour	Power kW	Irradiance W/m^2	Time hour	Power Wh	Irradiance W/m^2
00:00	0.6	0	12:00	0.84	494.023
01:00	1.72	0	13:00	0.62	472.315
02:00	0.46	0	14:00	0.56	418.492
03:00	0.9	0	15:00	4.34	308.193
04:00	2.18	0	16:00	7.02	198.642
05:00	5.72	0	17:00	2.82	82.118
06:00	6.98	15.418	18:00	2.48	4.934
07:00	4.82	119.344	19:00	8.48	0
08:00	1.44	233.282	20:00	3.66	0
09:00	4.24	336.534	21:00	3	0
10:00	1.16	438.693	22:00	2.58	0
11:00	4.6	482.247	23:00	0.68	0

Table II: System parameters.

Value maximal	State of charge	Energy price [9, 16]
$P_{Gr}=P_{PV}=P_B=8.5$ kW	$SOC_{min}=40\%$ $SOC_{max}=95\%$	$p_1=1.2196$ $p_2=0.65$

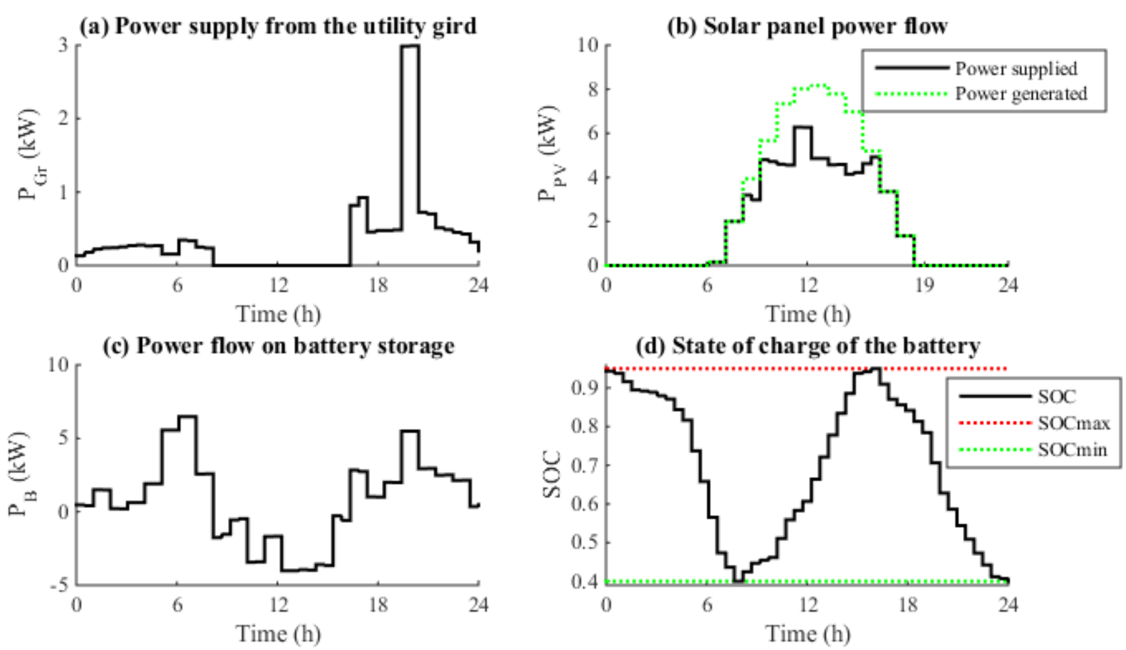

Fig. 2 Optimal power flows on the electrical system and state of charge of the battery.

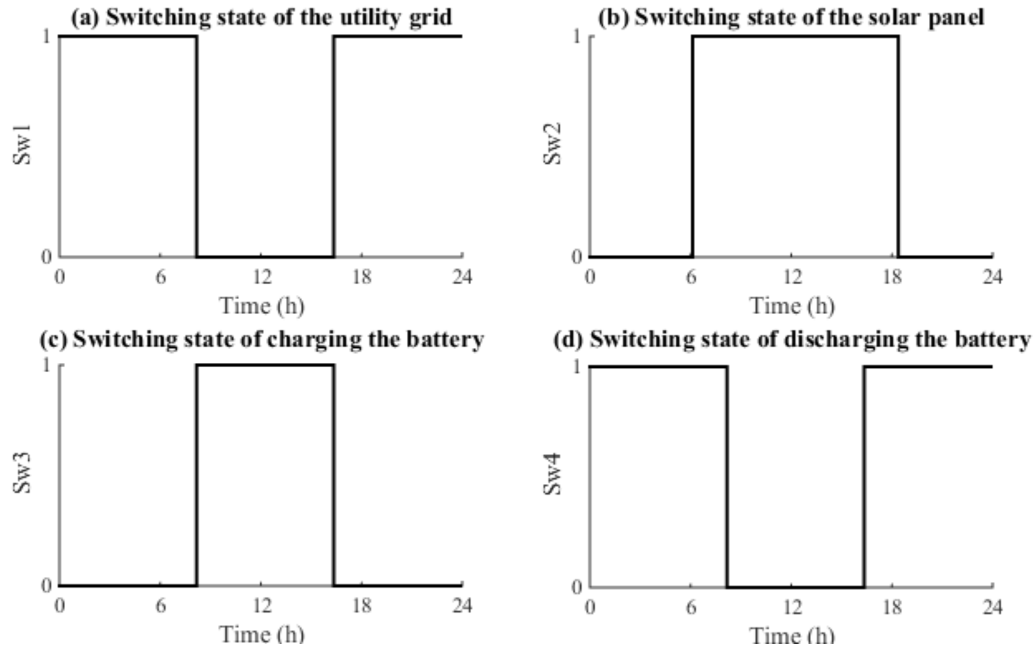

Fig. 2 Optimal control the smart switching of the system electrical system.

Table 4: Cost of energy consumption to pay the utility grid

Without the OCMS	With the OCMS
R87.6892	R10.5367

V. Conclusion

The proposed OCMS strategy created a dynamic environment that coordinated the power flow on the electrical system optimally. Through the simulation results, it is shown that the system objective function was met and the power from the utility grid was reduced while the electricity from the renewable energy is maximized. The designed OCMS managed the charging and discharging process of the battery optimally. It is observed that the OCMS in the smart metering framework can save the energy from the grid at about 87.98% of the total power demand.

Future work will focus on the scenario when the daily profile of the SOC can start at its minimum value. The comparison of proposed OCMS with other optimal metods is also considered as the extension of future this research.

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