Demand Response Implementation in an Optimization Based SCADA Model Under Real-Time Pricing Schemes

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Abstract. Advancement of renewable energy resources, development of smart grids, and the effectiveness of demand response programs, can be considered as solutions to deal with the rising of energy consumption. However, there is no benefit if the consumers do not have enough automation infrastructure to use the facilities. Since the entire kinds of buildings have a massive portion in electricity usage, equipping them with optimization-based systems can be very effective. For this purpose, this paper proposes an optimization-based model implemented in a Supervisory Control and Data Acquisition, and Multi-Agent System. This optimization model is based on power reduction of air conditioners and lighting systems of an office building with respect to the price-based demand response programs, such as real-time pricing. The proposed system utilizes several agents associated with the different distributed based controller devices in order to perform decision making locally and communicate with other agents to fulfill the overall system's goal. In the case study of the paper, the proposed system is used in order to show the cost reduction in the energy bill of the building, while it respects the user preferences and comfort level.

Keywords: Optimization, SCADA, Multi-Agent System

1 Introduction

Currently, power distribution networks are being updated and move towards the smart grids paradigms [1]. The use of smart gird brings flexibility on the resource management somehow it enables the network operator to have control on electricity consumption and generation [2]. On the other hand, the daily increment of electricity usage forced the network operators to reduce the method of generation by fossil fuels [3], and move towards sustainable and renewable energy resources, especially Photovoltaic (PV) systems and wind turbines [4]. A significant part of electricity consumption is allocated to commercial buildings, especially office buildings [5]. In this context, Air

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Conditioners (ACs) have great contribution on the consumption of these kinds of buildings [6]. Demand Response (DR) programs are considered as a solution for managing the consumption of the demand side [7].

DR program is referred to modification of consumption pattern by the end-users in response to the incentives payment by the DR managing entities, which is due to any economic or technical reasons [8]. Real-Time Pricing (RTP) is an example of price-based DR programs, which is applied in day-ahead economic scheduling [9]. In order to implement these programs, the end-users should be equipped with several automation infrastructures in order to be able to perform these programs [10]. Supervisory Control And Data Acquisition (SCADA) system plays a key role in DR implementation, since it offers various advantages in order to have automatic load control in different types of buildings [11].

Multi-Agent System (MAS) is an essential tool for SCADA systems for controlling strategies and exchanging system status [12]. In fact, MAS based SCADA systems would be able to perform complex optimization algorithm, and simultaneously, manage the controllable loads connected to SCADA system [13]. Flexibility and adaptability are two main capabilities that a MAS offers [14].

This paper represents an optimization algorithm implemented in a MAS based SCADA model for an office building. The proposed algorithm manages the consumption of the building under RTP tariff and manages the consumption of the ACs and illumination systems of the building based on defined priorities by the office users. Furthermore, the controlling of the loads is performed through a MAS model, which each agent is associated with particular part of the implemented SCADA system. This enables the model to perform decision making locally and communicate with other agents to fulfill the overall system's goal.

The rest of the paper is organized as follows. The MAS implemented in SCADA model is described on Section 2. Section 3 represents the proposed optimization algorithm. A case study is represented in Section 4, and its results are illustrated in the same section. Section 5 details the main conclusions of the work.

2 Multi-Agent Model Architecture

This section shows the details about the MAS in implemented SCADA system in order to control the consumption of building. The automation infrastructures have been implemented in a part of GECAD research center building, which contains 8 offices, 1 server room, and a corridor. Moreover, there is 7.5 kW PV installation on the building, which supplies a part of total consumption. For managing the consumption of building, three distributed based Programmable Logic Controllers (PLCs) dedicated for a zone including three offices. Therefore, there are three zones somehow each PLC associated with one zone. Moreover, there is a main PLC that is responsible for supervising the other distributed based PLCs. The main controlling panel of the SCADA system including all PLCs is shown on **Fig. 1**. The controllable loads by the SCADA include lighting systems and ACs, which are controlled by several communication protocols.

Moreover, the real-time consumption of the building is measured through several energy meters. In this model, there are five main agents that each of which is run by a Raspberry Pi (www.raspberrypi.org). As **Fig. 1** illustrates, Agent Z1, Z2, and Z3 are devoted for each zone, where these agents are equipped with a PLC for performing controlling decisions locally.

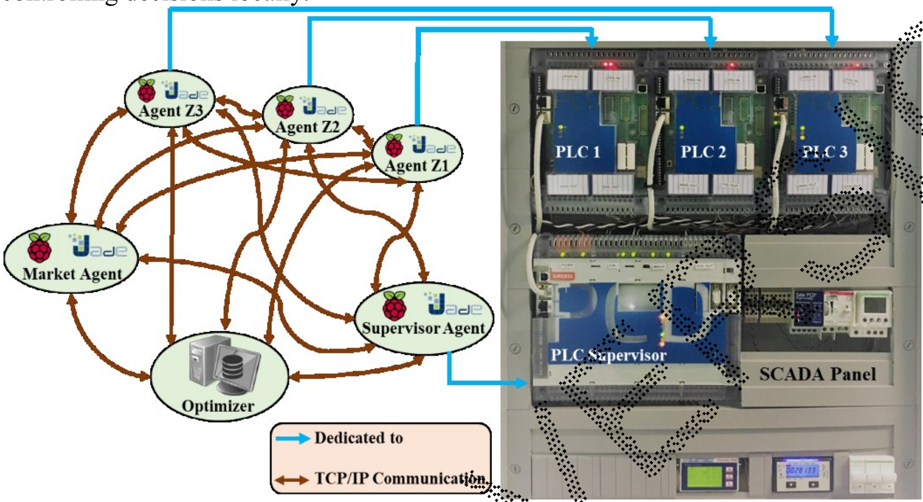

Fig. 1. Multi-agent model of the implemented SCADA system for office building.

Moreover, Market Agent is responsible to inform the other agents from the real-time electricity price of the market. In this model, the unit called Optimizer is accountable to perform the optimization algorithm, which will be demonstrated in the next section. Additionally, the Supervisor Agent continuously check the status of other agents and if there is any faulty agent, it reconfigures the system. All agents in this system continuously exchanges messages for sharing their latest status through TCP/IP communication. By this way, the response time to any changes will be reduced and adaptability of the system will be increased. Furthermore, flexibility and reconfigurability are two features that will be offered by this MAS.

3 Optimization Algorithm

This section introduces the algorithm implemented in the Optimizer agent, which is responsible for optimizing the power consumption of the building based on RTP. **Fig. 2** represents the algorithm of this methodology, based on the power reduction of air conditions and lighting system. To achieve the purpose of running this algorithm in the Optimizer agent, all the other agents are obligated to many tasks, such as providing the essential data for the algorithm.

As it is clear in **Fig. 2**, all data of the building, which are transmitted from other agents, and also the external data received from Market agent, such as electricity price and DR programs, are considered as input data of the algorithm. After definition of the input data, the algorithm performs the decision making for starting optimization. This optimization considered as RTP based, since it will be triggered if the electricity prices goes greater than a specific value. In this optimization, comfort level of user is a critical input. For each AC and light, a specific priority value attributed, which determines contribution of each device in optimization. In the User Data inputs, there is an optional rate for the users, which defines the desired rate of power reduction.

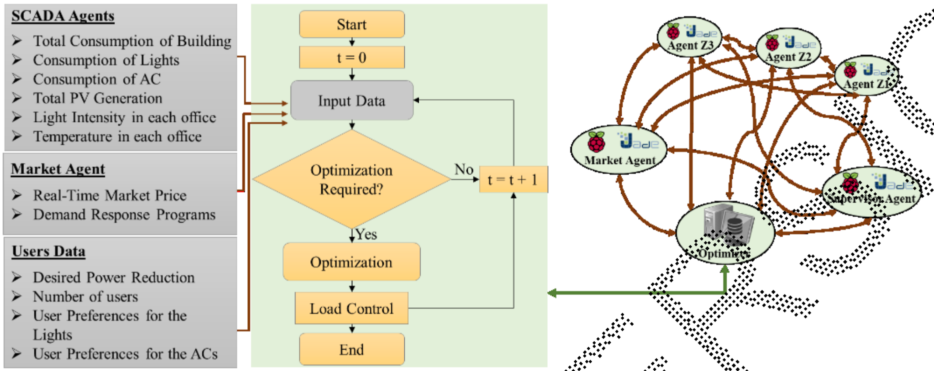

Fig. 2. The procedure of optimization algorithm.

The ACs devices have various priority numbers in each period, since the algorithm should not turn off only specific devices in all periods. Also, in the lights, they are not obligated to participate in the optimization in all periods. This means in certain periods that ACs optimization is not enough to achieve the amount of required reduction of algorithm, lights are as auxiliary part for the ACs. For maintaining the comfort of user, the lights optimization also is based on the priorities defined by the users. Moreover, none of the lights should not be cut completely, and a minimum illumination level is considered for each light.

The proposed methodology is modelled as a linear Programming (LP) optimization problem, which is solved via "Lp_solve" package of Rstudio® (www.rstudio.com). The main objective function of the optimization algorithm is shown by (1), which aims to minimize the Energy Bill (EB).

$$\begin{aligned} Minimize\ EB = \sum_{t=1}^{T} (((\sum_{a=1}^{A} P_{RED.AC(a,t)} \times W_{AC(a,t)}) \\ + (\sum_{l=1}^{L} P_{RED.Light(l,t)} \times W_{Light(l,t)}) + P_{total(t)} - PV_{(t)}) \\ \times COST_{(t)}) \end{aligned} \tag{1}$$

Where $P_{RED.AC}$ is the power that will be reduced from each AC, and $P_{RED.Light}$ is the rate of power that will be reduced from each lights, which are based on the defined input data by users for the rate of desired power reduction. W_{AC} and W_{Light} are the abbreviation of weight of the priority of the ACs, and the lights respectively. P_{total} expresses the total power consumption of the building, PV stands for total PV generation of the building, and $COST$ is the electricity price. T is the maximum number of periods, and finally, A and L are maximum number of ACs and lights, respectively.

Equation (2) and (3) shows the limitation of priority number, which should be a value between 0 and 1. Each priority number closer to 0 is the lowest important device for the users and algorithm as well. Equation (4) illustrates the required reduction of the algorithm, which should be decreased to fulfill the goal of the algorithm. Equation (5) shows that the lights will not participate in entire periods of optimization, and they are limited to be reducted only in critical periods.

$$0 \leq W_{AC(a,t)} \leq 1 \qquad \forall 1 \leq t \leq T; \forall 1 \leq a \leq A \tag{2}$$

$$0 \leq W_{Light(l,t)} \leq 1 \qquad \forall 1 \leq t \leq T; \forall 1 \leq l \leq L \tag{3}$$

$$\sum_{a=1}^{A} P_{RED.AC(a,t)} + \sum_{l=1}^{L} P_{RED.Light(l,t)} = RR_{Total(t)} \qquad \forall 1 \leq t \leq T \tag{4}$$

$$RR_{Light(t)} = RR_{Total(t)} - \sum_{l=0}^{L} P_{RED.AC(l,t)}^{MAX} \qquad \forall 1 \leq t \leq T \tag{5}$$

RR_{Total} is for total Required Reduction, and $P_{RED.AC}^{MAX}$ is the maximum capacity of ACs for reduction. RR_{Light} stands for required power reduction from lights, which should be a value lower than maximum reduction capacity of all lighting system ($P_{RED.Light(t)}^{MAX}$), as shown on (6). For the limitation of power reduction, (7) shows the technical limitation for each light. and (8) shows the discrete control of ACs, which should be off or on.

$$RR_{Light(t)} \leq \sum_{l=0}^{L} P_{RED.Light(l,t)}^{MAX}; \forall 1 \leq t \leq T \tag{6}$$

$$0 \leq P_{RED.Light(l,t)} \leq P_{RED.Light(l,t)}^{MAX} \tag{7}$$

$$P_{RED.AC(a,t)} = \{0, P_{RED.AC(a,t)}^{Max}\} \; \forall 1 \leq t \leq T; 1 \leq a \leq A \tag{8}$$

4 Case Study and Results

In this section, a case study will test and validate the proposed methodology. As it previously mentioned, main purpose of this paper is to optimize the building consumption with taking advantages of MAS in the implemented SCADA system. There are 8 ACs devices in the building that all are turned on during working hour. Moreover, an AC is located in the server room that is always turned. The lighting system contains 19 fluorescents lamps that are controlled by SCADA via Digital Addressable Lighting Interface (DALI). In this case study, it is considered that SCADA model is configured somehow that if the electricity price is greater than 0.08 EUR/kWh (considered as Base Price), it will perform the optimization algorithm. Also, if the prices increased, the SCADA system specifies more reduction in the optimization algorithm. **Fig. 3** illustrates obtained results after and before performing the optimization algorithm for 24 hours (24 periods).

The consumption and generation curves used in this case study are the real consumption and generation of GECAD building adapted from GECAD database. Moreover, the market prices are for a winter day in 2018 and have been adapted from Portuguese sector of Iberian Electricity Markets (MIBEL – www.omie.es)

As you can see in **Fig. 3**, the optimization process starts at 9:00 and finishes at 20:00, since the electricity price is higher than Base Price, therefore, the system performs the optimization in order to reduce the energy bill. Furthermore, PV generation profile shown on **Fig. 3** is the maximum generation capacity of the system.

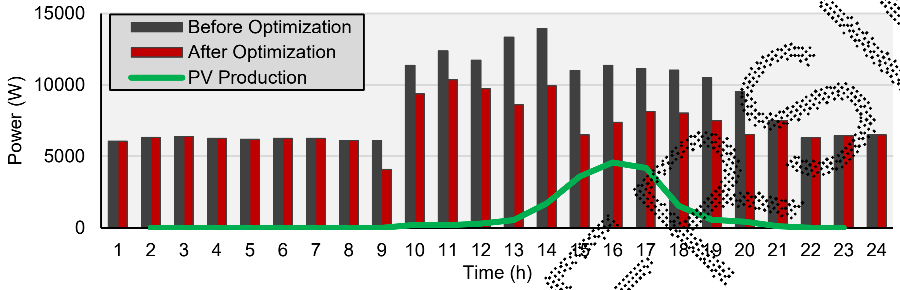

Fig. 3. Total consumption and generation of building.

In fact, the power reduction shown on **Fig. 3**, can be related only to the ACs reduction, or in some periods can be the cooperation of ACs and the lights reduction in order to achieve the desired reduction. **Fig. 4** illustrates the contribution of ACs, and **Fig. 5** demonstrates the contribution of lighting system in the optimization process based on RTP for one day.

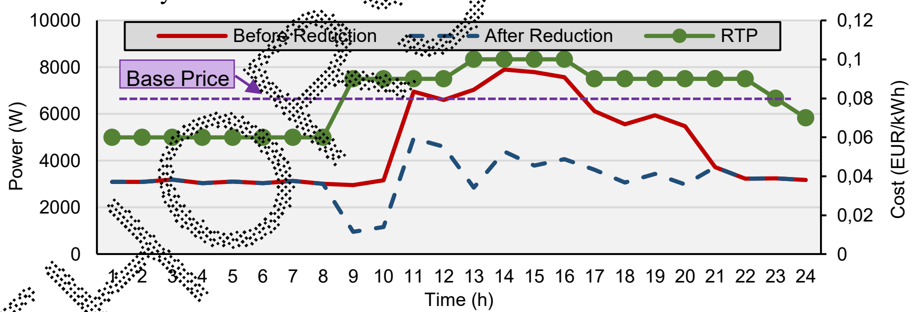

Fig. 4. Consumption reduction in AC devices based on RTP scheme.

The amount of power reduction may be different in each period and depends on the required reduction of the algorithm and the priority of each devices defined by the users. As **Fig. 4**, and **Fig. 5** show, whenever the electricity prices increased and goes above the Base Price, the optimization process reduces the consumption of ACs as much as it can, and some periods that ACs reduction would not fulfill the system goal, the optimization reduce the rest of consumption from the lighting system (period #13 to #20 in **Fig. 5**).

Moreover, as **Fig. 4** and **Fig. 5** demonstrates, in period #21 and #22, even though the electricity price is greater than the Base Price, the optimization is not performed, since there was not enough available consumption in order to be reduced. As a last result, **Fig. 6** illustrates the effect of optimization in the energy bill of the building for one day.

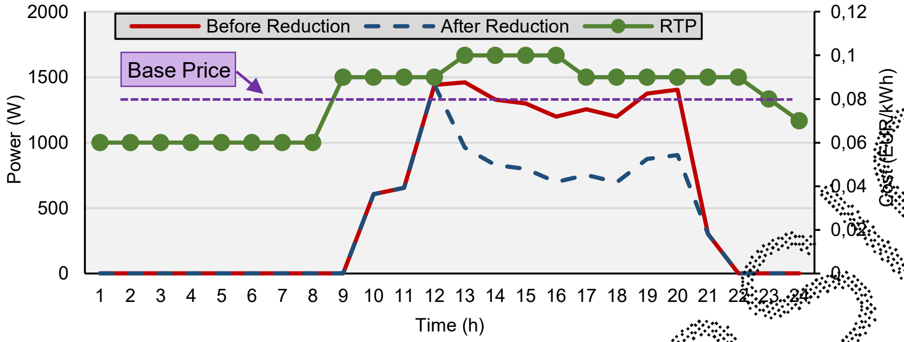

Fig. 5. Consumption reduction in lighting system based on RTP scheme.

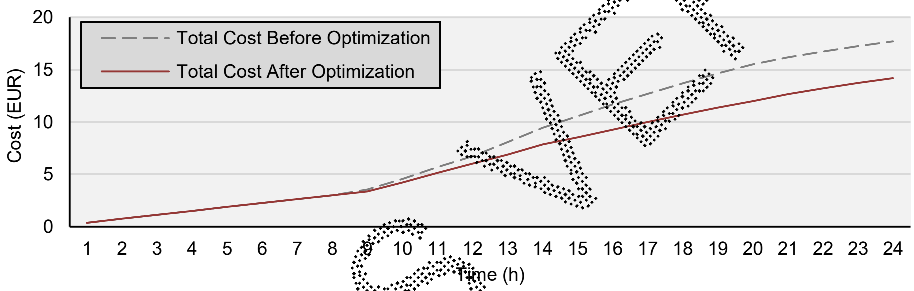

Fig. 6. Accumulated energy cost for 24 hours.

As it can be seen in **Fig. 6**, the optimization process leads to reduce the electricity bill of the building from 17.80 EUR to 14.18 EUR, by respecting to the user's preferences.

5 Conclusions

In this paper, an optimization algorithm has been proposed for a multi-agent based SCADA system. This algorithm considered real-time pricing schemes and optimize the consumption of an office building in the periods that electricity price is greater than a specific value. The main purpose of the paper was to optimize the power consumption and reduce energy bill with take advantages of a multi-agent system. The presented model considered several agents associated with several distributed based controller devices in order to perform decision making locally and communicate with other agents to fulfill the overall system's goal.

The results of case study demonstrated that how the proposed optimization algorithm can reduce the energy bills of an office building via the implemented automation infrastructure and multi-agent system. The amount of cost reduction was for a single day, therefore, if the optimization procedure performed for long-term, the consumer will see a significant reduction in the monthly energy bill, while its preferences and comforts did not much affected.

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