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Intelligent load management in local and wholesale demand response markets
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Direct Load Control Demand Response Program for Air Conditioners

Mahsa Khorram, Pedro Faria, Zita Vale

GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering - Polytechnic of Porto, Porto, Portugal

Abstract

According to importance of demand response programs in last decades, many efforts have been made to change the consumption patterns of the users, and the use of renewable resources has also increased. Significant part of energy consumption belongs to the entire kinds of the buildings such as residential, commercial, and office buildings. In this context, the air conditioners can play an important role in demand response programs. Air conditioners can be as thermostatically controllable appliances for direct load control demand response program. In this paper, an optimization algorithm is developed to optimize the power consumption of air conditioners based on the user preferences to maintain the user comfort. The methodology of this work is proposed as a linear optimization problem that consider the generation of a renewable energy resource, which supplies a part of the energy consumption of the building. For the case study, the amount of the renewable energy generation, total consumption of building, and the consumption of the air conditioners in a real research building are considered and the optimization has been done based on the realistic data.

Keywords: demand response, direct load control, renewable energy, optimization

1. Introduction

Nowadays, the world is facing increasing energy consumption in many sectors like industrial, transportation, residential, and commercial [1], and this increment of using fossil fuels has led to many environmental problems [2]. The use Renewable Energy Resources (RERs), such as Photovoltaic (PV) and wind turbine, have been widely discussed, since they have no environmental impact [3]. In addition, RERs have more economic benefits for the users. For instance, the consumers are able to consume their own produced energy and sell the surplus of their generation to the energy market [4], [5]. Following this general increase of energy, electricity usage has a specific enhancement and the commercial and domestic buildings have a significant impact on the electricity consumption increment [6].

In this situation, Demand Response (DR) programs are very important in the topics of energy consumption. Programs with variable prices in the time, require a response from the customers that change their energy consumption pattern according to the price variation over time [7]. The different types of the DR program can be mentioned as, Direct Load Control (DLC), Interruptible/Curtailable Service (ICS), In Demand Bidding/Buyback (DBB) programs, Emergency Demand Response (EDR), Capacity Market (CM) programs, and Ancillary Services Market (ASM) [8].

In this context, the Air Conditioners (AC) have a significant power consumption in the buildings and can play a key role in participating in DR programs [9]. The regulation of the DR in ACs is made by the actuation in the AC. Thus, this type of DR program is called DLC, because there is ACs that can be considered as thermostatically controllable appliances [10].

This paper represents an optimization based model for optimizing the consumption of the AC system of an office building with interference of RERs, specially a PV system that supplies part of power demand of the building. The building consists of the several laboratorial and commercial equipment and instruments, such as several Programmable Logic Controllers (PLCs) and several energy meters, which enable the system to have real implementation of the optimized data.

This paper is proposed in four sections. After this introductory section, the optimization problem is presented in section 2. Section 3 demonstrates the case study, and its obtained results. The conclusions of this work are presented in Section 4.

2. Optimization Model

The proposed model regarding the optimization of consumption of AC and in reducing the total cost of the energy consumption in the building is based on the priority of them. In this way, the maximum consumption reduction for each air conditioner has been considered. The overall architecture of the presented optimization problem is illustrated in Fig. 1.

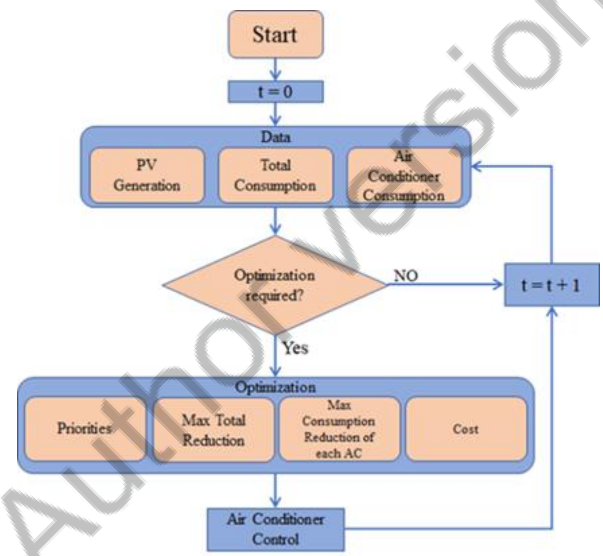

Fig. 1: The flowchart of the proposed optimization model.

As you can see in Fig. 1, the optimization model starts with definition of input data including generation of the PV, total consumption of the building, and the detail of the total consumption of the air conditioning system. After checking these values, if the desired power consumption is met, the optimization process is not required and should check the values again as long as the system is in the high consumption level. Then, the program starts to optimize the consumption of the AC to fulfil the system goal. For this purpose, priorities are defined in the program. This means each air conditioner of the building has a priority based on its location and user preferences. After that, the required power reduction of whole air conditioning system and the maximum consumption reduction of each air conditioner is defined, as well as several constraints for the proposed optimization problem. This methodology is run for a single period, however, the optimization process depends on the input values of the system. Equation (1) demonstrates the objective function of the optimization problem:

$$Minimize\ EB = \sum_{t=1}^{T}\sum_{d=1}^{D}((P_{red_{(d,t)}} * W_{(t,d)}) + P_{total} - PV) * Cost_{(t)} \quad (1)$$

$$\forall\, t \in \{1, \dots, T\}$$

$$\forall\, d \in \{1, \dots, D\}$$

Where P_{red} is power consumption reduction of each air conditioner, and W is abbreviation of weight of the priority of each air conditioner that depends on the user and situation of the room. D and T represent the total number of devices that mean the AC and number of time periods respectively. Moreover, P_{total} represents the total power consumption of the building, *PV* indicates the generation of Photovoltaic system in the building, and *Cost* is the electricity energy cost in each period. Moreover, the model constraints are shown by equations (2)- (4).

$$0 \leq W_{(d,t)} \leq 1 \tag{2}$$

$$Maximum\ Reduction: \sum_{t=1}^{T} \sum_{d=1}^{D} P_{red_{(d,t)}} = P_{total} - PV \tag{3}$$

$$P_{red(d,t)} = \{0, P_{red(d,t)}^{Max}\} \forall 1 \leq t \leq T; 1 \leq d \leq D \tag{4}$$

The equation (3) indicates that the required consumption reduction of the system. Actually, the process of optimization depends on the input data. As it illustrated in Fig. 1, total consumption of the building and the generation of the PV, are the values that specify the required reduction for the system, and equation (4) shows that consumption reduction for each device is limited to maximum consumption reduction of each device.

3. Case Study

This section represents the case study used for verifying the proposed optimization model. As it was mentioned, the main purpose of this section is to optimize the consumption of the air conditioning system in an office building (The office building is a part of GECAD research centre located in ISEP/IPP, Porto, Portugal). This building consists of 9 offices and a corridor as Fig. 2 shows. Daily, the building has more than 16 researchers working inside. The control of the AC was made by developing an infrared emitter to transmit the air conditioner signals to turn on/off or to regulate the desired temperature and operation mode. The infrared emitter is connected to a PLC that receives orders using a Modbus/TCP connection and then send the desired signals to each air conditioner.

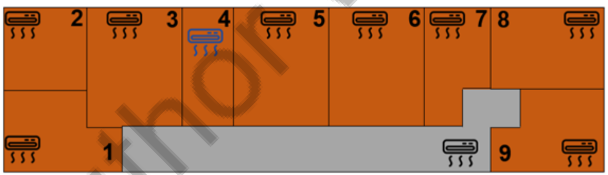

Fig. 2: Plan of GECAD office building.

As it was previously mentioned, the optimization is based on the weight of the priority of the AC and the cost of electricity in each period. The order of priority is the importance of each device for the user or for the building rules. For instance, the air conditioner placed in office number 4 has the highest importance as its placed in the server room, so they should be always on.

The time period used in this case study is one minute, within a total period of 24 hours. Two situations should consider for defining the required reduction value: periods that the generation of the PV is more than the power consumption of the building (that requires a reduction with a negative value), and periods of the day where the power consumption of the building is higher than PV generation (where the optimization must reduce the consumption). Fig. 3 illustrates the results of the optimization for entire building.

As it is clear in Fig. 3, most of the optimization periods are in the working hours of the office building where the total power consumption is more than the PV generation.

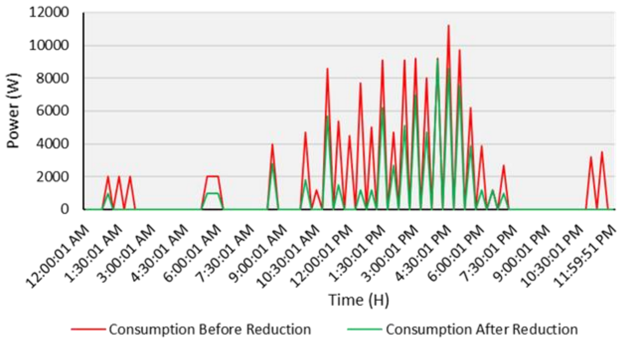

Fig. 3: Comparison of the power consumption before and after the optimization.

4. Conclusions

This paper presented an optimization algorithm for optimizing the power consumption of air conditioners of an office building based on the user preferences. Renewable generation were considered on the algorithm, which it supplies a part of building consumption. The optimized data has been implemented in the building using several programmable logic controllers and energy meters.

The results obtained show that optimization of the air conditioning consumption in the buildings can effectively reduce the final energy consumption and keeps the preferences and comforts of the users by specifying priority to each device. In this way, the use of renewable energy can be increased in residential, commercial, and office buildings, since it can benefit both sides of the network. The demand side can benefit by reducing their electricity bills, and the grid side will be benefit by reducing the generation in critical periods.

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