A New Method for Demand Response by Real-Time Pricing Signals for Lighting Loads

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Abstract— **Recently by presenting the smart grid concept, possibility of managing renewable resources uncertainty and distribution generations has been increased. Moreover by infrastructures of smart grid, such as AMI (Advanced Metering Infrastructure), EMS (Energy Management System), and smart controllers, possibility of load management and implementing demand response programs, have been provided. Controllable loads have the opportunity to participate in the real-time operation of transmission and distribution networks and can follow generation variation. Even by these infrastructures, small domestic loads such as lighting loads can be controlled too. A recent research shows that 20%~30% of building energy consumption can be saved or shifted to non-peak periods, with optimized operation and management.**

One of the high consumed domestic loads is the lighting load. This paper proposed a method for controlling these loads by electrical market real-time prices. These price signals is sent to EMS of a home by AMI, then EMS calculate illumination level of desired lighting loads with proposed method. A minimum and suggested illumination value for various places have been presented in lighting references, which controlling these loads by proposed method has been done in this permitted interval. In order to validate proposed method, a numerical example for lighting loads has been presented, and then the process of controlling these loads by energy price signals has been shown.

Keywords- Smart grid, Demand response, Energy management system, Smart controller, Lighting loads, Energy price signals

I. INTRODUCTION

Nowadays energy efficiency, reduced fossil fuel resources, environmental impact of power supply systems, and reliability are issues of global concern. Moreover recessions and political crisis, caused fluctuations in fuel prices and have been propelled many countries to decrease their dependency on these energy resources. Therefore using renewable resources such as wind energy has dramatically grew. But one of the main concerns about these sources is uncertainty of generation. Hence in power systems operation, there are several uncertain factors such as generation of renewable resources and energy price. One of the ways to deal with these uncertainties is demand side management.

Reduction of the electrical loads consumption or coordinating them with uncertainties are important tools for maintaining supply-demand balance and are applicable on several timescales. In the traditional power system structure, only generation could follow demand, but by restricting this system, demand could follow generation too. These methods are good ways, to deal with existing uncertain parameters. In fact by these methods, we can create a coupling method between these uncertainties and load demands, which over high energy cost or low renewable energy generation periods can decrease the demand of electrical loads.

Demand response (DR) can be defined as the changes in electric usage by end use consumers from their normal consumption patterns in response to changes in the price of electricity over time [1]. These methods could also be implemented in residential loads level. A recent research shows that 20% ~ 30% of building energy consumption can be saved with optimized operation and management of these loads [2]. [3] claimed that lighting devices consume about 40% of the total produced power. It is estimated that over 45% of energy can be reduced if we use an efficient energy management system. Therefore there is a huge potential for building energy saving through efficient operation.

Implementing these new solutions in traditional power systems is very difficult or impossible. Hence researchers proposed smart grid concept. The smart grid concept identifies the addition of intelligence and two-way digital communication lines to the power grid which significantly improve system reliability and security, achieve real-time fine-grained signals on network performance, outage condition and pricing. It facilitates rapid outage detection, real time pricing signals to end-user, and demand response programs, or enable user appliances to be turned on/off automatically [4].

The smart grid concept has also been composed of small smart grid networks known as smart microgrids. These microgrids could be consists of residential, commercial, and industrial loads with DGs, which could be managed by smart energy management system (SEMS). In [3] a survey on smart grid concept and instruments has been done, then the hardware architecture and software of the smart controller for use as the platform in smart grid system to reduce energy consumption especially lighting loads, have been proposed. [5] claims that there is potential for energy storage or energy saving in some residential appliances. Then a method for controlling and energy storage by air-conditionings and refrigerators has been proposed. In [6] an active controller with thermostat has been used to control air-conditioning by price signals. This method

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could be generalized to other residential appliances. [7] described possible integration of demand side resources in electricity market as a demand response programs. This paper performed preliminary analysis of load impact by a couple of demand responsive technologies in air-conditioning, lighting, and computing appliances for commercial buildings in Japan. Also in [7] three strategies which are demand saving, demand shifting, and peak-time generation have been proposed. Lighting loads were in demand saving strategy group. For energy saving of these loads five methods which are zone switching, luminaire switching, daylight, stepped/continuous dimming, and turn off outdoor lights have been presented. Then zone switching method has been used for controlling lighting loads. This strategy turns off lights of unoccupied zones or zones where daylight is enough during a DR period. This strategy can be applied to common spaces in commercial buildings such as entrance, lobby, stockroom, and corridor, where are less occupied than other spaces of building.

A new algorithm for controlling consumption level of lighting loads in a smart home by real-time pricing signals will be proposed in this paper. These signals could be sent by microgrid manager and then this reduced energy could be bid in market by micrigrid. The privilege of this method is that in time intervals which energy cost is high, the consumption level of lighting loads with regrads to the welfare level of consumers is reduced, then this reduced energy could be sold in upstream network market or the purchasing energy from the upstream network could be reduced. In both cases consumers and microgrid are beneficiary. The rest of the paper has been organized as follows: in section III infrastructure of smart grid especially for controlling lighting loads of homes has been surveyed. An algorithm for controlling lighting loads by price signals has been presented in section IV. Simulations and results of this method and conclusions have been presented in sections V and VI respectively.

II. INFRASTRUCTURE OF SMART GRID FOR HOMES

In order to apply smart grid system and finally proposed method of this paper in the homes, three components are necessary, energy management system (EMS), advanced metering infrastructure (AMI), and smart controllers. In the modelling of this paper, these homes were located in a microgrid. AMI refers to the technology which by using the Bi-direction communication lines, communicates with SMES of microgrid which the information like the energy cost and the electric consumption level of home appliances are exchanged. The EMS controls the smart appliances and manage the energy consumption pattern of the home. Also EMS is in connection with SEMS of microgrid by the AMI. A communication network is required to apply demand response programs in home which is known as home area network (HAN). With regards to the position of various home appliances, wireless or wired technology can be used in order to build HAN. In this network, for each appliance, a smart controller system is used to perform controlling commands of EMS.

Fig. 1 shows a HAN structure of smart grid for a house. In this structure a smart controller was implemented beside each appliance. These smart controllers, perform controlling commands of EMS, and measure energy consumption level of related appliance then send it to EMS by HAN. Afterwards EMS sends required information such as consumption value to microgrid SEMS through AMI. Also, microgrid SEMS sends DR commands or pricing signals through AMI to EMS of HAN, and EMS controls proper appliances by smart controllers. However EMS can exclusively controls home appliances with regards to owner's benefits.

This paper proposed a method for EMS to control lighting loads according to price signals. In this method pricing signals of electric market will be sent to EMS by microgrid SEMS through AMI, then by proposed method, EMS calculates illumination level for desired place of home and send it to the related smart controller. In addition to the smart controller, a

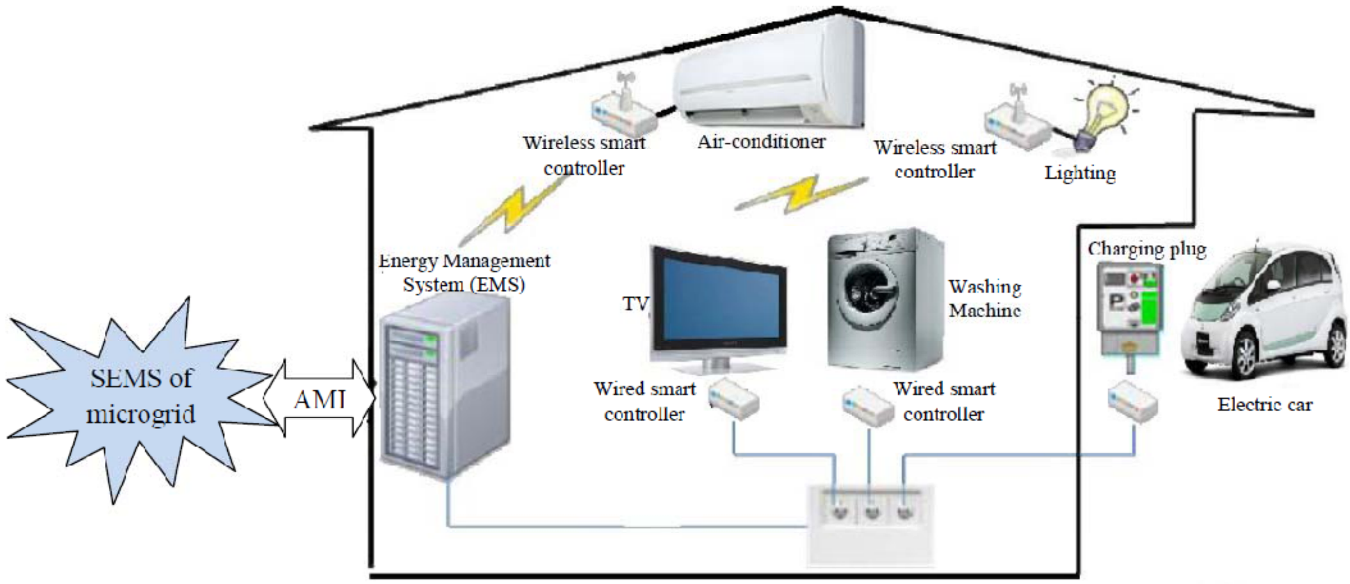

Figure 1. the smart grid infrastructure for a Home Area Network (HAN)

illumination detector sensor has been installed for each lighting load. Smart Controller adjusts consumption value of lighting system according to the sent illumination value from EMS and measured illumination level of that place by sensor, so that it achieves the desired illumination.

In order to regulate lighting loads by calculated illumination level, electrical ballasts have been used. These ballasts adjust consumption level of lighting loads and therefore change the scattered luminous flux. For example the luminous flux of the compact fluorescent lamps is affected by pressure of mercury vapour gas inside them. In these lamps, by changing voltage-current and frequency-current characteristics through electrical ballasts, we can change luminous flux. Also, because sensitivity of human eyes characteristic to the light changes is logarithmic, then by logarithmic changing of light, we would induce better feeling for residents.

III. CONTROLLING METHOD FOR LIGHTING LOADS

A. Calculating illumination level of lights by pricing signals

In most of the lighting calculations, illumination quantity is used. This quantity is defined by luminous flux to desired surface ratio. The lighting references, usually propose minimum and suggested illumination level for various places, such as living rooms, bedrooms, corridors, pavements, streets and etc. In the presented method of this paper illumination of lights is changed in the mentioned interval according to pricing signals variations. Fig. 2 shows illumination versus price curve which schematically shows the proposed method. In this figure, horizontal axis shows deviation of electrical energy price from minimum predicted price of that day. The reason for using minimum predicted price is that, lighting loads doesn't have the capability of virtual energy storage like air-conditioning loads, so maximum illumination level should be occur in minimum predicted energy price. Also vertical axis shows illumination permitted interval (according to lighting references) for any desired place. According to the Fig. 2, deviation of illumination related to price has been shown by a parabola curve with downward concavity. So in low price deviations for more welfare of consumers, illumination changes are small, but in high price deviations vice versa.

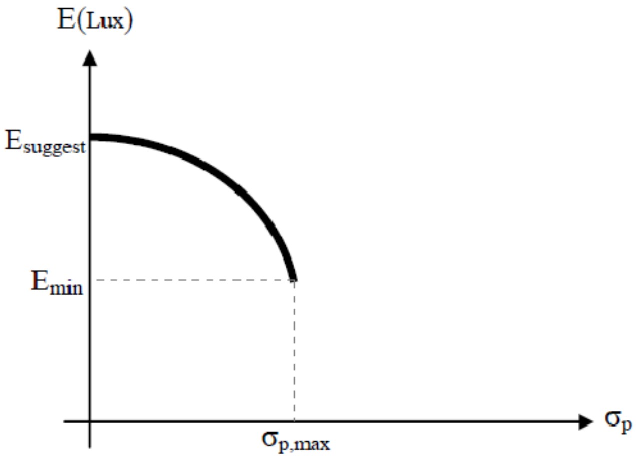

Figure 2. illumination versus electric market price curve which schematically demonstrate the proposed controlling method

By considering two point of Fig. 2, $(0,E_{suggest})$ and $(\sigma_{p,max},E_{min})$, and this fact that the slope of tangent line in $(0,E_{suggest})$ is zero, then equation of Fig. 2 has been calculated as (1).

$$E = -\frac{E_{suggest} - E_{min}}{\sigma_{p,max}^{2}}\sigma_p^{2} + E_{suggest} \tag{1}$$

Where:

E	illuminance (Lux)
E_{min}	minimum illuminance for desired place (Lux)
$E_{suggest}$	suggested illuminance for desired place (Lux)
σ_p	deviation of price from predicted minimum price of day
$\sigma_{p,max}$	maximum deviation of predicted price and minimum predicted price of that day

According to (1), illumination level of the desired place, has been calculated by the pricing signals which had been sent from SEMS of microgrid to EMS of the home. Then this calculated illumination is sent to smart controller. Smart controller by using illumination sensor, adjusts lights so that total illumination of daylight and lights are equal to (1). This method could be used for every place of home or outside.

B. Computing consumption power of lighting loads to obtain calculated illumination level

In this section, power consumption value of lighting loads has been computed by lighting calculations to obtain desired illumination level. Because total produced illumination of lights is not reached to desired surface, so coefficient of utilization defined as (2). According to the lighting calculations, lights should produce luminous flux as (3). Cu and LLF are extracted from lighting references, according to the type of lamps, chandeliers, and places [8].

$$Cu = \frac{\varphi'}{\varphi} \tag{2}$$

$$\varphi = \frac{E_{Lamp}.L.w}{Cu.LLF} \tag{3}$$

Where:

E_{Lamp}	lamp illuminance (Lux)
φ	total produced Luminous flux of lamp (Lm)
φ'	luminous flux of lamp which reach to desired surface (Lm)
Cu	coefficient of utilization
LLF	light loss factor

Power consumption of lighting loads can be obtained by (4) with regards to (3), in order to achieve illumination level of (1). According to (4), consumptive power of light is related to price. Fig. 3 shows flowchart of the proposed method.

$$P_{Light} = \left[-\frac{E_{suggest} - E_{min}}{\sigma_{p,max}{}^{2}} \sigma_p{}^{2} + E_{suggest} - E_{day} \right] \frac{L.w}{Cu.LLF.\eta} \qquad (4)$$

Where:

P_{Light}	consumptive power of lighting loads (W)
E_{day}	daylight illuminance (Lux)
η	light utilization coefficient of lamp (Lm/W)

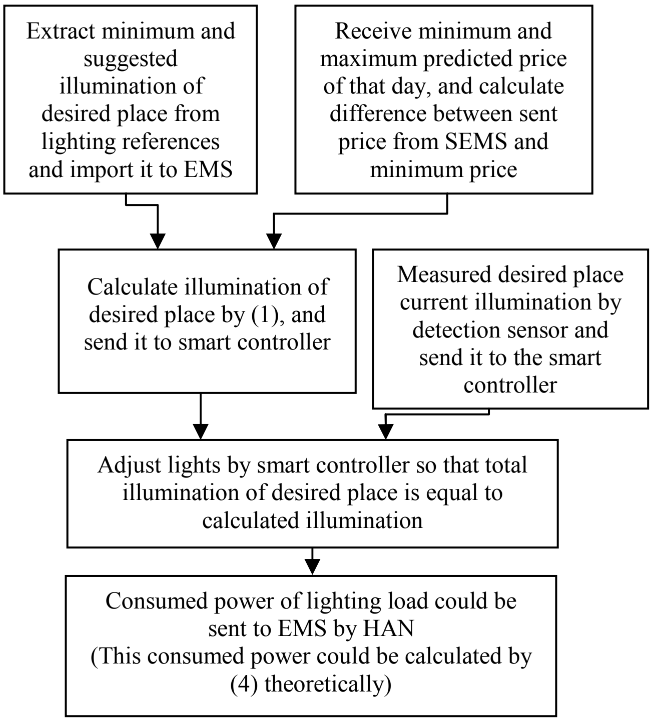

Figure 3. flowchart of the proposed controlling method for the lighting loads

IV. Simulations and Results

In order to validate presented controlling method for lighting loads, a microgrid with some residential buildings is considered. Each of these buildings has a number of lighting loads with EMS. This simulation has been done for a typical day. In this simulation, we assume that illumination level of daylight in each hour is as Fig. 4. The amount of daylight illumination which enters to the desired place is shown by DF which is expressed in (5). The lighting sensors are installed beside lights, and send illumination level of desired place to the smart controllers. If this sent illumination level is less than calculated level by proposed method, then smart controller adjusts lights to achieve that level.

In this microgrid, we assume that all of the used lamps are in type of compact fluorescent or fluorescent lamps. Also we assumed that there are 50 living rooms, 50 kitchens, 150 bedrooms, 200 corridors, 50 reading rooms, and 200 outdoor lighting lamps, in this given microgrid. Table 1 shows lighting specifications and the calculated results of the required lighting flux for each of the given places.

$$DF = \frac{\begin{pmatrix} illumination\ level\ caused\ by \\ daylight\ in\ the\ desired\ place \end{pmatrix}}{daylight\ illumination} \times 100 \qquad (5)$$

Simulation results of energy consumption profile for lighting loads, before and after implementing the proposed controlling method have been shown in Fig. 5. Also for better realization, energy pricing signals have been shown in this figure. According to this figure, by implementing the proposed method, coordination has been established between lighting loads consumption level and hourly energy pricing signals. For example in the time interval 7, which the energy price is the least, consumptive energy of lighting loads in controllable and incontrollable statues are the same. Also in time interval 6, which the energy price is a little more than minimum price, the consumptive energy of these loads are decreased too low. But in the time interval 22, which the energy price is the highest, consumptive energy of lighting loads is approximately half of the incontrollable statue.

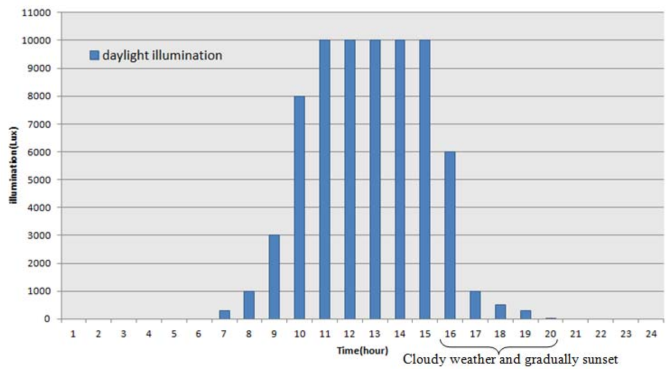

Figure 4. assumed illumination level of a typical day in each hour

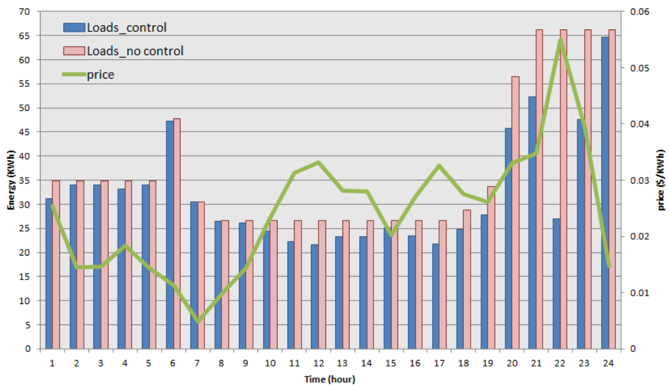

Figure 5. hourly lighting loads consumed energy before and after implementing proposed method

In this paper, with regards to the smart controllers potential, we propose that in the midnights when the traffic of pavement and corridors is too low, illumination level of them is reduced to the minimum value, which results in energy saving. Fig. 6 shows the result of implementing this proposal, which causes

TABLE I. LIGHTING SPECIFICATION AND THE REQUIRED LIGHTING FLUX FOR DESIRED PLACES

place	proposed illumination level (Lux)	minimum illumination level (Lux)	required flux on surface (Lm)	type of lamp	number of lamps	η(Lm/W)	DF(%)
living room	200	70	24193	compact fluorescent (57W) 4300Lm	6	75.44	60
kitchen	200	100	8744	compact fluorescent (57W) 4300Lm	3	75.44	30
bedroom	100	50	3278	compact fluorescent (26W) 1800Lm	2	69.23	30
corridor	100	40	10582	fluorescent (39W) 3100Lm	4	79.49	0
reading room	500	300	3809	compact fluorescent (57W) 4300Lm	1	75.44	70
pavement	6	2	3113	compact fluorescent (42W) 3200Lm	1	76.19	100

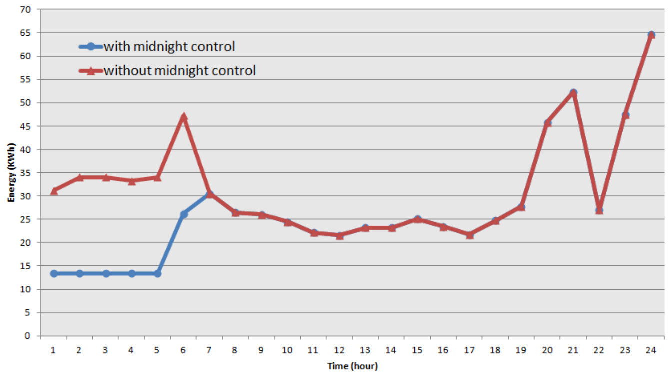

Figure 6. Energy consumption of the lighting loads after midnight control

significant reduction in the midnight energy consumption of lighting loads. Also by the smart controller potentials, we can turn off the lightings of places where no one exists.

V. CONCLUSIONS

In this paper, a new method for controlling lighting loads with regards to the variations of the energy prices was proposed. By implementing this method, lighting loads become price-sensitive loads. For implementing this method, some infrastructure of smart grid, such as smart controllers, energy management systems (EMS), and advanced metering infrastructures (AMI) are needed for buildings. In this paper, we suppose that these lighting loads belong to a microgrid which consists of some residential buildings. This microgrid connects and sends pricing signals to the EMS of the buildings by AMI infrastructure. Then by using these pricing signals, EMS calculates illumination level of the desired places with the proposed controlling method. For each places, this illumination level must be in the permitted range. Then this calculated illumination level, is sent to the smart controller of the desired place. With regards to the existing illumination level in that place and calculated illumination level, smart controller adjusts lights in order to achieve the given illumination level.

The presented method of this paper is so that, by using predicted minimum energy price for that day and sent pricing signals in each time intervals, a mathematical equation is proposed for calculating the illumination level of that time interval. This equation is adjusted such that, if deviations of the pricing signals from the minimum price are low, then illumination level are near to the proposed illumination level for that place. Simulation results showed that, by implementing the proposed controlling method for the microgrid lighting loads, their consumption level is changed by pricing signals. Because these changes are so that when the cost of energy is high, the energy consumption of lighting loads becomes low, then this causes increasing profit for the operation of microgrid and decreasing the cost of electricity for the consumers.

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