Smart Residential Buildings And Its Effect On Reducing Energy Consumption With The Approach Of Energy Consumption Optimization

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Abstract : Due to the scarcity of energy resources and the high cost of production and transmission, human beings are always looking to optimize energy consumption so that they can pay the lowest cost while using all the tools that need to consume energy. Consumption optimization is not only economically beneficial to the consumer but also beneficial to production units and the environment. Equipping residential buildings with smart equipment is a solution to this problem, the implementation of which can be costly at first, but in the long run can reduce many economic costs and environmental pollution. Smart control systems have high flexibility and can be easily adapted to different needs. The smart management system, using the latest technologies, is the percentage that creates ideal conditions, along with optimal energy consumption in buildings. Therefore, in this paper these systems examined, and we have tried to examine how to control and reduce electrical energy. In this regard, two optimization algorithms have been used to reduce energy costs, the results of which have been compared with each other. There is now a smart control tool that allows the consumer to schedule their home appliances on a daily or weekly basis while using them to pay less for non-peak times. Energy hub is a concept that has recently been introduced in energy systems integrated with multiple energy carriers. Specifically, it is the central energy hub in which all the activities related to a system, including production, storage and energy consumption in the application equipment are determined. In this paper, the YALMIP toolbox of MATLAB software is used in energy efficiency optimization with the aim of reducing the costs of fossil fuels by considering the production capacity of a photovoltaic production unit. With this toolbox, the right time to turn on each of the appliances is determined according to the practical limitations of each of them, and the most possible use is made of the photovoltaic unit that produces clean energy.

Keywords: residential building, cost reduction, smart management, photovoltaic unit, energy hub

1. INTRODUCTION

Due to the scarcity of energy resources and the high cost of production and transmission, human beings are always looking to optimize energy consumption so that they can pay the lowest cost while using all the tools that need to consume energy [1]. Consumption optimization is not only economically beneficial to the consumer but also beneficial to production units and the environment [2]. Smart grids are a solution to this problem, the implementation of which can be costly at first but in the long run reduce many economic costs and environmental pollution [3]. Smart grids can use local renewable energy such as wind and solar energy to solve environmental problems, increase the credibility of systems and equipment, and reduce the cost of infrastructure [4]. Smart grids connected to home networks allow the consumer of electrical products, networks and services to operate as seamlessly as possible [5]. The development of smart grids can play a very effective role in reducing energy costs. In this regard, how to coordinate these consumer devices as much as possible has become particularly important [6]. There is no doubt that one of the most important challenges and controversial issues of the current century around the world is the issue of energy [7]. In general, there are various ways to conserve energy resources. The most common method of saving is through culture building [8]. The latest idea for energy conservation is the use of new equipment and systems that are designed for this purpose [9]. These include building energy management systems. A smart building is a building that incorporates a dynamic and cost-effective environment by integrating the four main elements of systems, structure, services, and management and the relationship between them. A smart building offers these benefits through intelligent control systems [10]. Another issue that plays a role in the return on capital is the optimal use of facilities that increase the life of equipment: for example, in a mechanical installation system, by dividing operating times between all members, a set of work pressure is distributed among all members. And while it permanently prevents a part of the collection from being inactive, which in itself makes the whole collection work better [11]. The concept of microgrids is being used today to help reduce production costs and environmental pollution with several renewable and available sources such as wind and solar energy along with other traditional energy producers such as fuel cells and microturbines [12]. Not only are these resources interconnected, but this interaction continues at higher levels, such as distribution networks. The limitations of fossil fuels and the growing demand for energy, rising living standards, global warming, and ultimately environmental problems have led to advances in technology and the use of new energy every day [13]. The growth and development of human societies has always been parallel to the production and consumption of energy. According to recorded statistics, the world's energy needs have increased significantly over the past 30 years [14]. Today, the use of new energy in providing network load is one of the most important and discussed issues. The use of new energy, especially in cases such as remote areas, where the possibility of connecting the load to the national grid is more important, is more important [15]. In this research, a multi-objective energy management system is considered to optimize the performance of the energy hub to reduce costs in one day. Intelligent electricity distribution networks are one of the latest technologies in the world and the result of the efforts of experts to modernize distribution networks and enter the digital age [16]. The main goal is to provide reliable electricity and meet the growing needs of customers with the least damage to the environment. The goal of designers is to use intelligent technology around the three main axes of customers, equipment and communications [17]. Intelligent technology has the ability to make fundamental changes in the generation, transmission, distribution and use of electricity along with economic and environmental benefits that ultimately lead to meeting the needs of customers and the availability of reliable and sustainable electricity [18]. Solar radiation is the largest source of renewable energy on the planet, and if only one percent of the world's deserts are used with solar thermal power plants, the same amount will be enough to generate the world's annual demand for electricity [19]. However, the use of this energy also has certain limitations, including limitations related to the effect of latitude, the existence of cloudy days and the reduction of solar radiation power on the earth's surface. If a country wants to get its energy from the sun, it needs the area needed to install solar equipment [20]. In addition, provided that this is the case, the supply of this amount of energy requires large warehouses and huge facilities for transmission. All of the above factors increase the cost of supplying this type of energy by twice as much as fossil fuels [21]. In a simple definition, smart grid can be expressed as a community of power grid infrastructure with extensive telecommunication network. This type of network allows two-way communication and the use of advanced sensors to improve system performance and reliability, transmission security and power consumption [22]. As another definition, a smart grid can be defined as a community of communication networks with a power system in order to create a suitable path for electrical energy and information. This collection will be able to monitor its accuracy at all times and also in case of any problems can inform it much higher and automatically take corrective actions and prevent a local accidental event is hierarchical [23]. The idea of a smart grid began with the idea of advanced metering equipment (AMI) to develop demand-side management, increase energy efficiency, and a self-healing electrical grid to improve resource reliability and response to natural disasters or deliberate sabotage. But subsequent developments improved the basic aspects of the smart grid and helped shape the new face of the electricity industry [24]. In this research, smart residential buildings and its effect on reducing energy consumption with the approach of energy consumption optimization was examined.

2. Simulation

2-1 YALMIP toolbox optimization

The Yalmip box of Matlab software is introduced in this section. It also addresses how YALMIP can be typically used to model and solve optimization problems in control systems and theory. Two of the most important mathematical tools in control theory and systems in the last decade are semi-finite optimization (SDP) and linear matrix inequality (LMI). The SDP integrates a large number of control problems, including Lyapunov's 100-year-old theory of linear systems and modern control theory from the 1960s, based on the Riccati equation of algebra and recent developments such as ∞H is control in the 1980s. Most importantly, LMI and SDP have given new results in terms of stability and synthesis for uncertain system, model prediction control, iterative systems control, and robust system identification to name limited applications. We know that a control program can be solved if it is summed in the Riccati equation as a quadratic linear control.

2-2 Description of decision variables

Decision variables are a key component of an optimization problem. Decision variables in YALMIP are represented by sdpvar objects. The use of the P matrix is described according to the following command:

```
>> P = sdpvar(n,n,'symmetric' , 'real' )
```

Square matrices are assumed to be symmetric and real, so the common variable can only be defined using dimensional arguments.

```
>> P = sdpvar(n,n);
```

A set of standard parameters are predefined and can create complete parametric matrices and different types of matrices with complex variables.

```
>> Y = sdpvar (n,n,'full')
>> X = sdpvar (n,n,'hermitian','complex')
```

Most standard MATLAB statements and operators can be used for sdpvar variables, so the following instructions are important:

```
>> X = [ P P(:,1) ; ones(1,n) sum(sum (P))]
```

3-2 Solutions of optimization problems Once all the variables and constraints are defined then the optimization problem can be solved. Simply put, we have matrices A, b, and c that we want to minimize subject to the constraints of Ax <b. The use of YALMIP to solve a new innovative problem is essentially a drawing of mathematical descriptions. The solvesdp3 command is used for all optimization problems and typically consists of two arguments, including a set of constraints and a function related to its purpose.

```
>> x = sdpvar ( length(C), 1);
>> F = set (A*x<b) + set (sum(x)==1);
>> solvesdp(F, c' ,1);
```

YALMIP automatically categorizes the linear programming problem and a suitable solver. The optimal solution can be extracted with the double (x) command.The second argument is used to guide YALMIP in selecting the solver, adjusting the screen levels, and changing the solver with specific choices.

```
>> ops = sdpsettings('solver','glpk');
>> ops = sdpsettings(ops,'glpk.dual',0);
>> ops = sdpsettings(ops,'verbose',1);
>> solvesdp(F,c'*x,ops);
```

3- Modeling

3-1 Modeling method

Energy hub is a concept that has recently been introduced in energy systems integrated with multiple energy carriers. The hub is defined as the system activity center. Specifically, the hub is the central energy in which all activities related to a system, including production, storage and energy consumption in the application equipment are determined. Large appliances consume a large portion of energy in homes, and only some of them can have less effect on the cost and greenhouse gas emissions for the consumer by planning. There is now an intelligent control tool that allows the consumer to plan their home appliances on a daily or weekly basis while using them to pay less in non-peak times. Also, the use of home appliances can be controlled using the home network system and remote control can be used to activate them. These systems usually have several dedicated controls that allow the appliances connected to the power socket and the home control center to be turned on and off by connecting them. As a result, the user can control various programs and events and implement rule-based decision making in controlling central appliances. In this regard, an intelligent decision-making core is considered here that can optimally plan the use of home appliances to avoid paying energy costs as much as possible. This intelligent core is an integral part of EMSs that are modeled based on mathematical equations. Figure 1 provides an overview of the use of an energy hub with a variety of appliances including energy storage systems (e.g., batteries), power generation systems (e.g., photovoltaic solar, wind power), and two-way communication links. You see between these components.

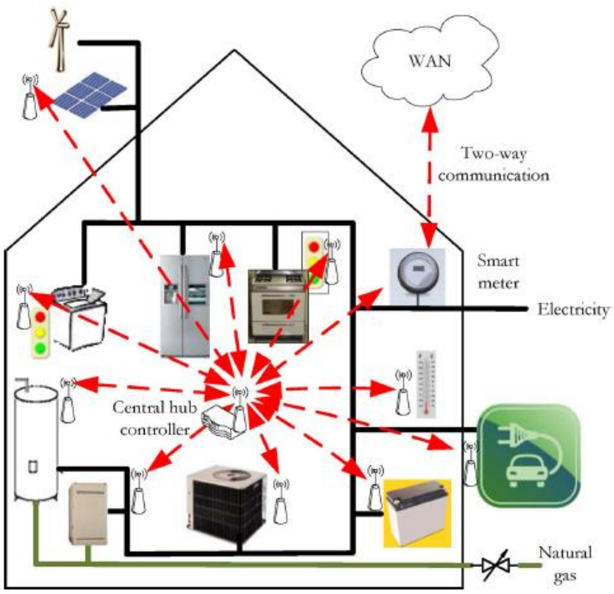

Figure 1: *Household energy hub structure*

There is a proposed mathematical model as well as a control method for the use of equipment in the central hub controller. This controller tries to obtain the optimal time in using the devices by using the mathematical model of each component in the hub, parameter settings and other external information such as user needs at the time of consumption. This problem is shown in Figure 2. The device database includes all the technical features of the components (e.g., power rate, storage / production level), and external information including price energy information, weather forecast, solar radiation, and CO emissions forecast.

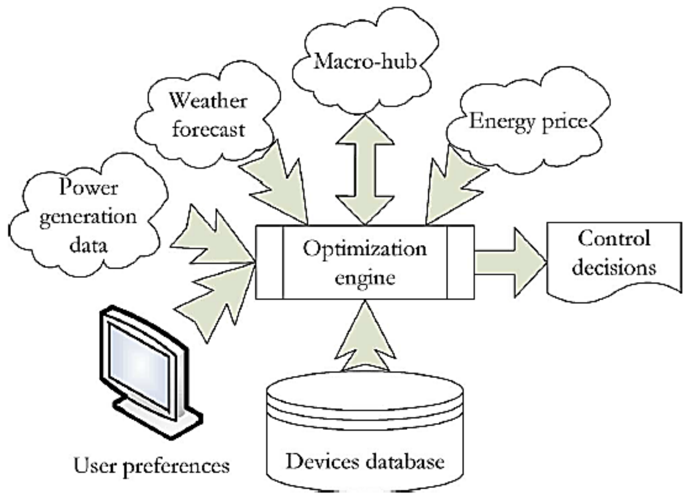

Figure 2: *A central hub controller*

The planning horizon and length of each time period in optimization models can vary depending on the type of hub and the energy activity that occurs at the center. Now we try to have a brief description of each of the determining factors in the implementation of optimization.

1- User request (Consumer):
Execution models of home energy hubs should be a priority for the user's request and needs, and sufficiently, these execution commands should be simple and executable for the consumer. This model should include the user's usual behavior (for example, setting the room temperature or the time of use of appliances). The model must be able to execute this request even when the user wants the most changes for a component.

2- Activity level
In residential areas, the presence of people at home (home occupation) has a major effect on the pattern of energy consumption, in addition, the pattern of consumption in each house can be different depending on the season and days of the week and weekends. To consider the effect of home occupation on the pattern of energy consumption, we introduce a term called "activity level". This term indicates the level of hourly activity of energy consumption in a programmable area. Historical data on energy consumption provided by smart metering tools installed in each home can be used to determine a reasonable amount of energy center residential activity. Therefore, previous measurement data of weeks, months, and years can be used to predict energy consumption on a given day and thus generate residential load profiles. This load profile can be used to get an option for the activity level of a house on an hourly basis. An example of this activity level is shown in Figure 3.

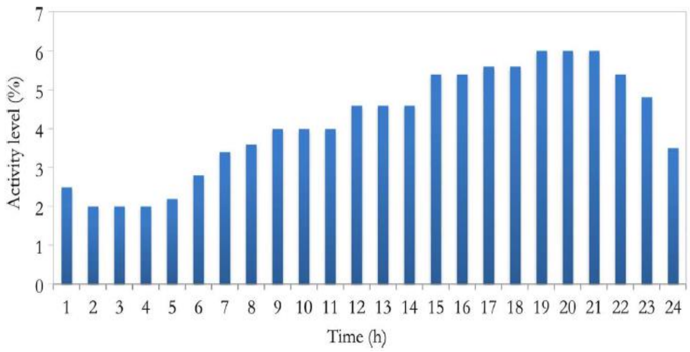

Figure 3: *Percent of the activity level during the day*

3- Energy cost

The main purpose of dynamic pricing is to encourage a reduction in energy consumption during peak load times. Fixed rate plan, usage time and real-time pricing are the three possible pricing options for customers provided by the government. Currently, the first two designs are used more for home use.

The form of the general optimization model used in this research for a home energy hub is as follows. Optimization involves minimizing the set of cost functions that will be introduced.

Min j=objective function

$$s.t \sum_{i \in A} P_i S_i(t) \le P^{\max}(t), \forall t \in \mathrm{T}$$

Where each i is one of the home appliances. The limitation in the second phrase indicates that the power consumption cannot be more than the specified P^{max} at any time of the day or night.

3-3 modeling results

In this research, we have used Yalmip optimization software for energy hub programming with the aim of reducing costs. First, we define device power as Binary. This means that each device can only be on and off, and to calculate their power consumption, if they are on, they are multiplied only by their nominal power.

P = binvar (5.48);

Here, the number 5 indicates the five consumables for which we are supposed to get the optimal on state, and the number 48 indicates that the time interval for calculating the power is thirty minutes.

(30 minutes * 24 = 48 hours a day)

To show the difference in cost at peak times compared to other times, we have used cost coefficients as follows.

cost=zeros(1,48);
cost(1,1:12)=1;
cost(1,13:24)=2;
cost(1,25:36)=5;
cost(1,36:48)=2;

We have used power coefficients to determine the unit power that each device consumes.

power(1,1:48)=450;
power(2,1:48)=500;
power(3,1:48)=600;
power(4,1:48)=400;
power(5,1:48)=500;

After running the program, the power output of each of the consumer devices, storage and production is shown in the following figures (Figure 4 to 10).

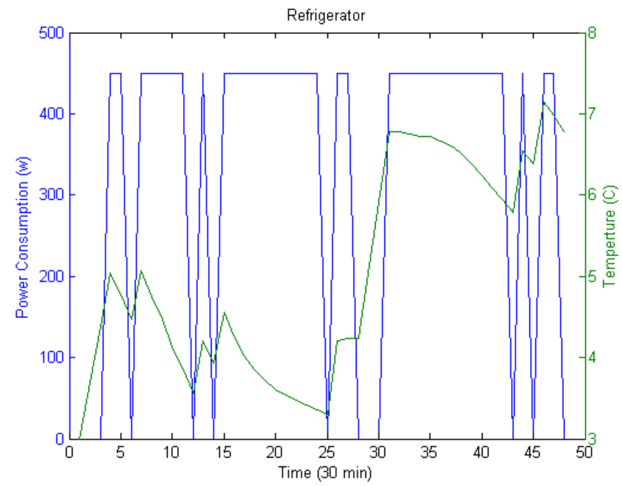

Figure 4: *Refrigerator temperature and power*

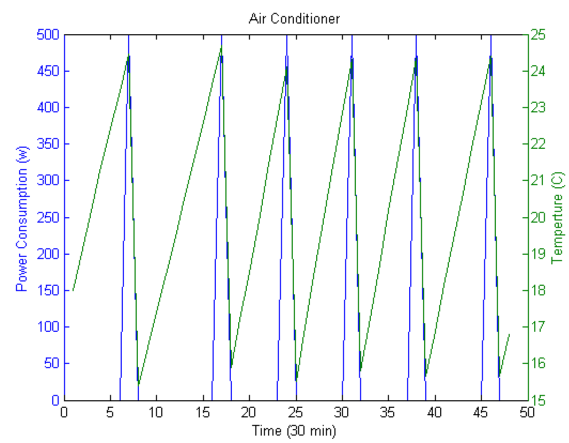

Figure 5: *Cooler temperature and power*

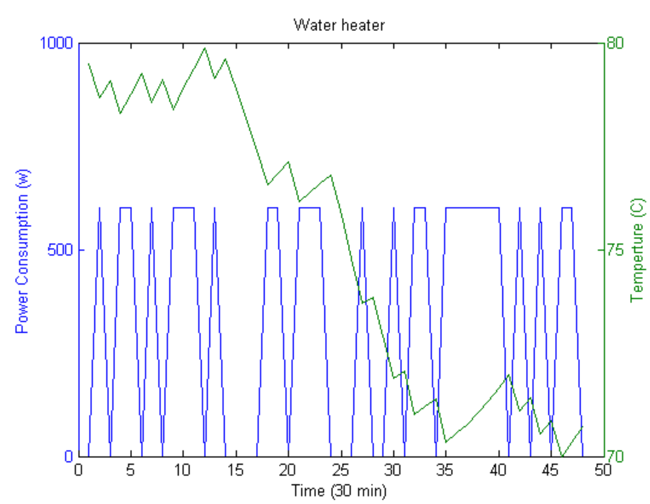

Figure 6: *Water heater temperature and power*

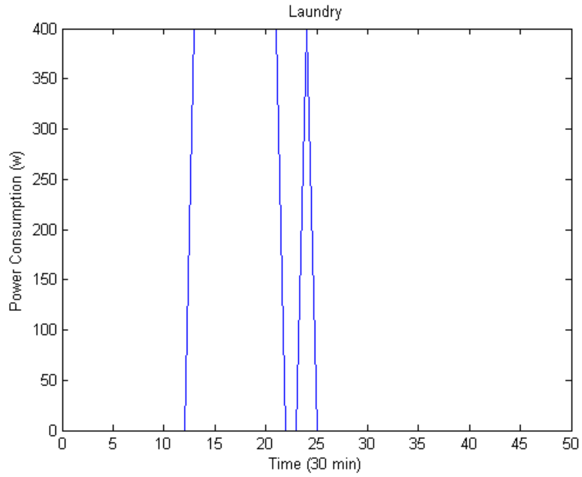

Figure 7: *Washing power*

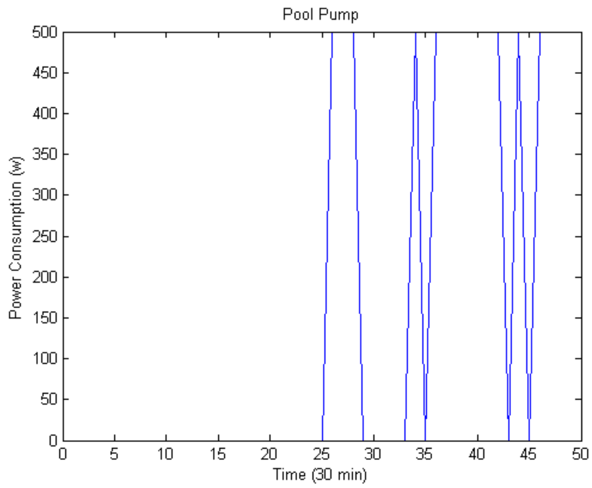

Figure 8: *Pump power*

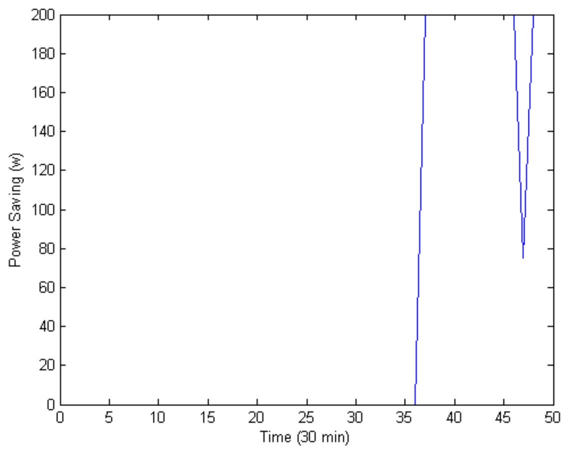

Figure 9*: Power stored by the battery*

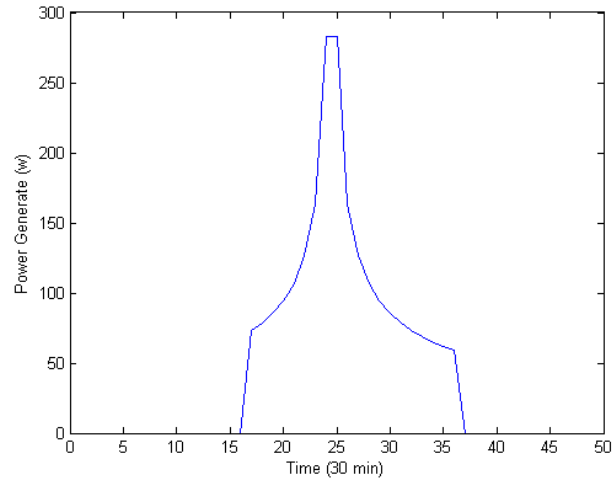

Figure 10: *Solar panel production capacity*

In this section, we want to determine the success rate of using Yalmip optimization method in reducing consumption costs as well as courier based on the obtained results and obtained diagrams. As you can see in Figure 4, the power consumption, which indicates the times when the refrigerator motor is on, is shown in blue and on the other side, the air temperature inside the refrigerator. As it turns out, one of the considered limitations is the temperature of the refrigerator, which is assumed to be between 3 and 8 degrees Celsius. The refrigerator consumes 450 watts of power when turned on. The function of the refrigerator is such that whenever the refrigerator motor starts, the refrigerator air temperature starts to decrease. Yalmip optimization software tries to reduce fuel consumption in general by spending the least amount of power on the device. Of course, Figure 4 is drawn for when we want to do the optimization for only one day. If it is better to plan the constraints on optimization in such a way that the goal of reducing fuel consumption is pursued for a longer period of time. To do this, one limitation that we can add to the optimization program is that the final temperature is less than the initial temperature of the refrigerator during the day. This eliminates the need to put a lot of energy into the device to achieve the user's needs on the first day. The result of applying this constraint can be seen in Figure 11.

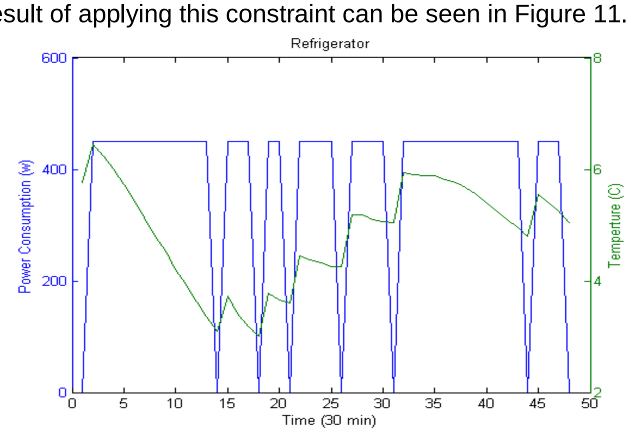

Figure 11: *Refrigerator temperature and power*

As you can see, the initial and final temperatures of the refrigerator are around five degrees Celsius during the day. This limitation can be considered for other devices that work with temperature regulation. All the optimizations made for home appliances are according to the production capacity that the photovoltaic panel can produce during the day. All devices try to get their energy consumption from the solar panel used to reduce energy consumption and costs, as well as pollution from fossil fuels. In this optimization, the maximum power consumption limit is considered. This means that the total power consumption of household appliances cannot exceed a certain amount at a certain time. As can be seen from the diagrams, the Yalmip optimization toolbox has been able to optimize the power consumption for high-consumption home appliances and has shown the right time to turn on each of the appliances, thus reducing costs and economic savings. Be.

4. Conclusion

The concept of microgrids is being used today to help reduce production costs and environmental pollution with several renewable and available sources such as wind and solar energy along with other traditional energy producers such as fuel cells and microturbines. Not only are these resources interconnected, but this interaction continues at higher levels, such as distribution networks. The limitations of fossil fuels and the growing demand for energy, rising living standards, global warming, and ultimately environmental problems have led to advances in technology and the use of new energy every day. The growth and development of human societies has always been parallel to the production and consumption of energy. According to recorded statistics, the world's energy needs have increased significantly over the past 30 years. Today, the use of new energy in supplying the network load is one of the most important and discussed issues. The use of new energy, especially in cases such as remote areas, where the possibility of connecting the load to the national grid is more important, Is located. In this research, a multi-objective energy management system is considered to optimize the performance of the energy hub to reduce costs in one day. In this algorithm, according to each of the limitations of the main consumer appliances such as refrigerators, air conditioners, washing machines, pool pumps, etc., the optimization operation has been performed. Here we have used the nonlinear optimization section of Yalmip program for each of them due to the recurrence of the temperature limitations of the sources and the standby time desired by the user. The use of MATLAB software YALMIP software box in energy consumption optimization was aimed at reducing the costs of using fossil fuels by considering the production capacity of a photovoltaic production unit. With the help of this toolbox, we were able to determine the right time to turn on each of the home appliances according to the practical limitations that each of them has, and make the most of the photovoltaic unit that produces clean energy. Using this method on a larger scale will greatly reduce the cost of generating electricity.

References

[1] Iqbal J, Khan M, Talha M. (2018). A generic internet of things architecture for controlling electrical energy consumption in smart homes. Sustain Cities Soc. 2018; 43: 443- 450.

[2] Lee C-H, Lai YH. (2016). Design and implementation of a universal smart energy management gateway based on the internet of things platform. (2016). IEEE International Conference on Consumer Electronics (ICCE). Piscataway, NJ: IEEE; 2016: 67- 68.

[3] Aburukba RO, Al-Ali AR, Landolsi T, Rashid M, Hassan R. (2016). IoT based energy management for residential area. 2016 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW). Piscataway, NJ: IEEE; 2016: 1- 2.

[4] Althaher S, Mancarella P, Mutale J. (2015). Automated demand response from home energy management system under dynamic pricing and power and comfort constraints. IEEE Trans Smart Grid. 2015; 6(4): 1874-1883.

[5] Amini MH, Frye J, Ilic MD, Karabasoglu O. (2015). Smart residential energy scheduling utilizing two stage mixed integer linear programming. 2015 North American Power Symposium (NAPS). Piscataway, NJ: IEEE; 2015: 1- 6.

[6] Anvari-Moghaddam A, Monsef H, Rahimi-Kian A. (2015). Optimal smart home energy management considering energy saving and a comfortable lifestyle. IEEE Trans Smart Grid. 2015; 6(1): 324- 332.

[7] Abrishambaf O, Ghazvini MAF, Gomes L, Faria P, Vale Z, Corchado JM. (2016). Application of a home energy management system for incentive-based demand response program implementation. 2016 27th International Workshop on Database and Expert Systems Applications (DEXA). Los Alamitos, CA: IEEE Computer Society; 2016: 153- 157.

[8] Rastegar M, Fotuhi-Firuzabad M, Zareipour H. (2016). Home energy management incorporating operational priority of appliances. Int J Electr Power Energy Syst. 2016; 74: 286- 292.

[9] Li Y, Wen Z, Cao Y, Tan Y, Sidorov D, Panasetsky D. (2017). A combined forecasting approach with model self-adjustment for renewable generations and energy loads in smart community. Energy. 2017; 129: 216-227.

[10] Saleem Y, Crespi N, Rehmani MH, Copeland R. (2019). Internet of things-aided smart grid: technologies, architectures, applications, prototypes, and future research directions. IEEE Access. 2019; 7: 62962- 63003.

[11] Ejaz W, Naeem M, Shahid A, Anpalagan A, Jo M. (2017). Efficient energy management for the internet of things in smart cities. IEEE Commun Mag. 2017; 55(1): 84- 91.

[12] Shakeri M, Shayestegan M, Abunima H. (2017). An intelligent system architecture in home energy management systems (HEMS) for efficient demand response in smart grid. Energ Buildings. 2017; 138: 154- 164.

[13] Al-Ali AR, Zualkernan IA, Rashid M, Gupta R, Alikarar M. (2017). A smart home energy management system using IoT and big data analytics approach. IEEE Trans Consum Electron. 2017; 63(4): 426- 434.

[14] Hargreaves T, Wilson C, Hauxwell-Baldwin R. (2018). Learning to live in a smart home. Build Res Inf. 2018; 46(1): 127- 139.

[15] Abedinia O, Amjady N, Ghadimi N (2018). Solar energy forecasting based on hybrid neural network and

improved metaheuristic algorithm. Comput Intell. 2018; 34(1): 241- 260.

[16] Geng L, Wei Y, Lu Z, Yang Y. (2016). A novel model for home energy management system based on internet of things. 2016 IEEE International Conference on Power and Renewable Energy (ICPRE). Piscataway, NJ: IEEE; 2016: 474- 480.

[17] Seyedzadeh, S., Rahimian, F., Glesk, I. (2018). Machine learning for estimation of building energy consumption and performance: a review. Vis. in Eng. 6, 5. (2018). https://doi.org/10.1186/s40327-018-0064-7

[18] Moreno, M. V., Úbeda, B., Skarmeta, A. F., & Zamora, M. A. (2014). How can we tackle energy efficiency in IoT based smart buildings?. Sensors (Basel, Switzerland), 14(6), 9582–9614. https://doi.org/10.3390/s140609582

[19] Meysam Razmara, Guna R. Bharati, Mahdi Shahbakhti, Sumit Paudyal, and Rush D. Robinett. (2018). Bilevel Optimization Framework for Smart Building-to-Grid Systems. IEEE TRANSACTIONS ON SMART GRID, VOL. 9, NO. 2, MARCH 2018

[20] M. Razmara, M. Maasoumy, M. Shahbakhti, and R. D. Robinett. (2015). Optimal exergy control of building HVAC system," J. Appl. Energy, vol. 156, pp. 555–565, Oct. 2015.

[21] M. Maasoumy, M. Razmara, M. Shahbakhti, and A. S. Vincentelli. (2014). "Selecting building predictive control based on model uncertainty", in Proc. Amer. Control Conf. (ACC), Portland, OR, USA, 2014, pp. 404–411.

[22] Muratori, M. (2018). Impact of uncoordinated plug-in electric vehicle charging on residential power demand. Nat. Energy 2018, 3, 193–201. doi:10.1038/s41560-017-0074-z.

[23] García-Villalobos, J.; Zamora, I.; San Martín, J.I.; Asensio, F.J.; Aperribay, V. (2014). Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches. Renew. Sustain. Energy Rev. 2014, 38, 717–731. doi:10.1016/j.rser.2014.07.040.

[24] Luthander, R.; Shepero, M.; Munkhammar, J.; Widén, J. (2019). Photovoltaics and opportunistic electric vehicle charging in the power system – a case study on a Swedish distribution grid. IET Renew. Power Gener. 2019, 13, 710–716. doi:10.1049/iet-rpg.2018.5082