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THE DSR MODEL IS APPLYING TO MITIGATE THE PEAK DEMAND: WHEN AC IS USED FOR PRE-COOLING METHOD

Diksha Pareta
Department of Electrical Engineering,
Madhav Institute of Technology & Science, Gwalior, (India)

ABSTRACT

This paper shows that the DSR model is used by electricity consumers for mitigating the air-conditioning price and load peak impact on the electricity system. The proposed model allows consumers through an aggregator to manage air-conditioning when as a function of spike and possible a price spikes. The main purpose of this research is to denote how consumers can minimize the total market cost by optimizing air-conditioning to account for occurrences of a price spike in the electricity market during hot days on weekdays in the period 2011 to 2012.If a spike may occur in the middle of the day then the optimal solution is assessed for the energy cost and considering the probability of a spike and the benefits of the DSR programs are also identified. When there is a substantial risk of an electricity price spike then this model investigate show pre-cooling a building can be used to minimize energy costs. The model was tested with Queensland electricity market data from the Australian Energy Market Operator and Brisbane temperature data from the Bureau of Statistics during hot days, 2011 to 2012.This research aimed to develop a consumer demand side response model to assist electricity consumers to mitigate peak demand in the middle of the day. The proposed model allows consumersto independently and proactively manage air conditioning peak electricity demand. The main contribution of this research is how to show consumers can mitigate peak demands by optimizing energy costs for air conditioning in a several cases, no spike and spike cases. This model also investigates how air conditioning applied a pre-cooling method when there is a substantial risk of a price spike.

Keywords: Consumer, Electricity, Demand Side Response, Energy, Price Spike, Pre-Cooling.

I INTRODUCTION

In Queensland, peak demand generally occurs on hot days between 10:00 to20:00. On hot summer days, significant increases in demand occur due to the widespread use of air-conditioning [1]. This means a price spike will be more likely on hot days. Price spikes often occur in the middle of the day when ambient temperatures increase resulting in a significant increase in the use of air conditioners. There is an increased cost with respect to energy markets when many air-conditioners operate at the same time. A load survey study undertaken by the Queensland Government indicated that each kilowatt of air-conditioning installed in Queensland costs up to $3000 in new energy infrastructure to meet peak demand [2]. Therefore, air-conditioning usage contributes greatly to peak load growth in both the commercial and residential sectors in Queensland [3].Seasonal climate variation has a significant impact on the operation of electrical power systems. Due to the temperature rises in summer, the electricity demand will increase with the load of air conditioning or other appliances. Moreover, if the consumers all turn on the air conditioning at the same time, then the total demand will be increased. Temperature is an important driver for electricity consumption. More than40% of end-use energy consumption is related to the heating and cooling needs in the residential and commercial sectors [4]. The following Figure 1 indicates the electricity demand and temperature situation on 9 January 2012. This figure indicates the pattern of demand following the form of temperature. The temperature increased at 09.00 to be30℃ followed by an electricity demand of 7500 MW. Based on the regulation of electricity market, small consumer is not allowed direct participation to the wholesale electricity market. Under such a mechanism, only large consumers can offer to curtail or shifting a proportion of their load or bid to wholesale electricity market price and demand. The small-consumer is only able to register in the electricity market through the aggregator. This is envisaged that this mechanism could be rolled out to smaller consumers. The following Figure 2 indicates the competition of power structure in the electrical system. Aggregator is a third party is allowed to negotiate of electricity market direct to the market operator and transmission company. The physical electricity flows delivery from generator by transmission and distribution companies to the consumer. In contrast, the financial electricity flow delivery from consumer through Retailer Company to the market operator then continues to generator. In the competitive electricity market structure, aggregator is needed to do coordination with the retailer and distribution company to provide good service to the consumer. These service include the information about electricity market price and demand. As a result, small-consumer can participate to the wholesale electricity market.

II RESEARCH METHODOLOGY

2.1Numerical Optimization

The model shows how air-conditioning should decrease temperature loads in high temperature periods when there is a substantial risk of a price spike, that is, by applying a pre-cooling method to avoid high prices in a critical peak period. Consumers are able to operate the air-conditioning usage by controlling the desired levels of room temperature, turning on the air-conditioning when the temperature rises to a maximum threshold (i.e., 25℃) then turning it off for the next period until the temperature drops to the minimum threshold (i.e., 19℃). In addition, this research investigated how consumers can optimize energy costs when they have not committed to the permitted temperature. On this optimization process, when the room temperature is less or more than the minimum or maximum temperature threshold then a penalty to the optimization process will be identified. The cycling time of the air-conditioning is based on the result of temperature optimization. In this research, a pre-cooling method was examined as a way to minimize energy costs. Pre-cooling is a method to reduce the room temperature in advance of apossible spike. This method is considered to be effective because it can minimize energycosts and can keep room temperatures comfortable for the consumer. However, precoolingis only undertaken when there is a substantial risk of a price spike because itcosts a lot and the spike may not always occur on the system.The objective is to minimize energy costs by optimizing room temperatures. The energy cost is based on the air-conditioning status, that is, no cost when the air-conditioningstatus is off (U=0) and market cost if the air-conditioning status is on (U=1). To achieve this objective, an optimization package such as MATLAB allows the user to carry out optimization within operational constraints such as a permitted temperature range. In the optimization process, the MATLAB optimization toolbox function ***fmincon*** and the ordinary differential equation solver **ODE45** were used. The toolbox functions of ***fmincon*** were applied using the default option to be acceptable in this work. The ***fmincon*** was used to determine the optimal parameter of the ordinary differential equation. The **ODE45** is used to solve the initial value of problems involving an ordinary differential equation. The ODE45 is more complicated and will take longer steps. However, the accuracy of the result obtained in this study was higher than the accuracy of the result using the **ODE23**. That made the **ODE45** more favorable and reliable than the **ODE23** [7].

In order to formulate the participation of the consumer in the DSR program, the energy cost model which represents the changing temperature and electricity price was developed as reported here. The optimization problem can then be represented as minimized energy cost (Z), or mathematically [8, 9].

$Z(t)=\int_{t=1}^{t=n}[\, S(t).P(t).D(t).U(t)\, d(t)]$ (1)

Subject to constraints[6,10]:

$\frac{d\theta}{dt} = \frac{Q.A(\theta_o(t)-\theta(t))}{H} - \frac{B.U(t)}{H}$ (2)

Where:

Z=minimized energy cost (A$)

S = Electricity price (A$/kWh)

P = Rating power of AC (kW)

D = Duration time for operating AC during a day (hours)

U = Continuous time binary variable (1 or 0)

Q = Heat transfer coefficient from floor walls and ceiling (W/m^2 ℃)

B = Heat transmission from the AC (W)

A = Total area (m^2)

H = Heat capacity of the room (J/℃)

θ_o = Temperature outside (℃)

$\theta(t)$ = Temperature inside the room at time t (℃)

n = interval time t (hour)

During the optimization, if the room temperature is more or less than themaximum or minimum temperature (θ_{max} or θ_{min}) threshold, the minimization willadd a penalty to the computed cost.

If $\theta(t)>\theta_{max}$ or If $\theta(t)<\theta_{min}$ then Penalty =Pen (3)

Else penalty =0 (4)

Therefore, the energy cost will be calculated by:

$$Z(t)=\min\int_{t=1}^{t=n}[S(t).P(t).D(t).U(t)d(t)]+\text{Penalty} \quad (5)$$

Based on equation (2) above indicates that the time to obtain of temperature (T) at any time t as expressed in the following equation:

$$\frac{d\theta}{dt}=k_1*(\theta_o-\theta_{(t)})-k_2*U \quad (6)$$

If the air-conditioning status is off then U=0 and the last term of the equation (6) is zero. The value of the constant k1 can determine by the physical characteristics of the building. When the outside temperature is constant the solution of this equation is:

$$\theta_{(t)}=\theta_o+C*e^{k_1*(t1-tn)} \quad (7)$$

where the value of the constant C is determined by the initial condition when $t_1=t_s$; then:

$$\theta_s(t)=\theta_o+C*e^{-k*0} \quad (8)$$

$$\theta_s(0)=\theta_o+C \quad (9)$$

2.2 Price spike in the electricity market

In this paper, after analysis of the historical test data, a threshold value of A$75 per MWh was used for the analysis of Queensland electricity market during weekday periods.This means any regional reference price more than A$75 per MWh is called a price spike. The average of the electricity prices under A$75 per MWh is calledthe non-spike price, which in this period was A$30.69 per MWh. The datapresented in the table shows clearly that any price above the red line is a so-called pricespike.

2.3 Hot Days and Outside Temperature

In this paper, any day on which the average daily temperature was more than30℃ is called a hot day, as given in Figure 4. The temperature data on 29 February 2012 was selected for the outside temperature (To), as given in Figure 5.

III PROBLEM FORMULATION or MATHEMATICAL FORMULATION

3.1 Description of Methodology

Due to the pattern of high outside temperature, the consumer is required to participate in the DSR program starting from 10:00 to 19:00. The case study reported in this paper illustrates the optimization of the air conditioning if a spike may only occur at midday. This model is only appropriate when we know the spike may only occur in the middle of the day. Numerical modeling is a possible solution to minimize the energy cost by control the room temperature with consideration of the varying electricity market prices and outside temperatures. In this simulation, the maximum and minimum permitted temperatures of 25℃ and 21℃ were chosen. The energy cost was calculated when the air conditioning was on, and the cost was zero when the air conditioning was off. This method continued until the time of operating the air conditioning had expired. To make the temperature comfortable for the consumer, the room temperature was only allowed to be between 19℃ and 25℃. This means the temperature was not allowed to reach the maximum and minimum permitted temperatures. For the purpose of the simulation, the starting point temperature of 22°Cwas chosen with the air conditioning status off. Table 1 summarizes the parameters of the typical room and the air conditioning used in this optimization. Applying the pre-cooling method was needed to anticipate the expensive cost when a price spike may occur in the middle of the day.

3.2 Cost as a Function of Price Spike Under DSR Program

The control system optimized the room temperature of the air conditioning to define the energy cost for consumers. The aim of the controller is to maintain the temperature between the permitted maximum and minimum temperatures in order to provide a comfortable room temperature for the consumer. In this optimization, the maximum and minimum temperatures were 25°C and 21°C. Temperature starting of22°C was chosen. Under DSR program the cycling temperature room was longer than without DSR program. This is to give more option and more flexibility for the optimization. In addition, since the price spike may occur in the middle of the day, the consumer is required to optimize to achieve minimum expected energy costs. Under the DSR program, the control system applied the pre-cooling method to avoid high costs when a spike happens. Similar to the previously described method, the air conditioning was turned on once the temperature rose to the maximum permitted temperature. Then, it was turned off when the temperature dropped to the minimum permitted temperature. The control system kept the room temperature between the maximum and minimum permitted temperatures. If is the electricity price when a spike occurs, Pen is the penalty, then the total market cost for the spike case (Mcs) is determined by the following equation:

$$MCs(t) = \min \int_{t=1}^{t=n} [(Ss(t) \cdot P(t) \cdot U(t) \cdot D(t)) d(t)] + \text{Penalty} \quad (6)$$

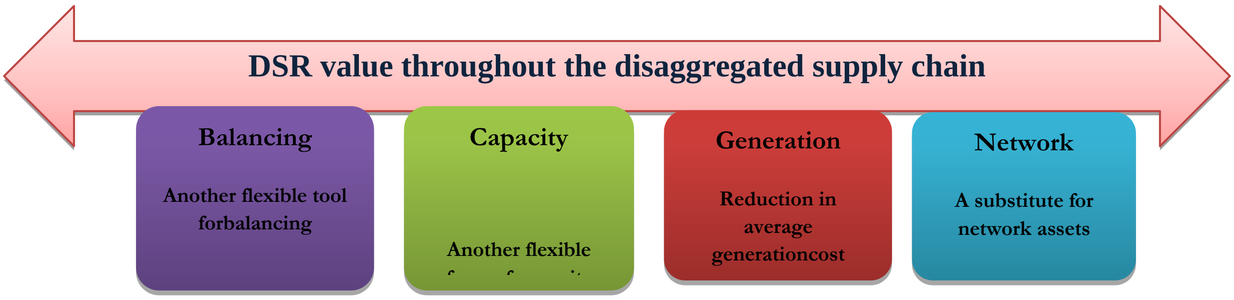

Fig.1 Useable DSR model across the electricity system.

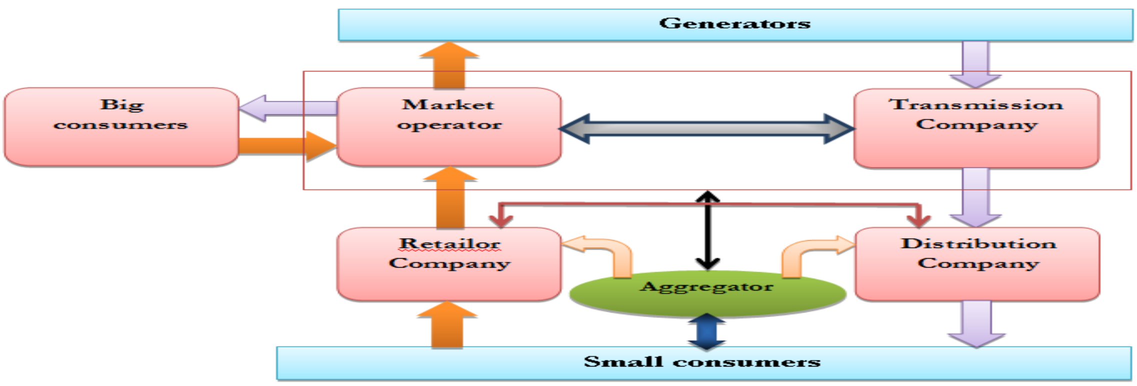

Fig.2 Competitive electricity market model

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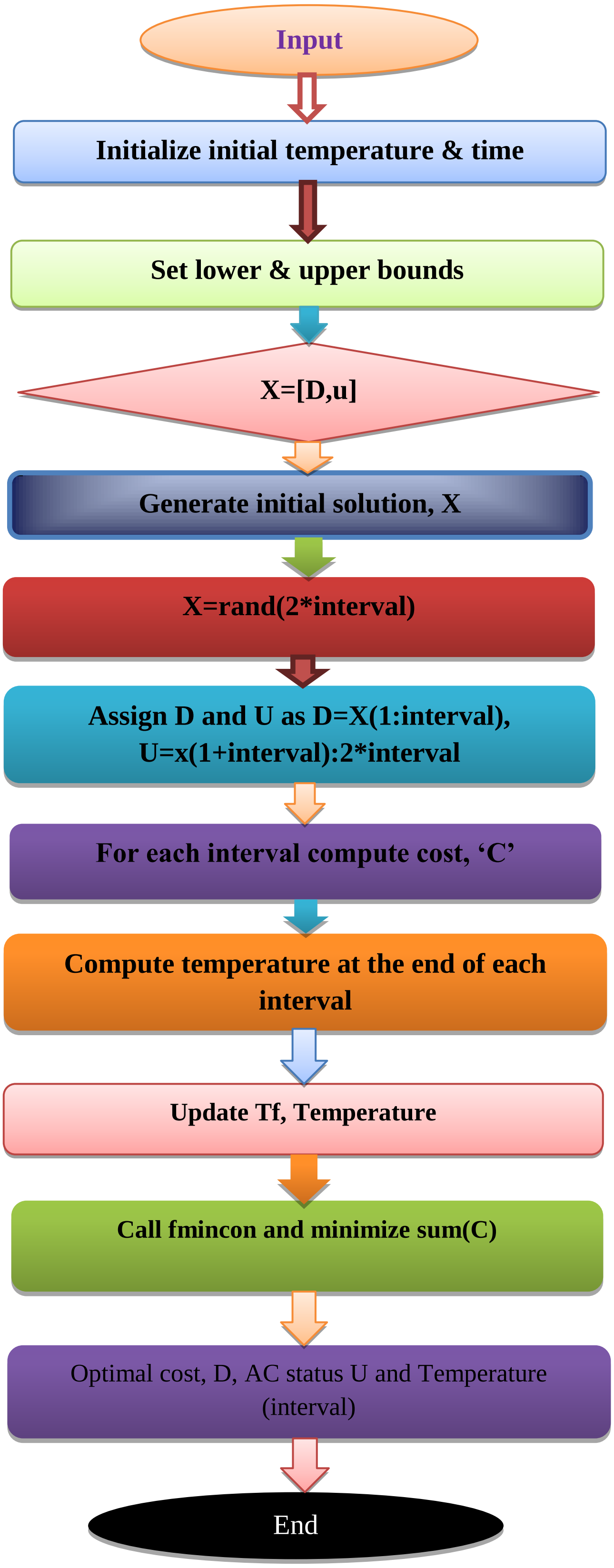
IV FLOW CHART FOR OPTIMIZATION



V NUMERICAL RESULTS

Table1.Test data table of outside temperature for day 1,2 &3 and Electricity price.

S.no.	Outside temperature of day 1	Outside temperature of day 2	Outside temperature of day 3	Electricity non-spike price (S)	Electricity price spike (S)
1.	27	28	20	38	38
2.	28	23	23	40	40
3.	32	21	25	45	45
4.	33	28	46	52	52
5.	35	29	32	58	58
6.	34	30	31	63	63
7.	31	34	28	65	65
8.	30	32	29	67	67
9.	45	48	23	72	72
10.	41	26	37	35	75
11.	39	32	36	40	78
12.	36	36	35	55	95
13.	34	23	34	62	97
14.	30	41	45	28	100
15.	28	43	41	43	103
16.	27	42	40	55	50
17.	25	45	24	47	47
18.	24	30	22	69	39

Table2. Test data table of a building for the analysis. [12]

S. No.	Parameters	Value	Unit
1.	Heat transfer coefficient from floor wall and ceiling(Q)	1	w/m^2
2.	Total areas (A)	54	m^2
3.	Heat capacity of the room (H)	44.4	j/c
4.	Heat transfer from the AC (B)	900	w
5.	Reference of temperature	22	C
6.	Hysteresis	3	C
7.	Maximum temperature (θ_{max})	25	C
8.	Initial temperature (θ_{in})	21	C
9.	Duration time in hours	9&18	h
10.	Number of switches (N)	40	
11.	Rating power of AC (P)	2.6	kw

Table3.Minimized cost and Temperature for 9 intervals for 1st day.

Iteration	Duration time in hour (D)	Continuous time binary variable (U)	Temperature (T2) in ℃	Computed cost
1.	0.5000	0	22.8225 24.0684	0
2.	0.1667	1	22.8224 21.0000	17.3336
3	0.1676	1	20.7144 21.0010	48.1689
4.	0.1668	1	22.8093 24.4875	51.1162
5.	0.4155	1	21.4307 21.1034	91.2212
6.	0.5000	1	24.2803 24.9378	110.4521
7.	0.1667	0	22.8209 21.0703	0.0000
8.	0.1667	0	25.8790 22.4041	0.0000
9.	0.1668	1	22.8855 29.9322	31.2296

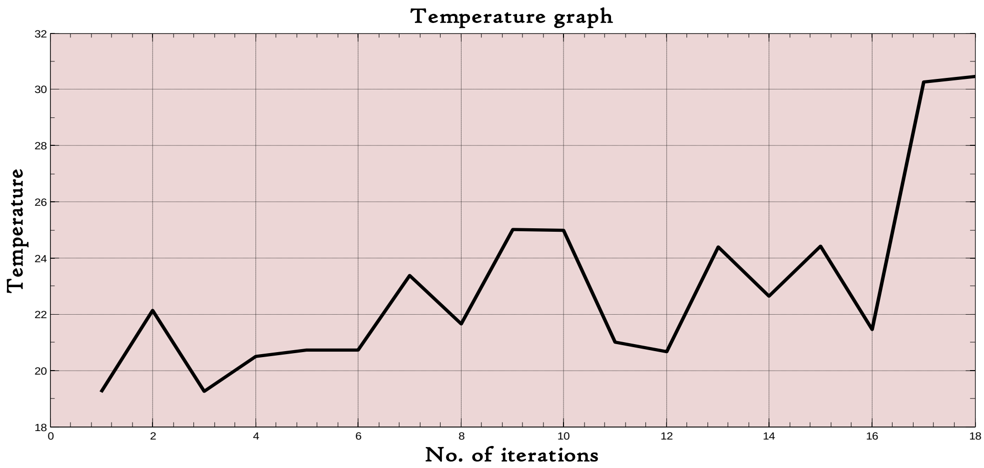


Fig3.Temperature graph of 9 intervals for 1st day

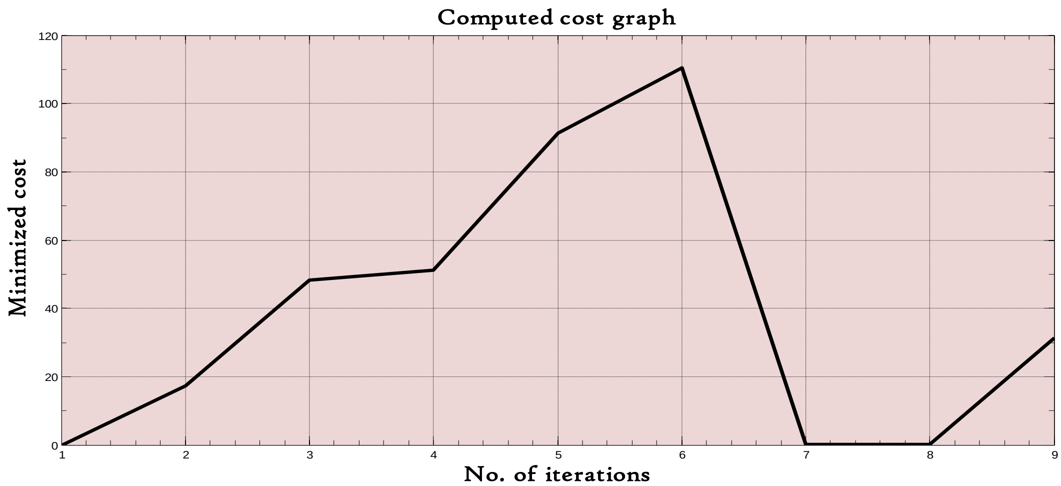


Fig4.Minimized cost graph of 9 intervals for 1stday

Table4. Minimized cost and Temperature of 9 intervals for 2nd day

Iteration	Duration (D)time in hour	Continuous time binary variable(U)	Temperature T2 in ℃		Computed cost
1.	0.1669	1	19.2241	24.9947	16.4907
2.	0.1668	1	22.1473	21.0199	194.9406
3.	0.4992	0	19.2439	20.6800	175.6116
4.	0.3735	0	20.4954	24.3834	27.4953
5.	0.4997	0	20.7250	22.6493	27.4953
6.	0.1667	1	20.7099	24.4342	27.3033
7.	0.2679	0	23.3715	21.4566	0.0000
8.	0.1742	0	21.6553	30.2570	0.0000
9.	0.3312	0	25.0000	30.4568	0.0000

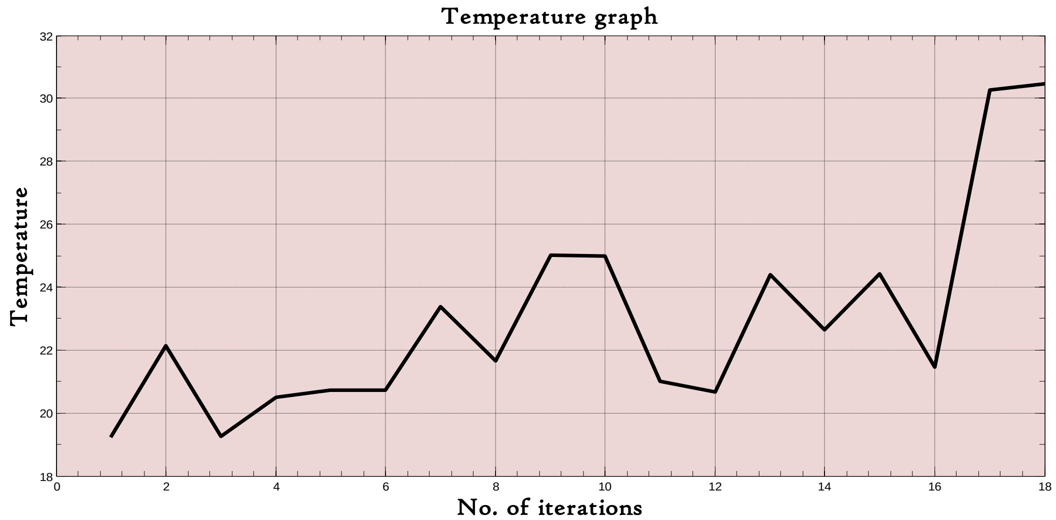


Fig.5 Temperature graph of 9 intervals for 2nd day.

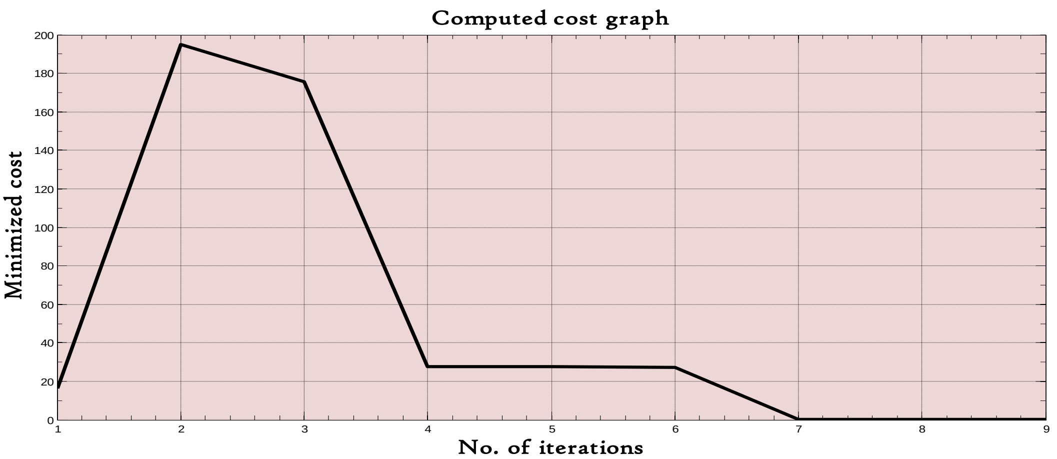


Fig.6 Cost Graph of 9 Intervals For 2nd Day.

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Table5. Minimized cost and Temperature of 9 intervals for 3rd day

Iterations	Duration (D) time in hour	Continuous time binary variable(U)	Temperature T2 in ℃		Computed cost
1.	0.50000	0	20.5444	20.5443	0
2.	0.1667	1	17.9360	19.6235	62.9012
3.	0.4656	0	21.9480	21.3898	306.3993
4.	0.4983	1	25.0000	25.0436	373.7682
5.	0.4323	1	21.0732	21.9370	65.1890
6.	0.1675	0	23.6078	20.5233	0.0000
7.	0.1686	0	21.9094	18.4010	0.0000
8.	0.3073	0	21.7065	19.7486	0.0000
9.	0.3506	0	22.2656	20.2825	0.0000

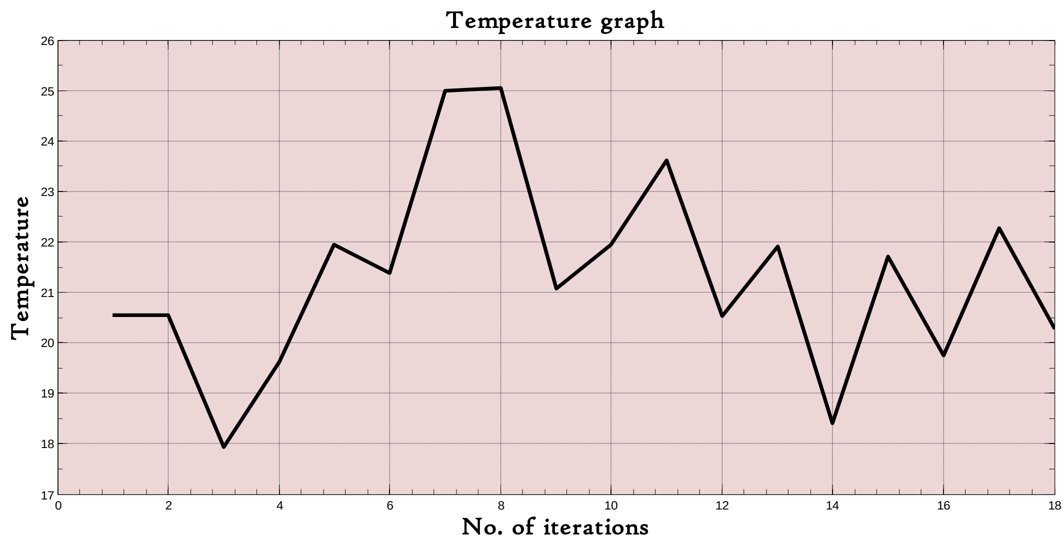

Fig7. Temperature graph of 9 intervals for 3rd day

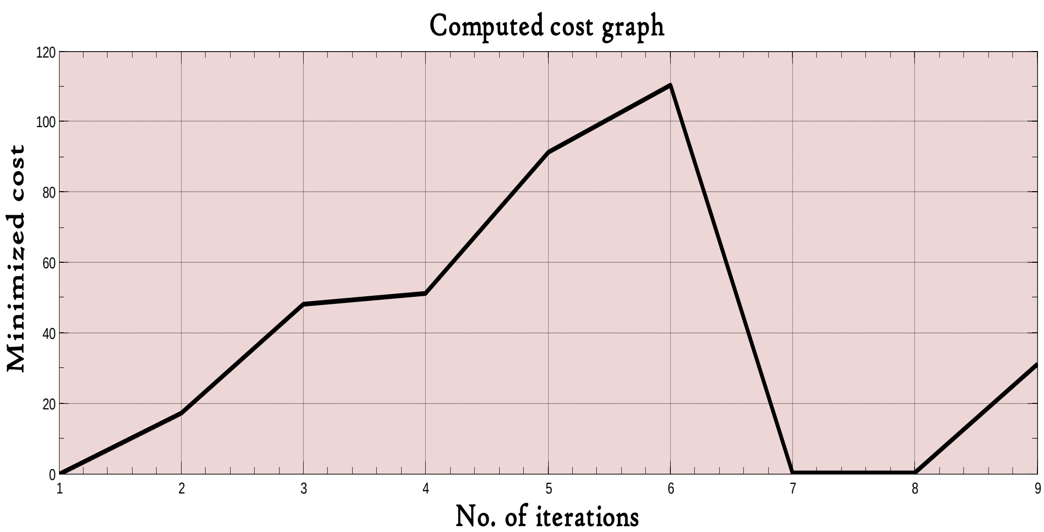

Fig.8 Minimized cost graph of 9 intervals for 3rd day

Table6. Minimized cost and temperature for 18 intervals.

Iterations	Duration(D) time in hour	Continuous time binary variable(U)	Temperature T2 in ℃	Computed cost
1.	0.2167	1	18.5285 20.4146	21.4119
2.	0.1989	1	18.4631 21.0805	267.8348
3.	0.2330	1	19.6624 22.5289	280.9532
4.	0.2486	0	25.000022.7168	133.7565
5.	0.1667	1	21.912326.2737	25.1416
6.	0.1809	1	24.507828.8471	29.6374
7.	0.4469	1	22.761523.8395	75.5264
8.	0.4416	1	19.474121.0196	76.9190
9.	0.4461	1	24.081925.4101	236.0951
10.	0.2109	0	28.937827.5730	152.5926
11.	0.4604	1	25.3266 25.9703	487.1355
12.	0.2054	0	28.1878 25.5218	32.6608
13.	0.4533	1	22.0517 22.7120	433.0925
14.	0.1667	0	24.0496 20.4785	318.7802
15.	0.2329	0	22.3337 19.2824	318.7802
16.	0.2425	0	21.2535 18.3172	318.7802
17.	0.3697	0	20.7371 18.9189	318.7802
18.	0.2147	1	16.2567 18.5270	48.0577

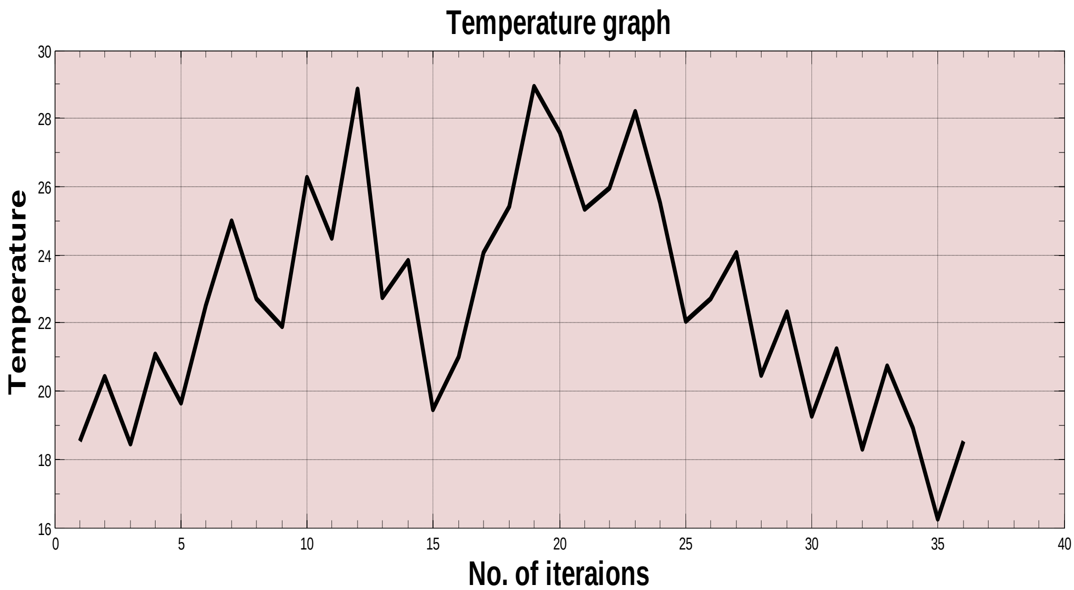

Fig.9 Temperature graph for 18 intervals

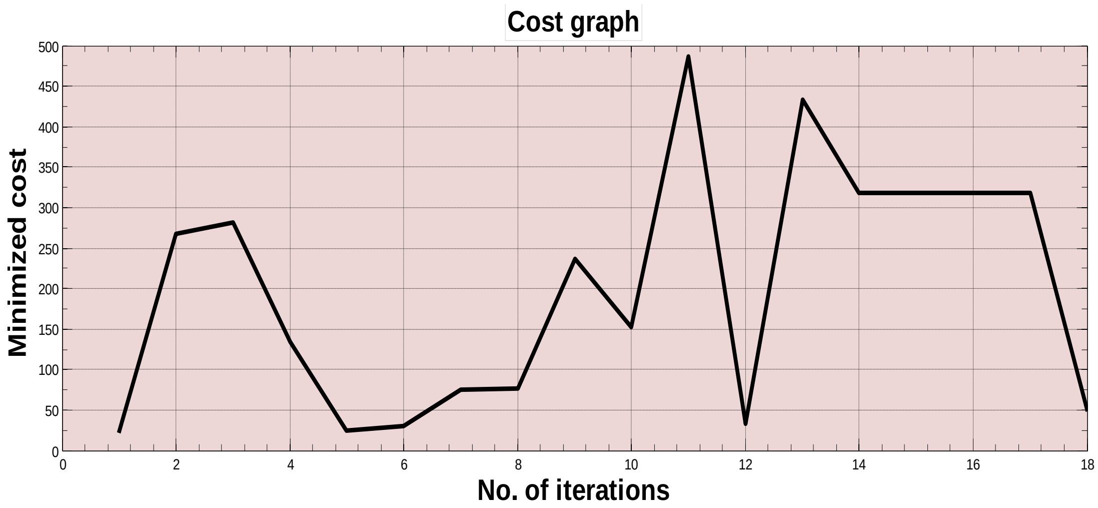

Fig.10 Minimized cost graph for 18 intervals.

VI CONCLUSION

This paper has demonstrated that the proposed DSR model allows consumers to manage and control air conditioning for every period based on the electricity market price. The model is applicable for both residential and commercial consumers to minimize the cost of fluctuating energy prices. The proposed model can assist the consumer to optimize the energy cost of air conditioning to meet a price spike. Numerical modeling is a possible solution to minimize the energy cost by optimizing the temperature room considering the varying electricity market price and outside temperature. This result indicates that, the consumer should apply the pre-cooling method to minimize energy costs by anticipating the electricity price spike when we know the spike may occur in the middle of the day. In addition, a pre-cooling method should be applied to avoid electricity prices at critical times. However, pre-cooling should only be undertaken when there is a substantial risk of a price spike high.

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