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# Demand side response model for cost and peak load demant demand optimization

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**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. The model was tested with Queensland electricity market test data from the Australian Energy Market Operator and Brisbane temperature test data taken 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 consumers to independently and proactively manage air conditioning peak electricity demand.

**Keywords—**Consumer, Electricity, Price-spike, fmincon, ODE45.

## I. INTRODUCTION

Demand Side Management is the modification of consumer's demand of electricity through various methods such as financial incentives and consumer education. Usually the goal of DSM is to encourage the consumers to use less energy during peak hours or to move the time of energy use to the off-peak hour's viz. night. From the test data of Queensland, it is shown that the peak demand generally occurs on hot days between 10:00 to 20:00. 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. For minimizes the cost and temperature the **MATLAB** toolbox **FMINCON** and **ODE45** is used. The Queensland costs up to $3000 in new energy infrastructure to meet peak demand is installed [2]. Therefore, air-conditioning usage contributes greatly to peak load growth in both the commercial and residential sectors in Queensland [3]. Seasonal climate variation has a significant impact on the operation of electrical power systems. Due to the temperature rises in summer, the electricity demand will increase with the load of air conditioning or other appliances. Moreover, if the consumers all turn on the air conditioning at the same time, then the total demand will be increased. Temperature is an important driver for electricity consumption. More than 40% of end-use energy consumption is related to the heating and cooling needs in the residential and commercial sectors [4]. The following Table 1 indicates the electricity demand prices as normal and price-spike and outside temperature data for 1$^{st}$, 2$^{nd}$, & 3$^{rd}$ day. The temperature increased at 09.00 to be 30℃ 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 1 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 services include the information about electricity market price and demand. As a result, small-consumer can participate to the wholesale electricity market.

## II. PROPOSED METHODOLOGY

### 2.1 Mathematical 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. 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. This method is considered to be effective because it can minimize energy costs and can keep room temperatures comfortable for the consumer. 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-conditioning status 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].

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

Subject to constraints [6,10]

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

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/℃)
$\theta$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 the maximum or minimum temperature ($\theta$max or $\theta$min) threshold, the minimization will add 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:

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

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 called the non-spike price, which in this period was A$30.69 per MWH.

### 2.3 Hot days and outside temperature

In this paper, any day on which the average daily temperature was more than 30℃ is called a hot day. The temperature data on 29 February 2012 was selected for the outside temperature (To), as given in Table1.

## III. PROBLEM 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℃ was chosen with the air conditioning status off. Table 2 shows the parameters of the typical room and the air conditioning used in this optimization.

### 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℃ and 21℃. Temperature starting of 22℃ was chosen. 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. 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:

$$MCs(t) = \min\int_{t=1}^{t=n}[(Ss(t)\,.\,P(t).\,U(t).\,D(t))d(t)]+\text{Penalty} \quad (10)$$

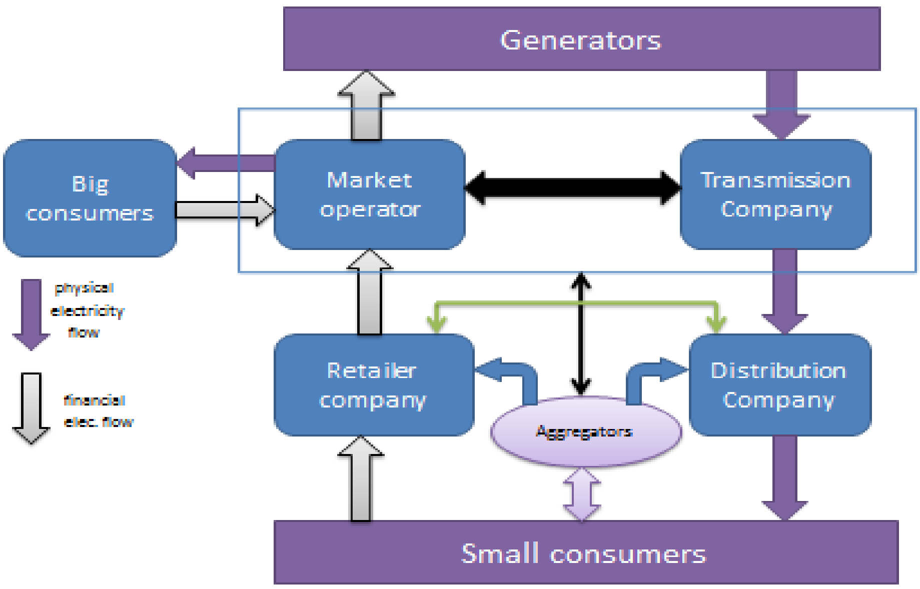


*Fig 1. Competitive model of electrical system*

 

# IV. NUMERICAL RESULTS

***Table 1. 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 | 36 | 52 | 52 |
| 5. | 35 | 29 | 32 | 58 | 58 |
| 6. | 34 | 30 | 30 | 63 | 63 |
| 7. | 31 | 34 | 23 | 65 | 65 |
| 8. | 30 | 32 | 28 | 67 | 67 |
| 9. | 22 | 23 | 24 | 72 | 72 |
| 10. | 41 | 26 | 27 | 35 | 75 |
| 11. | 39 | 32 | 29 | 40 | 78 |
| 12. | 36 | 36 | 35 | 55 | 95 |
| 13. | 34 | 23 | 37 | 62 | 97 |
| 14. | 30 | 40 | 40 | 28 | 100 |
| 15. | 28 | 43 | 29 | 43 | 103 |
| 16. | 27 | 26 | 26 | 55 | 50 |
| 17. | 25 | 21 | 24 | 47 | 47 |
| 18. | 24 | 24 | 22 | 69 | 39 |

***Table 2. 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 ($\theta_{max}$) | 25 | C |
| 8. | Initial temperature ($\theta_{in}$) | 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 |

 

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*Table 3. 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 (per MWH) |
|---|---|---|---|---|---|
| 1. | 0.1686 | 1 | 18.6521 | 21.1174 | 31.5548 |
| 2. | 0.2328 | 0 | 20.7581 | 24.2563 | 234.7584 |
| 3 | 0.1667 | 0 | 22.2971 | 23.2880 | 234.7584 |
| 4. | 0.4399 | 0 | 18.9776 | 23.3086 | 0.0000 |
| 5. | 0.5000 | 1 | 21.0000 | 23.3112 | 126.0886 |
| 6. | 0.1691 | 0 | 18.4448 | 26.7408 | 0.0000 |
| 7. | 0.4999 | 1 | 24.0611 | 26.2718 | 133.8669 |
| 8. | 0.1667 | 0 | 23.4459 | 22.5643 | 0.0000 |
| 9. | 0.1692 | 1 | 21.1167 | 22.7086 | 194.7520 |

**Total minimized cost=995.7791**

*Table 4. 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 (per MWH) |
|---|---|---|---|---|---|
| 1. | 0.1687 | 1 | 18.6521 | 23.6348 | 31.5825 |
| 2. | 0.1667 | 1 | 22.1229 | 19.9099 | 211.8237 |
| 3. | 0.1667 | 1 | 19.2256 | 19.9399 | 211.2448 |
| 4. | 0.4982 | 0 | 20.4835 | 25.0000 | 347.9990 |
| 5. | 0.1667 | 1 | 17.5200 | 23.8535 | 390.0397 |
| 6. | 0.1667 | 1 | 18.6798 | 25.3494 | 48.0348 |
| 7. | 0.3668 | 0 | 22.9153 | 22.0124 | 109.0090 |
| 8. | 0.1668 | 0 | 22.8902 | 22.3329 | 0.0000 |
| 9. | 0.3226 | 0 | 20.9530 | 19.2273 | 34.9406 |

**Total minimized cost=1384.6741**

*Table 5. 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 (per MWH) |
|---|---|---|---|---|---|
| 1. | 0.50000 | 0 | 20.5444 | 23.2764 | 0 |
| 2. | 0.1733 | 1 | 20.5437 | 25.0000 | 79.3468 |
| 3. | 0.1668 | 1 | 17.8437 | 21.8739 | 349.4675 |
| 4. | 0.1700 | 0 | 19.5345 | 22.3868 | 352.2474 |
| 5. | 0.2454 | 1 | 17.4775 | 22.3830 | 414.1377 |
| 6. | 0.2435 | 0 | 19.9837 | 20.3480 | 88.9727 |
| 7. | 0.4998 | 0 | 22.9756 | 23.2267 | 0.0000 |
| 8. | 0.1674 | 1 | 21.7716 | 20.1651 | 21.7577 |
| 9. | 0.1759 | 1 | 20.1103 | 21.4143 | 86.7005 |

**Total minimized cost=1392.6303**

 

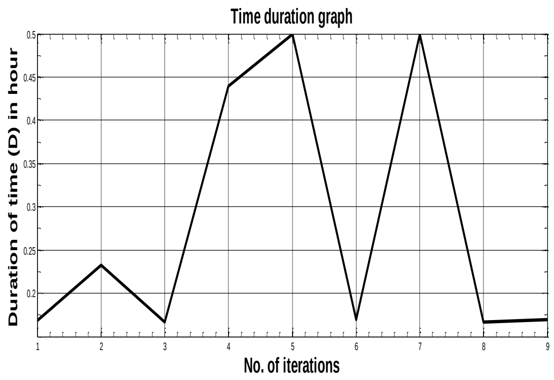


*Fig. 2. Duration of time plot of 1st day for 9 intervals.*

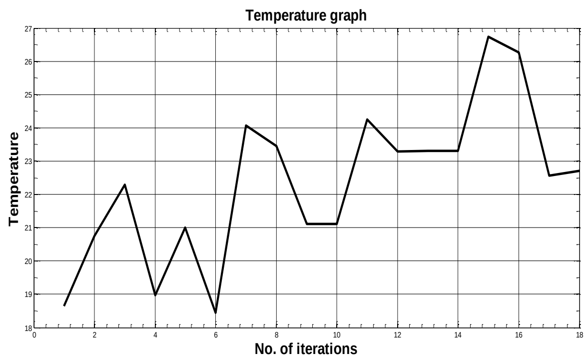


*Fig. 3. Temperature plot of 1st day for 9 intervals.*

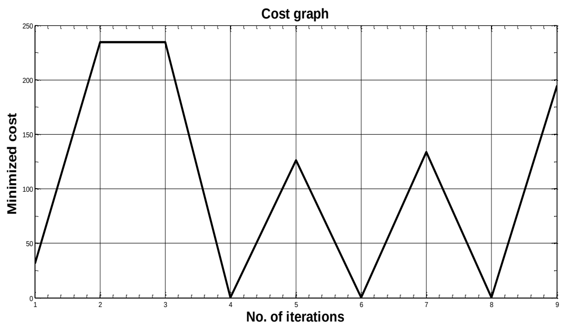


*Fig. 4. Minimized cost plot of 1st day for 9 intervals.*

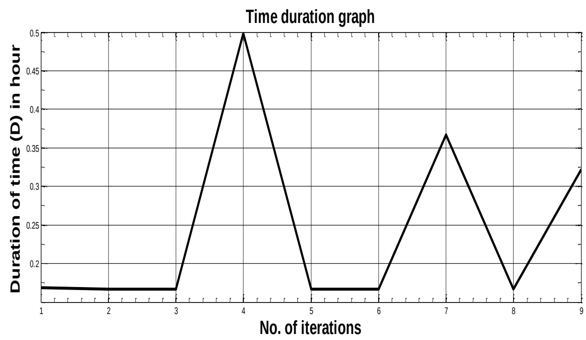


*Fig. 5. Duration of time plot of 2nd day for 9 intervals.*

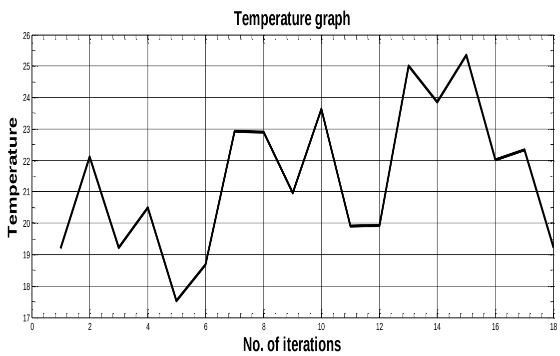


*Fig. 6. Temperature plot of 2nd day for 9 intervals.*

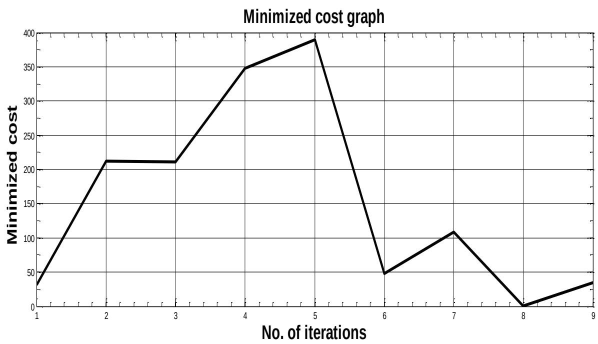


*Fig. 7. Cost plot of 2nd day for 9 intervals.*

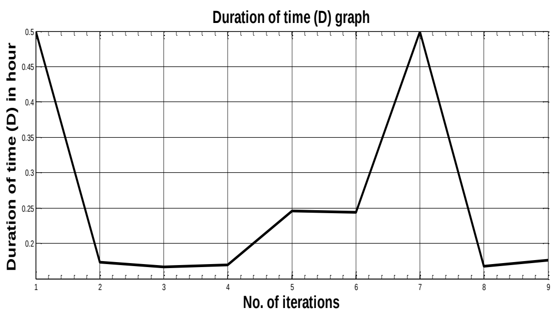


*Fig. 8. Duration of time plot of 3rd day for 9 intervals.*

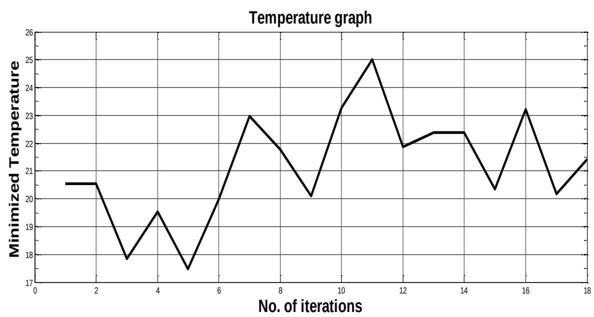


*Fig. 9. Minimized cost plot of 3rd day for 9 intervals.*

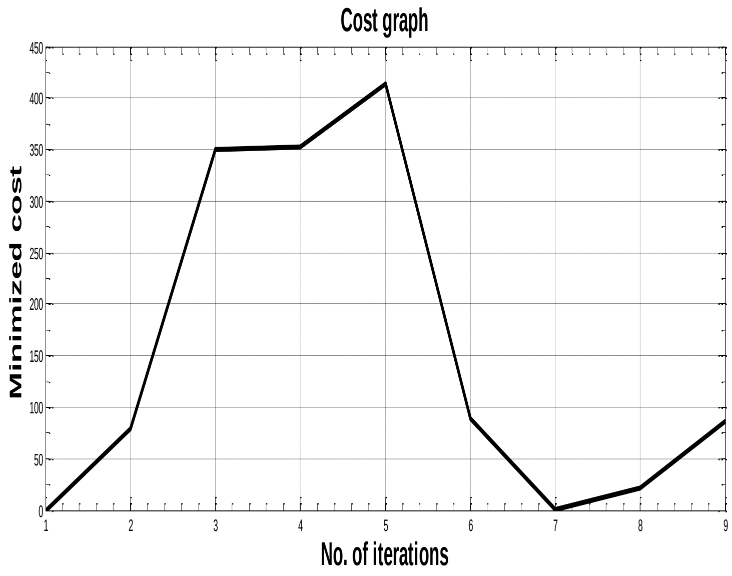


**Fig. 10. Minimized cost plot of 3rd day for 9 intervals.**

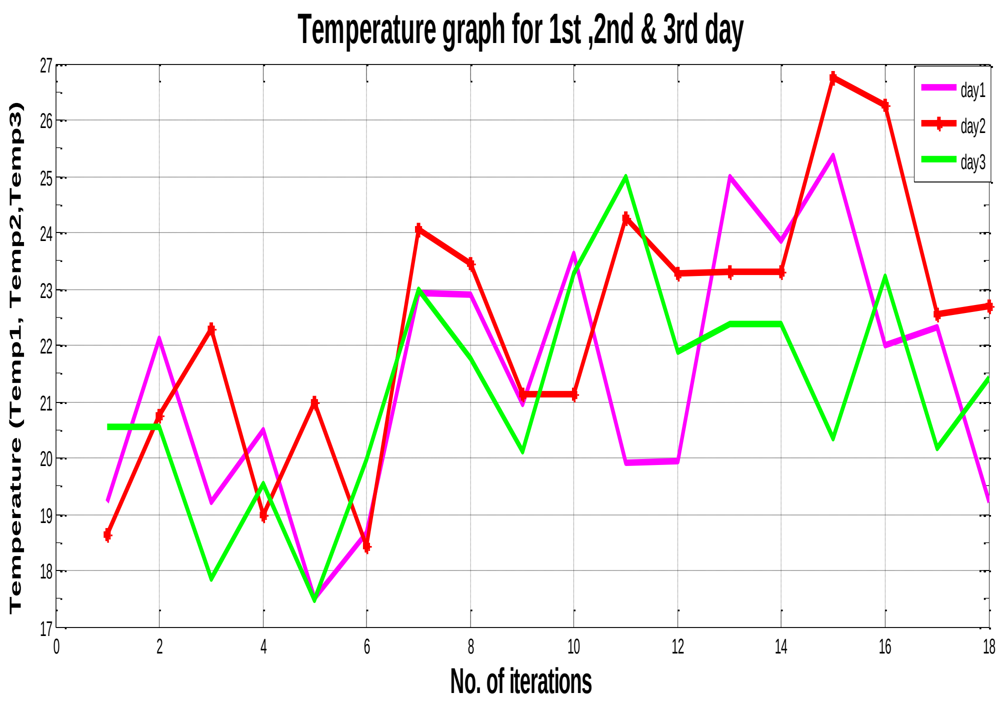


**Fig. 11. Comparison of Temperature of 1st, 2nd & 3rd day for 9 intervals.**

 

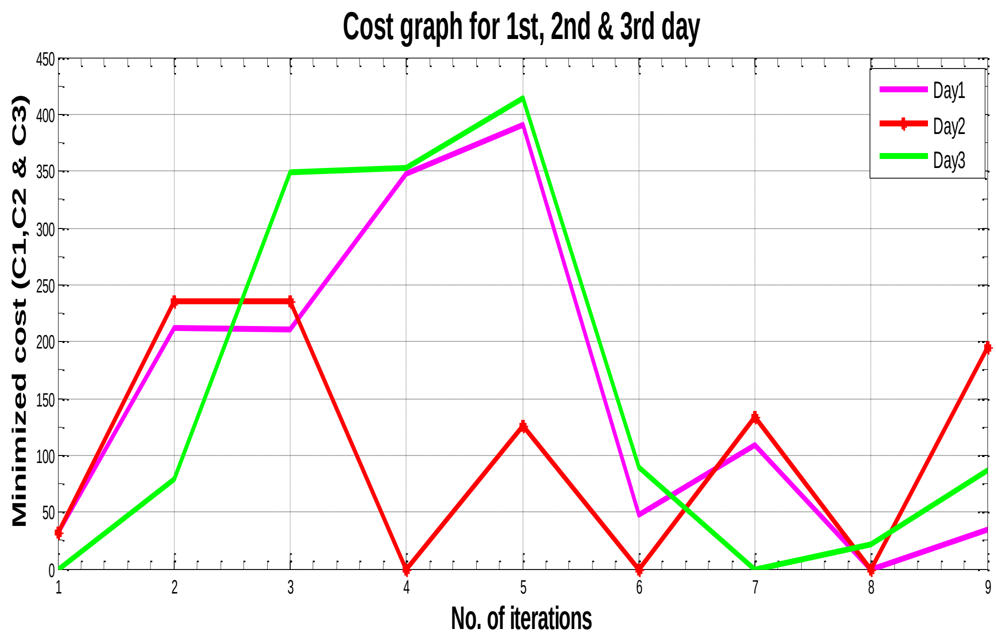


**Fig. 12. Cost comparison of 1st, 2nd & 3rd day for 9 intervals.**

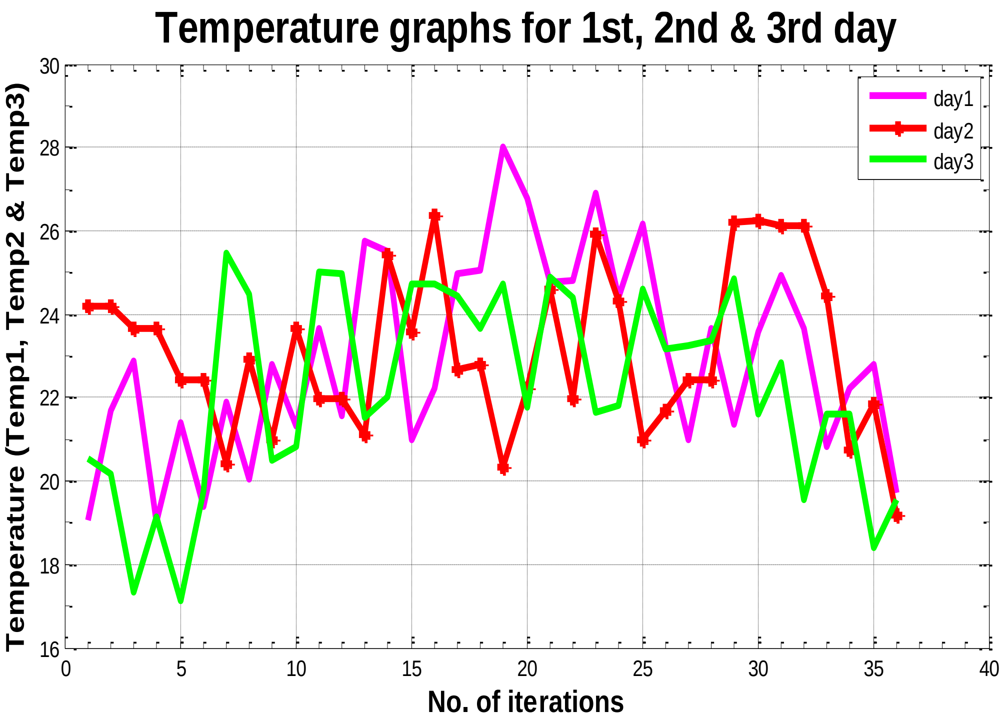


**Fig. 13. Comparison of Temperatures of 1st, 2nd & 3rd day for 18 intervals.**

 

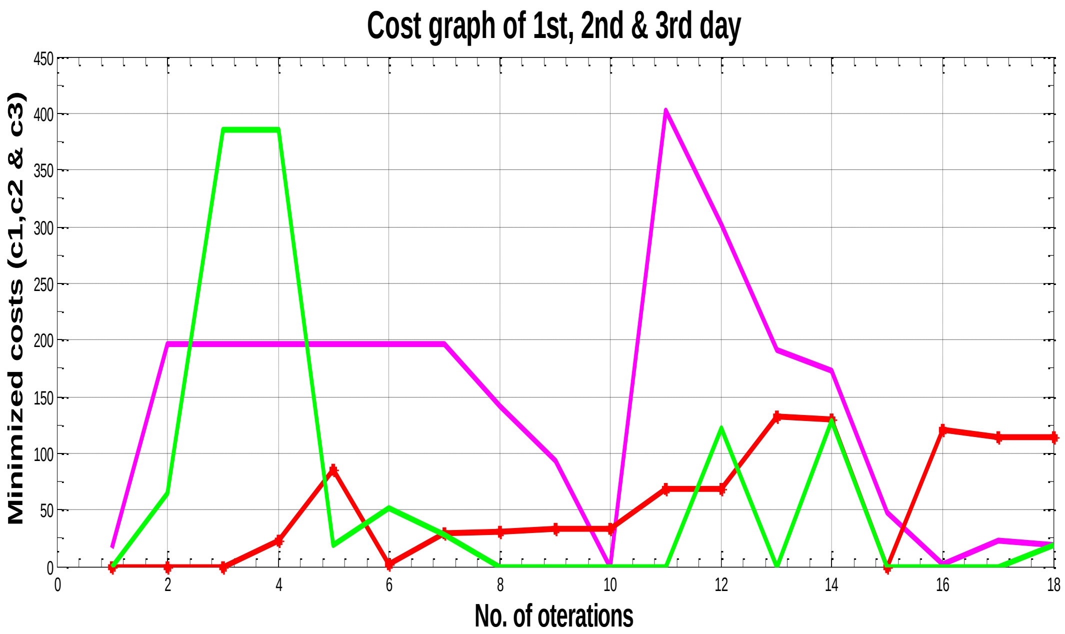


**Fig. 14. Cost comparison of 1st, 2nd & 3rd day for 18 intervals**

## V. 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.

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