

# Load Optimization in Ceylon Steel Corporation through Economic Demand Response Model: A Case Study

W.M.U. Wijeratne, K.A.C. Udayakumar and R.H.G. Sasikala

**Abstract:** Ceylon Steel Corporation Ltd (CSCL) is one of the ten largest industrial electricity consumers in Sri Lanka which produces steel products, with contract demand over 8000 kVA, owing to Rs. 35 million monthly electricity bill. Therefore, it is needed to find strategies and opportunities of energy saving to reduce this high electricity cost. Load optimization techniques play a significant role in electricity cost reduction in industrial consumers.

This case study investigates the opportunities to reduce electricity cost in CSCL through energy efficiency solutions and load profile optimization solutions according to mathematical Demand Response (DR) model. Therefore, detailed energy audit is carried out to identify the load profile of the CSCL and obtained data is analyzed to develop a mathematical model.

Economic DR model is developed based on constant elasticity of substitution utility function known as one of the most popular utility functions in microeconomics. This economic DR model can change consumption patterns from high energy prices to other times to maximize their utility functions. MATLAB simulation results indicate the most suitable load profiles that can interchange electricity consumption. This mathematical model improves the consumption patterns in a load profile over time to reduce electricity cost. The results showed that the model is beneficial for attaining the optimal load control according to time of use (TOU)-based tariff structure.

**Keywords:** Demand response, Energy audit, Load profile optimization, Mathematical model, Utility function

## 1. Introduction

At present, CSCL is one of the ten largest industrial electricity consumers in Sri Lanka, producing a bulk of steel products to the local market. Monthly electricity consumption of the CSCL is around 2,407,500 kWh, and maximum demand is about 6500 kVA. According to Ceylon Electricity Board (CEB) consumer tariff charging system, it belongs to industrial customer category I3. Therefore, approximately 35 million rupees is paid to Ceylon Electricity Board as a monthly electricity bill. Maximum demand of CSCL is 75% of its contract demand where contract demand is around 8000 kVA. 132 kV HT bulk supply is used to obtain electricity from CEB, and two 8.3 MVA transformers are used to step down the voltage to 6.6 kV.

Demand-Side Management (DSM) is used to improve the electrical load profile in the industrial sector. Energy efficiency solutions and demand response (DR) programs are the main components in demand-side management. An energy efficiency solution reduces the total electricity consumption and peak electricity load with the help of energy-efficient equipment and other efficiency improvements [1].

This research study aims to find out strategies and opportunities for energy savings to reduce the monthly electricity bill. For that, it needs to study

the energy-consuming behaviour of CSCL through an energy audit. Possible energy management measures need to be identified and analyzed using the data obtained from the energy audit.

This study focused on developing a demand response mathematical model for load profile optimization and suggests the strategies for optimized load profiles.

## 2. Material and Methods

A detailed energy audit is carried out to identify each plant's load patterns, and the key energy-consuming processes were identified. A mathematical model is used to optimize the load profile with key consideration referring to cost reduction. A new operating schedule is

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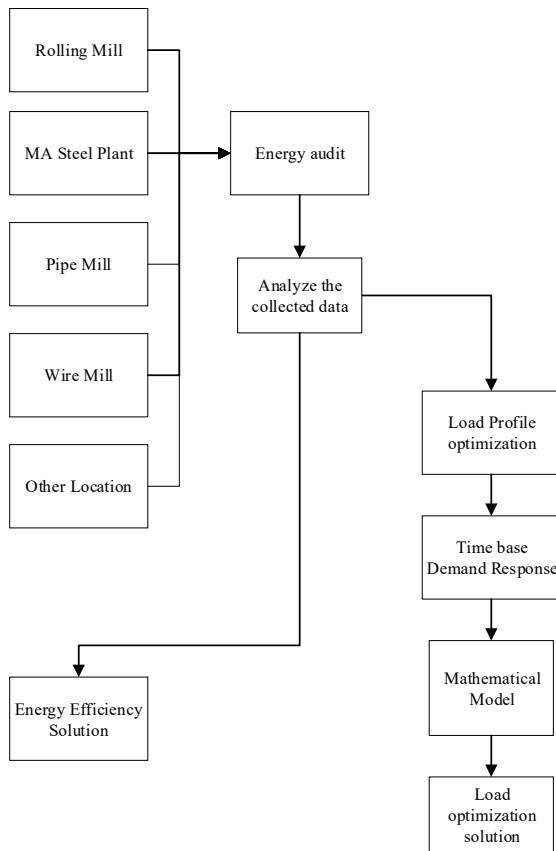
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then proposed according to the optimized results of load profile while providing several energy saving solutions. Figure 1 provides a block diagram for the methodology.



**Figure 1 - Block Diagram for Methodology**

### 2.1 Energy Audit

An energy audit is recommended to determine the energy consumption associated with a facility and the potential savings associated with that energy consumption. From a general point of view, an energy audit provides enormous benefits in different areas [2]-[4], [10], [11].

As the first step, a working-through audit was carried out for three weeks. Afterwards, mill wise energy consumption details were obtained according to operating schedules in every energy-consuming location. Daily and annual energy consumptions were calculated for each mill. A detailed energy audit was carried out during one month using the power analyzer to understand the present electrical energy consumption scenario. Power analyzers having 0.3% accuracy were installed in all plant locations to gather electricity consumption. All the data were downloaded from power quality analyser and used for analysis.

Demand curves for each mill in CSCL were prepared using recorded data. Further, a

harmonic analysis was also carried out to identify existing harmonic orders and relevant harmonic currents in the CSCL power system. In the audit process, Total Harmonic Distortion (THD) level was compared with IEE-519 standard and identified the locations where THD exceeds the standard level (THD in Voltage > 5%).

### 2.2 Economic Demand Response Model

DSM can change an inelastic demand to a unit elastic demand. The DSM results in numerous advantages in deregulated load profiles and provides beneficial effects on demand sides (electricity consumer). DR model should have the feature of adjustability to time preference of consumption. This means that the remaining load profile should quickly shift from the high price period to low price period. The concept of adjustability denotes the ability to merge the desire of electrical load [1]-[5].

In microeconomics, consumer theory is needed to show the electrical demand changes in reaction to the change in the price. This means that consumers' electricity demand depends on the price elasticity of the demand [6].

#### 2.2.1 Consumer Theory

This theory relates to adjusting the consumers' demand curve. Consumer theory is one of the most influential theories in economics. This theory concerns how consumers spend their money given their preferences and budget constraints. This theory's two primary tools are utility functions and budget constraints, allowing industrial consumers to decide regarding their consumption level. This model enables consumers to make decisions based on their maximum benefits while satisfying the budget constraints and production constraints. Moreover, the constant elasticity of substitution (CES) function is used as the utility function of consumers, which is the most widely used utility function in economic studies [6].

#### 2.2.2 CES Utility Function

Constant Elasticity of Substitution (CES) function was developed by a group of reserchers in 1961 [7]. CES, in economics, is a property of some production functions and utility functions. Specifically, it arises in a particular type of aggregator function that combines two or more types of consumer goods, or two or more production inputs into an aggregate quantity [8].

The utility function is one of the basic economic concepts and reflects the interest to earn more

profit. The utility function is derived from the concept of potential in physics, and its maximization represents reaching an equilibrium from the economic perspective. Unlike the potential energy, there is no specific method to find utility function, and economists usually derive the related formulation through empirical methods. Researchers have developed several utility functions for microeconomics; CES is considered one of the most important functions. This function is especially popular for multiproduct scenarios. CES utility function for two different products is as follows

$$U(X_1, X_2) = (X_1^\rho + X_2^\rho)^{\frac{1}{\rho}}, 0 \neq \rho < 1 \quad \dots (1)$$

Where  $X_1$  and  $X_2$  are the products and  $(1 - \rho^{-1})$  is called the elasticity of substitution. In the extension of this function for the electricity market, electricity offered at different prices is assumed as multiple products. For instance, a market where electricity has three different prices is considered as a market with three products. This utility function is employed in this research to develop a model for DR programs [9].

$\rho$  is called the substitution parameter between  $X_1$  and  $X_2$ .  $C$  is called the electricity power consumption in each of the period and  $B$  is called the budget constraint. In the absence of DR model, it is assumed that the power consumption during these three periods are  $C'_{peak}, C'_{day}, C'_{off peak}$ , respectively, while enabling DR action changes these values to  $C_{peak}, C_{day}, C_{off peak}$  accordingly. The utility function of the consumer regarding a DR model mentioned in Equation (1) is expressed as follows:

$$U(C_{peak}, C_{day}, C_{off peak}) \quad \dots (2)$$

$$B = C_{peak} \cdot P_{peak} + C_{day} \cdot P_{day} + C_{off peak} \cdot P_{off peak}$$

where,  $B$ = budget constraint.

Based on the previously mentioned elements of the consumer theory, i.e. utility function and budget constraint, consumers can present two different reactions to DR programs:

- (i) Can decrease their electricity usage in the peak times without any shift to the othertimes (Reduce electricity usage).
- (ii) Can shift their electricity usage from the peak times to other times.

This model assumes that consumers do not intend to reduce their electricity usage (total energy consumption before and after executing the DR program remains the same) but to save money through changing the consumption pattern and reducing the electricity cost. With

this assumption, the consumer should shift a part of its consumption from high price hours to those with lower prices, thus:

#### Case I:

Consumer shifts a part of consumption from day time to off-peak time. In this scenario, the following utility function should be maximized.

$$Max \left\{ U(C_{day}, C_{off peak}) = (C'^{\rho'}_{day} + C'^{\rho'}_{off peak})^{\frac{1}{\rho'}} \right\}; 0 < \rho' < 1 \quad \dots (3)$$

$$B' = C_{day} \cdot P_{day} + C_{off peak} \cdot P_{off peak}$$

#### Case II:

Consumer shifts a part of consumption from peak time to day time and off-peak time. In this scenario, the following utility function should be maximized:

$$Max \left\{ U(C_{peak}, U(C_{day}, C_{off peak})) = (C^{\rho}_{peak} + (U(C_{day}, C_{off peak}))^{\rho})^{1/\rho} \right\}; 0 < \rho < 1$$

... (4)

$$B = C_{peak} \cdot P_{peak} + C_{day} \cdot P_{day} + C_{off peak} \cdot P_{off peak}$$

Here, we are dealing with optimization problems with equality constraints in Equations (3) and (4). These types of problems can be solved by Lagrange multipliers [8].

$$Max\{f(x)\}; s. t h_j(x) = 0 \quad \dots (5)$$

If  $x^*$  is considered as the local maximum, then there exists a new variable

$$\lambda_j (j = 1, 2, 3, \dots)$$

such that:

$$\Delta f(x^*) + \sum_{j=1}^l \lambda_j \nabla h_j(x^*) = 0 \quad \dots (6)$$

$$h_j(x^*) \leq 0; \forall j = 1, 2, 3, \dots, l$$

$$\mu_i \geq 0; \forall i = 1, 2, \dots, m$$

By applying the same procedure to Equation (3), we could create the Lagrange function of the Case I as follows:

$$L = (C'^{\rho'}_{day} + C'^{\rho'}_{off peak})^{\frac{1}{\rho'}} + \lambda [B' - C_{day} \cdot P_{day} - C_{off peak} \cdot P_{off peak}] \quad \dots (7)$$

Finding the partial derivatives of Equation (7) with respect to  $C_{day}, C_{off peak}$  and  $\lambda$  would yield

$$\frac{dL}{dC_{off peak}} = C'^{\rho'-1}_{off peak} \cdot (C'^{\rho'}_{off peak} + C'^{\rho'}_{day})^{\frac{1-\rho'}{\rho'}} - \lambda P_{off peak} = 0 \quad \dots (8)$$



$$\frac{dL}{dC_{day}} = C_{day}^{\rho'-1} \cdot (C_{off\ peak}^{\rho'} + C_{day}^{\rho'})^{\frac{1-\rho'}{\rho'}} - \lambda P_{day} = 0 \quad \dots(9)$$

From Equations (8) and (9)

$$\frac{C_{off\ peak}^{\rho'-1}}{C_{day}^{\rho'-1}} = \frac{P_{off\ peak}}{P_{day}}$$

$$C_{off\ peak} = C_{day} \cdot \left(\frac{P_{off\ peak}}{P_{day}}\right)^{\frac{1}{\rho'-1}} \quad \dots(10)$$

Substituting Equation (10) into Equation (3)

$$U(C_{day}, C_{off\ peak}) = (C_{day}^{\rho'} + (C_{day} \cdot (P_{off\ peak} / P_{day})^{1/\rho'-1})^{1/\rho'})^{\frac{1}{\rho'}}$$

$$= C_{day} \cdot \left(1 + \left(\frac{P_{off\ peak}}{P_{day}}\right)^{\frac{\rho'}{\rho'-1}}\right)^{\frac{1}{\rho'}}$$

$$= \sigma \cdot C_{day} \quad \dots(11)$$

By substituting Equation (11) into Equation (4), the optimization problem formulation for the Case I is as follows:

$$Max\{U(C_{peak}, U(C_{day}, C_{off\ peak})) = (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1}{\rho}}\} \quad \dots(12)$$

$$B = C_{peak} \cdot P_{peak} + C_{day} \cdot P_{day} + C_{off\ peak} \cdot P_{off\ peak}$$

The budget constraint can also be formed as follows:

$$B = C_{peak} \cdot P_{peak} + C_{day} \cdot P_{day} + C_{day} \cdot \left(\frac{P_{off\ peak}}{P_{day}}\right)^{1/\rho'-1} \cdot P_{off\ peak}$$

$$B = C_{peak} \cdot P_{peak} + C_{day} \cdot \left[ P_{day} + \left(\frac{P_{off\ peak}}{P_{day}}\right)^{\frac{1}{\rho'-1}} \cdot P_{off\ peak} \right]$$

$$= C_{peak} \cdot P_{peak} + C_{day} \cdot \omega \quad \dots(13)$$

Now, create the Lagrange function for Case II introduced in Equation (12).

$$Max\{U(C_{peak}, U(C_{day}, C_{off\ peak})) = (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1}{\rho}}\}$$

$$B = C_{peak} \cdot P_{peak} + C_{day} \cdot \omega \quad \dots(14)$$

Using the Lagrange multipliers, Equation (14) can be rewritten as follows:

$$L = (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1}{\rho}} + \lambda [B - C_{peak} \cdot P_{peak} - C_{day} \cdot \omega] \quad \dots(15)$$

Calculating the partial derivatives of Equation (15) with respect to  $C_{peak}$ ,  $C_{day}$  and  $\lambda$  would result in

$$\frac{dL}{dC_{peak}} = C_{peak}^{\rho-1} \cdot (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1-\rho}{\rho}} - \lambda P_{peak} = 0$$

$$\Rightarrow \lambda = \frac{1}{P_{peak}} C_{peak}^{\rho-1} \cdot (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1-\rho}{\rho}} \quad \dots(16)$$

$$\frac{dL}{dC_{day}} = \sigma^{\rho} \cdot C_{day}^{\rho-1} \cdot (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1-\rho}{\rho}} - \lambda \omega = 0$$

$$\Rightarrow \lambda = \left(\frac{1}{\omega}\right) \sigma^{\rho} \cdot C_{day}^{\rho-1} \cdot (C_{peak}^{\rho} + \sigma^{\rho} \cdot C_{day}^{\rho})^{\frac{1-\rho}{\rho}} \quad \dots(17)$$

$$\frac{dL}{d\lambda} = B - C_{peak} \cdot P_{peak} - C_{day} \cdot \omega = 0$$

$$\Rightarrow B = C_{peak} \cdot P_{peak} + C_{day} \cdot \omega \quad \dots(18)$$

From Equations (17) and (18) it can be concluded that

$$C_{peak} = C_{day} \cdot \left(\frac{\sigma^{\rho} P_{peak}}{\omega}\right)^{\frac{1}{\rho-1}} \quad \dots(19)$$

From Equations (18) and (19) it can be concluded that

$$C_{day} = \frac{B}{(\sigma^{\rho} P_{peak} / \omega)^{1/\rho-1} \cdot P_{peak} + \omega} \quad \dots(20)$$

Taking Equations (19) and (20) into consideration, the following can be derived:

$$C_{peak} = \frac{B}{(\sigma^{\rho} \cdot \frac{P_{peak}}{\omega})^{\frac{1}{\rho-1}} \cdot P_{peak} + \omega} \cdot \left(\frac{P_{off\ peak}}{P_{day}}\right)^{1/\rho-1} \quad \dots(21)$$

$$C_{off\ peak} = \frac{B}{(\sigma^{\rho} \cdot \frac{P_{peak}}{\omega})^{\frac{1}{\rho-1}} \cdot P_{peak} + \omega} \cdot \left(\frac{P_{off\ peak}}{P_{day}}\right)^{\frac{1}{\rho'-1}} \quad \dots(22)$$

$$C_{off\ peak} = \{C_{All} - (C_{peak} + C_{Day})\} \quad \dots(23)$$

Equation (22) is used to obtain  $C_{off\ peak}$  in simulation under constant budget constraint. Equation (23) should be used to obtain constant total consumption.

In this context,  $C_{peak}$ ,  $C_{day}$  and  $C_{off\ peak}$  represent electric energy consumed in peak, day and valley period, respectively. To obtain the energy consumption at each time interval of the study period, one must use the following equations:

$$C_{t,peak} = C'_{t,peak} \times \left(\frac{C_{peak}}{C'_{peak}}\right) \quad \dots(24)$$

$$C_{t,day} = C'_{t,day} \times \left(\frac{C_{day}}{C'_{day}}\right) \quad \dots(25)$$

$$C_{t,off\ peak} = C'_{t,off\ peak} \times \left(\frac{C_{off\ peak}}{C'_{off\ peak}}\right) \quad \dots(26)$$

### 3. Results and Discussion

#### 3.1 Measuring Details of the Energy Audit

The CSCL energy consumption pattern is identified in terms of mill wise where each

equipment in the mill is subjected to measure its demand through power analyzer. Figure 2(a) shows the data gathering using power analyzer in rolling mill. Using the same procedure, power analyzers were installed in all main plant locations, and consumption was recorded. Energy consumption of different mills located in CSCL is provided in Figure 2(b).

According to Figure 2(b), it can be seen that major electricity consuming locations are rolling mill and MA steel plant. The analysis shows that the major portion of the electrical energy is used for steel bar production in the rolling mill.

### 3.2 Energy Saving Opportunities

When analyzing the data from the energy audit, a low power factor operation in several mills was observed, and there were inefficient motors used in some mills. Therefore, power factor correction was calculated to increase the power factor to 0.96, for those low power factor locations. Energy-efficient motors are introduced with calculating their payback period.

#### 3.2.1 Selecting Energy Efficient Motors

Rolling mill plant used 150 kW and 315 kW standard efficiency induction motors for billet rolling purpose in rolling stands. It can be replaced with grade 03(IE3) premium efficiency motors. Table 1 shows the cost saving calculations due to 150 kW premium efficiency motor replacement.

**Table 1 - Cost Saving Calculations Due to 150 kW Premium Efficiency Motor Replacement**

Remaining Model	Siemens-1PQ8 315-6PB70-Z
Quantity	08
Operating Hours	8300 hrs./year
Motor power	150 kW
Energy Charge	LKR 11.58/kWh
Demand Charge	LKR 1,100/kVA
Standard Efficiency	95.2%
Standard PF	0.72
Premium Efficiency	96.1 %
High Efficiency PF	0.87
EE Motor Cost Increment	2,200,000 LKR
Power Saving	$= \frac{150}{0.952} - \frac{150}{0.961}$ = 1.473 kW
Annual Savings: Energy saving	= 1.473*8300 = 12225.9 kWh
Demand reduction	$= \frac{150}{0.72*0.952} - \frac{150}{0.87*0.961}$ = 39.43 kVA

Energy cost saving	= 12225.9 kWh*11.58 = 141,575 LKR
Demand cost saving	= 39.43 kVA*1100*12 = 520,476 LKR
Total cost saving	= 141575+520,476 =662,051 LKR
Simple Payback	= 2,200,000/662,051 = 3.3 Years

For all of eight motors (150kW), total annual cost saving is around 5,296,408 LKR. Similarly, for all eight 315 kW motor replacements, total annual cost saving is about 5,768,856 LKR.

#### 3.2.2 Power Factor Improvement

Table 2 shows the calculations for power factor correction in different mills.

**Table 2 - Power Factor Correction**

Location	Existing P. F	KVA	Corrective kVA	Recommended units (kVAr)
Pipe mill	0.58	242.7	157.82	160
MA Steel	0.90	3355	586.52	600
GZ plant	0.85	314.6	88.13	90
Wire mill	0.41	502.3	401.42	400
Other Buildings	0.91	47.5	7.10	10

### 3.3 Demand Curve Analysis

Total load profile of CSCL was plotted considering each mill wise electricity consumption. Figure 3 shows that CSCL electricity demand is over 6000 kW during the day, from 6.am to 6.pm. Mainly rolling mill consumes nearly 2900 kW during 24 hours while the MA steel plant consumes about 3400 kW during the day. These mills are directly affected by the increase in the cost of electricity in CSCL. Existing Load factor is calculated as 66%.

### 3.4 Sensitivity Analysis

Sensitivity analysis has been done by changing two control parameters.  $\rho$  (substitution parameter between peak consumption and consumption in other times) and  $\rho'$  (substitution parameter between day consumption and off-peak consumption) is treated as a variable that adjusts the consuming level of participation and preference over the time. The proper ranges of these two parameters can be obtained through a sensitivity analysis [6].



Figure 4 represents the existing total load profile of CSCL, in which daily time horizon is divided into three time frames. Electricity tariff is defined based on time of use (TOU) scheme, where each time interval has its unique price.

The consumption level of daytime and peak-time can be easily controlled by parameter  $\rho$  and  $\rho'$ . As can be seen, these two control parameters provide a powerful tool to adjust the consumption levels according to consumer preferences. To determine the suitable range of  $\rho$  and  $\rho'$ , it must consider the consumer constraints [6].



Figure 2(a) - Data Gathering Using Power Analyzer in Rolling Mill

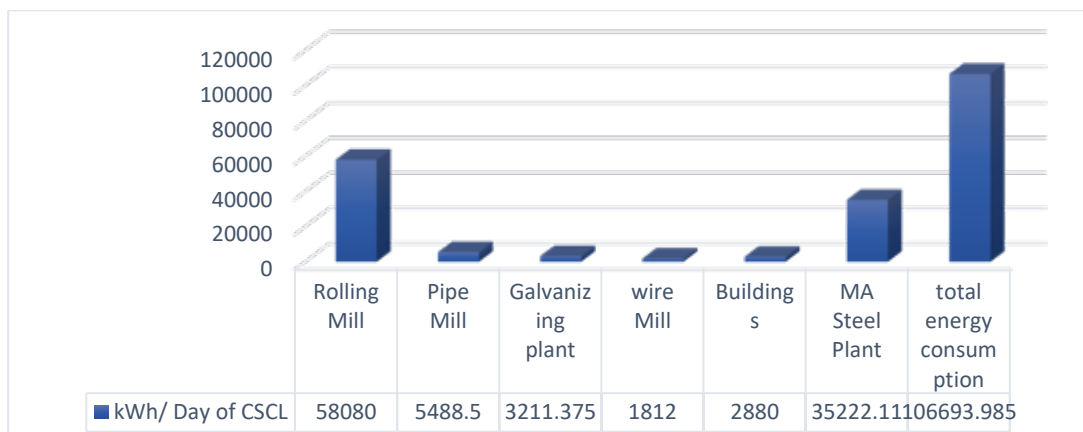


Figure 2(b) - Mill Wise Energy Consumption Per Day

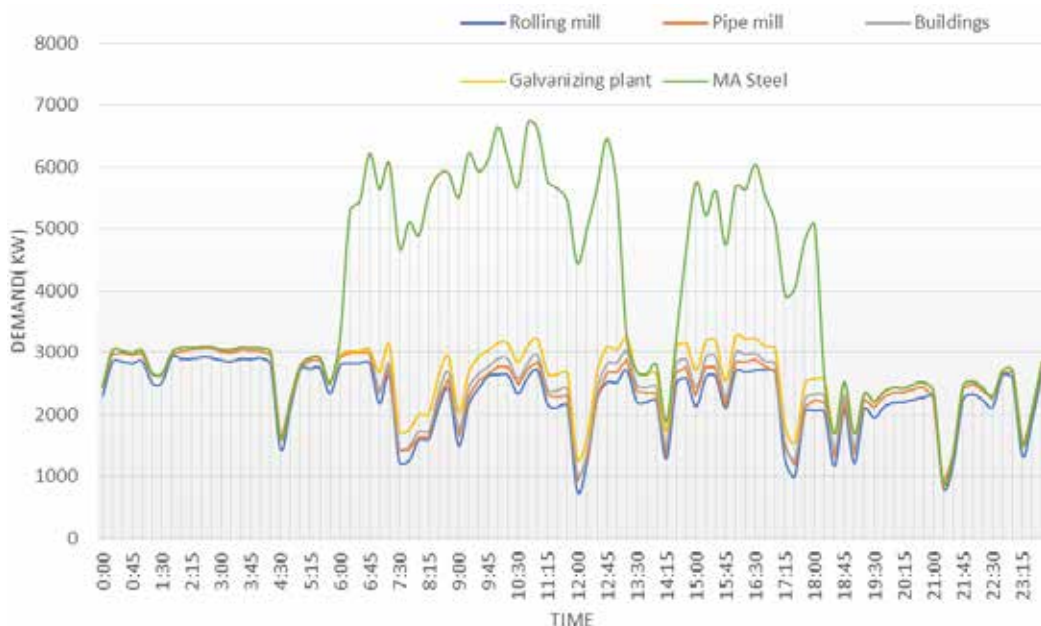


Figure 3 - Total Demand (kW) Curve of CSCL

Changes in the consumption level of different periods are plotted by changing  $\rho'$  and  $\rho$  values which can be seen in Figures 5, 6 and 7.

This step of sensitivity analysis is carried out for range of  $0 < \rho < 1$  and  $0 < \rho' < 1$ . CSCL needs to find out economical load profiles without any change of rolling mill production, thus in a sensitivity analysis that should be considered when selecting  $\rho$  and  $\rho'$ . Intersection line of DR consumption plane and without DR plane is selected to obtain values for economical load profile as seen in Figure 5.

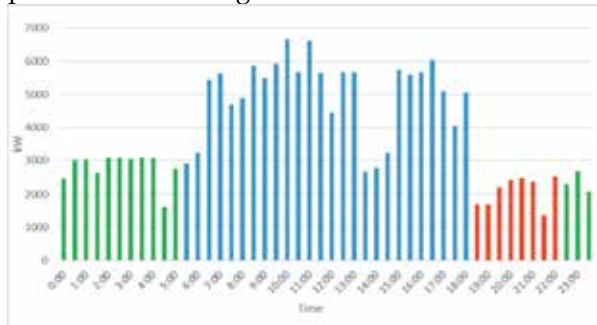


Figure 4 - Existing Total Load Profile of CSCL for Optimization

### 3.4.1 MATLAB Simulation

All equations and algorithms that were presented previously can be coded into a MATLAB program to draw the best performance out of the examined system under different ranges of  $(\rho, \rho')$  values. Figure 5 shows consumption in peak time before and after applying the demand response model. Demand changes in peak time can be obtained according to various  $\rho$  and  $\rho'$  values.

Figure 6 shows consumption in the day time before and after applying the demand response model. It can be seen that demand changes in day time according to various  $\rho$  and  $\rho'$  values. Figure 7 shows consumption in off-peak time before and after applying the demand response model. It can be seen that demand changes in off-peak time according to various  $\rho$  and  $\rho'$  values. CSCL can choose this consumption model, which consumes the energy saved during day time due to the lower energy price of day time compared to the one in the peak-time (the area above the intersection of the baseload surface and the load surface with DR actions).

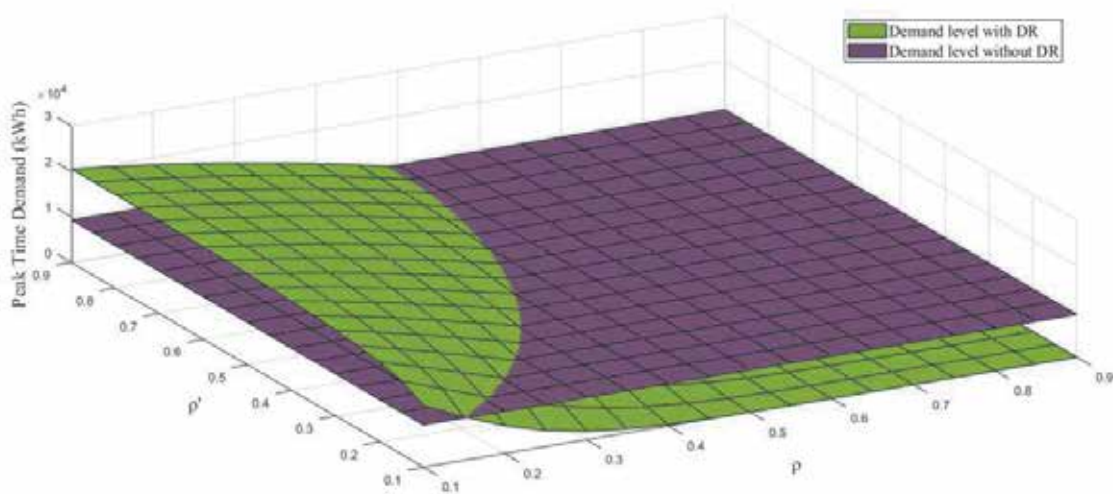


Figure 5 - Consumption Levels for Different Values of Substitution Elasticity (Peak Time)





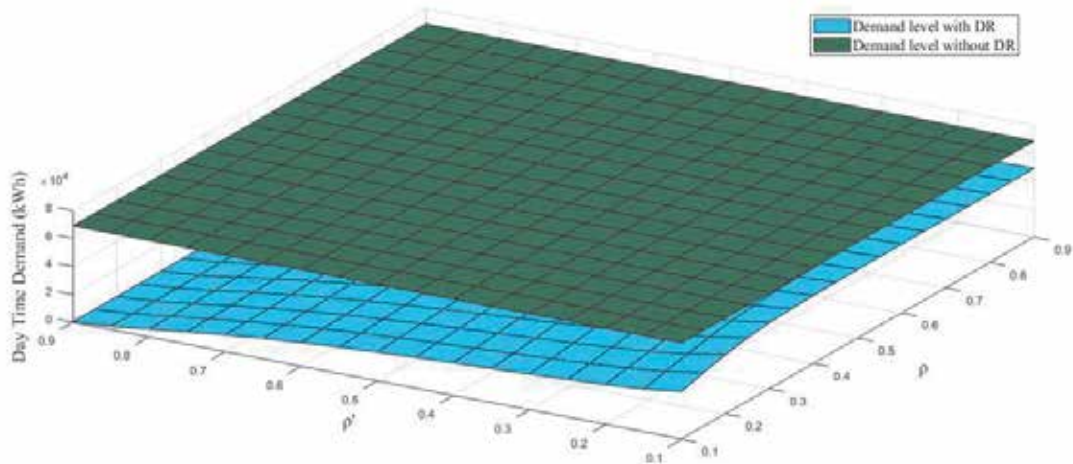


Figure 6 - Consumption Levels for Different Values of Substitution Elasticity (Day Time)

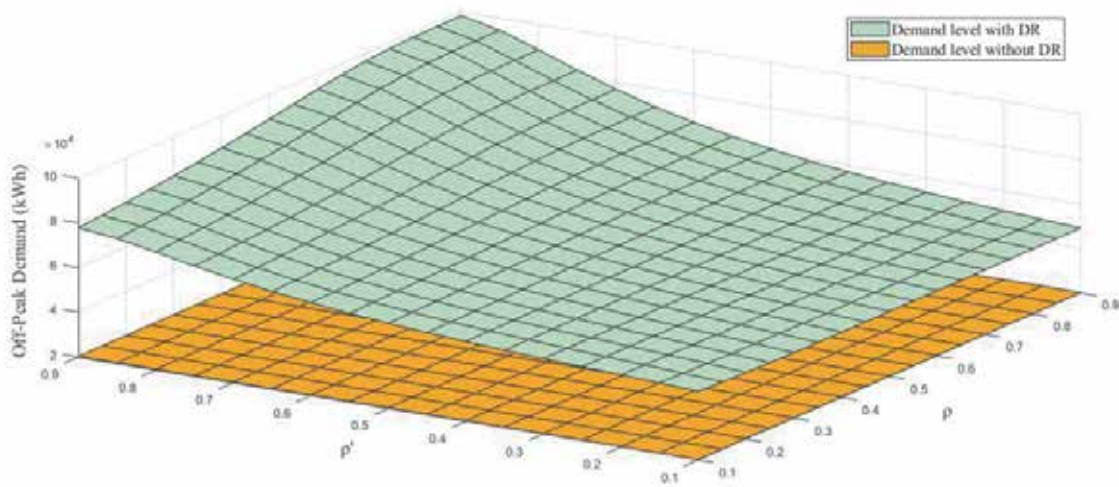


Figure 7 - Consumption Levels for Different Values of Substitution Elasticity (Off-Peak Time)

Table 1 shows the changes in the peak time power consumption for different values ( $\rho, \rho'$ ). The obtained results fully agree with the results of the sensitivity analysis. As can be seen, for a given  $\rho'$ , as  $\rho$  increases, the peak time consumption decreases, reflecting the consumer's desire to participate in the DR model.

Table 1 - Changes in Power Consumption During the Peak Time

$\rho$	$\rho'$	base case-with DR model ( $C_{peak}, kWh$ )	base case-without DR model ( $C_{peak}, kWh$ )
0.21	0.15	8664	8694.1
0.22	0.16	8661	
0.28	0.23	8684	
0.3	0.26	8766	
0.34	0.32	8679	
0.41	0.47	8698	
0.2	0.3	13990	
0.35	0.45	10680	
0.45	0.1	102	
0.1	0.05	8734	

Table 2 shows the budget changes and the total power consumption for different values ( $\rho, \rho'$ ). The total daily power consumption with and without DR Model is the same, as consumption is only shifted among different periods.

Table 2 - Total Consumption and Changes in the Budget (Rs) According to DR Model

$\rho$	$\rho'$	Total consumption with DR model (kWh)	Total consumption without DR model (kWh)	Changes in the budget with DR (Rs)	Budget without DR model (Rs)
0.21	0.15	92684	92679.05	856,270	981,090
0.22	0.16	92681		855,590.5	
0.28	0.23	92674		850,908	
0.3	0.26	92676		849,622.5	
0.34	0.32	92679		843,150	
0.41	0.47	92678		825,121.5	
0.2	0.3	92680		915,140.5	
0.35	0.45	92690		855,377.5	
0.45	0.1	92682		749,937	
0.1	0.05	92684		815,042.1	



### 3.5 Load Profile Optimization

In this section, the load profiles for some of the case scenarios presented in the above tables are plotted using Equations (23), (24) and (25). As shown in Figure 8, the day time and peak-time consumption levels can be adjusted simply by changing the values of  $\rho$ ,  $\rho'$ . This means that the proposed model can merge the desire of consumer (according to shift the load over time) into the DR model to adjust the consumption over time in a cost-effective way.

In Figure 8 it can be seen various load profiles that can be applied for CSCL. But most suitable load profile is DR ( $\rho=0.1$ ,  $\rho'=0.06$ ) due to production constraints. According to the DR model, the change in the CSCL load profile seen in Figure 8 shows that the load shifting technique can be applied to the MA Steel plant and galvanizing plant to maintain the above load profile. Tariff category of Industrial I-3 customer is considered for charge procedure. Expected optimized load profile ( $\rho=0.1$ ,  $\rho'=0.06$ ) reduces the cost of electricity and reduction was calculated as 48,772,404 LKR per year.

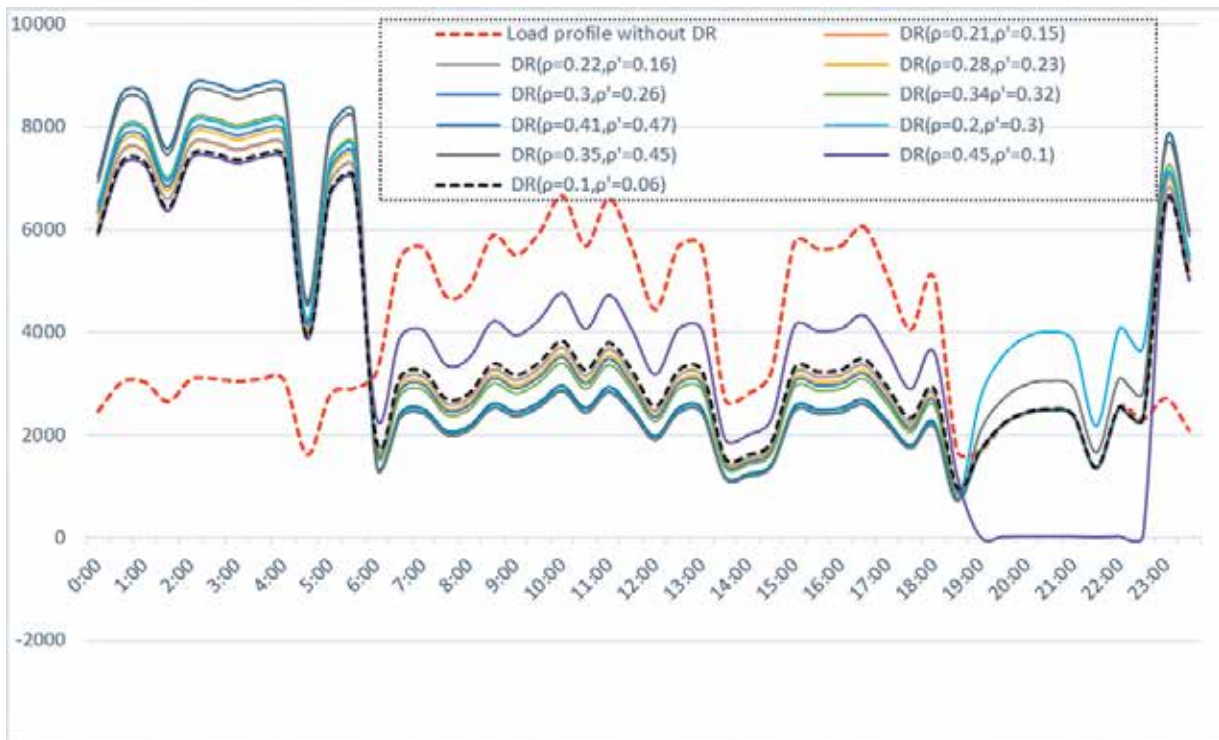


Figure 8 - Load Profile with and without DR Model

#### 3.5.1 Rescheduling MA Steel Plant

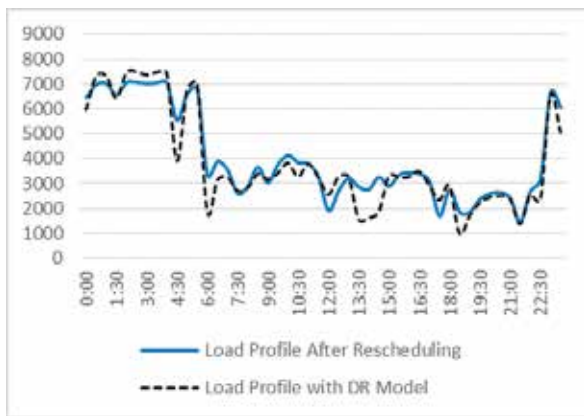
MA steel plant is working from 6 a.m. to 6 p.m. and the daily energy consumption is around 28,131 kWh. MA steel plant provides batch-wise production using 6 steel bar manufacturing machinery. Therefore, the load shifting technique can be applied to reduce day time high peak electricity demand. The reason for the high electricity demand of the MA steel plant is the parallel working of all machinery to achieve their production targets. In day time this plant consumes a maximum of around 3565 kWh.

According to DR model, this significant load can be shifted from day time to off-peak time. Then MA steel plant will be operated for 07 hours at off-peak time and can consume 24,957

kWh. The rest of 3,173 kWh should be consumed at the daytime period since the off-peak period is insufficient to complete daily target production.

Day time should be used only to operate minimum power demand machinery to maintain DR modelled load profile. According to the DR model, the galvanizing plant can be shifted from day to night to increase off-peak time demand. The comparison of load profiles is shown in Figure 9 after rescheduling MA steel plant and galvanizing plant. It is proven that the selected DR model can easily be applied to the actual scheduling of the plants.





**Figure 9 - Expected Load Profile after Rescheduling**

#### 4. Conclusions

This research study aims to reduce the electricity bill of CSCL through load profile optimization. Energy efficiency solutions and demand response (DR) programs is used as possible solutions. At first, the daily electricity consumption pattern in CSCL is identified using demand curves. Demand response model is used to obtain the most suitable daily load profile where constant elasticity substitution can give optimized daily load profile. Total energy consumption before and after executing the DR model remains the same value since the model is constrained that consumption is unchanged and can be shifted to each period.

According to this DR model results, it was found that changing the consumption pattern from day time period to off-peak time period, electricity bill can be reduced by shifting part of consumption from high priced hours to lower-priced hours. DR model was applied to CSCL load profile using MATLAB simulation. As a result of this simulation, it is clearly proven that the selected DR model can easily be applied to the plants' actual scheduling as CSCL preference.

#### 5. Future Work

Future extensions of this study will be mainly focused on developing an application that gathers the energy details and forecasts the real optimal load profile.

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