Demand Based Electricity Pricing in Bangladesh: in a Deregulated Market Scenario

by

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Declaration of Authorship

This is to certify that the work in this thesis paper is the outcome of research carried out by the students under the supervision of Dr. Fahim Abid, Assistant Professor, and Department of Electrical and Electronic Engineering (EEE), Islamic University of Technology (IUT).

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List of Acronyms

PPP	Public Private Partnership
IPP	Independent Power Producers
ISO	Independent System Operator
PGCB	Power Grid Company of Bangladesh Ltd.
BPDB	Bangladesh power Development Board

Acknowledgements

The research work to find the prospect of deregulated market scenario could not be visualized without the open access database of Power Grid Company of Bangladesh (PGCB). The daily load curve from the database allows us to work with the demand in a deregulated market scenario in Bangladesh. Furthermore, we would like to acknowledge the open database of Bangladesh Power Development Board (BPDP) which gave information regarding generation capacity of power plants in Bangladesh.

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Abstract

Deregulation in electricity market allows for competition and makes the system economically efficient. In Bangladesh, electricity is centrally controlled and regulated where the electricity prices vary on the type and amount of usage. This study reports the prospect of demand-based electricity pricing in the context of a deregulated electricity market in Bangladesh. The market clearing price is determined from the supply and the demand curve on half hourly basis. To determine the supply curve, the generating power plants capacity are placed in ascending order according to their per unit power generating cost. The demand is considered inelastic and is determined from the daily load curve. The effect of seasonal variation on demand-based electricity price is further analyzed. The demand-based electricity prices are generally found to be lower than the existing prices. Furthermore, generating electricity from the units with least generating cost can save significant amount of cost which can be utilized in transmission and distribution network. The demand-based dynamic price can be useful in implementing demand response in the system.

Chapter 1

Introduction

Electricity sectors are traditionally vertically integrated i.e., the generation, transmission and distribution are carried out by state owned companies [1]. Customers in such a vertically integrated system cannot choose their power producers and are bound to their local utility. As a result, this system lacks competition and becomes economically inefficient. To allow free competition between the power producers, electricity market has been liberalized in many parts of the world. Liberalization of electricity market involved unbundling of power sector with the aim to separate the generation, transmission, distribution and retail activities.

Chile was the first country to test run the concept back in 1980 to check its feasibility [2]. After the test run, huge improvements had been found in terms of efficiency. The price remained stable during the test. Additionally, the private capitalist became more interested to invest in the power sector as competition was introduced [3]. Since then, many countries like England, the United States of America, Canada, New Zealand, Australia, Chile, and many Nordic countries have adopted deregulated electricity market [4]. This deregulated electricity market has led to the creation of the Independent Power Project which has produced 40% of energy production in most countries [5]. A major part of Nigeria's energy reform was implementation of a decentralized electricity market. This restructure of power-system allowed for active participation from private stake-holders in vital power sector processes such as regulation, institution and legislation [6]. In California, the government insisted on creating platforms to increase renewable energy and put in measures to conserve electricity rather than creating more energy production plants [7].

1.1 Current Scenario of Bangladesh Power Sector

Currently, the electricity system in Bangladesh is regulated through unbundled utility companies [2]. From generation to retail, the entire process is overseen by the Bangladesh Power Development Board (BPDB) authorized by the government [2]. The electricity price is fixed in this scheme as there is no competition in the market. However, upon the enactment of the private sector power generation policy in 1996, a handful of independent power producers

(IPP) were added to the power generation [2]. Later public private partnership (PPP) power plants also came into operation.

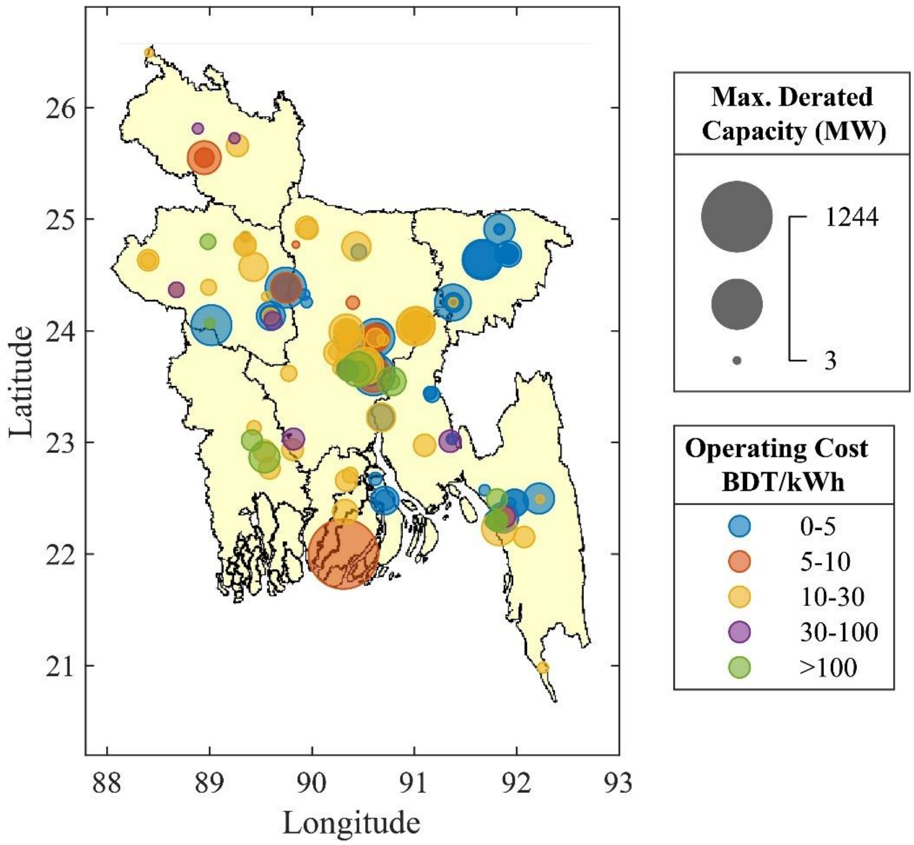

Figure 1.1 Power plants in Bangladesh [8]

There are 133 power plants in Bangladesh with a total generation capacity of 20,697 MW. Among these, 52 are state-owned & 78 are privately owned plants [8]. Figure 1.1 illustrates the exact locations of all the active power plants around the country where the size of the bubbles represents the generation capacity of each power plant while the colors represent the price range at which they are operating. Up till date, the largest power plant in the country is the Payra 1320 MW thermal power plant in Patuakhali, which is producing electricity at a rate of 6.27 BDT/kWh.

In the past, insufficient generation capacity was the main challenge in the electricity sector of Bangladesh. To overcome the lack of generation capacity, a lot of new power plants have been commissioned in the last decade. At present, one of the main challenges in the electricity sector of Bangladesh is to ensure efficient and economic operation of the existing power plants. As such, a deregulated electricity market can play a pivotal role to ensure efficient power generation and supply.

Up till date, no or very little work has been carried out on the prospect of deregulated electricity market in Bangladesh [2]. The main advantage of demand-based pricing is that it increases the benefit for both the producer & consumers. Furthermore, it motivates consumers to shift the usage of the flexible loads when the price is high, i.e., taking active part in demand response. In this paper, the prospect of demand-based electricity pricing in the context of a deregulated electricity market is investigated for Bangladesh. Market clearing price is calculated from the hypothetical supply and demand curve. All the generating plants are assumed as an independent entity. The supply curve is drawn by placing all the power plants in ascending order according to their operating costs. The demand is considered inelastic as the demand elasticity is not known for Bangladesh. The demand curve is drawn from the daily load curve. The price obtained from the demand-based method is further compared with the existing pricing schemes in Bangladesh.

1.2 Problem Definition

Currently the power sector of Bangladesh is centralized, where the Government single handedly chooses the energy producer and has a monopoly over the transmission and distribution line. Thus, it leaves very little scope for renewable energy integration. And as the times go by, fossil fuel being depleted the country has to move towards green energy integration. Furthermore, the consumers are fixed with a single energy provider without any options. So, moving towards a deregulated electricity market can provide to the problems stated above. It can also bring private investment building the age-old electrical infrastructure. However, very few research has been done in Bangladesh addressing this issue. So, this paper is focused on the prospect of demand-based electricity pricing in a Deregulated market scenario in Bangladesh.

1.3 Aims and Objectives

1.3.1 Aims

The aim of this is to evaluate the prospect of demand-based electricity pricing in a deregulated market scenario in Bangladesh.

1.3.2 Objectives

1. Analyze the limitations of the centralized electricity market in Bangladesh.
2. Gather information regarding current generation facilities to find the prospect of the deregulated system in the current scenario.
3. Analyze the current supply curve of generation to determine market clearing without taking elasticity in account.
4. Analyze the cost saving potential for deregulated market scenario in non-elastic and elastic scenario.

1.4 Methodology

The methodology is based on three parts. At first the information of all the active generation plant is collected along with all the daily load curve data are attained from the Power Grid Company of Bangladesh (PGCB) daily reports [9]. Secondly the supply and demand curve are generated where the demand is considered inelastic. Then necessary calculations are done to find the cost saving potential in a deregulated market compared to present state. And lastly elasticity is taken into account for a realistic deregulated market. As the price of commodity increase in certain time the demand will drop. Additionally, the cost saving potential has been calculated.

1.5 Main Findings

It has been found that based on the existing power plants and daily load curve, the demand-based market clearing prices are calculated. The market clearing price is further compared with the existing pricing scheme in Bangladesh. Average market clearing price in a deregulated market is generally found to be lower than the existing electricity price in Bangladesh. If the demand elasticity is taken into consideration the market clearing price would further fall. The cost saving potential using demand-based electricity pricing is found to be significant in this simplified model.

1.6 Thesis Disposition

In the report Chapter 1 gives a brief overview of the current situation, problem definition, aims and objectives, main findings of the thesis. Chapter 2 includes literature review that describes the fundamental idea about the deregulated market of the report. Methodology of the thesis is included in chapter 3. Chapter 4 includes the results and calculations. Finally, chapter 5 and chapter 6 is about the conclusions drawn based on the results and scope for future work. The chapters of the report are subdivided so that the reader can easily follow the objectives, previous works, methodology and the findings of the thesis with minimum background on the topic.

Chapter 2

Literature Review

Electricity Worldwide researchers are researching to explore the possibilities for introducing deregulation in electricity market for different parts of the world. The works that have been done up until now in this front include research on the reformation of the structure of power systems across different parts of the world as well as deeper dives into how those reformations are taking place. Urpelainen et al. [10], in their work, have attempted to provide an update on the how the patterns of global power reform had been shaping up until 2013. The detail reports the said researchers have provided were based on 8 key factors of reformation. Now moving onto works that actually investigate the possibilities of formation of a deregulated electricity market, Necoechea-Porras et al. [11] did a comprehensive overview of how a deregulated electricity market can be implemented for any power sector and what kind of economic ramifications would actually be yielded from such implementation. They did so by evaluating the process of deregulation policies and their micro and macroeconomic effects on the power sector. The work was extended and gratified by analyzing the impacts of such changes on power pricing, the market, access to power, innovation and competition. Now shifting focus to the works that have been done domestically, unfortunately no such feasible research on the subject matter has been done until now. Which makes this research paramount as it is the first in its kind. However, Mostofa et al. [12] did a study on the prospective model of the electricity market in the country. On the said study, at first the current scenario of the power sector of Bangladesh was presented. Then the idea of a deregulated electricity market was introduced. It was compared with the current structure of power sector starting from generation, transmission and distribution. The whole history of the power sector and numerous reformations attempts that have taken place to improve the scenario for both the power generation companies and the consumers have been mentioned. A brief idea of how a deregulated electricity market works have been stated with adequate details. Then they proposed a restructured power sector model for the domestic scenario that integrates deregulation in the power sector. The proposed model was divided into three main factors: Restructuring of the market, Exchange of Power and most importantly introducing competition in the market which will give the consumer a choice of which retail vendor they want to purchase the power from. Competition in the retail front would allow for the price of electricity to be set by the market itself which in turn would benefit both the generation companies as well as the consumers. Albeit being a rather comprehensive study, the said work does not provide any solid mathematical foundation or enough data representation to actually realize the model they proposed. Nonetheless, this was one of the only works that deal with the idea of deregulation in the domestic power sector and electricity sector and served as a great inspiration for this research. Now internationally, Yadav et al. [13] did comprehensive research on the deregulation electricity market in India. It is to be mentioned that in India, to this day, the process of generation, distribution and transmission of electricity largely remain a monopoly business. Even though there have been several attempts taken by the Government of India to segmentize the power sector and disintegrate it to make it a deregulated non-monopoly business, the endeavors have largely failed to come to fruition due to the shortcomings that plague the infrastructure that is already in place. The said paper proposes a model that deregulates the market working its way around the different barriers that are in place as well as compares it with the currently competing models that share the same idea and are being attempted to be implemented in different parts of the country with varying degrees of success. Another rather enticing work on this front have been done by Karthikeyan et al. [14] where they not only analyzed the possibility of implementation of deregulated electricity market in context of a large power sector but also has taken into account different mathematical parameters such as different Market Power Indices as well as stimulators that influence the market of power. This work also analyzes how different algorithms such as Game Theory can be integrated to mathematically realize a model where the electricity price is set by the market and not the monopoly. Watanabe et al. [15] conducts similar research where they test out the feasibility of a deregulated electricity market in Japan's power sector by comparing a proposed model with the structure that is currently in place and also by analyzing the possible challenges for such implementation in the context of the infrastructures that are in place. On the technical front, researchers have made it a priority to figure out different techniques that aid in realizing the deregulated market model for any power sector. Nargale et al. [16] proposed a method where they forecasted the electricity price by using feed forward artificial neural network based on historical price data. The said work somewhat resembles this research in the manner that it also relies on prices of previous years to estimate a new price in the context of a deregulated market. An Artificial Neural Network (ANN) model is designed for short term price forecasting of electricity in the restructured environment of electricity market. As mentioned before, the challenge in realizing a deregulated market model lies in finding out the market clearing price that will be set by the market and will benefit both the power providers and the consumers. Savelli et al. [17] attempts to provide a possible remedy to the problem by obtaining a mixed integer linear programming model that is computationally governable and able to provide a solution to the uniform purchase price problem. Moving on, Toyama et al. [18] propose an approach to reduce the prediction error at occurrence time of peak electricity price. The said approach aims to increase the accuracy of next day electricity price forecasting. They used the weekly variation data for input factors of the Neural Network at the time when peak electricity price occurs with the objective of detecting the variation in pricing. Lastly, Sood et al. [19] conducted a bibliographical study where the analyzed the wheeling of power under deregulated environment of power system. The said study was conducted by analyzing as many as 170 published articles that deal with deregulation and related subject matters. The study aims to aid countries that still have their power sector in the developing stage in a way that the can unbundle the supply industry at the earlier stage of development.

Chapter 3

Overview of Deregulated Electricity Market

Deregulated electricity market introduces competition in generation and retail of electricity by providing level playing field to the market participants. Open access of different types of generating plants to the transmission network enhances the reliability of the power system [21]. In deregulated market, the contracts are performed in either pool or bilateral contract or both. Non-utility market participants own power plants and sell electricity into a wholesale market. Figure 3.1 shows the flow of power, information and money in such electricity market. The electricity is transmitted using the existing transmission and distribution network operated by an independent system operator (ISO). The generation companies sell electricity in a wholesale market to the retailer whereas the retailer further sells the electricity to the consumers. The large industrial consumers can directly buy electricity from the generation companies. The independent system operator charges network fee for providing reliable power to consumers. Bid is placed by the retailers and the generating companies based on the forecasted demand on previous day. As the forecast is not accurate, some additional generation units are kept in reserve to meet the demand.

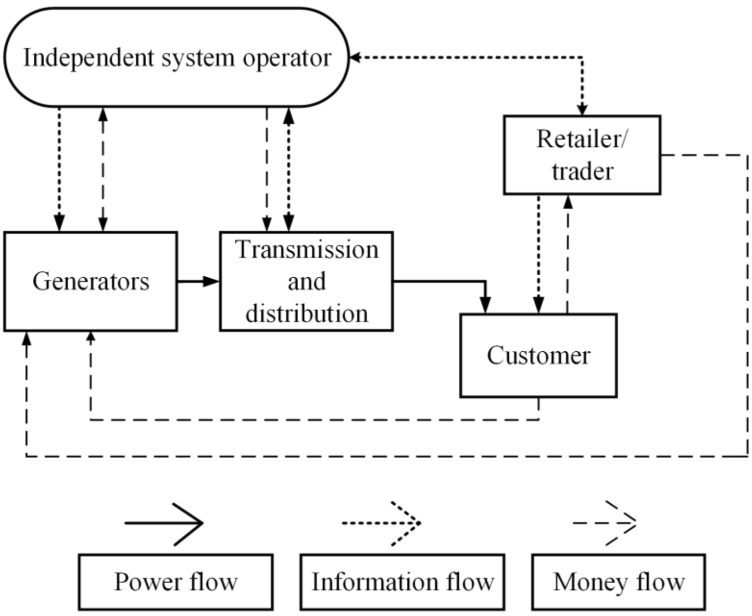

Figure 3.1 Deregulated Power System [20]

Retail competition in distribution allows buyers to choose between power suppliers, thus allowing competition between the retailers. The deregulated electricity market's main objective is to remove as many barriers as possible while increasing the competition to ensure affordable pricing [22]. It aims to do so without sacrificing the safety and security of the overall power system by ensuring proper distribution of power, information, money throughout the system. It is optimum for both the consumers and the producers as the price is set by the market itself [23]. Furthermore, it provides the incentive for the integration of renewable energy [24].

3.1 Market Clearing Price

A market-clearing price is the price of a good or service at which quantity supplied is equal to quantity demanded, also called the equilibrium price. It can also be shown graphically by the intersection of the demand curve and the supply curve, as shown in Figure 3.2. If the demand of the product exceeds the supply, then the market price increases which in turn demotivates the customer to purchase the commodity. As a result, the demand decreases to meet the supply [25]. From Figure 3.2, it can be seen that the x-axis represents the quantity of a commodity and the y-axis represents the price. The intersecting point of the supply curve and the demand curve indicates the market clearing price and the equilibrium quantity [26].

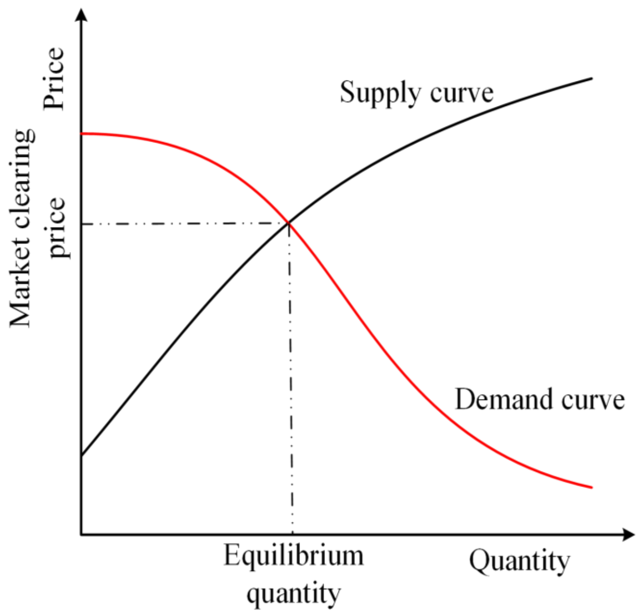

Figure 3.2 Calculation of market clearing price [26]

Chapter 4

Methodology

In this study, deregulation is considered only on the generation side. Actual demand, obtained from the load-curve of a particular day, has been taken as the forecasted demand for that day. Based on that, market clearing prices have been calculated. As forecasted demand is not same as the real time demand, some balancing is required. However, for simplicity balancing of the market is not considered in this study.

4.1 Assumptions

Firstly, it has been assumed that the demand is inelastic, so the consumers are willing to buy electricity regardless of the price. In reality, the consumers' electricity usage will vary depending on the price. Considering the demand elasticity, the market clearing price would further fall. So, elasticity has been introduced.

However, in this study the demand-based pricing is calculated without considering the congestion of transmission line. Hence, it is assumed that the plants with least generation costs will produce the electricity first. In reality, however, the scheduling of the generating plants is based on the existing transmission and distribution capability. While calculating the market clearing prices it is assumed that all the generating plants are available throughout the year. But, in reality due to maintenance issue some of the generating plants will always be out of production. Furthermore, certain generating plants need longer startup time i.e., all the power plants are not capable of instantly being turned on, especially during peak demand. For this reason, peaking power plants are required which are significantly costlier in comparison with the said power plants.

4.2 Data Collection

The daily load curve data are attained from the Power Grid Company of Bangladesh (PGCB) daily reports [9]. To determine the supply curve, the generating power plants capacity are placed in ascending order according to their per unit power generating cost. Here the actual demand which is obtained from the load-curve, has been taken as the forecasted demand for that day. Based on that, market clearing prices have been calculated for the mentioned years.

4.3 Introducing Elasticity

To introduce elasticity an exponential decaying curve is considered which has been shown in Figure 4.1. When the price is higher consumer will tend to shift more of their load than any other time. As price decrease the rate to change of demand decreases and when price becomes lowest consumers don't shift their load.

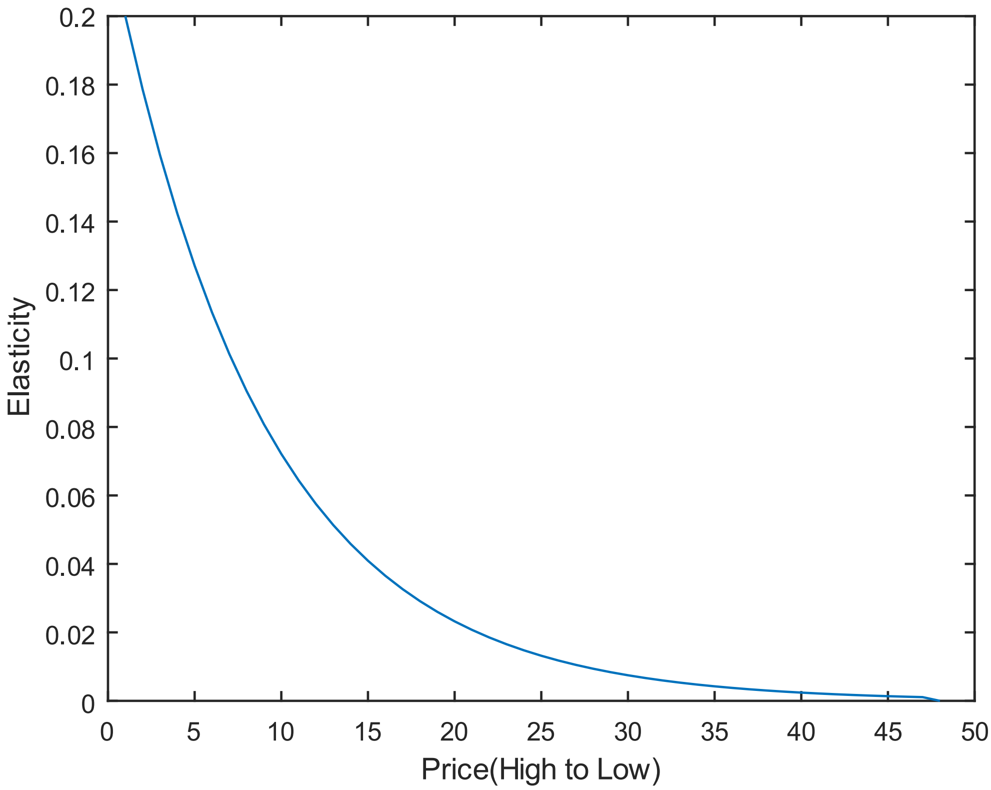

Figure 4.1 Elasticity vs Price Curve

Here, two type of elasticity is involved, one is cross elasticity which is denoted by ε_{ab}. The value of cross elasticity is positive as it how much load will be increased in a time period due to shifting of load. Another type of elasticity is self-elasticity which is denoted by ε_{aa}. The value of this is negative as this basically means that when price is increased the demand for demand will decrease which can be represented as negative value which is shown in first equation. Using the elasticity curve this self-elasticity is distributed to all the lower price points. The highest value of self-elasticity is considered to be 5% and 10% of the load respectively.

Using those values, elasticity matrix has been generated. Using elasticity matrix change of demand, ΔQ has been calculated which has been shown in the equations below.

$$\Delta q = \varepsilon_{aa} q_a \qquad \varepsilon_{aa} < 0$$
$$\Delta q = \varepsilon_{a_b} q_b \qquad \varepsilon_{ab} > 0$$
$$\begin{bmatrix} \Delta q_a \\ \Delta q_b \end{bmatrix} = \begin{bmatrix} \varepsilon_{aa} & \varepsilon_{a_b} \\ \varepsilon_{ba} & \varepsilon_{bb} \end{bmatrix} \begin{bmatrix} q_a \\ q_b \end{bmatrix}$$
$$\Delta Q = EQ$$

4.4 Market Clearing Price Calculation

Firstly, the demand is assumed inelastic, i.e., the consumers are willing to buy electricity regardless of the price. In other words, it has been assumed that the demand will not change if the price varies. Secondly demand is considered elastic. For all those demand for the mentioned years market clearing price have been calculated.

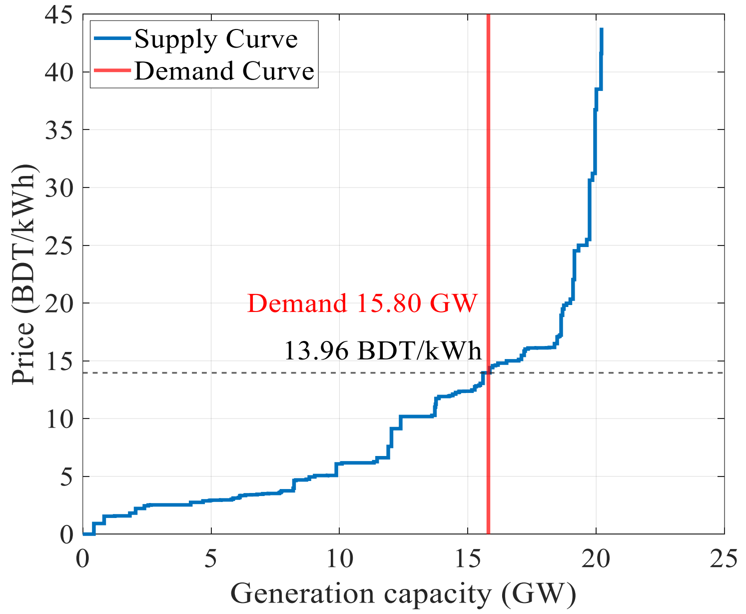

Figure 4.2 Determination of market clearing price from supply and demand curve

The demand curve for a case is shown in Figure 4.2, where in this specific time the demand was 15,800 MW. The supply curve is drawn by sorting the power stations in ascending order in terms of their per unit production cost. The width of each stair in the supply curve represents the generation capacity of each power plant and the height of each stair represents the per-unit cost of that particular power plant. The capacity of the power plant and the per-unit cost of each power plant have been collected from the BPDB Annual Report 2019-20 [27]. It is worthwhile to mention that, per unit costs for some of the power plants could not be found in BPDB Annual Report and as such, per unit cost of those power plants have been assumed in coherence with other similar power plants. The market clearing price is the intersection of the supply and the demand curve, and in this case, it is 13.96 BDT/kWh.

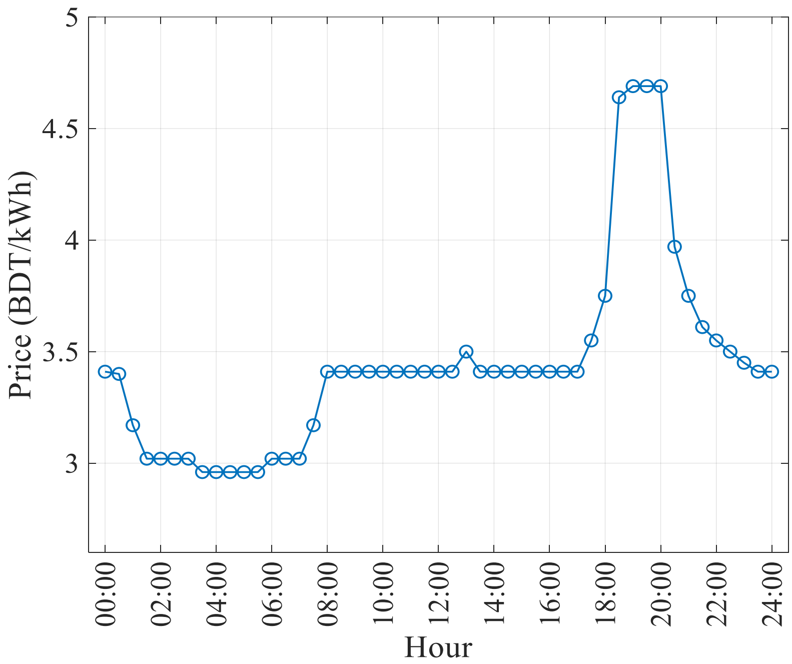

Figure 4.3 dynamic demand-based price

The market clearing price is calculated at 30 minutes interval thus having 48 price points in a day. The market clearing price for a particular day is illustrated in Figure 4.3. It can be seen that the price points are higher from 6.00 PM to 9.00 PM compared to the rest of the day, ranging between 3.75 BDT/kWh and 4.7 BDT/kWh, as shown in Figure 4.3. This is due to the fact that the daily evening peak occurs at this time of the day. In contrast, from 1.30 AM until 7.00 AM, the prices seem to be lower due to low electricity demand. The yearly generation cost is calculated considering the demand-based pricing scheme, i.e., calculating the cost of generation using the generators that are committed only. Based on that, the cost saving potential is further calculated for the whole year.

Chapter 5

Results

5.1 Price points

Calculated demand and price points for some particular day (January 16, 2020, July 1, 2020, September 20, 2020, December 15, 2020) have been shown in the following figures (Figure 5.1, Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5, Figure 5.6, Figure 5.7, Figure 5.8). Demand is shown as if there is no elasticity, 5% elasticity, 10% elasticity. As elasticity is introduced the demand from peak hour is shifted to the off-peak hours as the price at that time is lower. As more elasticity is introduced more shifting is noticed. Despite the small change of the demand because of elasticity electricity generation cost during peak hour can be significantly reduced which can be seen from the figures.

The demand during January 16, 2020 and December 15, 2020 was low comparing to other two days as it was during winter season. This is occurred due to seasonal variation. The price is observed to be low during the winter season due to low demand as the weather does not warrant high usage of electrical appliances such as fans and air conditioners. As a result, the market clearing price is also lower in those two days than summer days.

Price is shown with an interval of half-hour throughout the day. From the figures, it can be seen that ranging between 3 BDT/KWh and 5 BDT/KWh during winter days and 5 BDT/KWh and 10 BDT/KWh during summer days. The price points are higher from 7 PM to 9 PM compared to the rest of day. This is due to high electricity usage during that period of time.

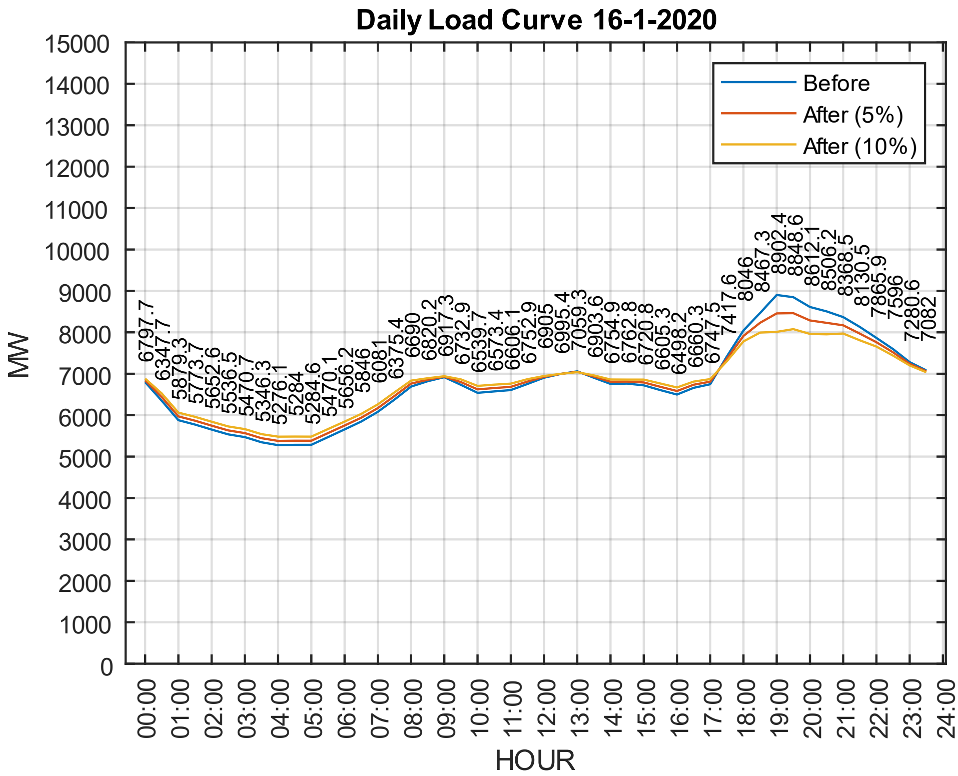

Figure 5.1 Daily load curve in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 16 January 2020

Figure 5.2 Price Points in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 16 January 2020

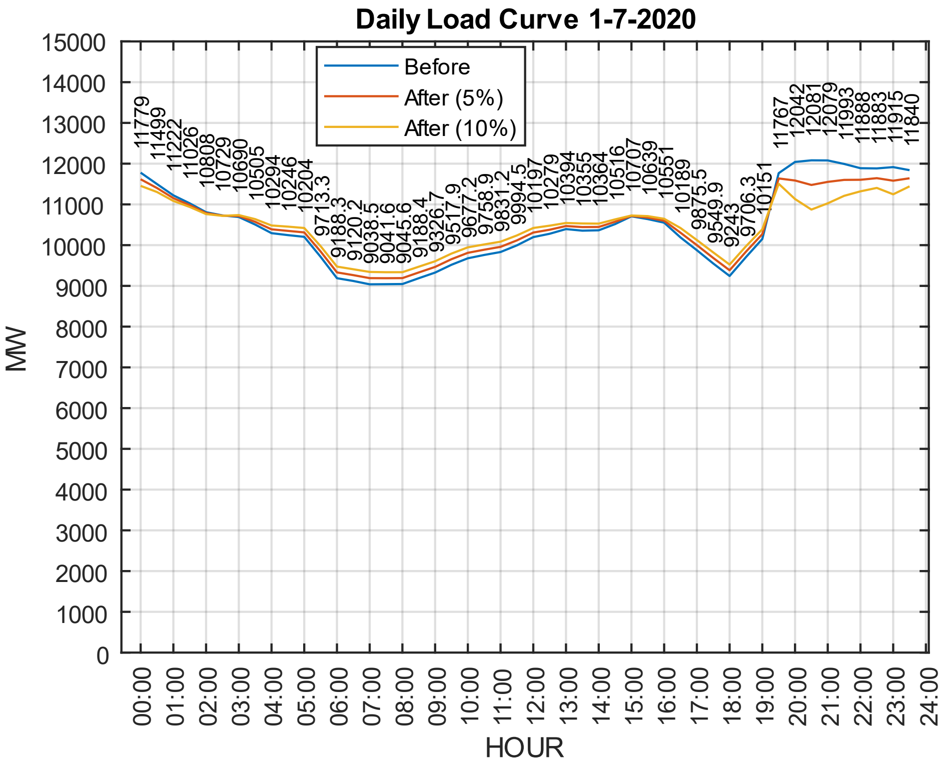

Figure 5.3 Daily load curve in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 1 July 2020

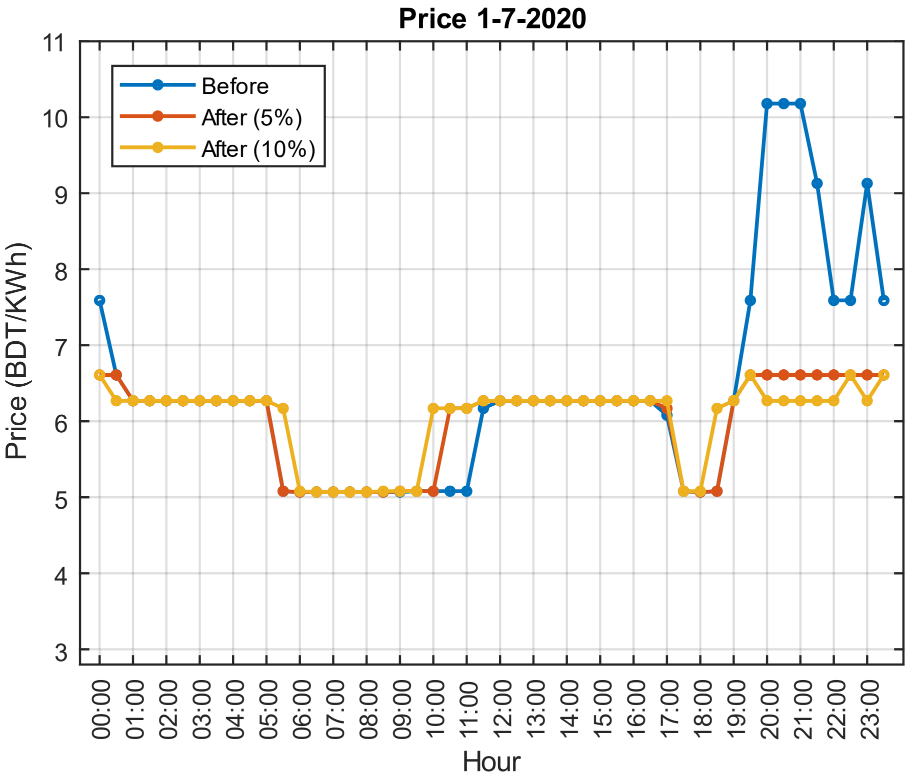

Figure 5.4 Price Points in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 1 July 2020

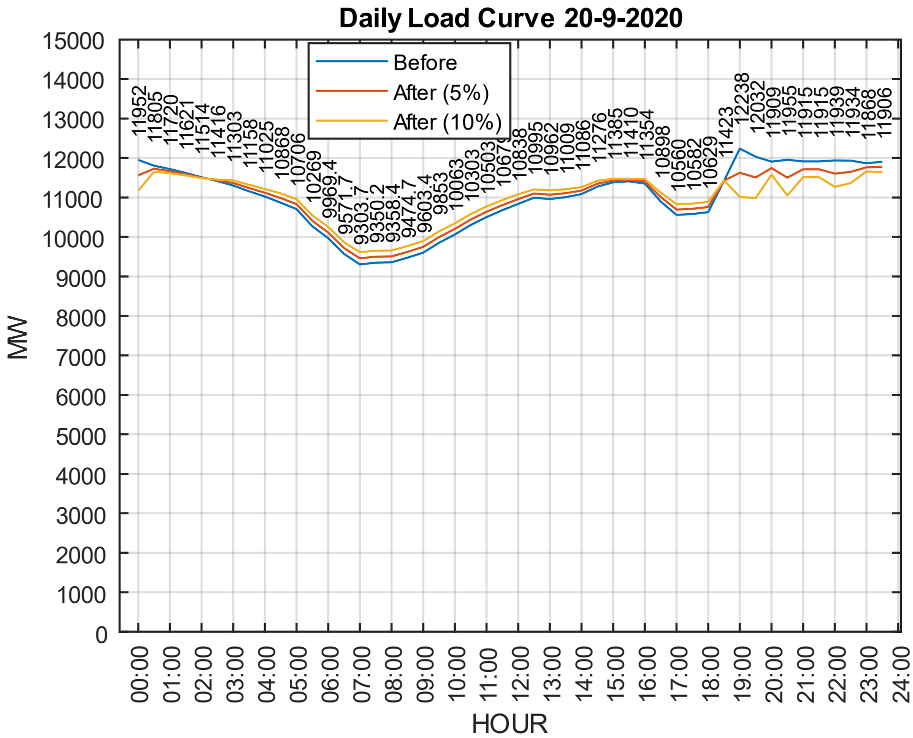

Figure 5.5 Daily load curve in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 20 September 2020

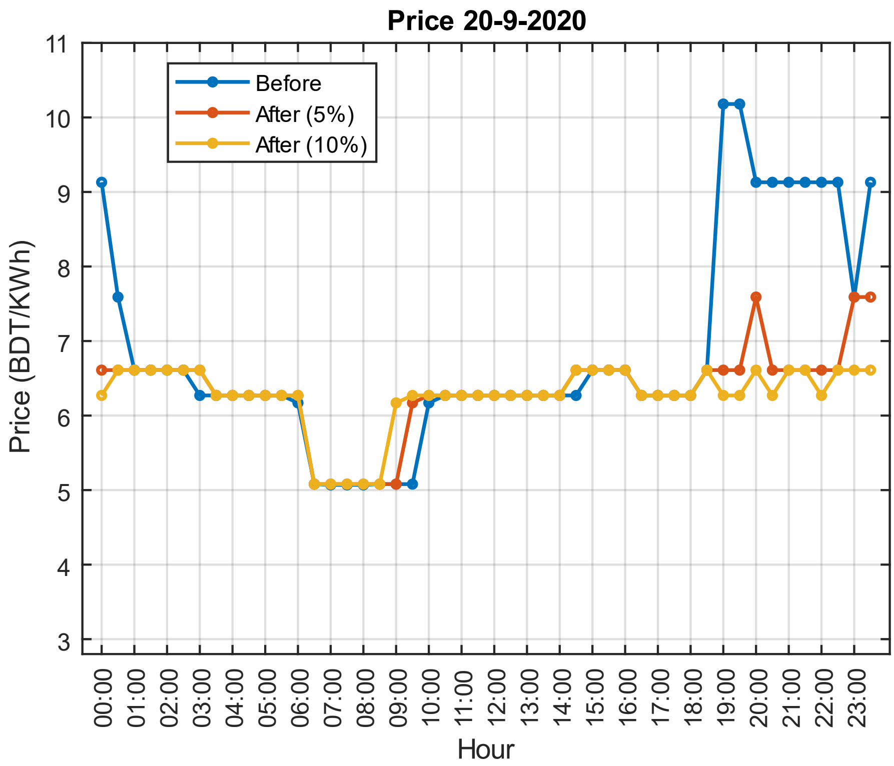

Figure 5.6 Price Points in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 20 September 2020

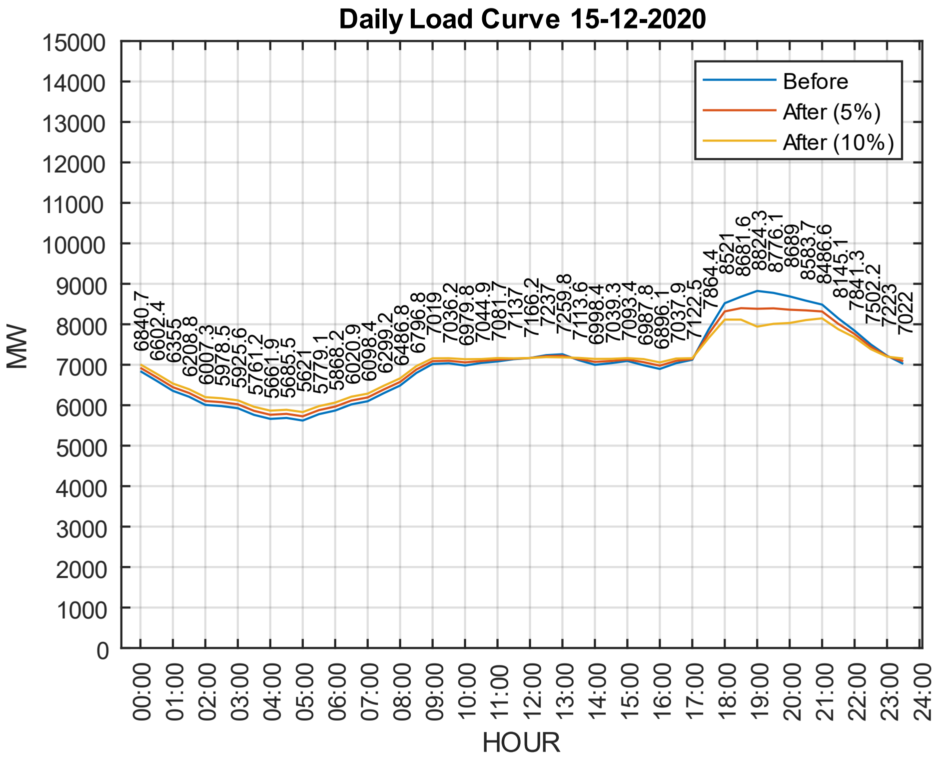

Figure 5.7 Daily load curve in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 15 December 2020

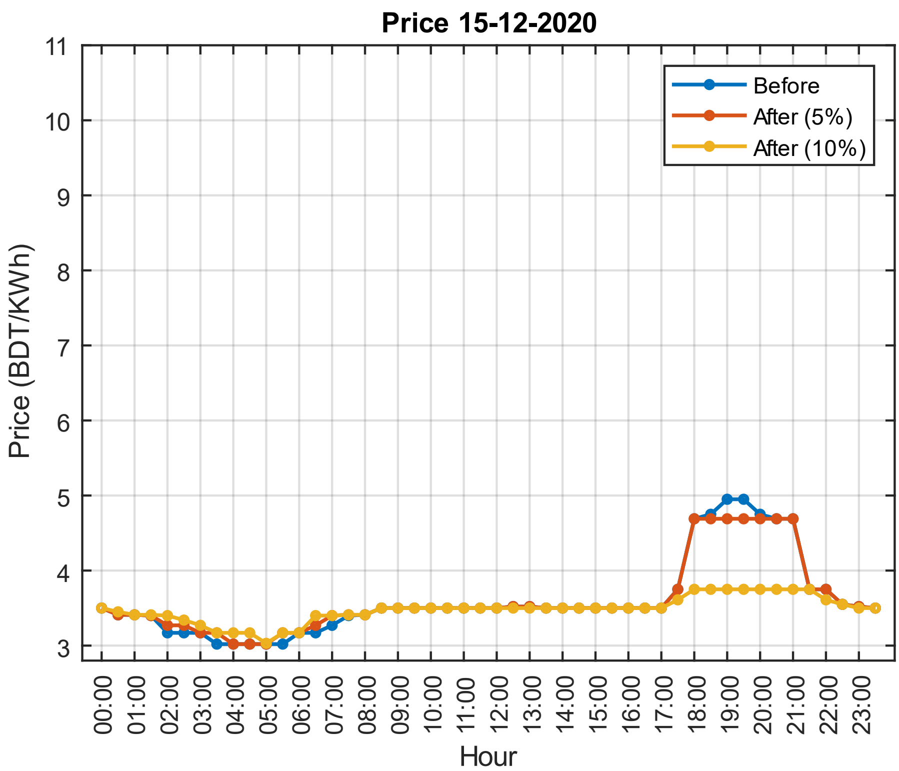

Figure 5.8 Price Points in deregulated market in (i) Inelastic (ii) 5% elasticity (iii) 10% elasticity scenario for 15 December 2020

5.2 Distribution of Price Points

To illustrate the variation of market clearing price within a month, box plot is used. The red horizontal line is the median market clearing price in the month whereas the edge of the box represents 25th percentile and 75th percentiles respectively. The skewness of the distribution of market clearing price can be observed from the boxplot. There are some single data points outside the lower to the extreme upper range that may have been caused by the significant reduction of demand during nighttime and the significant increase in demand during peak hours.

5.2.1 2020

As illustrated in Figure 5.9, in January 2020 with inelastic demand, the median of all the market clearing prices is approximately 3.5 BDT/kWh. The 25th percentile is approximately 3.25 BDT/kWh and 75th percentile is approximately 3.6 BDT/kWh which means that the frequency of having the price around 3.25 BDT/kWh is very high in January, 2018. In Bangladesh, the average load during winter time is low compared to the loads during summer. So, the market clearing price is similar from January to May. But there is a rise in median market clearing

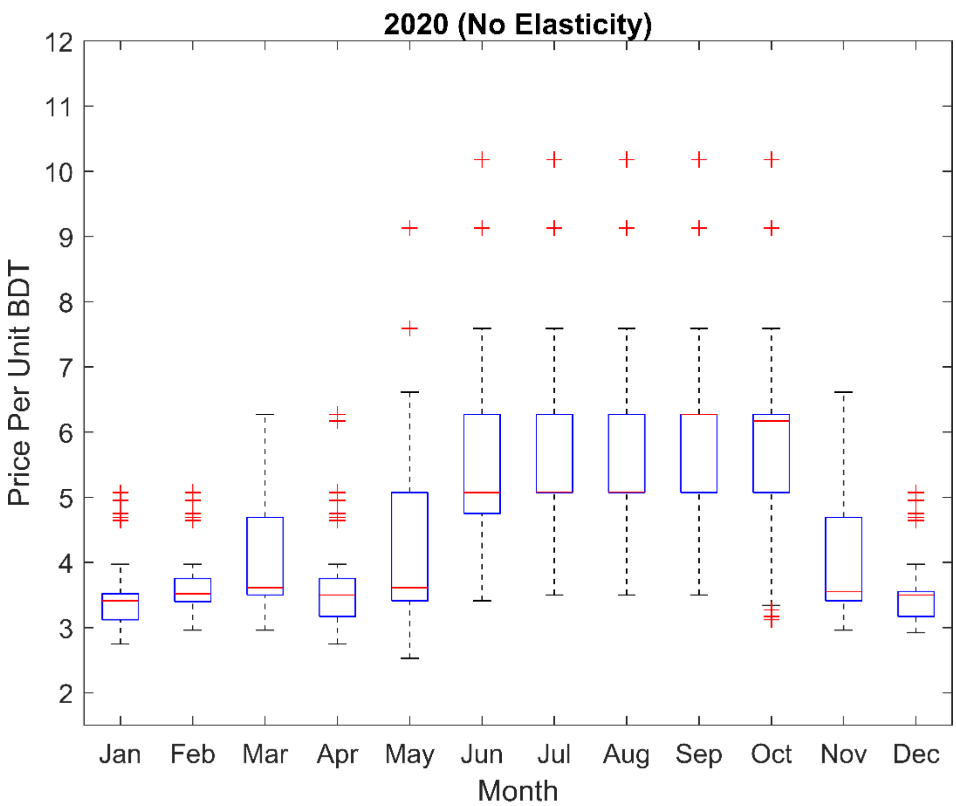

Figure 5.9 Distribution of Electricity Price for 2020 (No Elasticity)

price in June to approximately 5.05 BDT/kWh with 25th percentile being approximately 4.7 BDT/kWh and 75th percentile being 6.2 BDT/kWh. It almost remains similar until October as summer season ends. The highest median for the whole year can be seen in September being 6.1 BDT/kWh. A deregulated electricity the market clearing price is calculated from the supply and demand curve.

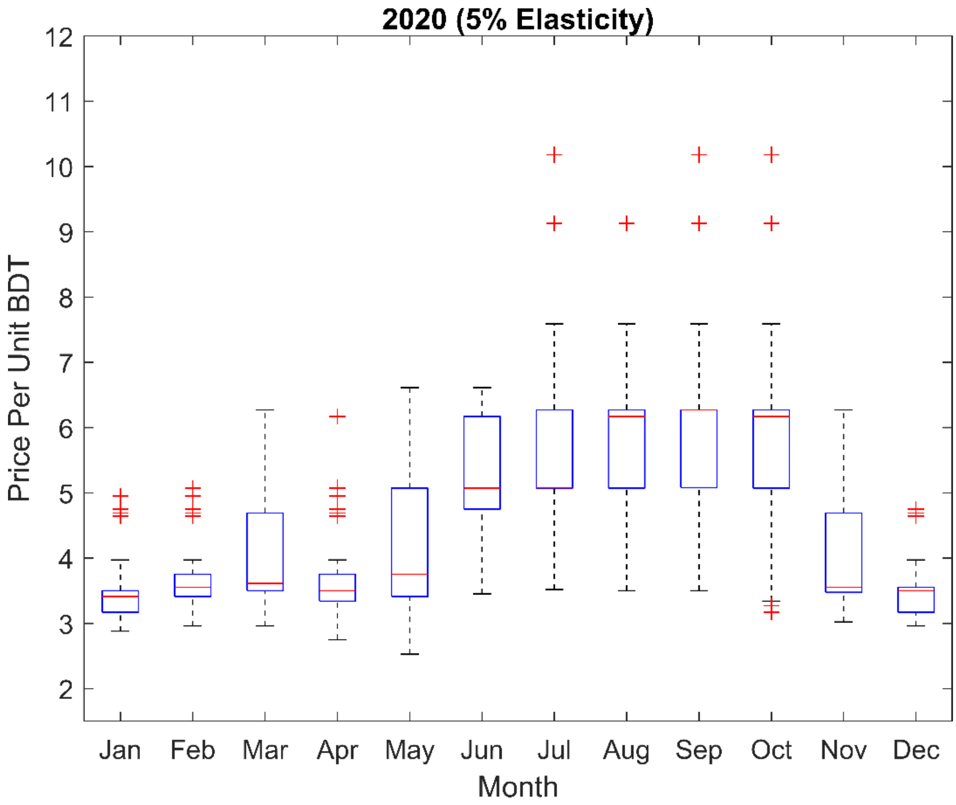

Figure 5.10 Distribution of Electricity Price for 2020 (5% Elasticity)

In the Figure 5.10 shows the boxplot for 2020 with 5% elasticity. It can be seen from the figure that the median market clearing price is similar to the figure 5.9 of inelastic demand. In January the median of market clearing price is approximately 3.5 BDT/kWh. The 25th percentile is approximately 3.25 BDT/kWh and 75th percentile is approximately 3.55 BDT/kWh. But there is a change in the outliers. Due to elasticity, there has been reduction in peak prices.

Then in the Figure 5.11 represents the boxplot for 2020 with 10% elasticity. It can be seen that the median market clearing price is similar to previous two figures. There is slight reduction in the 75th percentile in September and October. The major difference being the greater reduction in the outliers resulting in less peak prices.

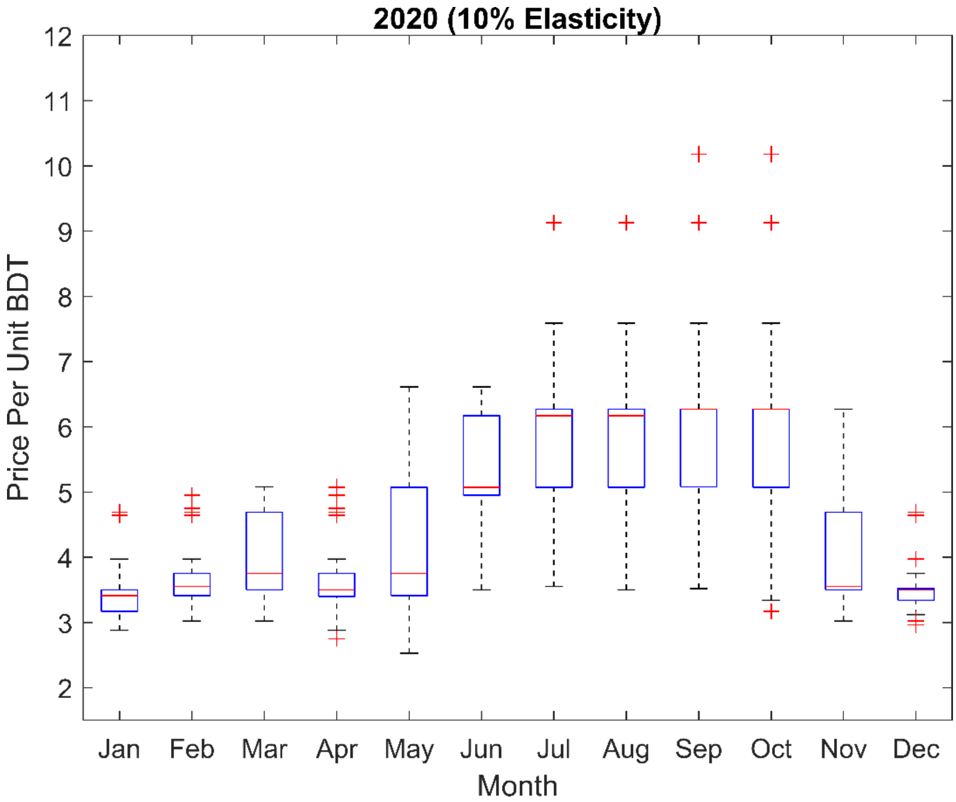

Figure 5.11 Distribution of Electricity Price for 2020 (10% Elasticity)

5.2.2 2019

Figure 5.12 represents the boxplot for 2019 with inelastic demand, where it can be seen that the median of all the market clearing price is 3.5 BDT and the 25th and 75th percentile being approximately 3 BDT/kWh and 3.6 BDT/kWh in January. Then the median jumps to approximately to 3.65 BDT/kWh in March, a bigger jump in 75th percentile to approximately 4.7 BDT/kWh. In summer season from April to October the median of market clearing price is around 5 BDT/kWh. Then in November and December the median decreases to 3.5BDT/kWh.

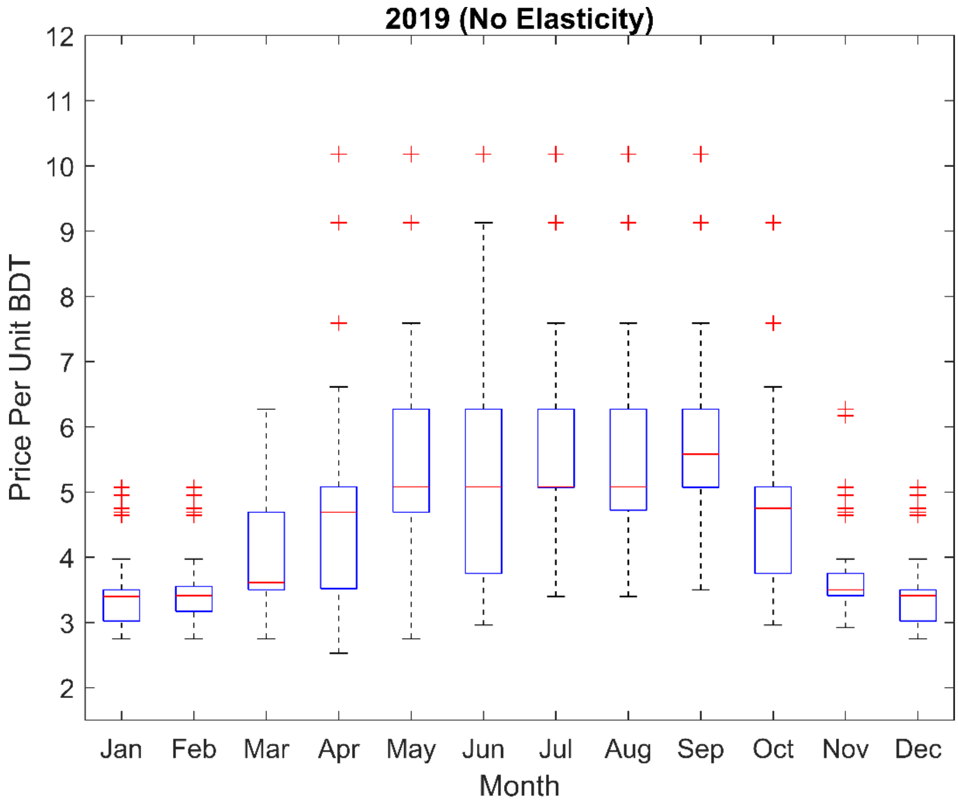

Figure 5.12 Distribution of Electricity Price for 2019 (No Elasticity)

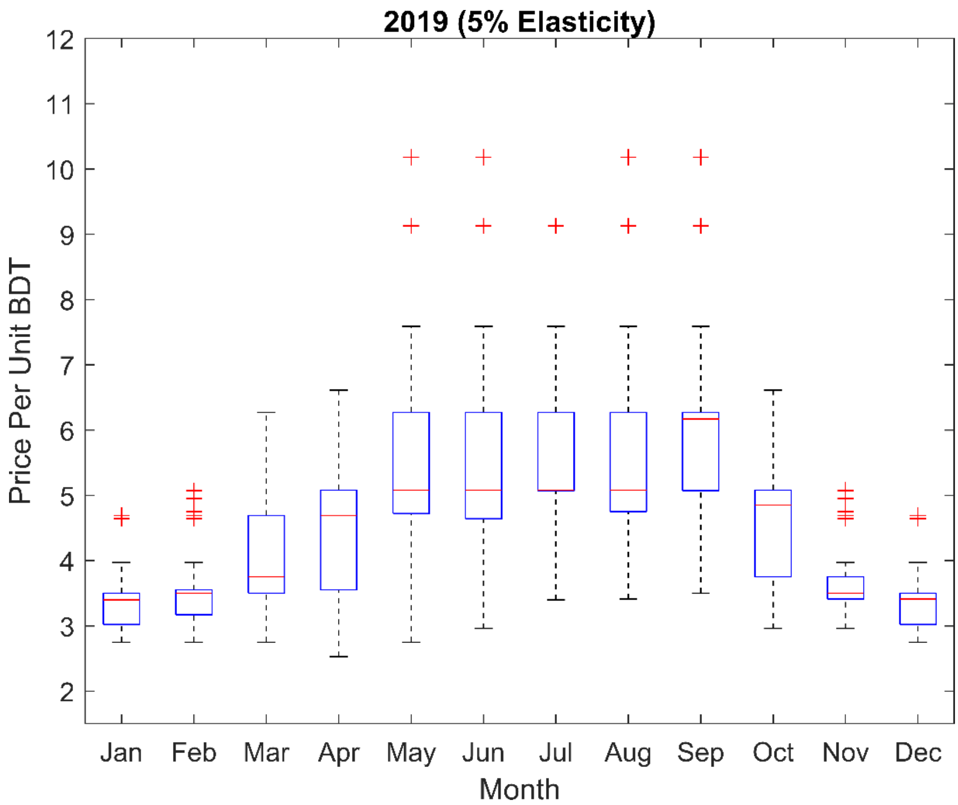

Figure 5.13 Distribution of Electricity Price for 2019 (5% Elasticity)

Figure 5.13 shows the boxplot for 2019 with 5% elasticity where it can be seen that the median price is quite similar at 3.5 BDT/kWh in January. There is a slight decrease in the 75th percentile in February compared to Inelastic demand. Then there is huge reduction in the range of 25th and 75th percentile in June compared to the previous figure. In general, the median price is similar to Inelastic load. But there is reduction in the outliers.

In Figure 5.14 there is the boxplot for 2019 with 10% elasticity. If compared with the previous two figures the median of market clearing price is more or less same. But the main difference being the reduction in the outliers as there is significant reduction in peak prices.

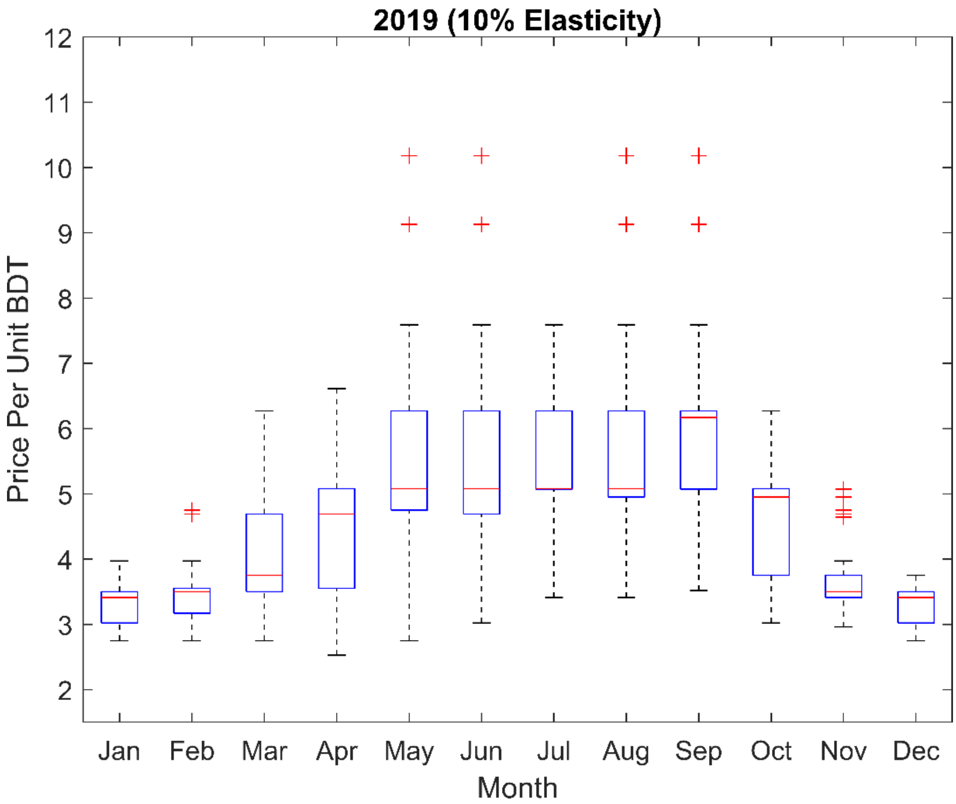

Figure 5.14 Distribution of Electricity Price for 2019 (10% Elasticity)

5.2.3 2018

Figure 5.15 represents the boxplot for 2018 with inelastic demand, where the price points are much lower than the price points of other two years as there was significant difference in demand. It can be seen that the median of all the market clearing price is 3.1 BDT and the 25th and 75th percentile being approximately 3 BDT/kWh and 3.5 BDT/kWh in January. In summer season from April to October the median of market clearing price is around 5 BDT/kWh. Then in November and December the median decreases to 3.3 BDT/kWh.

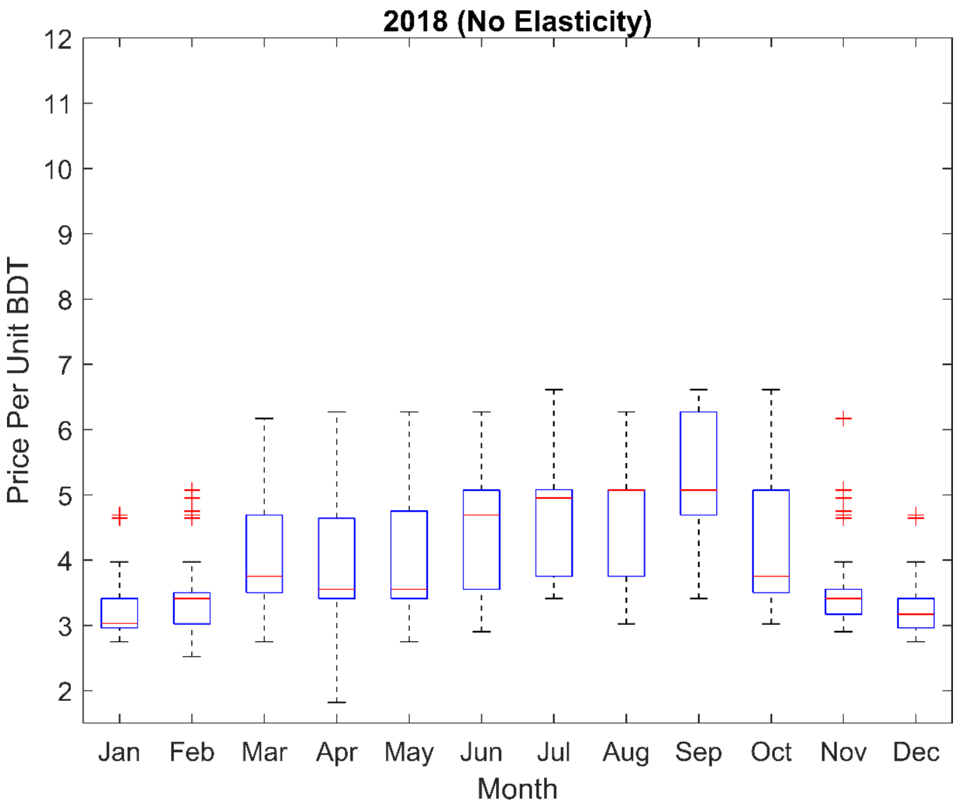

Figure 5.15 Distribution of Electricity Price for 2018 (No Elasticity)

Figure 5.16 shows the boxplot for 2019 with 5% elasticity where it can be seen that the median price is quite similar at 3.5 BDT/kWh in January. There is a slight decrease in the 75th percentile in February compared to Inelastic demand. Then there is huge reduction in the range of 25th and 75th percentile in June compared to the previous figure. In general, the median price is similar to Inelastic load. But there is reduction in the outliers.

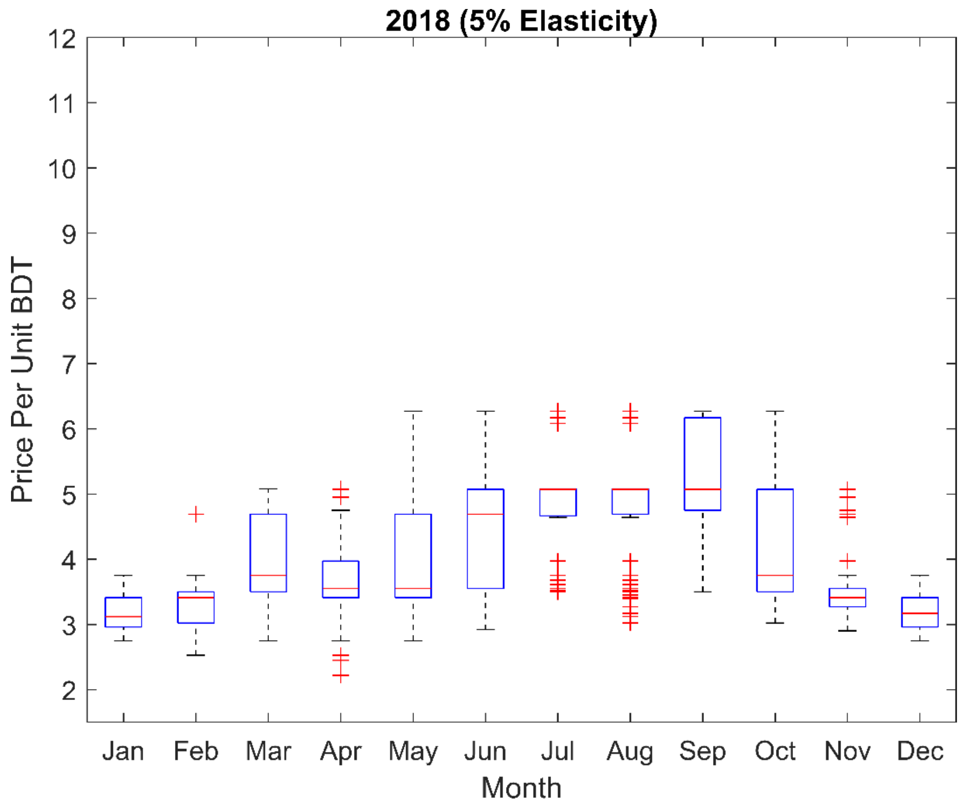

Figure 5.16 Distribution of Electricity Price for 2018 (5% Elasticity)

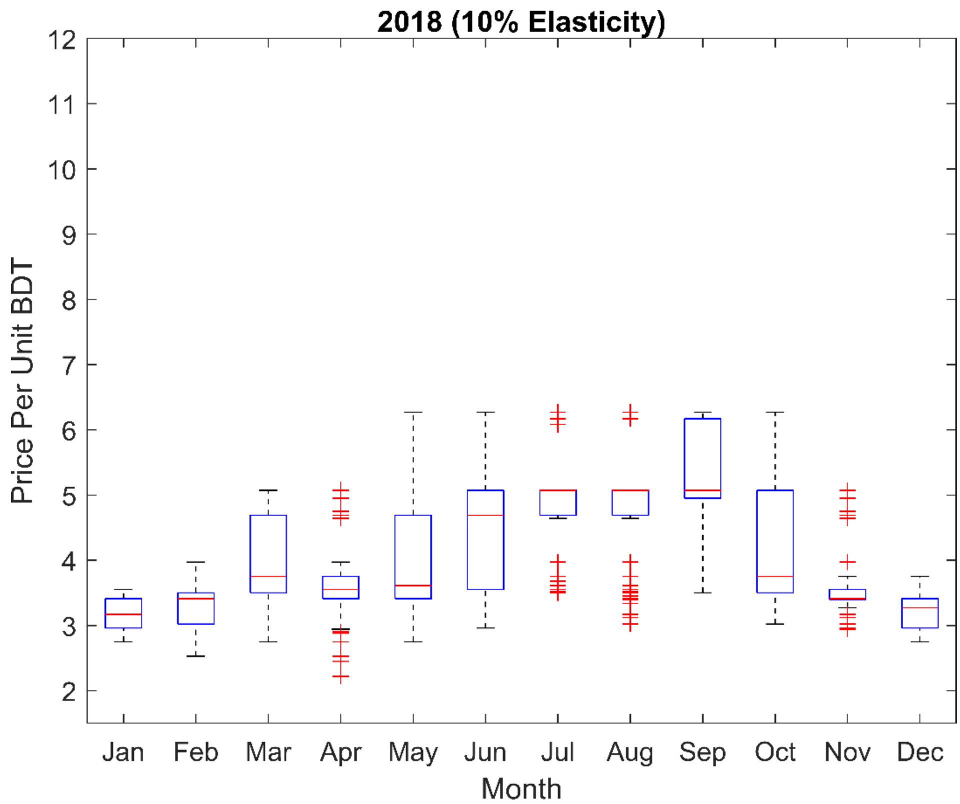

Figure 5.17 Distribution of Electricity Price for 2018 (10% Elasticity)

In Figure 5.17 there is the boxplot for 2018 with 10% elasticity. If compared with the previous two figures the median of market clearing price is more or less same. Same as the other two years, the main difference being the reduction in the outliers as there is significant reduction in peak prices.

5.3 Monthly Mean Value

5.3.1 2020

In Figure 5.18, we can see the monthly variation of price of electricity in form of BDT/KWh for the year 2020. The blue line represents the price points when no elasticity was taken into account. The orange line represents price points with 5% elasticity factored in. And the yellow line demonstrates the price points for each month when the elasticity was assumed to be 10%. It can be noticed that when elasticity was not taken into account, there is a pronounced variation prices for each month. The years starts off with around 3.5 BDT/KWh for the month of January, and then a jump in the prices for the next two months can be noticed. The price is found to be at around 4 BDT/KWh for the month of March. The price then falls to a little over 3.5 BDT/KWh for April. Then an upwards trend is noticed which sees the prices to rise in a steep manner for the next few months. The price goes as high as a little over 6 BDT/KWh for the month of September. It is to be mentioned this is the highest calculated price for any month between the years 2020, 2019 and 2020. This can be attributed to the fact that COVID-19 was prevalent very strongly for the year 2020 which caused a greater deal of power being used by consumers due to lockdown situation.

A downward trend in prices can be noticed after September. There is a steep jump from the month of October to November which is largely due to the arrival of winter and household appliances such as AC and fans not being operated as often. In case of 5% elasticity the curve is similar across the board with a little reduction in price for each month. This is due to the fact that when elasticity is taken into account the peak loads are shifted to different periods of the day when the load isn’t that high. This in turn causes the prices to drop. In case of 10% elasticity, the curve has a similar shape with a greater reduction in prices for each month. The reduction in price is more noticeable for months with the higher prices such as August, September and October.

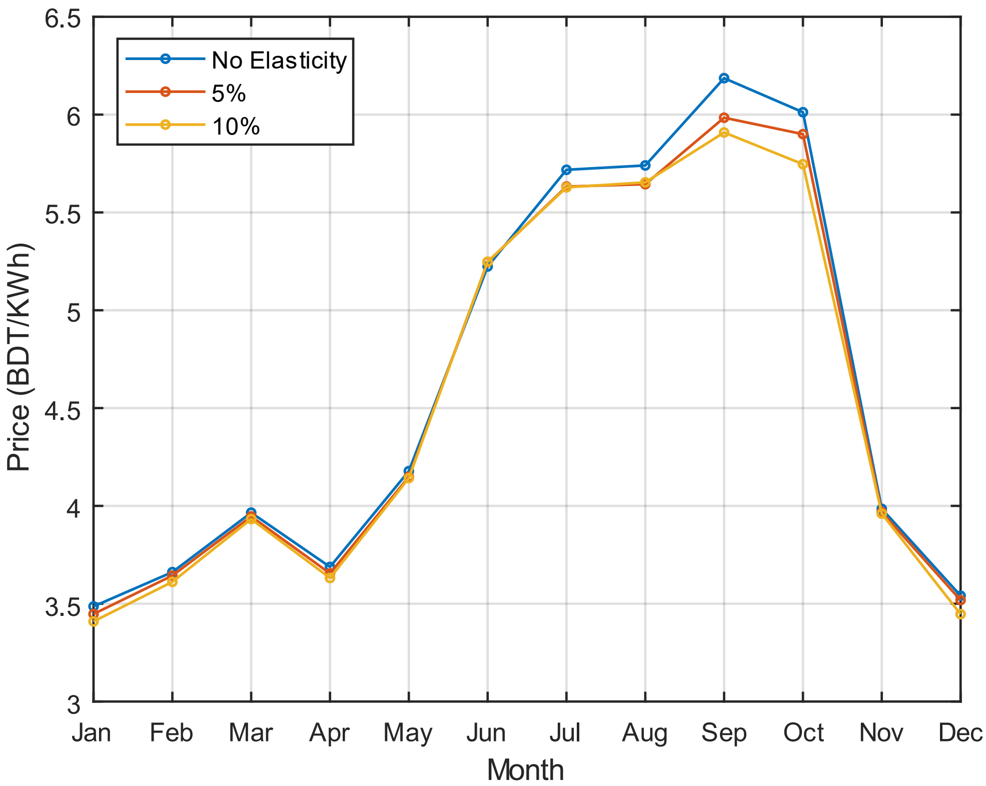

Figure 5.18 Monthly mean value for 2020

5.3.2 2019

For the year 2019, the year starts off with the monthly price of a little less than 3.5 BDT/KWh for the month January. The curve then experiences a upwards trend which the sees the prices to rise in a gradual manner. The price is at around 5.6 BDT/KWh for the month of May. Between May and September, the price ranges between this 5.6 and around 5.9 BDT/KWh which is found to be the highest calculated monthly price for the year. The high prices for the said period can be attributed to the fact that the temperature at this time of the year is higher due to summertime which results in more electrical appliances being used. There is a steep fall in price for the next few months, starting from September. The lower prices for the latter part of the year are due to the same reason as mentioned in case of 2020 which is less electrical appliances being used due to colder atmospheric temperature caused by seasonal change. The curves in case of 5% and 10% elasticity follow similar patterns for all the months albeit with slightly lower prices. For example, for the 5% curve, the highest price calculated for the year is 5.8 BDT/KWh which is slightly lower than the highest price recorded in the original curve.

Same can be said about the lower price calculated for the year as well. The lower prices in case of elastic demand are due to the same cause as mentioned before.

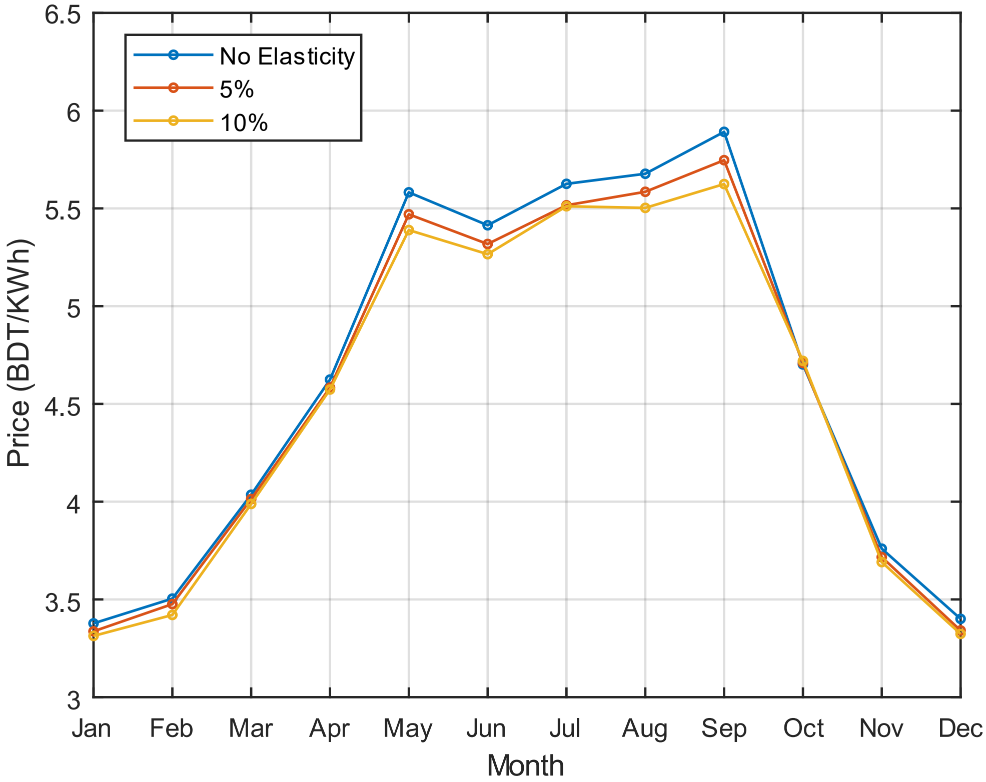

Figure 5.19 Monthly mean value for 2019

5.3.3 2018

In 2018, the prices seem to be lower across the board for all months compared to the years already discussed. In January the price is the lowest at just over 3 BDT/KWh. The curve then experiences a gradual rise to just under 4 BDT/KWh for March. From March to September the curve mostly enjoys an upwards trend with occasional dips. The highest price is calculated to be just over 5 BDT/KWh which is the lowest among all three years. The highest price occurs at September and after that the curve experiences a steep fall. The lower prices for the start and the end of the year are due to seasonal variation resulting in varying patterns of appliance usage. In case of 5% elasticity, the curve almost follows the exact same pattern as that of no elasticity. So, it can be concluded that no significant improvement in terms of price was found by applying 5% elasticity. The 10% elasticity curve also has a similar shape with insignificant differences in terms of prices with respect to the original curve. It can be noted that, introduction of elasticity by 5% and 10% respectively resulting in changes in price points for each month in case of all three years. Even though, the degree at which those changes occurred varied for different years, it is safe to conclude introducing elasticity in the demand by shifting peak load to other parts of the day can go a long way to improve electricity prices.

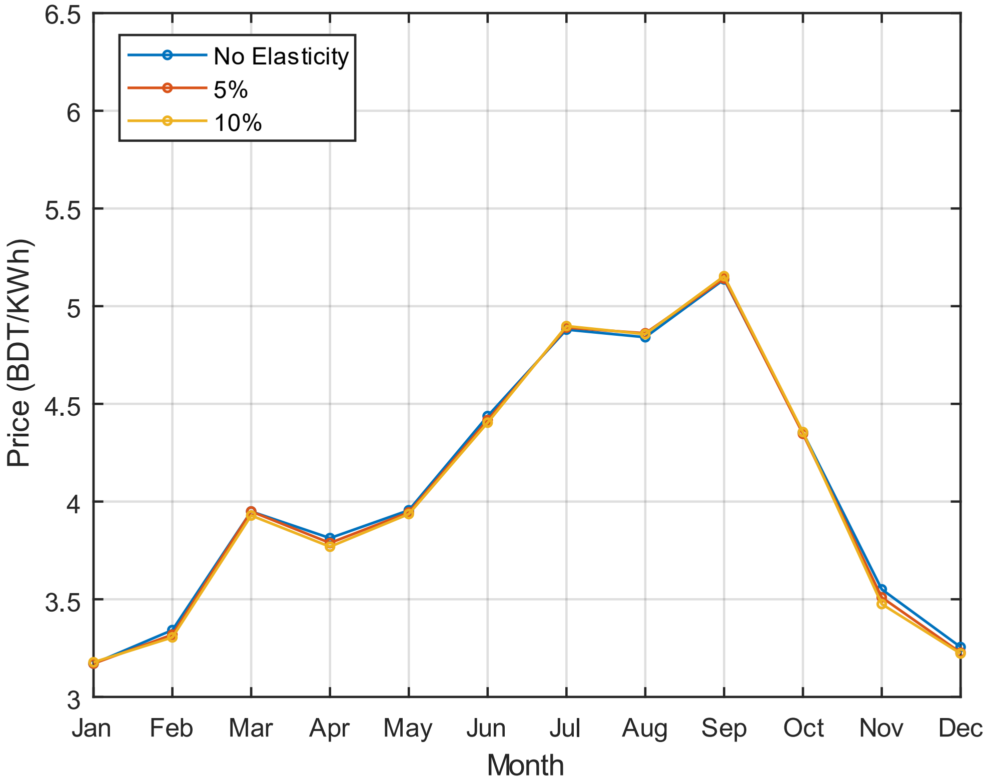

Figure 5.20 Monthly mean value for 2018

5.3.4 Market Clearing Price Comparison

Figure 5.21, 5.22 and 5.23 depict the variation of market clearing prices in case of no elasticity, 5% elasticity and 10% elasticity respectively for all three years. In Figure 5.21, with elasticity not taken into account, it can be seen that the price points vary very acutely for all three years. The highest market clearing price is calculated to be just over 6 BDT/KWh which was for the month of September in 2020. It has already been mentioned that 2020 experienced really price points for power attributing to the excessive use of electricity caused by the pandemic. Price points from July up to October are the highest in 2020 among all three years for the same reason. The lower price point recorded among all three years was for the Month of January in 2018. 2018 experienced lowest numbers in terms of both the highest price and the lowest price recorded in a month which were 3.2 BDT/KWh and 5.2 BDT/KWh respectively. In the next figure, the same data is represented but with 5% elasticity taken into account. As stated before, the curves are almost similar across the board with little changes in price points caused by shift of load during peak hours. For instance, the highest market clearing price recorded among all three years here is exactly 6 BDT/KWh as opposed to 6.2 BDT/KWh. The degree at which the price reduced for each month is varying for each year which is attributed to the unpredictability factor of introducing elasticity. In figure, 5.22 which demonstrates the market clearing prices for 10% elasticity, the curves are even shallower due to the prices dipping even further for increased elasticity. They follow a similar pattern to the original one, but with slightly lower prices. The prices are reduced even further than they were in case of 5% elasticity. For example, the highest price recorded among all three years is below 6 BDT/KWh which is less than both the numbers stated in the two previous cases. It is to be mentioned that the year that was affected the most in terms of monthly prices by the introduction of elasticity was 2020. In contrast, 2018 saw very insignificant changes in prices across the board in all three cases. The monthly mean electricity price of all three years has a similar shape which indicates high prices during summer and comparatively lower prices during winter. A general trend of increasing price over the years can also be observed. One exception can be seen for the month of April and May, where the per unit price of electricity in 2020 can be found low compared to that of 2019. This can be linked with the COVID-19 lockdown in April and May 2020 where the electricity demand in industrial and commercial sectors plummeted due to the shutdown of offices and industries.

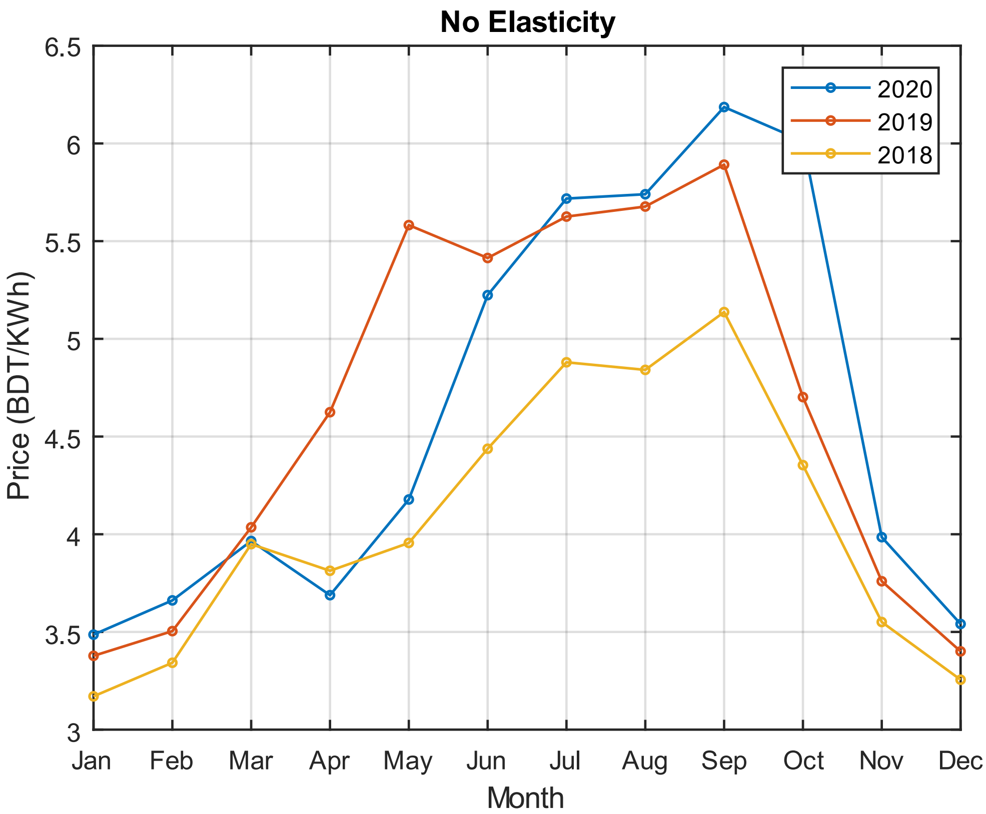

Figure 5.21 Monthly mean value comparison (No elasticity)

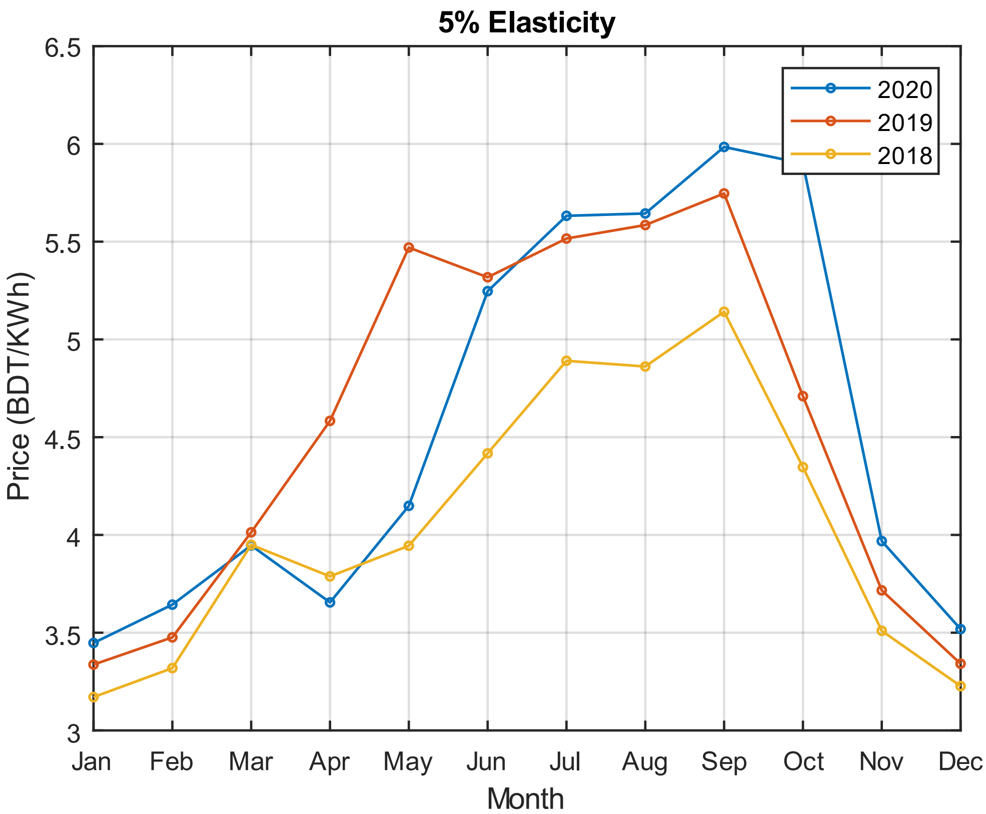

Figure 5.22 Monthly mean value comparison (5% elasticity)

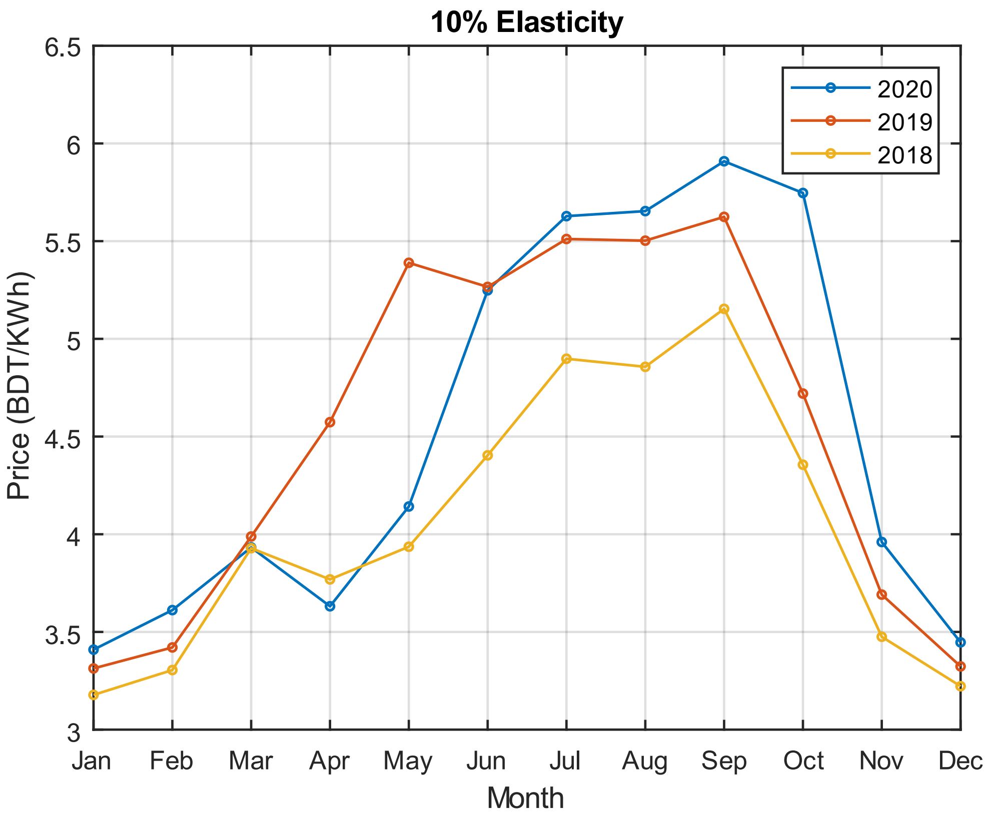

Figure 5.23 Monthly mean value comparison (10% elasticity)

5.4 Cost Comparison

The total electricity generation cost has been calculated considering the dynamic market clearing prices and total runtime of the generating plants for the whole financial year from 2017-18 to 2019-20. The calculated generation cost is compared in Table 5.1 Cost Comparison Between the Proposed and Existing Methods with the actual costs reported by BPDB [27]. It can be seen that the actual generation reported in BPDB yearly report is high compared to the calculated generation cost based on market clearing price. This is expected due to several reasons. First and foremost, in this paper the demand-based pricing is calculated without considering the congestion of transmission line. Hence, it is assumed that the plants with least generation costs will produce the electricity first. In reality, however, the scheduling of the generating plants is based on the existing transmission and distribution capability. Secondly, while calculating the market clearing prices it is assumed that all the generating plants are available throughout the year. However, in reality due to maintenance issue some of the generating plants will always be out of production. Furthermore, certain generating plants need longer startup time i.e., all the power plants are not capable of instantly being turned on, especially during peak demand. For this reason, peaking power plants are required which are significantly costlier in comparison with the said power plants.

Table 5.1 Cost Comparison Between the Proposed and Existing Methods

Year	Total generation (TWh)	Reported average generation cost in BPDB (BDT/kWh)	Inelastic demand		5% Elasticity		10% Elasticity	
			Calculated average generation cost BDT (BDT/kWh)	Average Market Clearing Price (BDT/kWh)	Calculated average generation cost BDT (BDT/kWh)	Average Market Clearing Price (BDT/kWh)	Calculated average generation cost BDT (BDT/kWh)	Average Market Clearing Price (BDT/kWh)
FY 2017-18	63.29	5.72	3.9123	4.36108	3.9	4.351212	3..89	4.34441
FY 2018-19	68.59	5.68	3.0022	4.63890	2.987	4.573646	2.978	4.53313
FY 2019-20	69.51	5.59	2.9617	4.61890	2.941	4.56453	2.938	4.52984

The amount of savings that can be achieved by adopting the demand-based electricity pricing is shown in Table 5.2 Cost savings using deregulated market It can be seen that the cost savings can be as high as 246.83 billion BDT as calculated during 2017- 2018. The cost savings by demand-based pricing can be used in the development and maintenance of transmission and distribution network.

Table 5.2 Cost savings using deregulated market

Year	Cost reported in BPDB (Billion BDT)	Inelastic demand		5% Elasticity		10% Elasticity	
		Cost (Billion BDT)	Reduction of Cost (Billion BDT)	Cost (Billion BDT)	Reduction of Cost (Billion BDT)	Cost (Billion BDT)	Reduction of Cost (Billion BDT)
FY 2017-18	362.25	247.61	114.64	246.83	115.42	246.20	116..05
FY 2018-19	389.52	205.92	183.6	204.88	184.64	204.26	185.26
FY 2019-20	388.88	205.87	183.01	204.43	184.45	204.22	184.66

The existing electricity pricing scheme in Bangladesh is shown in Table 5.3 Existing Tariff Rates in Bangladesh Electricity pricing is set based on the usage and the application of electricity, i.e., whether the customer is using it for residential, agricultural, commercial or industrial applications. It can be observed that for the residential sector, under 75 units, the price is 3.80 BDT/kWh, which is lower than the average market clearing price calculated in this paper. This is done to provide access to electricity for the economically challenged people in the country. However, users who use electricity between 76 to 200 units in a month, the price is above 5 BDT/kWh, which is higher than our calculated price. For the agricultural sector, it can be seen that the price is 3.82 BDT/kWh. This is again to give incentive to the farmers. For small industries, non-residential and commercial and office sectors, the price is above 5 BDT/kWh.

Table 5.3 Existing Tariff Rates in Bangladesh [28]

Customer category and slab	**Tariff per unit (BDT)**	**Customer category and slab**	**Tariff per unit (BDT)**
Category A: Residential		***Category F: Medium voltage, general purpose (11 KV)***	
Life Line: 1-50 Units	3.33		
From 00 to 75 units	3.80	Flat rate	7.57
From 76 to 200 units	5.14	Off-peak time	6.88
From 201 to 300 units	5.36	Peak time	9.57
From 301 to 400 units	5.63	***Category G: Extra high voltage, general purpose (132 KV)***	
From 401 to 600 units	8.70		
From 601 to above	9.98	Flat rate	7.35
Category B: Agricultural pumping		Off-peak time	6.74
Any amount	3.82	Peak time	9.47
Category C: Small industries		***Category H: High voltage, general purpose (33 KV)***	
Flat rate	7.66		
Off-peak time	6.90	Flat rate	7.49
Peak time	9.24	Off-peak time	6.82
Category D: Non-Residential		Peak time	9.52
Light & power	5.22	***Category J: Street light and water pumps***	
Category E: Commercial & Office			
Flat rate	9.80	Any amount	7.17
Off-peak time	8.45		
Peak time	11.98		

In this study, the dynamic demand-based prices are calculated for the whole year. The market clearing price is found high during the peak hours. This will motivate the consumers to shift their flexible loads from the peak hours [29]. This will lead to the load curve being flatter which will reduce the average price. As such, the dynamic demand-based price can be used for the implementation of demand response. However, in Bangladesh the customers are not used to dynamic prices. As such, a fixed price model can be used to reduce the price fluctuations.

Chapter 6

Conclusion

This chapter analyzes the prospect of a demand-based electricity pricing in the context of deregulated electricity market in Bangladesh based on the previous chapters. Based on the existing power plants and daily load curve, the demand-based market clearing prices are calculated where at first demand is inelastic and secondly demand elasticity is taken into account. The market clearing price is further compared with the existing pricing scheme in Bangladesh. Average market clearing price in a deregulated market without considering demand elasticity is generally found to be lower than the existing electricity price in Bangladesh. When the demand elasticity is taken into consideration the market clearing price further falls. As it encourages the consumers to shift their demand to reduce their costs thus reducing peak demands. This results in shutting down peaking power plants significantly reducing the costs. The cost saving potential using demand-based electricity pricing is found to be significant in this simplified model.

6.1 Future Work

As this work mainly focuses on the prospect of demand based deregulated electricity markets, a simplified model was taken to determine that. As a result, there are several aspects of future research and improvements. If these factors can be taken into account more accurate result can be expected.

6.1.1 Demand Elasticity

In a deregulated electricity the market clearing price is calculated from the supply and demand curve. And as the price increases the demand decreases. In this thesis elasticity is taken at random at 5% and 10% which shows the greater cost saving potential. But to find real life scenario the demand elasticity needs to be found accurately.

6.1.2 Transmission Line Congestion

In this simplified model transmission line congestion has not taken into consideration. But in a real life deregulated market it will play a significant role. As it could allow operating peaking power to meet local demand due to the congestion resulting in higher prices. So transmission line is a vital aspect of deregulated market which should be analyzed to get a more accurate result.

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