

Smart Price
A Dynamic Way
to
Reduce Load Shedding in Bangladesh

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“Iqra/ bi-ismi rabbika allathee khalaq”

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Abstract

This thesis is a study of how the fixed price in Bangladesh electricity systems causing load shedding. the unstable supply of electricity is hindering the normal progressions of socio economic developments of Bangladesh. People of Bangladesh still facing the load shedding problem after having enough power generations capacities. Fixed price does not have an impact on supply and demand of electricity to change according to their availability. A smart price (changes in price according to demand and supply ratio) formula could be a solution to reduce the load shedding problem in Bangladesh.

Followed by system dynamics methodology an economic model of Bangladesh electricity systems is built to analyze the applicability of smart price instead of fixed price. The price variations in smart price systems will adjust the demand and supply to reduce the load shedding. A battery based inventory system will store the cheap electricity. This policy can be applied through advanced metering infrastructure with the upgraded smart grid system. Both consumer and supplier will be benefited through the process of buying and selling of electricity.

The smart price policy is economically feasible to implement for consumers. Since, on average the price will be a little bit higher than the existing price for high-end consumers but the low-end consumers will pay less. Slow and phase wise implementation of the new smart price policy will give the society chance for easy adaptations and the burden of extra costs for implementations will be distributed in smaller amount.

Keywords: Load Shedding, System Dynamics, Smart Price, Electricity, Bangladesh.

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Chapter 1: Introduction

1.1 Introduction :

Bangladesh, is a developing country in southern asia with one of the highest density populations of the world. The country is showing booming economic growth since after the 90's with on average of over 6% annual gross domestic production (GDP) growth rates (Bangladesh Bank annual report 2004). The GDP growth rates remained over 6% until present day. From the fiscal year 2010-11 till 2014-15 it was 6.3% per annum. In the fiscal year 2016, the growth rate was 7.1% (World Bank). These economic growth rates were achieved after the country's economy transitioned from agriculture based to industrial. This economic growth starts urging more demand on infrastructure development and service sector. From CIA world factbook data shows that Bangladesh is experiencing 9-10% growth in industry sectors and a 6% growth in service sector.

Expansion of a booming economy is creating more demand for energy. As electricity is the main key factor for the energy supplies, the government of Bangladesh is trying to fulfill the pressurized demand of electricity. The government of Bangladesh is expanding its electrification every day to reach the goal of having access to electricity for every citizen by the year 2020 (NEP 2002). Still, 1/3 of the total population do not have access to electricity. Expansion of electrification and overpopulation increase the demand for electricity but the supply of electricity is not sufficient to fulfill the demand. There are approximately 6-7% on average demand increasing every year on electricity from the year 2004 till 2015 (IEEFA: Bangladesh Electricity transition 2016). On other hand, the supply side was not supportive to the demand. There was always a 1-2% gap between supply and demand. The higher gap between supply and demand is creating power outages, which are known as "load shedding" locally. Power outages are becoming one of the key obstacles to the country's desired goal for socio-economic development. Without a proper and reliable supply of electricity, it creates a negative impact on country's GDP and GDP is one of the key measures to understand country's economy (Rahman 2011).

Power outages are common phenomena in Bangladesh. Power outages happen due to lower production than the demand for electricity. After the 90's, when the rapid industrialization started in the Bangladesh economy, the demand for electricity increases rapidly. On an average 5.43% of demand for electricity supply increases every year whereas, only on average 5.37% generation capacity is increased (Rahman 2011). This gap is also accelerating the power outages more and more every year. Daily an average 2-3 hours of power outages are occurring all over the country. These power outages are distributed to consumers all over the country by a rationing system of the distribution company, which is known as scheduling "load shedding". The load shedding varies depending on the different seasons. The national grid system is still suffering

from 600-1200 MWh of load shedding on average every day. During the peak season (irrigation time) this load shedding reaches 1500 MWh. The consumers of electricity are 43% domestic and 44% industrial. Most of the demand reaches its highest peak during evening time due to lighting on households and commercial places.

The total power generation capacity of electricity in Bangladesh is 10939 MWh. Most of the electricity around 61.99% comes from a natural gas based generator. The rest of the generation of the electricity comes from different sources like Furness oil 21.03%, Diesel 8.47%, Hydro 2.10%, Coal 1.83% and power imported from neighboring country India is 4.57% (IEEFA:2016). Normally the generation of electricity cannot achieve 100%, because all the power generation unit cannot run together because of service and maintenance, shortage of gas supply and some the power generation units are old. Approximately 10% of the total installed capacity is always down. The highest electricity generation achieved 8719 MWh in the August 2016, while the demand was 9000 MWh during peak hours (17:01-00:00) and 6968 MWh during off-peak hours (00:01-17:00) (Monthly Report BPDB: August 2016).

The Bangladesh Power Development Board (BPDB) is solely responsible for production and supply of electricity on behalf of the Bangladesh government. In the past several years, BPDB was trying to reduce the load shedding by increasing the production of electricity by installing small quick rental power plant from the private sector and by importing electricity from the neighboring country India. From both sectors, BPDB is buying electricity at a higher price than the selling price. The government of Bangladesh has also taken a step to install two big power plant projects, one is 1320 MWh coal fired thermal plant and another is 2500 MWh nuclear power plant. Both of the projects are facing local political and environmental issues, which is making the future of those projects quite unstable. Also, high natural gas dependency for power generation is creating instability as the gas reservoirs are decreasing day by day. On the other hand, the government is trying to control the demand by regulating the price of the electricity depending on peak and off-peak hours the day. The price is fixed on a long-term basis for example on an annual or bi-annual basis. Both steps were taken to handle the emergency situation and the result has increased the production cost over than selling cost. Also, the consumers are not concerned about limit their uses or waste of electricity. On the other hand, consumers are more concerned about investing for a power back up device such as IPS batteries, a small generator. IPS batteries are creating more pressure on existing demands and small generators are increasing production cost for industries. Since the supply is not stable, so fixed prices do not give the option for the customer to participate in minimizing the demand.

Most of the policies implemented to reduce the power outages were increasing power generation in the short run (quick rental power plant) and in the long run (coal fired thermal power plant, nuclear power plant) new energy policy (NEP: 2002). Also, regulating price by peak and off-peak hours implemented by fixed price for the long run. Tariff policy is changed on an

annual basis and changing the price of electricity takes a long time (Bangladesh energy regulatory commission: BERC 2015). There is no such further studies or literature found, where system dynamics methodology is used to control electricity market in Bangladesh.

1.2 Hypothesis and Analysis of the problem:

1.2.1 Hypothesis:

Lots of different policies have been taken to reduce the power cuts in the Bangladesh electricity market but still the problem is existing in the system. Apart from fixing the price on a long-term basis, no other policy has been taken for electricity pricing. In this thesis fixed pricing policy has been taken as the major obstacle to reduce the load shedding. Bangladesh Energy Regulatory Commission (BERC), fixes the price for electricity on an annual basis. Fixed price for the customer does not give them the chance to contribute to controlling the demand. In a fixed price system, customer only have two options to change the electricity using amount according to “peak hour price” (High price) and “off peak hours” (Low price). In this case, customers are less concerned about the prices while consuming electricity. On other hand during peak hours electricity is consumed 100% while there is always excess energy during off peak periods. This excess energy also counted as system loss, which is also increasing the extra burden on loss in profit for the energy producers.

1.2.2 Analysis:

After analyzing the hypothesis this thesis will show the future possibility of implementing a smart pricing system. Through implementation of smart pricing, it is possible to analyze whether it is fruitful or not for the existing system to reduce the load shedding. Smart pricing is a dynamic pricing system where the tariff of the electricity will vary depending on the demand and the production cost in every hour. Through the system dynamics simulations, results showed that load shedding is reduced under a normal fixed price system. The simulations also show that the price of the electricity is higher during high demand period of electricity but it also served the electricity during the low demand period. This thesis is also going to analyze the possibility of storage system for cheap electricity which can be served during the high price period. If customers get the opportunity to buy the electricity at a cheaper price and sell during higher price, they will get some benefits apart from just consuming electricity. Also continuous participation in the buy and sell system means that the customer gain awareness of their use of electricity.

1.3 Policies and Recommendations:

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Chapter 2: Background theory

2.1 Background:

Policies have been taken only to reduce the gap between supply and demand only through increasing the production capacity. Continuous use of the generation system reduces the average life time and efficiency. As report says from Bangladesh power development board statistics, around 10% of the available production generators must be offline for maintenance purpose. That means BPDB cannot use the generation capacity during high demand periods like winter time or irrigation time, which is also increasing the possibility for more load shedding during high peak time. BPDB only took the policy to reduce load shedding is rationed the total load shedding throughout different period of the day. Also, BPDB divided the country's electricity system into different zone. So, the load shedding was also distributed according to demand from different zones. Existing electricity system does not allow the consumer to react on demand. Consumer are only paying for the usage. They do not have the option to benefit from using less electricity during the higher price. Without uninterrupted supply of electricity, the consumer do not have the opportunity to reduce their use of electricity. For example, if the consumer wants to use a washing machine during the off-peak hours, they need to have the available electricity. In this situation consumers have no other choice than to use 100% of the available electricity. This system is quite unfair between the consumers. For example, if consumer from within one zone are using the electricity during off peak hours, they are paying less while another consumer is not getting electricity because of the load shedding rationing time. In vice versa one consumer is

paying higher price for the electricity as they are using it during peak hours and they do not have available electricity during off peak hours. With smart pricing system the price will vary very frequently according to production price and the consumer will have the opportunity to decide whether they want to use lots or little electricity. To introduce smart pricing system the government needs to take the initiative to change the existing grid system with smart grid system. The age-old grid system does not get proper information of the demand. Through smart grid system and advance metering system the producer will have the proper information about demand from time to time. Advance metering technology will give the consumer to control their usage.

No such a literature found whether smart pricing policy or dynamic pricing policy has introduced to Bangladeshi electricity market system. Several research literatures have been found for dynamic pricing (Price variation according to demand and supply, same as smart pricing). From the article “The Power of dynamic price”- by Faruki, Hledik and Tsoukalis derived that the feasibility of dynamic pricing for all types of customers and the potentiality of reducing 1-9% high peak demands. This research was done based on utility system in California, USA.

2.2 Methodology:

This thesis research was conducted followed by system dynamics methodology based on data collected from different reliable sources. For example, Bangladesh power development board (BPDB) different reports (Daily, Monthly and Yearly), Bangladesh energy regulatory commission (BERC) and different research papers published based on Bangladesh electricity system. Using these data, future projection of the smart price was formulated by the following equations,

For fixed price system the price is equal to fixed price (existing price)

$$P=FP$$

For smart price, price is a formula of the following equations,

$$P = EP*(1+PS*D:S-1)$$

$$EP=EP_0+ CEP*dt$$

$$CEP=(P-EP) /time$$

$$D : S= total\ demand/total\ supply$$

Here,

P= Price FP=Fixed price

EP= Expected Price

EP₀= Expected price at time 0

CEP= Change in Expected Price

Time= Time to adjust expected price

D:S= Demand and Supply ratio.

Chapter 3: Explanatory Model

Through the principle of system dynamics, a model is created to oversee the behavior of Bangladesh electricity system. This model will give the proper insights of the system. The system dynamics model was created through the computerized software which has up to date functions to implements system dynamics theories. An overview of the model will give the opportunity to understand the model and an explanatory model will give the option to get insights of the total systems.

3.1 Overview of the Model

This is an overview of the total model created to understand the behavior of electricity system in Bangladesh. Here inventory is added as part of the future policy of the system to analysis.

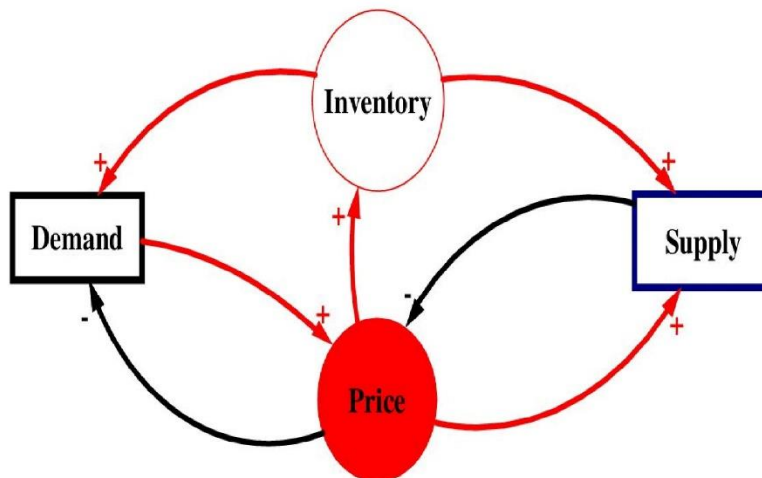


Figure 1: Simplified view of the model.

From the above figure we can see the simplified view the existing system and future of the system. Here we can see that the price is the major sector controlling all the other sectors. This is the simplified causal relationships between sectors. If the price increases then the supply will increase and demand will decrease and vice versa. Here we can see there is balancing feedback loops between price and demand and supply. This simplified model shows the relationship

3.2.1 Supply Sector:

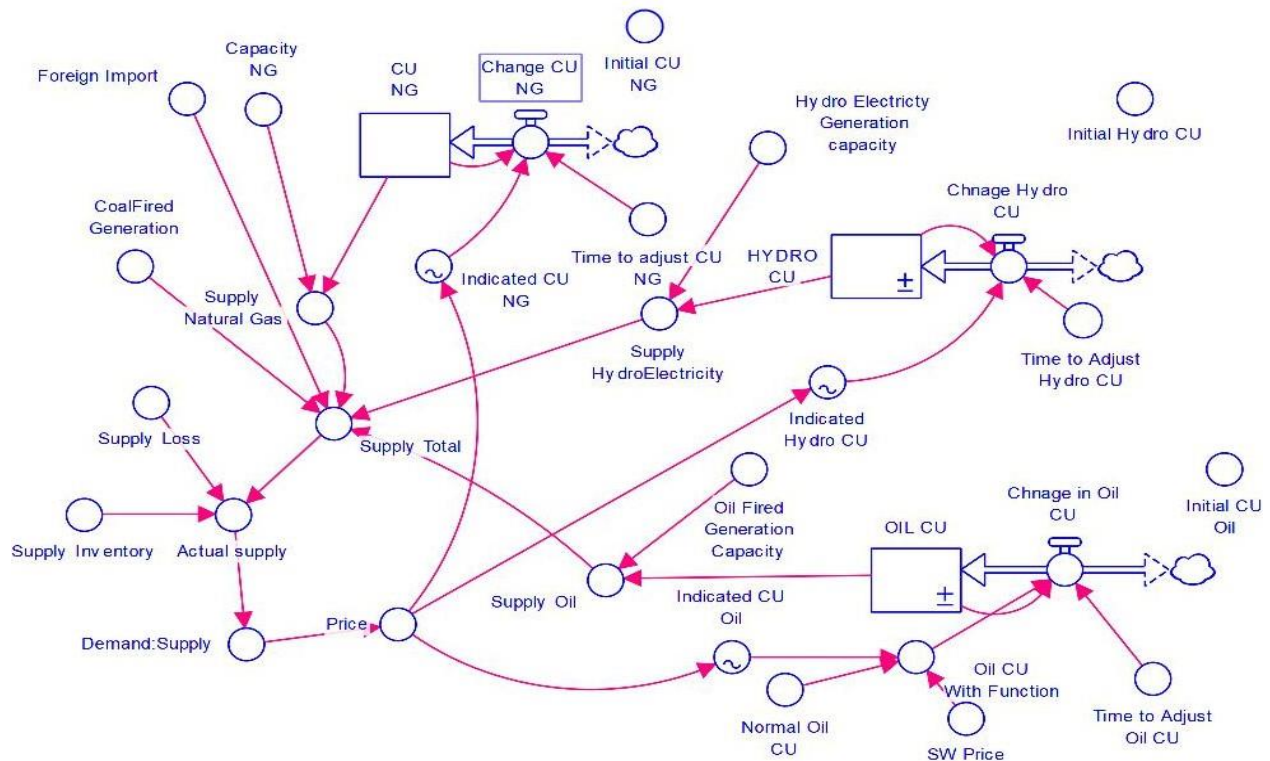


Figure 3: Stock and Flow Diagram for Supply sector.

Power generation for the Bangladesh electricity market consists of five different sources. They are natural gas, hydro, oil, coal and imported electricity from neighboring country (currently it is from India). The primary source of the electricity is natural gas as it is the cheapest source of energy. Almost 62% of the total supplies comes from this sector. As per the data from BPDB the base capacity utilization (CU) for the natural gas sector was 58% which can be increase up to 80%. The CU of natural gas also changes according to the price variations, this is reflected in indicated CU NG. Since the production costs for gas fired generators are cheap, it can be taken into consideration that highest possible of the CU will be used. Here, CU NG (Natural Gas) is stock and Change in CU NG is flow. So, the CU NG is the accumulations of change of CU NG over time. The equation for both stock and flow is below,

$$CU_NG(t) = CU_NG(t - dt) + (Change_CU_NG) * dt$$

$$Change_CU_NG = (Indicated_CU_NG - CU_NG) / Time_to_adjust_CU_NG$$

The change in CU NG is the flow of Indicated CU NG over adjustment time of CU NG. The indicated CU NG changes according to the price and the time to adjust CU NG is 30 minutes. Since it is mentioned above that natural gas based power generation is the cheapest mode of production, so it can be assumed that this production capacity will be online always. A similar formula was also used for hydroelectricity productions system as it is also the cheapest form of electricity generation system.

The second major sector is an oil based generation. There are two types of oil fired generation diesel and furnace oil. These sectors are also divided into two other types, government-owned and Quick Rental power plants. For simplifications of the modeling this thesis took all in one big sector and the production cost was taken as the average of different costs of different producers. The initial CU for oil based production was 58% when the data was collected. The CU for oil can be 90% as most of the producer of this sector is private and they are always ready to start production. SW Price switch is used here to control the difference between the use of this sector. Primarily, this sector was introduced mostly to cover the emergency need of the electricity to cover up the load shedding. Also, the price of this kind of production is comparatively very high. The equations are almost similar to natural gas and hydro except the switch function has been used, the equation is below,

$$OIL_CU(t) = OIL_CU(t - dt) + (Change_in_Oil_CU) * dt$$

$$Chnage_in_Oil_CU = (Oil_CU_With_Function - OIL_CU) / Time_to_Adjust_Oil_CU$$

$$Oil_CU_With_Function = Indicated_CU_Oil * SW_Price + Normal_Oil_CU * (1 - SW_Price)$$

Here, oil cu with the function used to change the capacity utilization with a fixed price to smart pricing policies. Normal oil CU is 70% of the constant. Indicated CU oil is a graphical function which is regulated by price. Here, an exception was taken as normal price for oil based generation cost is 25-30 Taka/kwh so with a low price most of the capacity will remain inactive. So, the highest price was kept till 15 taka/kwh to use the full capacity. The price was calculated according to different production cost from different producers including government and private both sector.

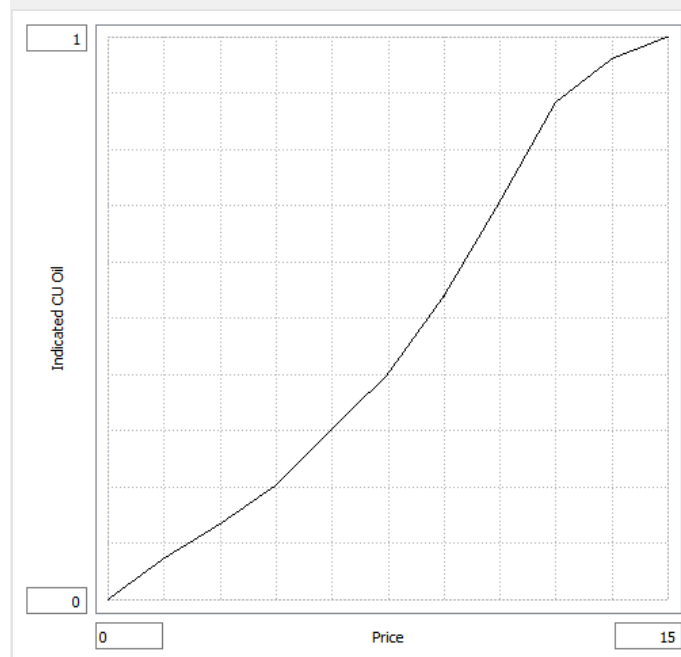


Figure 4: A Graphical function for Indicated oil CU.

Apart from the above three supply sources, there are two other sources of electricity that are existing in the system. Coal based electricity generation and imported electricity from the neighboring country of India. Since coal based production is cheaper and it always needs to be in production. The coal based generators need long start up times that's why it is not economically feasible to turn off and on instantly for according to demand and price. The power import from India is also cheaper source so, it is also considered as a constant supply of electricity during analyzation period.

On the other hand, there are also small solar and wind power based electricity generation sources. They generate a comparatively small amount and no actual data was found about their supply activity. So, these two sectors were deemed not suitable for this thesis analysis.

Total supply is the sum of the different sources of electricity generations including supply from inventory sector. The equation for the total supply is,

$$\begin{aligned} \text{Supply_Total} = & \\ & \text{Supply_Natural_Gas} + \text{Supply_HydroElectricity} + \text{Supply_Oil} \\ & + \text{Foreign_Import} + \text{CoalFired_Generation} \end{aligned}$$

The equation above is illustrating the available supply of electricity at generation end. According to BPDB data this total amount served to consumer ends after 10-13% losses. This loss is known as transmission and distribution losses. After subtracting the losses, the actual supply can be found to serve the existing demand at the consumer end. The equation for actual supply is below.

$$\text{Actual_supply} = \text{Supply_Total} - (\text{Supply_Total} * \text{Supply_Loss}) + \text{Supply_Inventory}$$

Here, supply inventory is the total available supply of electricity from inventories. This function works during the smart pricing policy start working with the inventory. In fixed price system there is no such a supply from inventories. As all the inventories are closed to consumers end so the electricity from the supply inventory can be served without any losses. This is the reason this supply is calculated with actual supply.

3.2.2 Demand Sector:

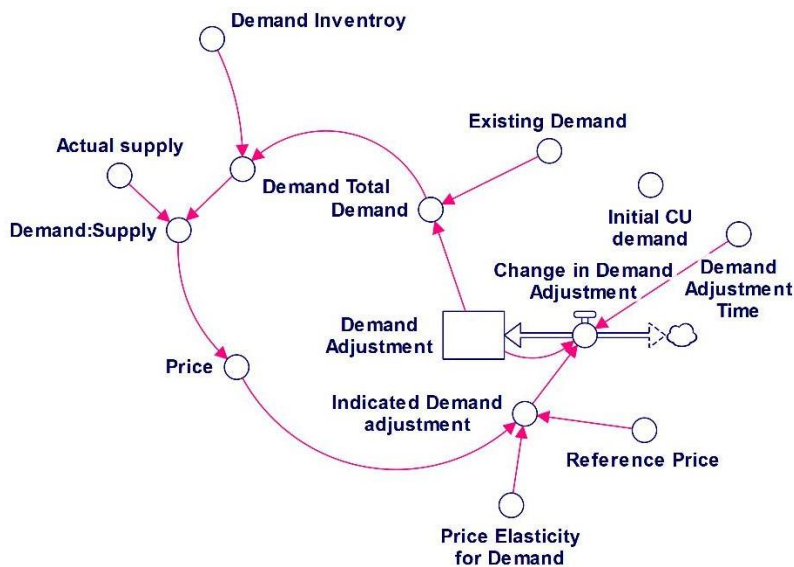


Figure 5: Stock and Flow diagram of Demand sector.

The demand sector reflecting the situation total consumers need for electricity. Total demand is the sum of demand inventory and demand. With fixed price the inventory demand is 0 since, the inventory demand works with SW price functions. The equation for inventory demand will be illustrated in inventory sector. The following equation can provide the insights,

$$\text{Demand_Total} = \text{Demand} + \text{Demand_Inventory}$$

$$\text{Demand} = \text{Existing_Demand} * \text{Demand_Adjustment}$$

Existing demand is the demand from the consumer at a fixed price. With the fixed price system, the existing demand is 132 MW with a variation of 10 MW. For the existing demand, a SIN function has been used to replicate the peak and off-peak periods demands variation. The equation for Existing demand is below.

$$\text{Existing_Demand} = 132 + 18 * \text{SIN}(2 * \text{PI} * \text{TIME} / (60 * 24))$$

Demand adjustment is stock. This stock accumulates the flow of change in demand adjustment over 30 minutes time. The time is set to 30 minutes to see the quick variation of demand according to changes in price. The price is changing the indicated demand adjustment. Without smart price function there is no variation in indicated demand adjustment. The equation for change in demand adjustment is below.

$$\text{Change_in_Demand_Adjustment} = (\text{Indicated_Demand_adjustment} - \text{Demand_Adjustment}) / \text{Demand_Adjustment_Time}$$

Here, indicated demand adjustment is the relationship between price over reference price and price elasticity. Demand is adjusted according to the price, if the price is higher than reference price then the demand will go lower and vice versa. The Indicated demand adjustment equation is below.

$$\text{Indicated_Demand_adjustment} = (\text{Price} / \text{Reference_Price})^{\text{Price_Elasticity_for_Demand}}$$

The reference price is the current fixed price. Price elasticity of the demand is the calculation of price over total demand and multiplications of change in demand quantity over the change in price. Here price elasticity for demand was taken as -0.1 (round figure of -0.093). The calculation was done outside of the model. The equation for price elasticity of demand is an economic formula, is shown in the equation,

Price elasticity of demand = (Price/ quantity of demand) *
 (change in quantity of demand/ change in price).

3.2.3 Price Sector:

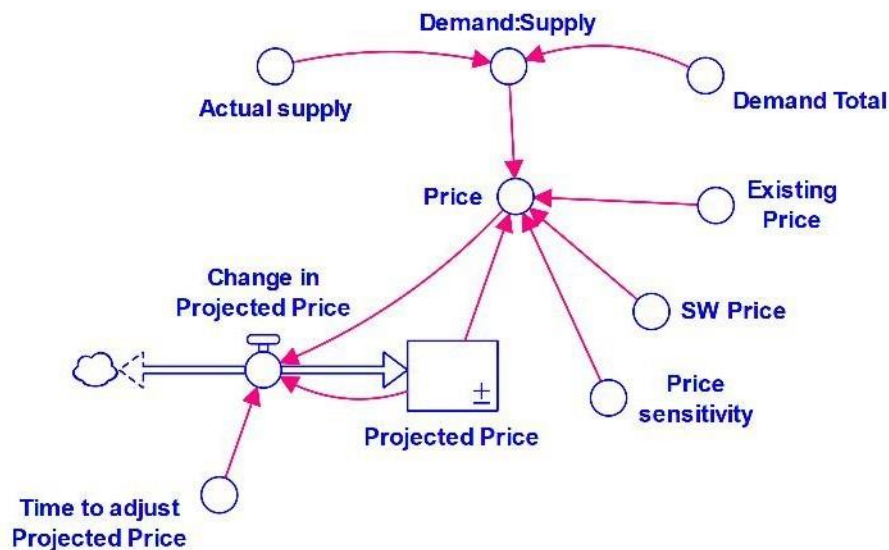


Figure 6: Stock and Flow diagram for Price.

In a fixed price system, price does not have a big function to change the load shedding scenario. In this thesis as the price has been taken the center of focus to control demand and supply. It is changing according to demand and supply ratio. In the existing system, the price is fixed, where it 9.5 taka/kwh. This price was taken as average price from different types of consumers. In current market system some consumers are paying highest 12 taka/kwh lowest 6 taka/kwh. For simplification of this model, the average price was taken as the existing price. In another part the price is changing according to a formula which is the representing the smart pricing policy.

$$\text{Price} = \text{Projected_Price} * (1 + \text{Price_sensitivity} * (\text{Demand:Supply} - 1)) * \text{SW_Price} + (1 - \text{SW_Price}) * \text{Existing_Price}$$

From the above formula, the price function is divided into two types. These two functions are changed through SW price switch. SW price can be 0 or 1. While price switch is 0 then price is fixed and it is equal to existing price. If the price switch (SW Price) is 1 then the price will be the dynamic price. This price adjusted through the projected price and changed through the demand and supply ratio and price sensitivity. In Bangladesh the price changes after a long interval of time. Sometimes it takes one or two years to change the price. For this reason, the price sensitivity was taken as 1. If the demand is higher than supply then the price will be higher and lower if demand lower than the supply. The projected price is the change of price over time according to the difference between projected price and reference price. It can show as the equation below.

$$\text{Change_in_Projected_Price} = (\text{Price-} \\ \text{Projected_Price})/\text{Time_to_adjust_Projected_Price}$$

Here, initial projected price 9.5 taka and time to adjust projected price is 30.

3.2.4 Inventory sector:

Inventory is another major focus of this thesis, since the excess production during off peak/low price time needs to store to supply during peak/high price time. Till recent days there was no inventory system introduced in the Bangladesh electricity market or system. It can be the new future investment on interest for the government to eradicate the load shedding problem. With smart market policy an inventory system is needed to reduce the load shedding. The inventories can conclude the different batteries. As a part of dependency future renewable source of electricity, batteries will play a vital role in the electric system. Since the renewable source of energies needs to store for future consumption. These batteries can be used as part of inventories. The report says almost 200000 thousand unit of the small solar home system has already been installed across the country and it is increasing (GSI Report 2014). Already lots of consumers installed a battery based capacity system like IPS (Instant Power System) to back up electricity during load shedding time. New advanced technology has resulted high capacity batteries like lithium ion batteries. One single battery can store up to 13 Kwh of electricity (Source: Tesla batteries). In addition, it is an assumption that the inventory system can be part of big investment since it will give profit to the investors.

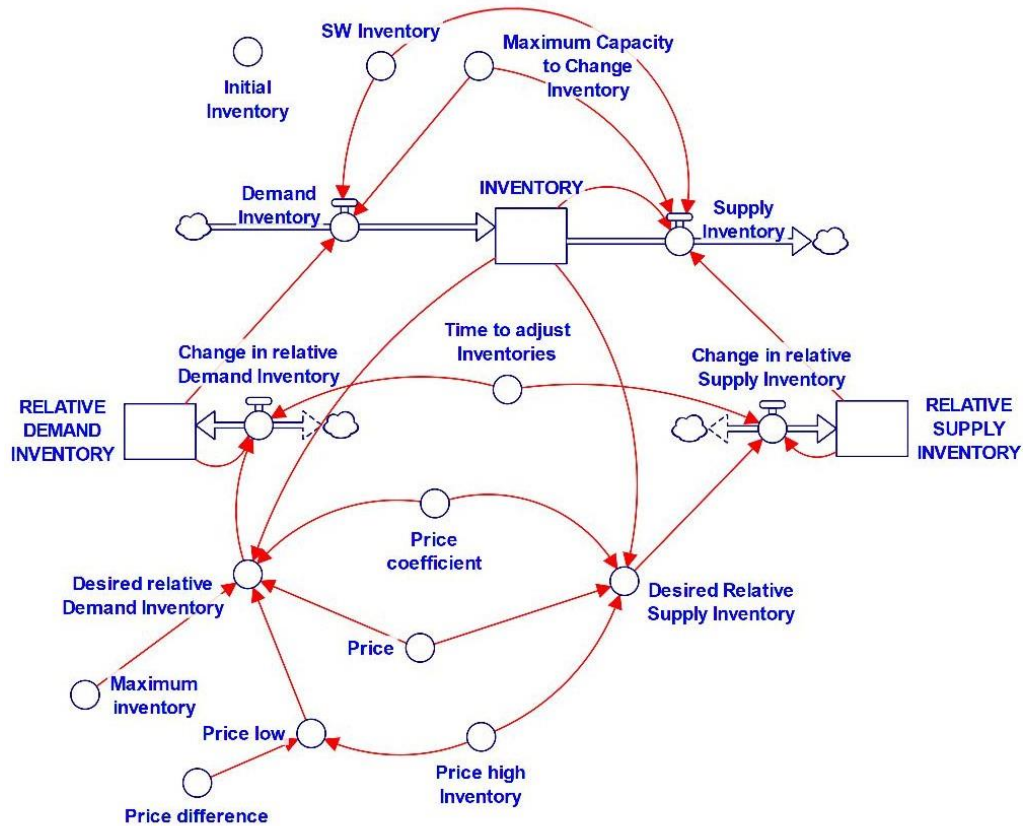


Figure 7: Stock and Flow diagram for Inventory.

Inventory is a stock, which is accumulated by demand inventory and depleted by supply inventory. Initial inventory is 60 mwh/minute. Supply and demand inventories are reflected by the equations below,

$$\text{Demand_Inventory} = \text{SW_Inventory} \\ * \text{RELATIVE_DEMAND_INVENTORY} \\ * \text{Maximum_Capacity_to_Change_Inventory}$$

Demand inventory is a flow of power purchased from the supply sectors according to its maximum capacity and relative demand inventory. Relative demand inventory is a stock and its accumulated over time by the change in relative demand inventory according to the low price. It

assumes the consumer will buy electricity to store when the price cheaper than normal price. This can be formulated by the following equation.

$$\text{RELATIVE_DEMAND_INVENTORY}(t) = \text{RELATIVE_DEMAND_INVENTORY}(t-dt) + (\text{Change_in_relative_Demand_Inventory}) * dt$$

$$\begin{aligned} \text{Change_in_relative_Demand_Inventory} = \\ (\text{Desired_relative_Demand_Inventory} - \\ \text{RELATIVE_DEMAND_INVENTORY}) / \text{Time_to_adjust_Inventories} \end{aligned}$$

Change in relative demand inventory is the difference between desired relative inventory and relative demand inventory over time. Here, time adjustment time is 5 minutes. Since it can be assumed that the consumer will start buying electricity as soon as the price goes lower than marginal price. Through desired relative demand inventory, it is formulated that the consumer will buy electricity at the low price.

$$\begin{aligned} \text{Desired_relative_Demand_Inventory} = \text{IF} \\ \text{INVENTORY} < \text{Maximum_inventory} \text{ THEN } \text{MIN}(1, \text{MAX}(0, (\text{Price_low} - \\ \text{Price}) / \text{Price_coefficient})) \text{ ELSE } 0 \end{aligned}$$

In this formula "IF THEN ELSE" has been used to replicate consumer decision to buy electricity for demand inventory. If the inventory is lower than maximum inventory and the price is lower than price low then the consumer will start buying electricity. Here price low is used to give the consumer or buyers to decide. Here maximum inventory was taken as the same capacity of the inventory. Price coefficient is the change of demand quantity according to change in price.

$$\begin{aligned} \text{Supply_Inventory} = \text{SW_Inventory} * (\text{IF } \text{INVENTORY} < 0.001 \text{ THEN } 0 \\ \text{ELSE } \text{RELATIVE_SUPPLY_INVENTORY} \\ * \text{Maximum_Capacity_to_Change_Inventory}) \end{aligned}$$

Supply inventory is the flow of electricity through this the inventory is depleting. This inventory is controlled by SW Inventory switch. The function of supply inventory is opposite of demand inventory. It is also assumed that the consumer will sell electricity from their inventory if the price is higher. The function is followed by relative supply inventory which accumulation of change of relative supply inventory over time. Following the formula for change in relative demand inventory,

$$\text{Change_in_relative_Supply_Inventory} = \frac{(\text{Desired_Relative_Supply_Inventory} - \text{RELATIVE_SUPPLY_INVENTORY})}{\text{Time_to_adjust_Inventories}}$$

Change in relative supply inventory is a flow of difference between desired relative supply inventory and relative supply inventory over time. Desired relative supply inventory is variable give chance to inventory holders whether or not to sell electricity to supply sector according to the price high or low.

$$\text{Desired_Relative_Supply_Inventory} = (\text{IF INVENTORY} > 0 \text{ THEN } \text{MIN}(1, \text{MAX}(0, (\text{Price} - \text{Price_high_Inventory}) / \text{Price_coefficient})) \text{ ELSE } 0)$$

From the above equation desired relative supply inventory reflects the consumer or inventory holder decision to sell electricity if they have some inventory. Here the difference between price and price high over price coefficient works as the marginal value to give the inventory holder decision to sell electric. If the difference is positive value then it will be an incentive for the inventory holders to sell electricity. "IF THEN ELSE" function is also used here to reflect the inventory holder's decisions.

Apart from all the sectors the thesis modeled **Load Shedding** to see the difference between fixed price and smart price policy. Since this is the focus of the thesis to solve the problem by smart pricing policy. The formula for load shedding is following,

$$\text{LoadShedding} = \text{MAX} (0, \text{Demand_Total} - \text{Actual_supply})$$

Load shedding is the difference between total demand and actual supply at the consumer end. Load shedding cannot be negative.

3.3 Parameter values:

Most of the parameters for the model were taken from a daily and monthly report published Bangladesh power development board (BPDB). The base date taken into consideration was 31st of August 2016. This date was chosen as day and night difference was found to be comparatively smaller, and the water level for hydroelectricity production is more than sufficient. Also during this time the electricity demand for irrigation very low. Some of the values of the parameters were taken with assumptions with considering the base values. For example, the average price for the different type of consumers. The value for the independent parameters are in below table.

Parameters names	Value with Units
Oil fired generations capacity	68 mwh/minute
Initial oil CU	0.58 dimensionless
Normal oil CU	0.7 dimensionless
Hydroelectricity generations capacity	3.83 mwh/minute
Initial Hydro CU	0.72 dimensionless
Capacity NG	80 mwh/minute
Initial CU NG	0.58 dimensionless
Foreign import	10 mwh/minute
Coal fired generations	3 mwh/minute
Existing price	9.5 Taka/kwh
Reference price	6 Taka
Price high for inventory	9.5 Taka
Price elasticity for demand	-0.1 dimensionless
Supply loss	0.1 dimensionless

Table 1: Different parameters and their values with the units.

3.4 Model Boundaries:

Several boundaries were taken into consideration during modeling. These boundaries were slightly unavoidable for several reasons.

- The data provided from BPDB was slightly changed. Since different research papers published for Bangladesh electricity system shows slightly different values from BPDB data.
- The price was as the average price. Calculated from a different level of consumers paying a different amount. The highest per kwh price was 12 Taka and lowest was 4 taka/kwh. This price difference was fixed by Bangladesh energy commission based on the level of consumer and amount of uses.
- Price elasticity demand should be changeable over time, but for simplification of this model it was taken as fixed.
- Time was taken as minute to analyze the situation on daily basis and tried to shorten the boundaries.
- The base date was taken into consideration was the 31st of August. The reason behind to choosing this date was because during hot summer day or dry winter days demand changes with high fluctuations. Also, during this time there was no extra demand from irrigation sectors.
- The supply source used was constant for example, Imports from foreign countries and coal fired generations remain constant during the analyzation period.
- It was assumed that all the available capacity for electricity production would be in service during the analysis period. The report shows that several machines were shut down due to servicing.
- The variations in demand were taken into considerations as a single demand sector. Since different sectors have different types demands. For example, household's demand changes according to day and night and weather temperature, but industrial demand is always same.
- It was assumed that highest 80-90% of the total generation capacity can be used considering the age of different production machines.

- Individual power generations from single power source were not counted since the focus of this thesis was to varying price according to demand and available supply at the consumer end.
- Sources for fuel was not modeled for simplifications of the modeling it was assumed that the supply of fuel is constant and sufficient.
- Time to adjust different variables were assumed with probable calculations.

3.5 Causal Loop diagram of the Model:

Causal loop diagram gives a quick overview of the inside of the whole model. These system dynamics tools are used to simplify an easy understanding of the stock and flow diagram of the model. Through the causal loop relationship diagram, it will give the insight for feedback mechanism of the whole system. There are two types of feedback loops working inside the model, the balancing feedback loop and the reinforcing feedback loop. With polarities of different variables, it also shows the impact of different variables. For example, if the ratio between demand and supply increases then the price will increase and vice versa. As the price has a negative impact on indicated demand adjustment so, it will decrease while the price increases followed the loops the demand will decrease. If demand decrease then the demand supply ratio will be lower as the price will follow the trend. In reinforcing loops all the variables will increase if one the variable increases.

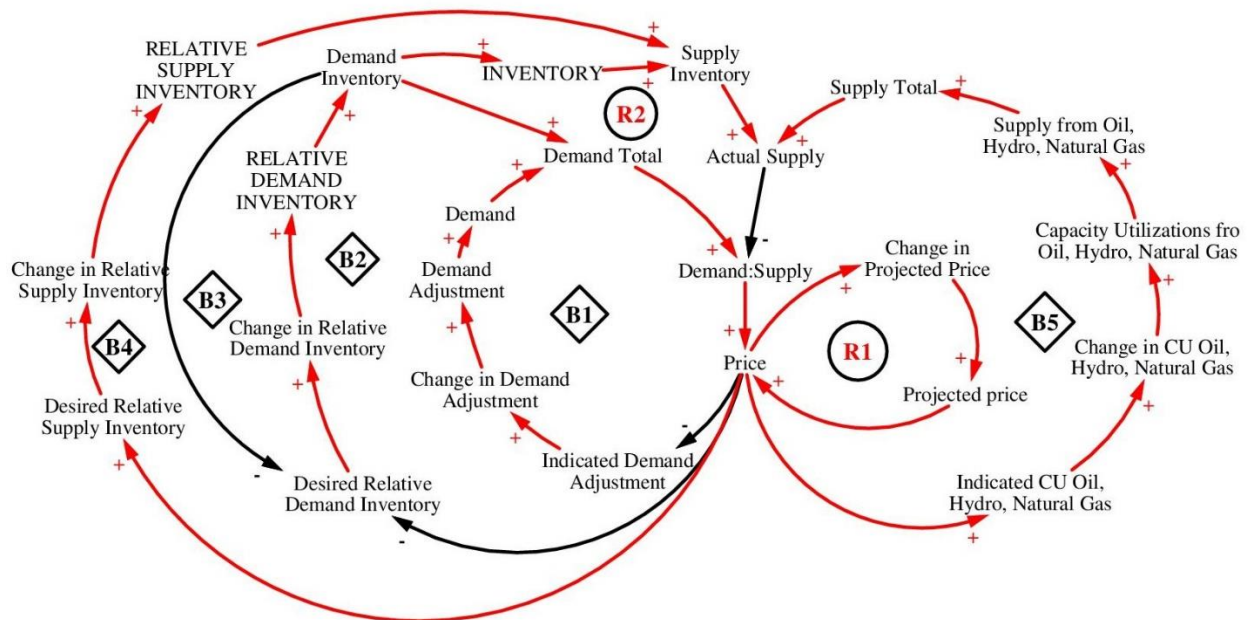


Figure 8: Causal Loop Diagram (CLD).

The produced model has five major balancing feedback loops and two reinforcing feedback loops. From the above figure it shows that the major balancing feedback loop **B1** governs the interaction between price and demand with demand adjustment. Another major balancing feedback loop **B2** is the reaction between demand from inventory and price. Balancing feedback loop **B3** is working inside inventory and demand inventory. Two other balancing feedback loops are focusing on the supply sector. Balancing feedback loop **B4** is the reaction between price and supply from inventory. Balancing feedback loop **B5** is the main reaction between price and supply from the production side. Apart from the balancing loops there are two reinforcing feedback loops working inside the model. Reinforcing loop **R1** is mainly focusing on inside the price sector. If the price increases it will increase the projected price and change in projected price. If the price decreases, it will decrease the projected price and change in projected price and so itself. The other reinforcing **R2** is a reaction between price, demand inventory and supply inventory. If the price goes lower, the demand inventory will be higher. As demand inventory increases inventory so, it will also increase the supply inventory. Supply inventory will decrease the demand supply ratio which will also decrease price.

Chapter 4: Behavior testing & verifications for validations of the model

For adequacy of the model a behavior testing is needed to verify if it is reflecting the reality of the existing systems. For model validation the assessment deals with sufficient accuracy between the computation results and hypothetical data from the system (Martis 2006). According to Sterman “All models are wrong” defines that validation does not indicate the full accuracy of the model but it is needed (Sterman 2002). There were several types of behavior tests conducted to see the adequacy of the model. The behavior test conducted were:

1. Equilibrium test
2. Without policy
3. With Policy

Before going for the behavior testing there some verification tests were conducted. According to Sterman, verifications tests were needed to show the adequacy of the model (Sterman 2000). The verifications tests were,

1. Structure verifications test
2. Variables parameter test
3. Unit consistency test

4.1 Structure verifications test:

The produced model was relatively accurate to real physical systems. As some of the data were based on assumptions so relatively accurate data used here. These assumed data produced based on different economic literature. Also, the detailed view of different parameters and equations with causal loop diagram in the previous chapter gives the properly structured view of the model. The structure of the model was produced according to the focus of the thesis.

4.2 Variables parameter tests :

Variables parameter tests were conducted in the previous chapter. Provided variables values were changed according to the model specifications. For example, the data provided from BPDB was hourly and daily basis but in the model, it was used as minute based. So calculated data were used here. Other parameters values were taken as round figure of the calculations. For example,

the data for price elasticity demand was calculations of the economic theory. As from calculation it was found -0.093 but in the model, it was taken as -0.1. Which is also relatively accurate since the value of the data was changeable for a different period depending on the price variations and change in demand for electricity.

4.3 Unit consistency test:

The unit consistency test was conducted during the modeling process through Stella Architect software. It can be checked through the attached model with this thesis. With Stella Architect software unit consistency tool was checked every time before simulations done.

4.4 Equilibrium test:

Before doing the behavior tests for the model with and without policy an equilibrium test will give adequacy of the model to analyze in future. If the model works in equilibrium conditions then it represents that all the parameters are working in conditions. Thorough equilibrium testing a model shows its sensitivity to changes in different parameters (Breierova & Choudhari 1996). An equilibrium was reached after conducting several simulations by changing the value of the different parameter. Through this process the before reaching the final concluded equilibrium tests beneath parameters values were taken in considerations,

- Initial CU NG (capacity utilization for natural gas) = 1
- Initial CU Oil (capacity utilization for oil) = 1
- Normal CU oil = 1
- SW Price (Switch for smart price function) = 0
- SW Inventory (Switch for inventory) = 0
- Initial CU Demand = 0.955

Apart from the above parameters other parameters values were kept constant. The results from equilibrium test will give an analysis of future policy design.

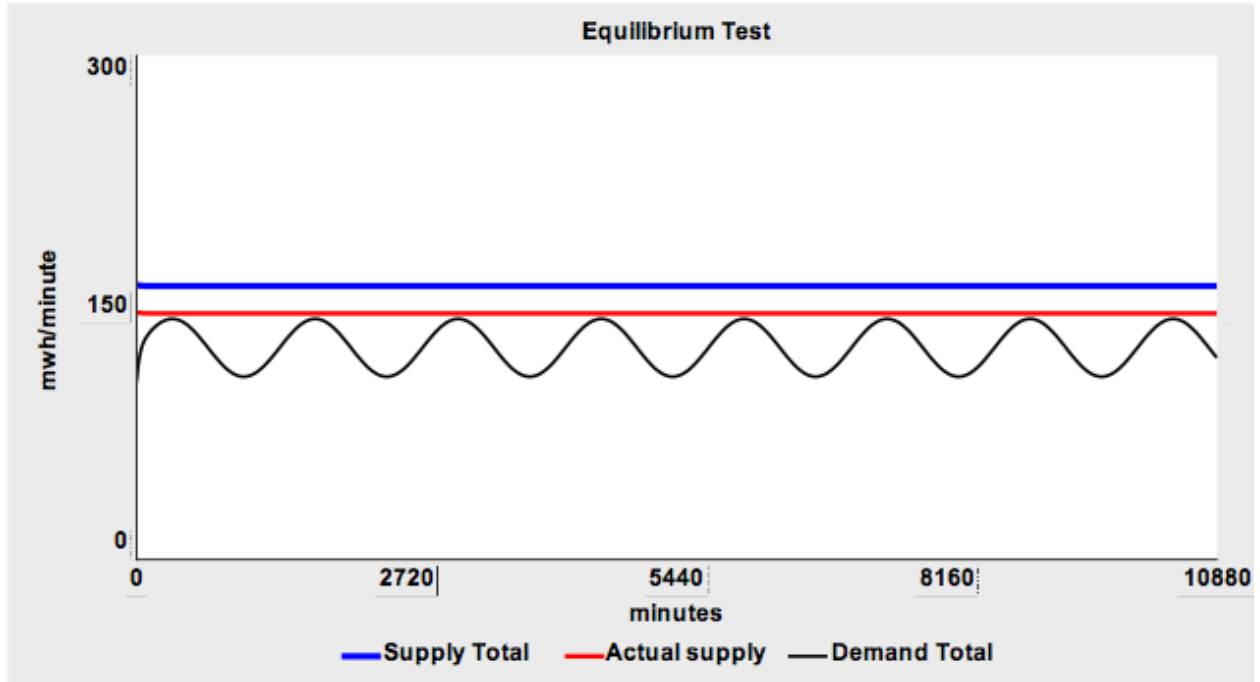


Figure 9: Total supply, actual supply and total demand in equilibrium.

From supply side natural gas and oil based power generations are the major sources of electricity. Through 100% use of these two sectors we can get more power supply than actual demand. From the above figure it shows the behavior of total supply, total demand and actual supply at consumers end during equilibrium tests. Here we can see the actual supply is more than existing demand, this mean that there will be no load shedding during that period. During the test total supply of electricity found 163 mwh/minute, as calculation 10% transmission and distribution losses the actual supply was 147 mwh/minute which still above than the highest demand for the day 143 mwh/minute. Here the demand shows sinusoidal behavior since the parameters consist sin function which represents a different amount of demand during whole days.

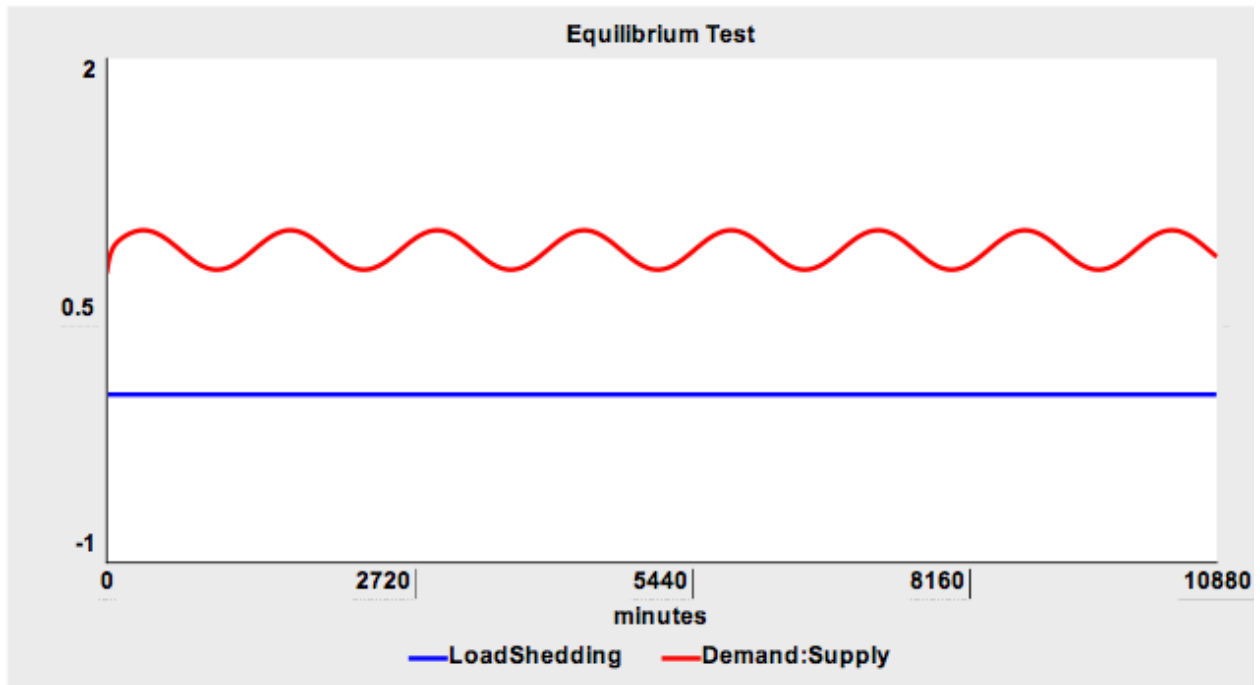


Figure 10: Load shedding and demand supply ratio in equilibrium.

The above figure shows the behavior of load shedding and demand supply ratio. As mentioned earlier, existing demand was lower than actual supply so there was no load shedding. It also needs to mention that load shedding does not have negative values. Demand and supply ratio has a sine wave since it reacts according to existing demand which has a sine function value.

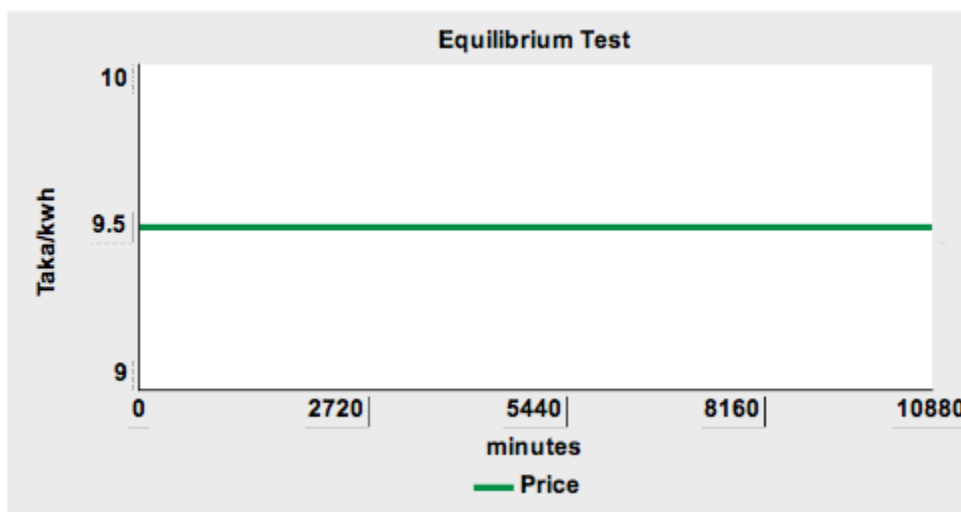


Figure 11: Price in equilibrium.

During the equilibrium test the price stays constant as the price switch was kept off and there were no variations in price.

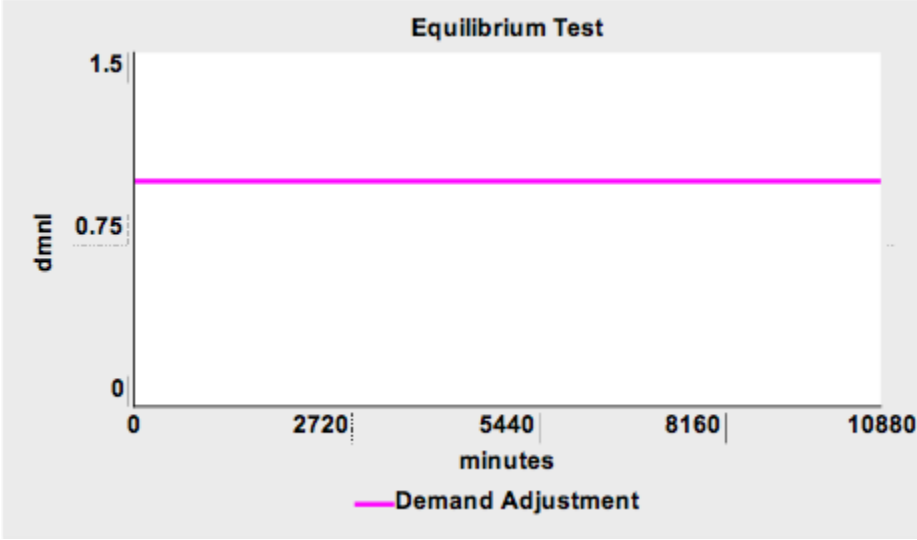


Figure 12: Demand adjustment in equilibrium.

With the optimal value 0.955 for demand capacity utilization the demand adjustment shows equilibrium behavior. This value was generated since the price elasticity for demand gives a small variation in demand capacity adjustment.

4.5 Behavior of existing model:

This part of the chapter deals with the behavior of the existing model. Here it will define if the model is replicating the real physical model or not. There are variations in some behavior because of the model boundaries.

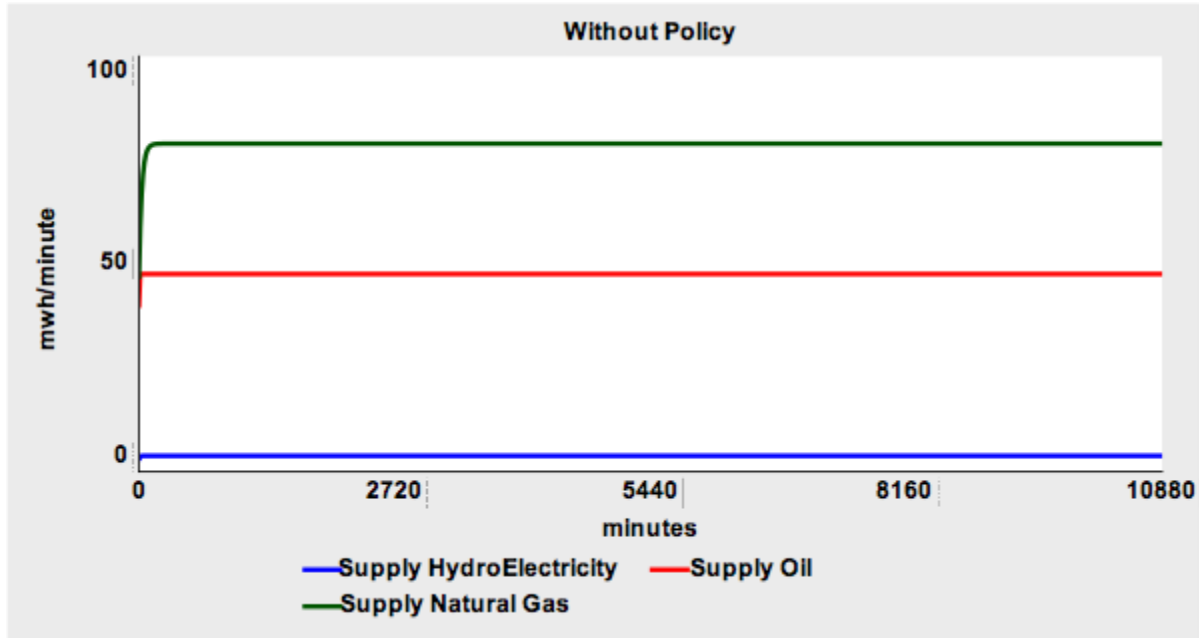


Figure 13: Supply of electricity from Hydro, Oil and Natural Gas.

Figure no. 13 shows the behavior of different power sources. These three electricity generation sources were taken since they must change capacity according to capacity utilization. Production from hydro starts with 2.76 mwh/minute then it increases till 3.83 mwh/minute and stays constant. Two other sources also behave same way except for the higher amount of production. Oil starts with 39.4 mwh/minute and increases till 47.6 mwh/minutes. Natural gas production starts with 46.5 mwh/minute and increases till 79 mwh/minute. The reason behind production increase is the adjustment of indicated capacity utilizations according to price.

The changes in capacity utilization are also reflecting the real physical model. Since the price for electricity in Bangladesh starts from 6 taka/kwh. Low price means lower demand and higher supply. As the price here fixed up by 9.5 taka/kwh its mean average supply and demand scenario will be higher than off peak demand and supply.

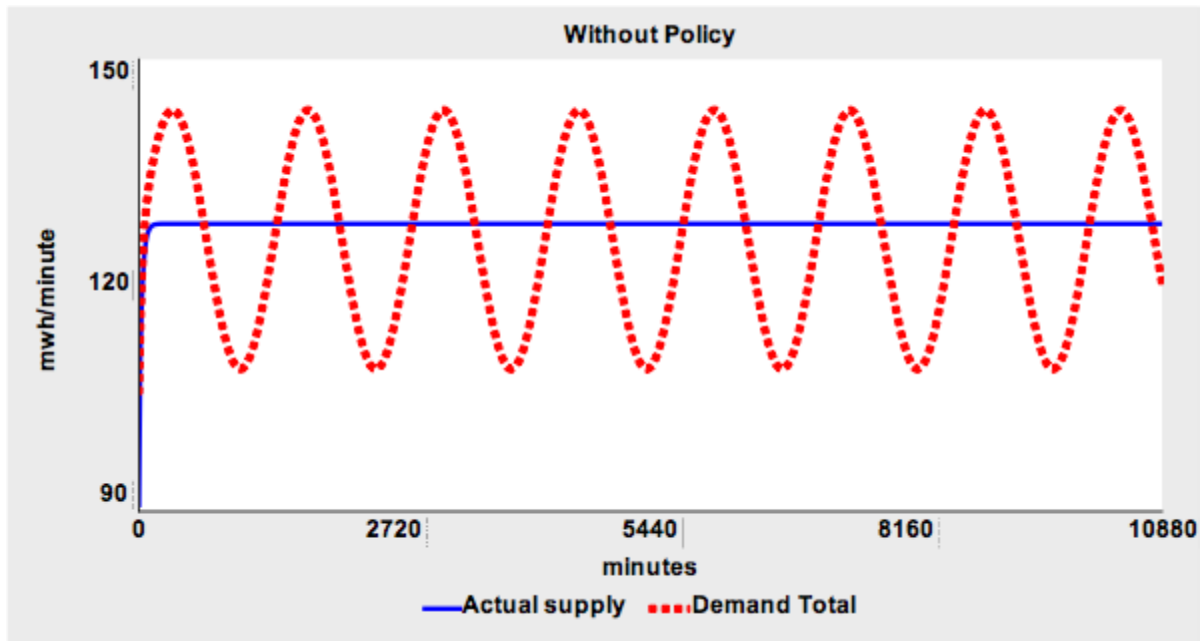


Figure 14: Actual supply and total demand.

Above figure no 14 illustrating the amount actual supply and total demand. Here total demand is the sum up for existing demand and the demand after the adjustment of demand. There is a slight increase in demand at the beginning, because of the adjustment of the demands. Similarly, the increases actual supply is because of increases in supply from oil, hydro and natural gas due to capacity utilizations adjustment for a higher price.

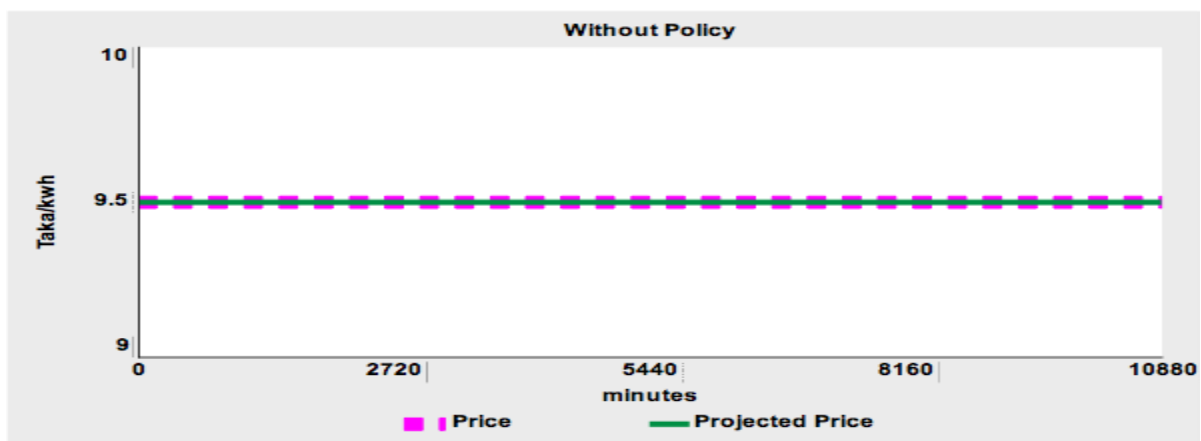


Figure 15: price without policy.

Without implementing policy switch the price stays constant at fixed price 9.5 taka/kwh and there no change in projected price. So, there will changes in other variables following the changes in price and price adjustment.

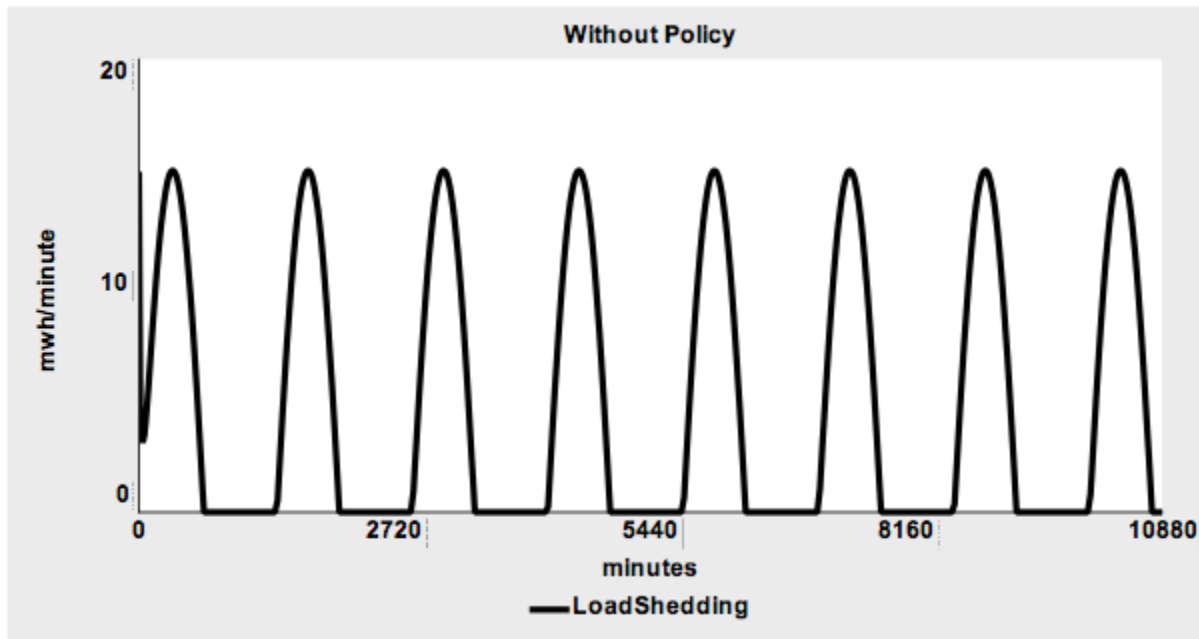


Figure 16: Load Shedding.

Figure 16 illustrates the load shedding scenario. Since the supply of electricity stays constant, the load shedding graph shows fluctuations according to the demand quantity. The graph shows the highest load shedding is 15.1 mwh/minute and lowest is 0. It is slightly representating the real load shedding, according to literature it says Bangladesh is facing highest 600-900 mwh of load shedding each day which is 10-15 mwh/minute.

4.6 Behavior with Policy

This part of the chapter deals with the behavior of the model after implementing smart price policy and introducing inventory system to the existing system. The behavior of the model in this part is futuristic. Here the thesis will compare the value and the model before and after the policies are implemented. Before conducting the simulations both of the switches were changed according to the policies.

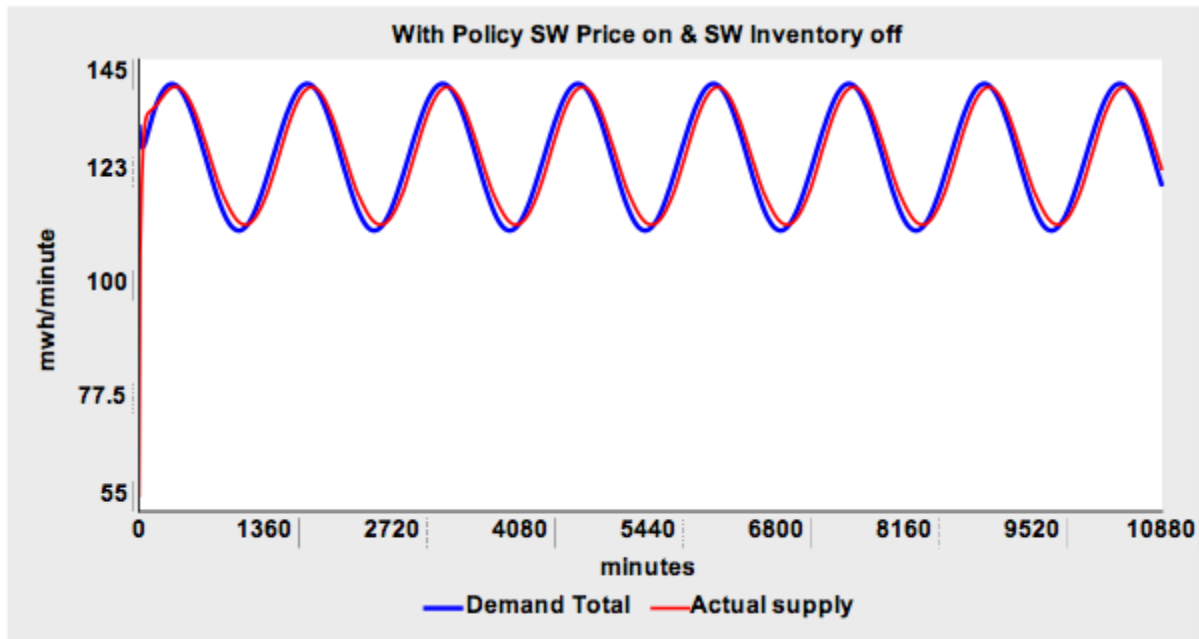


Figure 17: Total demand and Actual supply with price policy.

Figure 17 shows the behavior of total demand and supply (after subtracting losses) with price policy implemented. From the graph it shows that the supply has changed according to fulfill the demand. In comparison to figure 14 the supply was constant that means there was more supply than demand during off peak period and less supply during the peak period.

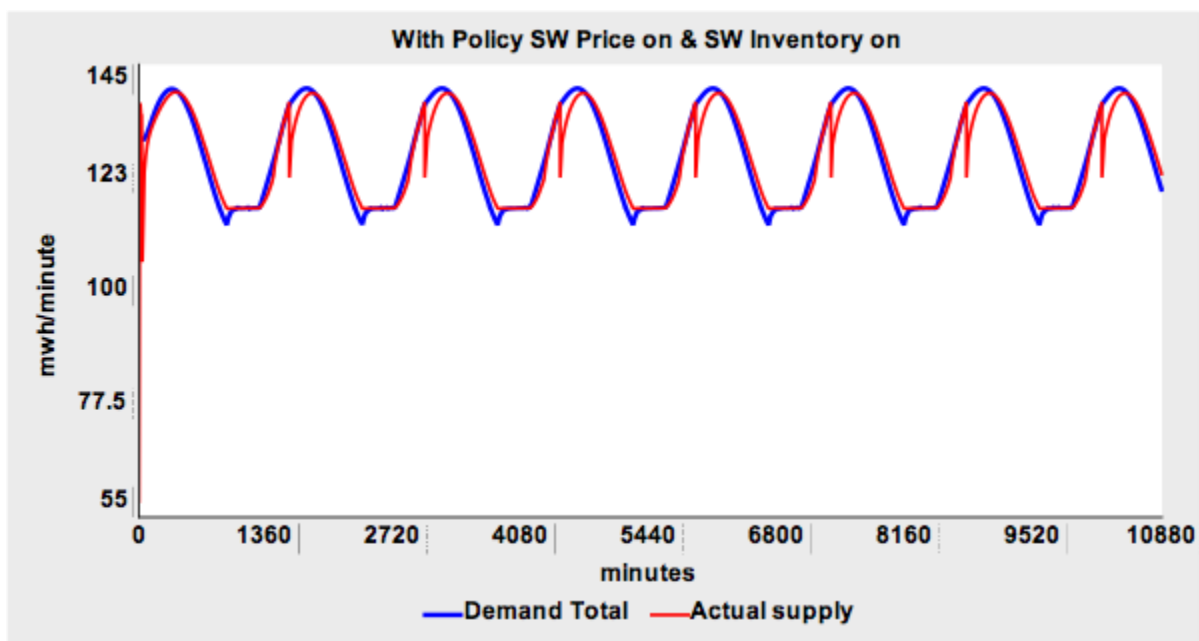


Figure 18: Total supply and demand with both policies implemented.

The above figure is based on both smart price policy and inventory system introduced to the existing system. Here we can see the change in both supply and demand. The reason is that the inventories start buying electricity at low price time and selling during high price time. There is a small shift in supply and demand, the reason is that the existing initial inventory is adding to the system. Inventories will only accept electricity if it is lower than maximum inventory no matter the price is low or high.

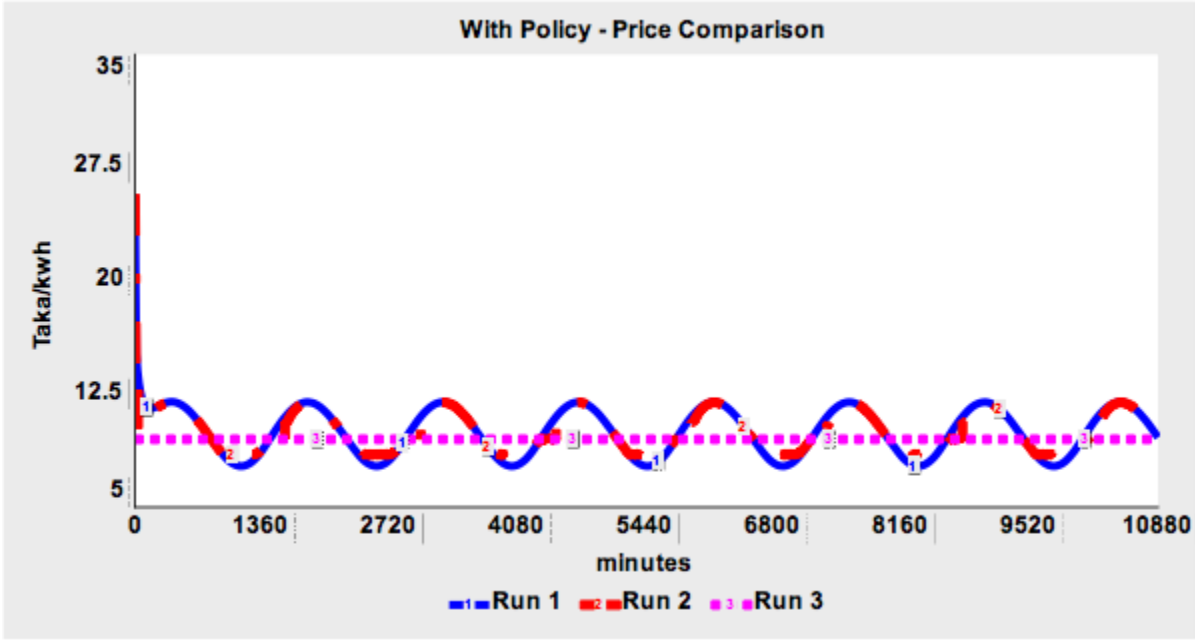


Figure 19: Price comparison in different policies.

Price is changing according to demand and supply after different policies were implemented. Run 1 reflecting only smart price policy is implemented, in run 2 both policies switches are on that means price with SMP and inventories implemented and run 3 is fixed price. From the above simulations price went up to 12 taka/kwh during both policies implemented. On the other side, price went down till 7.76 taka/kwh in only when SMP implemented but with SMP with inventory the price went till 8.51 taka/kwh. The reason is that while the price started going down inventory holders start buying electricity which increases the demand for demand supply ratio.

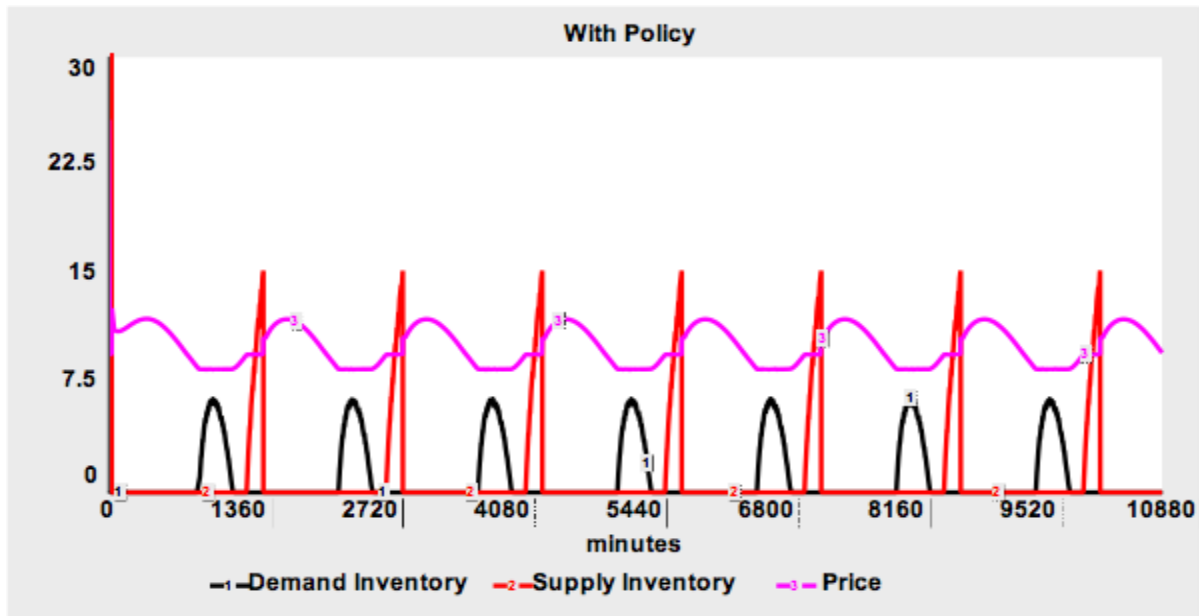


Figure 20: Demand and supply inventories.

Figure 20 shows the behavior of demand and supply inventories after the policies are implemented. Demand inventory defines inventory holders are buying electricity and supply inventory defines selling of electricity. From the figure it defines that inventory holders are buying electricity while the price decreases and start selling electricity of the price increases.

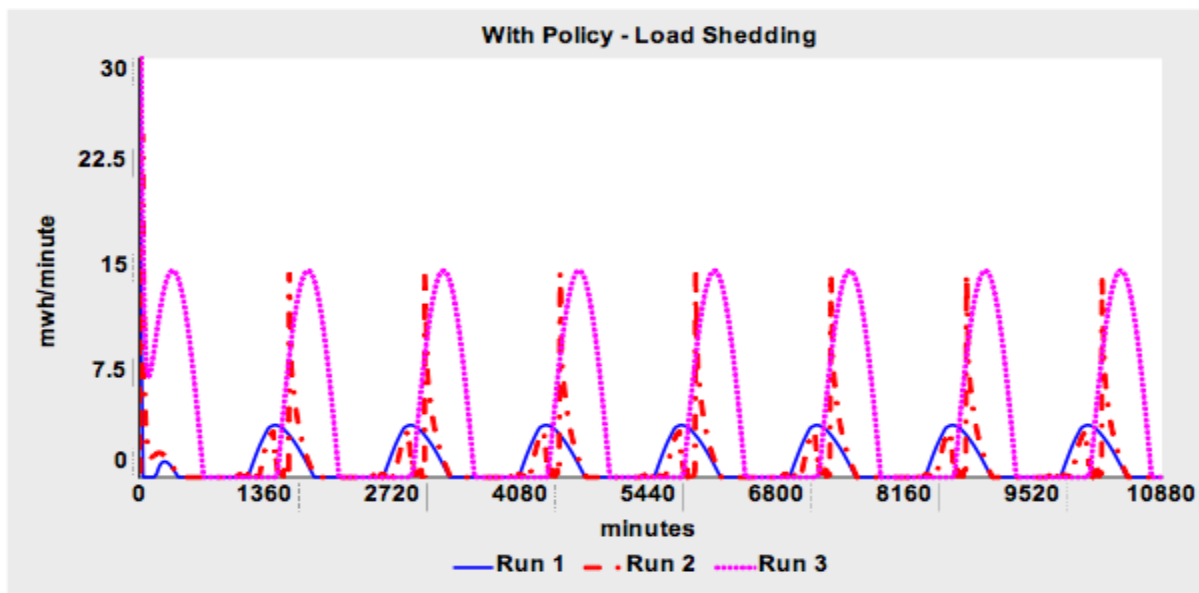


Figure 21: Load shedding in different policies.

From the above figure we can see the difference of the load shedding during different policies. Run 3 is fixed price policy here, the load shedding is higher. In run 2 is the scenario with inventory load shedding is high in some minutes but it lower than fixed price system. With only smart price policy load shedding is lower.

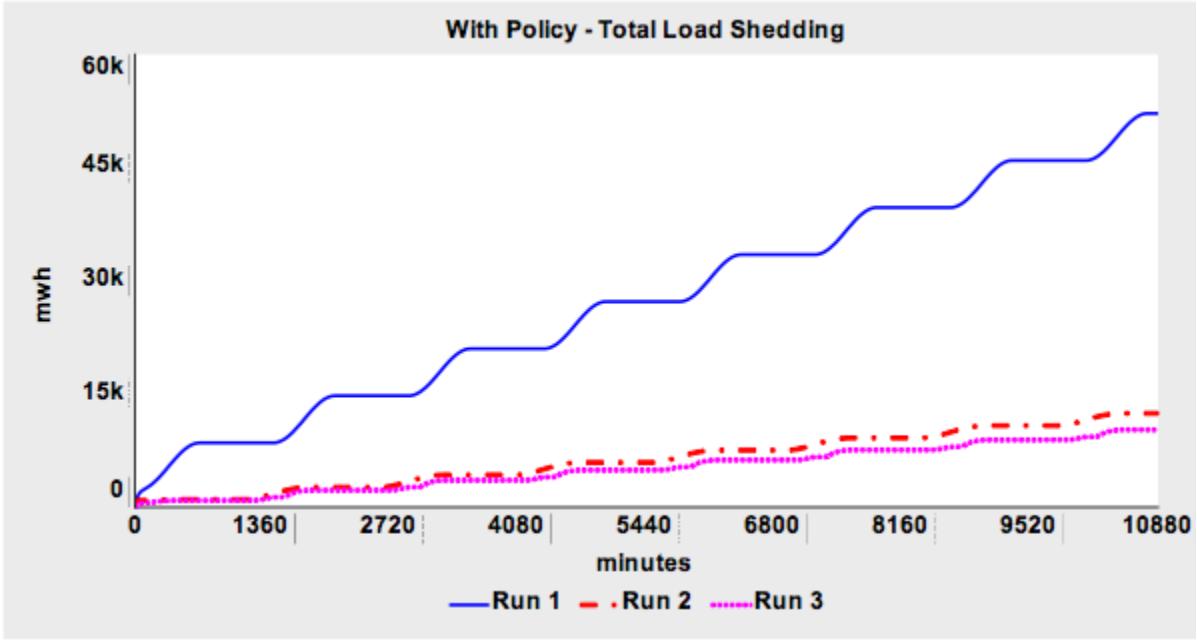


Figure 22: Total Load shedding.

If we see in figure 22, the amount of total load shedding is lowest in smart price policy with the inventory system. Here, run 1 is the total amount of load shedding with fixed price policy only, run 2 with only SMP and run 3 is both policies implemented. In the previous figure it seems like the load shedding is higher while both policies were implemented but in long run we can observe that total amount of load shedding less after smart price policy implemented.

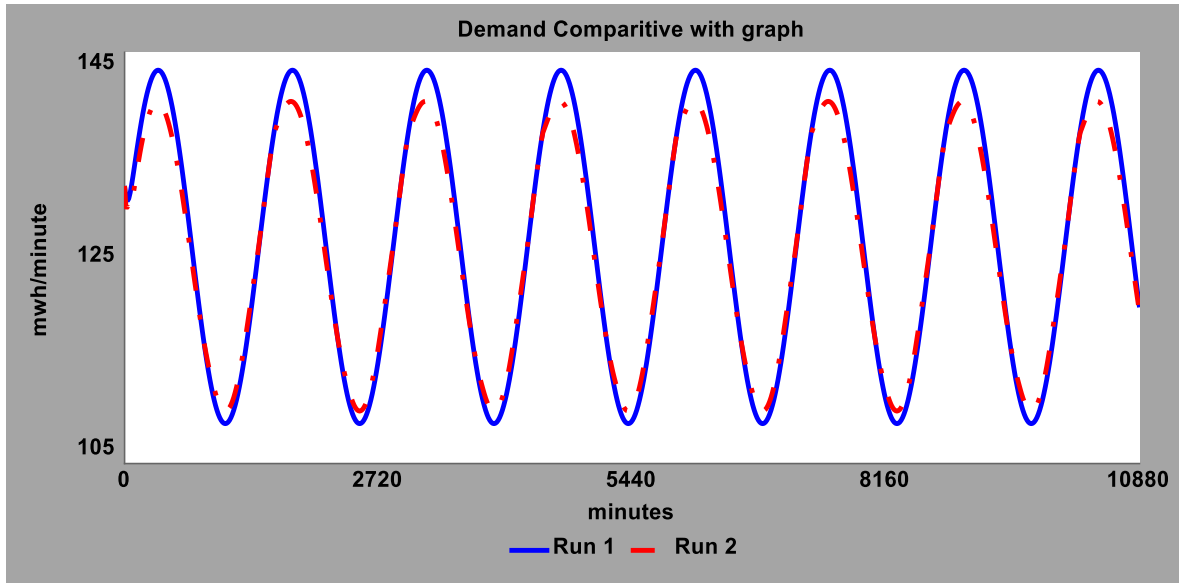


Figure 23: Demand before and after smart price policy implemented.

In the figure no. 23 it is showing the changes in demand after smart price policy implemented. In the figure run 1 represents demand before the policy has implemented and run 2 is after the policy implemented. From the above figure we can see the peak demand has reduced and off-peak demand has increased.

Chapter 5: Cost Benefit analysis for policies

This part of the thesis will analyze the total cost and benefits of the newly implemented policy. Without cost and benefit analysis it is not possible to see if the policies are fruitful to be implemented. The model has already shown that the policies can reduce load shedding. From the figure we can see the cost and benefits of the model.

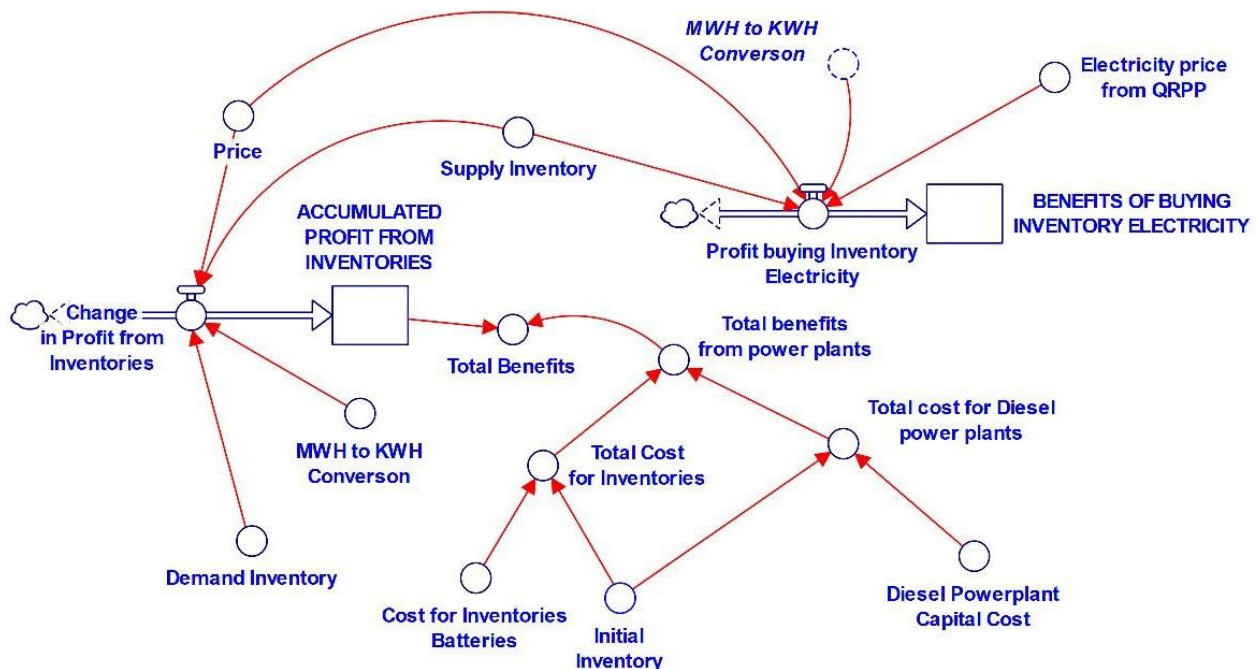


Figure 24: Stock and flow diagram of cost and benefits.

From the above SFD diagram we can see the benefits of the inventories. Accumulated benefits from inventories are the difference between buying and selling of electricity. The accumulation process is clearly defined in the equation.

$$\text{Change_in_Profit_from_Inventories} = (\text{Supply_Inventory} - \text{Demand_Inventory}) * \text{Mwh_To_Kwh_Conversion} * \text{Price}$$

Through the above formula we can get the total benefit for inventory holders. The total benefits for inventory holder can be shown in the graph,

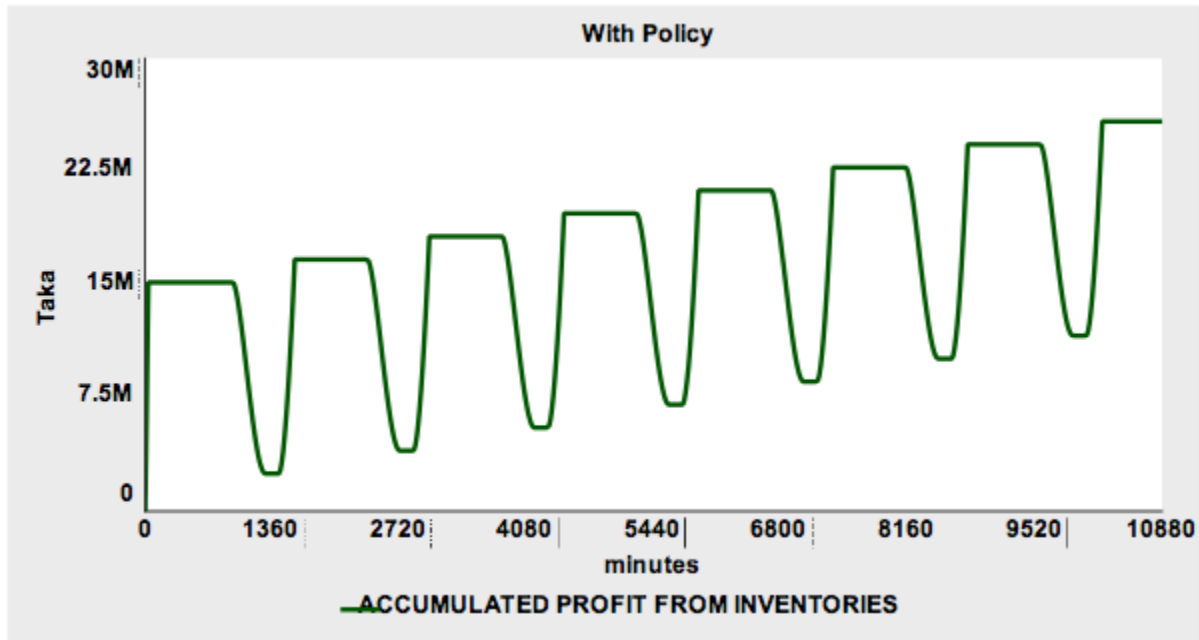


Figure 25: Profits for inventory holders.

From the above figure we can see the increase in profits for inventory holders. This profit comes from buying electricity at a cheaper price and selling them at a higher price. In the graph we can see some drops in profit accumulations. The reason behind this is due to the purchasing of electricity through demand inventory. Within this 7 days simulations process its shows that the profit can be reached till 25.8 million taka.

Apart from the profit for inventory holders there is another benefit of implementing inventory system. Since Bangladesh's electricity system already has the generations capacities to fulfill the demand the reasons for not enough supplies are the availability of natural gas during the peak load time. To reach the goal for existing demand government of Bangladesh is investing in the oil based power generation system. Which is costly but quick to support increased demands. Oil based electricity generators can give quick supply but it takes some time to start generation. Through investing in the inventory system, it can be also quicker than support from oil fired power generation systems. Since electricity will be stored and always ready to supply instantly. Investment in inventory system is also much cheaper than oil based power plants.

The literature says that capital costs for new oil based power plant is approximately 1000 USD/Kwh (US energy information administration) which means 83000 taka/kwh (1 USD= 83 taka

exchange rate xe.com April 15, 2018). Capital costs for battery based inventories are way cheaper, 407 USD/kwh (Tesla powerwall 2 price in the US) that means 33781 taka/kwh. In total 72.9-billion-taka capital cost can be saved for installing battery based inventory than oil based power plants for 1500 MW electricity capacity. This investment will also provide a quicker installation process.

On the other hand, buying electricity from inventory holders will be a cheaper option for BPDB. BPDB buys electricity from quick rental power plants (QRPP) with 15 taka/kwh during excess demand of electricity. The benefits of buying electricity from inventory holders can be illustrated in the following equation:

$$\text{Profit_buying_Inventory_Electricity} = \text{Supply_Inventory} * (\text{Electricity_price_from_QRPP} - \text{Price}) * \text{MWH_to_KWH_Conversion}$$

The profit of buying electricity from inventory is equal to supplied electricity multiply by the price difference between electricity from the quick rental power plant and smart price.

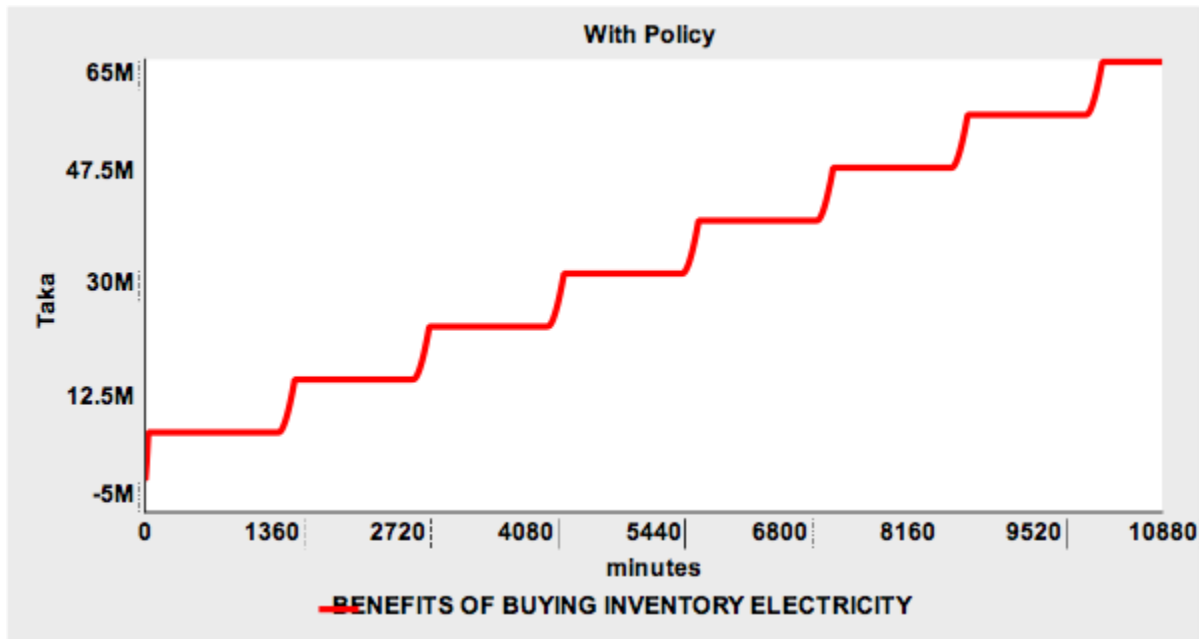


Figure 26: Benefits of buying electricity from inventory.

The figure shown above, shows the accumulated benefits of buying electricity from inventory systems in smart price policy. The red line shows the amount of money that could be saved by buying electricity from inventory holders. This is the benefits for the BPDB, since BPDB is the supplier of the electricity. This benefit is the money that will be saved for buying cheaper

electricity from the inventory holders than the electricity from costly quick rental power plants. Results show 64.6 million taka can be saved through this process.

The parameter value for cost and benefits model:

Parameters name	Value with units
Cost for inventories batteries (capital cost)	407*83*1000 taka/mwh
Cost for diesel power plant (capital cost)	1000*1000*83 taka/mwh
Electricity price from QRPP	15 taka/kwh
Mwh to Kwh conversion	1000 kwh/mwh

Table 2: Parameters value for cost and benefit analysis.

Chapter 6: Policy implementation & recommendations

This chapter deals with implementation of the smart price policy and inventory systems. Without policy implementation analysis it is not possible a research is not valid. Policy implementation analysis is an obvious part of a good research. Before implementing a policy it is good to analyze the implementation barriers to overcome. To implement smart price policy and inventory system in Bangladesh's electricity system there are various issues needs to be discussed. There are recommendations are also discussed next to these issues. The issues are,

1. Upgrading systems (metering and grid)
2. Economic situations
3. Educations
4. Political aspects and leadership
5. Society values and acceptance

6.1 Upgrading systems:

The first things that need to be changed to implement smart policy is upgrading age old electricity grid system of Bangladesh. The world is moving forward with new technology system everywhere in modern society including grid system. There was a big power failure in Bangladesh on November 1st, 2014 because of grid problem. The main reason was on the small part of the national transmission grid was failed and the whole system had to shut down for not having proper information for management. So, upgrading the whole grid system is essential for Bangladesh, right now even though smart price policy is going to be applied or not. Upgrading to smart grid system will give proper information about supply and end user demand information. Also through smart grid system has the option for proper management for electricity supplier and distributors. Examples from developed countries like the USA and Canada who has already applied smart grid system can be taken into consideration. For upgrade to a smart grid system there also needs to be and expansion in the communications system, for example broadband internet services. Though the internet has reached all over the country through mobile internet services but most parts of the country's connections are poor. Upgrading of the communications system does not only need to apply to smart price policy, it is also a mandatory part of countries developments.

Another part of existing system upgradation is Advance metering infrastructure (AMI). AMI consists advance metering smart devices, communications and data management system (Mohassel, Fung, Mohammadi, Raahemifar: Toronto 2014). Through AMI smart devices are a state-of-the-art electronic device which is capable to communicate both ways. This device has the option to act according to controller pre-set command. This smart device can communicate

with both sides (consumers and suppliers) for informing consumption data. (Mohassel, Fung, Mohammadi, Raahemifar: Toronto 2014). This type of metering device can measure the data for not only electricity consumption also another utility system. So, using this type device will also help in other utility service system also. To implement this system, it cost relatively higher than normal metering devices but the government or BPDB can take initiative for the cost management. A survey report shows that the price for AMI devices cost 81 USD-532 USD (Capital costs per device). On an average it will cost 221 USD (Smart grid watch: 2013). The price is decreasing day by day. Then the approximate cost for an AMI device will be 18,343 taka which relatively acceptable for consumers. Though this will cost the consumers extra but BPDB can take the initiative by taking back the money through installment process with the monthly billing system. For example, in US electricity market in some states does not charge for a new device at once but they charge extra 1-3 USD with monthly electricity bill for 10 years (Smart grid watch: 2013). In this process, BPDB can increase the service charge in their monthly billing system to cover the expenses of installing a new device. This will help BPDB get a return on the investments and consumer will not feel the extra burden of extra investment.

6.2 Economic situations:

In the previous paragraph it's already discussed about implementing cost for AMI system. Through that process it will be acceptable for the consumers to accept new system economically. It will not become an extra burden for consumers. Also in the cost benefits analysis chapter it also discussed how much economical support will come. Simulations results shows that it will help both supplier and consumer economically. Consumer can be benefited by selling cheap electricity in higher price during peak demand period. Though the price for electricity will be little bit higher, on average 0.52 taka/kwh consumers like household can save by using more electricity during low price times and less electricity during high price times. BPDB as a supplier of electricity can be benefitted by buying electricity in cheaper price than they were buying from quick rental power plants. It will also give the government to invest less money for same amount of back up for high demand of electricity. The government can save up to 72.9 billion taka for investing in 1500 MW power back up system for extra demand during peak periods rather than investing oil based power plants. This money can be used for investing in AMI upgradations. Smart price policy also helps government of Bangladesh to lower the subsidies for electricity price given to BPDB. BPDB get subsidies for selling electricity in cheaper price than production price. In fiscal year 2014 BPDB received around 63.5 billion taka subsidies grant from national budget for selling electricity in cheaper price (Sustainable & Renewable Energy Development Authority, Investment Plan for Bangladesh, October 2015) (IEEFA: November 2016). These subsidies were granted to give benefits for low level electricity consumers. BPDB tried to cover up the subsidies by giving higher tariff to commercial and industrial consumer. Still these subsidies were not covered through this

process because BPDB was still selling electricity in lower price than real production price. These subsidies can be lowered after implementing smart price policy since consumer will pay according to the supply cost. Since the price will be regulated by demand and supply ratio. It will also reduce the tremendous loss in socio economical value due to load shedding. So, these economical situations are giving positives aspects for implementing new policies.

6.3 Education:

Education will play a vital role in implementing the new policies. Using for new technology needs literate consumers. Without proper knowledge it will be harder to use smart metering devices. The literacy rate in Bangladesh is still low. Data from UNESCO shows that the literacy rate in Bangladesh is 72.76% (Unesco Institute of Statistics:2016). Still 27% of the populations are illiterate. Since the government of Bangladesh is giving first priorities in investing for education sectors in their national budget it will help to reduce the illiteracy rate. Government is investing 12.6% of their total national budget in the education sector (Bangladesh Budget 2017-18). According to this analysis in education sector it will be also suitable to implement smart price policies.

6.4 Political aspects and leadership:

The first reason for fixed price system is due to political motivation for the government of Bangladesh. Every ruling party in different periods always focus on increasing the production capacities and expanding transmission system. Those policies allowed them to gain the popularity of the public. Since still 1/3 of the populations are still not under electricity coverage people are eager to get access to electricity. If they get access to electricity they will be happier. Fixed and cheap price for consumers also an option for getting public support. These policies were good on one side since it is also needed to increase the capacities of electricity power generations according to increased demand for electrifications. Without sustainable supplies of electricity, it also gives a negative impact on popularities for the government from mass public. Lowering the load shedding through smart price system and inventories will give a positive aspect to accepting these policies.

On the other hand, BPDB has to take the first steps to accept and implement these policies, since Bangladesh power development board (BPDB) is the main board responsible for generating and supplying electricity system in Bangladesh. So, it will be their duty to take the responsibility to accept and implement this policy on behalf of Government of Bangladesh.

6.5 Society values and acceptance:

Though new technology and systems need time to accept in society but if it is for basic needs society accepts it in a quicker way. Implementing new policies can be done through the different small pilot project to give the bigger society a glance of positivity of it. Like the pre-paid metering system pilot project that was introduced in 2007 (BPDB report). After getting positive results people are more interested across the country to install the new system. So, from this aspect the new policy can be acceptable for the society if it gives positive result inside the country. Apart from the developed countries like the USA, Canada, Australia and other European countries who have already implemented the new system. Examples can also be taken from other developing countries like India that has already implemented AMI system in small pilot projects (EESLINDIA: 2018). Load shedding is always big news in Bangladesh's news media, since it is one of the major issues, many people are suffering. So, society is ready to accept any good policy to reduce the problematic power cuts. By analyzing this perspective, the society will accept this new system.

Chapter 7 : Conclusion

Load shedding is a common phenomenon in the daily life of Bangladesh. Load shedding is creating a major interruption in the normal life of peoples in Bangladesh. The price of one hour of load shedding is huge in socio economic aspects. The situation was worse decades ago. The government of Bangladesh tried to reduce it by increase supply capacity of electricity but still the electricity system is facing huge load shedding problem. The reason is increasing of electricity demand according to its high GDP growth rate than the accessible supply of electricity. This mismatch between demand and supply is happening due to mismanagement of the existing supply of electricity. This thesis analysis found that fixed price system is one of the major cause of load shedding problem. The fixed price is only creating pressure on the supply system to increase rather than control according to demand. The thesis analysis also found that the supply is more than the demand during off peak period and less during the peak period. During peak period the gap between demand and supply is only managed by power shut down policy.

The above chapters of this thesis tried to find a new smart price policy with an inventory system to reduce the load shedding by using existing power generation capacities. In the total study it found that the smart price policy is implementable in the existing system. The supply can be adjusted according to the demand and consumer can adjust their demand according to the price. The above study found that load shedding can be reduced by smart price policy. The price variation will not make a huge effect on consumer buying ability. On average the price goes a little bit higher than the fixed price. This smart price policy will not only cause the consumer to change their consumption limit also they will have the opportunity to make a profit by taking part in an inventory system for electricity.

This policy will be helpful if the existing demand stays stable. For stable electricity supply for increased demand, the government of Bangladesh needs to invest more in stable supply or power generation capacity. For example, nuclear power plants can be a good solution for stable power supply. The study suggests that before implementing the policies, the existing structure for a power grid system needs to be developed. Since there are huge transmission and distribution losses due to the poor age-old grid structure. This old power grid system is also creating a big power failure. Also implementing the policies is not possible overnight. It will be a better option to implement the policies in small zone wise pilot projects. BPDB can take the initiative to implement the policy as the pilot and the resultant value can be used for future implementation whole country. The government of Bangladesh also needs to create investor friendly environment to attract investors to invest in the inventory system.

Bangladesh's current electricity system has the best potentiality to implement smart price policy. There are several mega projects for power generations are going to join in the existing system in

near future. Like 2500 MWH nuclear power plant and 1320 thermal power plant. This will also help in near future to use the smart price policy for the long run. This thesis model simulations were done for a short-term period, for a long-term implementation further details and research need to be done. In addition, smart price policy will not only reduce the load shedding it will also create a new market system for an investor to invest in the inventory system.

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Appendix

Model Equations:

Top-Level Model:

ACCUMULATED_PROFIT_FROM_INVENTORIES(t) = ACCUMULATED_PROFIT_FROM_INVENTORIES(t - dt)
+(Change_in_Profit_from_Inventories)* dt

INIT ACCUMULATED_PROFIT_FROM_INVENTORIES = 0

INFLOWS:

Change_in_Profit_from_Inventories = (Supply_Inventory-
Demand_Inventory)*MWH_to_KWH_Conversion*Price

BENEFITS_OF_BUYING_INVENTORY_ELECTRICITY(t) = BENEFITS_OF_BUYING_INVENTORY_ELECTRICITY(t
-dt) + (Profit_buying_Inventory_Electricity) * dt

INIT BENEFITS_OF_BUYING_INVENTORY_ELECTRICITY = 0

INFLOWS:

Profit_buying_Inventory_Electricity = Supply_Inventory*(Electricity_price_from_QRPP-
Price)*MWH_to_KWH_Conversion

CU_NG(t) = CU_NG(t - dt) + (Change_CU_NG) * dt

INIT CU_NG = Initial_CU_NG

INFLOWS:

Change_CU_NG = (Indicated_CU_NG-CU_NG)/Time_to_adjust_CU_NG

Demand_Adjustment(t) = Demand_Adjustment(t - dt) + (Change_in_Demand_Adjustment) * dt

INIT Demand_Adjustment = Initial_CU_demand

INFLOWS:

Change_in_Demand_Adjustment = (Indicated_Demand_adjustment-
Demand_Adjustment)/Demand_Adjustment_Time

HYDRO_CU(t) = HYDRO_CU(t - dt) + (Change_Hydro_CU) * dt

INIT HYDRO_CU = Initial_Hydro_CU

INFLOWS:

Change_Hydro_CU = (Indicated_Hydro_CU-HYDRO_CU)/Time_to_Adjust_Hydro_CU

INVENTORY(t) = INVENTORY(t - dt) + (Demand_Inventory - Supply_Inventory) * dt

INIT INVENTORY = Initial_Inventory

INFLOWS:

Demand_Inventory =

SW_Inventory*RELATIVE_DEMAND_INVENTORY*Maximum_Capacity_to_Change_Inventory

OUTFLOWS:

Supply_Inventory = SW_Inventory*(IF INVENTORY<0.001 THEN 0 ELSE

RELATIVE_SUPPLY_INVENTORY*Maximum_Capacity_to_Change_Inventory)

OIL_CU(t) = OIL_CU(t - dt) + (Change_in_Oil_CU) * dt

INIT OIL_CU = Initial_CU_Oil

INFLOWS:

Change_in_Oil_CU = (Oil_CU_With_Function-OIL_CU)/Time_to_Adjust_Oil_CU

Projected_Price(t) = Projected_Price(t - dt) + (Change_in_Projected_Price) * dt

INIT Projected_Price = 9.5

INFLOWS:

Change_in_Projected_Price = (Price-Projected_Price)/Time_to_adjust_Projected_Price

$RELATIVE_DEMAND_INVENTORY(t) = RELATIVE_DEMAND_INVENTORY(t - dt) +$
 $(Change_in_relative_Demand_Inventory) * dt$
 INIT RELATIVE_DEMAND_INVENTORY = 0
 INFLOWS:
 $Change_in_relative_Demand_Inventory = (Desired_relative_Demand_Inventory -$
 $RELATIVE_DEMAND_INVENTORY)/Time_to_adjust_Inventories$
 $RELATIVE_SUPPLY_INVENTORY(t) = RELATIVE_SUPPLY_INVENTORY(t - dt) +$
 $(Change_in_relative_Supply_Inventory) * dt$
 INIT RELATIVE_SUPPLY_INVENTORY = 0
 INFLOWS:
 $Change_in_relative_Supply_Inventory = (Desired_Relative_Supply_Inventory -$
 $RELATIVE_SUPPLY_INVENTORY)/Time_to_adjust_Inventories$
 $Total_load_shedding(t) = Total_load_shedding(t - dt) + (Amount_of_load_shedding) * dt$
 INIT Total_load_shedding = 0
 INFLOWS:
 $Amount_of_load_shedding = LoadShedding$
 $Actual_supply = Supply_Total - (Supply_Total * Supply_Loss) + Supply_Inventory$
 $Capacity_NG = 80$
 $CoalFired_Generation = 3$
 $Cost_for_Inventories_Batteries = 407 * 83 * 1000$
 $Demand = Existing_Demand * Demand_Adjustment$
 $Demand_Adjustment_Time = 30$
 $Demand_Total = Demand + Demand_Inventory$
 $Demand:Supply = Demand_Total / Actual_supply$
 $Desired_relative_Demand_Inventory = IF INVENTORY < Maximum_inventory THEN MIN(1, MAX(0,$
 $(Price_low - Price) / Price_coefficient)) ELSE 0$
 $Desired_Relative_Supply_Inventory = (IF INVENTORY > 0 THEN MIN(1, MAX(0, (Price -$
 $Price_high_Inventory) / Price_coefficient)) ELSE 0)$
 $Diesel_Powerplant_Capital_Cost = 1000 * 1000 * 83$
 $Electricity_price_from_QRPP = 15$
 $Existing_Demand = 132 + 18 * SIN(2 * PI * TIME / (60 * 24))$
 $Existing_Price = 9.5$
 $Foreign_Import = 10$
 $Hydro_Electricity_Generation_capacity = 3.83$
 $Indicated_CU_NG = GRAPH(Price)$
 $(0.000, 0.000), (0.950, 0.086), (1.900, 0.164), (2.850, 0.267), (3.800, 0.405), (4.750, 0.737), (5.700,$
 $0.884), (6.650, 1.000), (7.600, 1.000), (8.550, 1.000), (9.500, 0.991)$
 $Indicated_CU_Oil = GRAPH(Price)$
 $(0.00, 0.000), (1.50, 0.073), (3.00, 0.134), (4.50, 0.203), (6.00, 0.302), (7.50, 0.401), (9.00, 0.539), (10.50,$
 $0.707), (12.00, 0.884), (13.50, 0.961), (15.00, 1.000)$
 $Indicated_Demand_adjustment = (Price / Reference_Price) ^ (Price_Elasticity_for_Demand)$
 $Indicated_Hydro_CU = GRAPH(Price)$
 $(0.000, 0.017), (0.950, 0.112), (1.900, 0.185), (2.850, 0.302), (3.800, 1.000), (4.750, 1.000), (5.700,$
 $0.996), (6.650, 1.000), (7.600, 1.000), (8.550, 1.000), (9.500, 1.000)$
 $Initial_CU_demand = 1$
 $Initial_CU_NG = 0.58$
 $Initial_CU_Oil = 0.58$
 $Initial_Hydro_CU = 0.72$

```

Initial_Inventory = 1500
LoadShedding = MAX(0, Demand_Total-Actual_supply)
Maximum_Capacity_to_Change_Inventory = 60
Maximum_inventory = 1500
MWH_to_KWH_Conversion = 1000
Normal_Oil_CU = 0.7
Oil_CU_With_Function = Indicated_CU_Oil*SW_Price+Normal_Oil_CU*(1-SW_Price)
Oil_Fired_Generation_Capacity = 68
Price = Projected_Price*(1+Price_sensitivity*(Demand:Supply-1))*SW_Price+(1-
SW_Price)*Existing_Price
Price_coefficient = 0.1
Price_difference = 1
Price_Elasticity_for_Demand = -0.1
Price_high_Inventory = 9.5
Price_low = Price_high_Inventory-Price_difference
Price_sensitivity = 1
Reference_Price = 6
Supply_HydroElectricity = Hydro_Electricity_Generation_capacity*HYDRO_CU
Supply_Loss = .1
Supply_Natural_Gas = (Capacity_NG*CU_NG)
Supply_Oil = Oil_Fired_Generation_Capacity*OIL_CU
Supply_Total =
Supply_Natural_Gas+Supply_HydroElectricity+Supply_Oil+Foreign_Import+CoalFired_Generation
SW_Inventory = 1
SW_Price = 1
Time_to_adjust_CU_NG = 30
Time_to_Adjust_Hydro_CU = 8
Time_to_adjust_Inventories = 5
Time_to_Adjust_Oil_CU = 1
Time_to_adjust_Projected_Price = 30
Total_Benefits = ACCUMULATED_PROFIT_FROM_INVENTORIES+Total_benefits_from_power_plants
Total_benefits_from_power_plants = Total_cost_for_Diesel_power_plants-Total_Cost_for_Inventories
Total_cost_for_Diesel_power_plants = Initial_Inventory*Diesel_Powerplant_Capital_Cost
Total_Cost_for_Inventories = Initial_Inventory*Cost_for_Inventories_Batteries
{ The model has 79 (79) variables (array expansion in parens).
  In root model and 0 additional modules with 3 sectors.
  Stocks: 11 (11) Flows: 12 (12) Converters: 56 (56)
  Constants: 33 (33) Equations: 35 (35) Graphicals: 3 (3)
}

```

List of Acronyms:

mwh – Megawatt hours

kwh – Kilo watt hours

AT – Adjustment Time

SFD – Stock and Flow Diagram

CLD – Causal Loop Diagram

AMI – Advanced Metering Interface

BPDB – Bangladesh Power Development Board.

SPP – Smart price policy.

SMP – Smart price

BERC – Bangladesh Energy Regulatory Commission