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Optimal Energy Mix and Operation Cost in the Presence of Nuclear and Solar PV Generation

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***Abstract*—This paper investigates electrical energy mix and operation cost in Bangladesh for sustainable development. Projecting tentative energy demand by the year of 2025, the aspect of economic load dispatch is discussed. Several ongoing Government projects and their contribution to meet future demand, along with renewable energy scenario are critically reviewed. The prospects of feasible renewable energy resources are considered. To fulfill the electrical energy demand, optimal energy mix has been proposed. Three plausible scenarios have been considered for the year 2018, 2021 and 2025 respectively. The west zone power grid comprises of generation stations and sub-stations are considered to carry out the load at different buses at a minimum cost. Linear programmed optimum power flow method has been used to evaluate the generating capacity, operation cost as well as the selling price of each generating stations for both off-peak and on-peak hour. The emission of CO_2 is calculated by considering the emission of each fuel type used in different generating stations.**

***Index Terms*—Energy mix, renewable energy, linearized optimal power flow (LOPF), locational marginal price (LMP), generation dispatch**

I. Introduction

A. Motivation

Bangladesh is blessed with different fossil fuels resources. Natural gas has the maximum contribution on electrical power generation (64.99%) (Fig. 1). Furnace oil (20.55%), Diesel (6.49%), Imported power (4.43%), Hydro (1.70%) and Coal (1.84%) together contribute to the majority of power generation [1]. Small scale Renewable Energy (RE) especially solar, wind and biomass is being harnessed. But most of these contribution limited to off-grid power supply. With the increasing energy demand and decreasing fossil fuels, future energy crisis is an alarming problem. Moreover, environment pollution in the cities is raising the tension even more. As Bangladesh is situated by the Bay of Bengal; there remains a huge risk that the southern regions could flood under water if the sea level raises much due to global warming. Leaning towards renewable energy can be appropriate solution to these problems. Renewable energy is said to be an unlimited energy source and rarely causes any harm to the nature. Because of the geographical location and geological structure of the country, there are immense potential of several renewable energy resources. Solar, micro hydro, wind, biomass, biogas, geothermal these are such feasible renewable energy resources. At present, installation cost of RE plants is high due to which these sources are not being considered that much. The key to effectively set the trend is to decrease the operating cost at long run which will comparatively be less expensive than conventional power cost.

B. Literature Review

Rofiqul Islam et al. reviewed the renewable energy resources and technologies (RETs) practicing in Bangladesh in terms of its implementations, research and development activities [19]. A solution has been suggested to improve the quality of rural life by focusing majorly on biomass, solar energy. Baky et al. presented a thorough review of the current status and future potentials of renewable energy sector in Bangladesh [13]. The forthcoming plans for renewable energy development have been considered. Mondal et al. estimated the potential renewable energy resources for power generation in Bangladesh.

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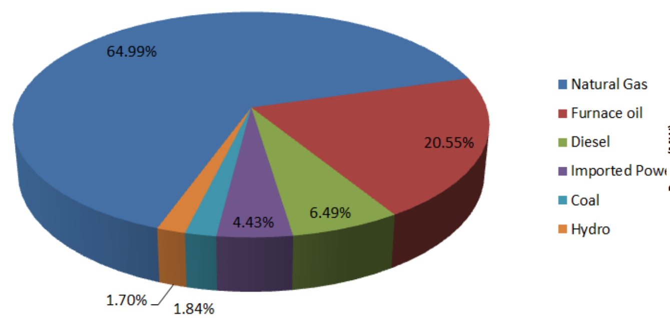

Fig. 1. Percentage of Installed Capacity (National) by Resources, 2017

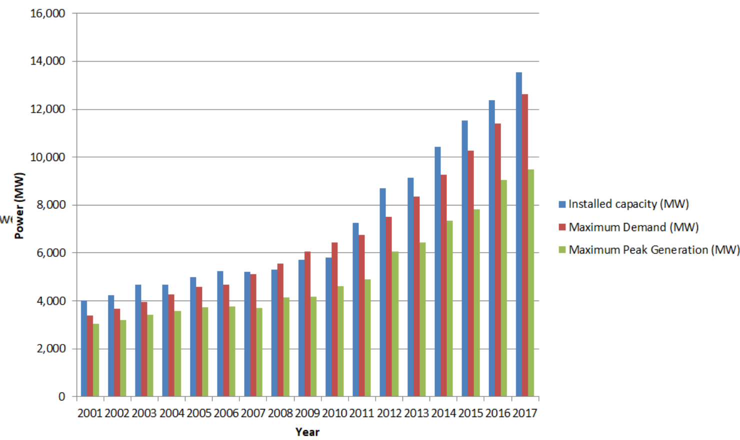

Fig. 2. Installed capacity, Maximum demand and Maximum Peak Generation Trend

Estimation of solar energy has been done using GsT, HOMER, SSE solar radiation data [21]. A wind map has been developed using NASA SSE wind data and HOMER model, which is used to estimated wind energy potential [21]. Halder et al. outlined the country's current energy scenario. The potential of available renewable energy resources has also been reviewed [18]. Recent achievement and future target in renewable energy development are presented. Hassanuzzaman et al. reviewed the present energy crisis of Bangladesh and proposed geothermal energy as a solution [22]. Feasibility of the energy and related geographical analysis has been observed. Several potential well are suggested and required cost comparison have been done. Tasbirul Islam et al. examined the current energy mix, present energy crisis and its way to overcome such scenario by utilizing alternative energy sources such as biomass, solar, wind and small scale hydropower energy, in the context of Bangladesh [38].

Rana et al. proposed a stochastic approach for the operation of distribution networks within a joint active and reactive distribution market environment [2]. Market-based active and reactive optimal power flow is used to determine the optimal capacity of WTs and PVs for evaluation of amount of power penetration and locational marginal prices a mixed linear programming is used [2]. It resulted in increase in total dispatched power and decrease in LMPs. Rishabh et al. identified an ideal framework and bidding mechanism for RE generators to maximize overall capital gain in Indian power market [3]. Bell et al. investigated the effect of increasing the number of WTs in the Australian National Electricity Market′s (NEM), given the existing transmission grid from 2014 to 2025, it is obtained that adopting locational marginal cost pricing would promote the optimal investment in generation and virtual networks as well as help to defer investment in transmission and distribution [4]. Nur Mohammad et al. investigated a competition driven supply offering strategies to meet a given demand in day ahead electricity markets which obtained that system without transmission constraints with lower demand leads to Nash equilibrium in terms of generation payoff [5], [6]. Another paper proposed a bi-level transactive market clearing model with a coordinated integration of large-scale renewable and end-users demand response (DR) capable loads using mixed integer linear programming MILP and SC-OPF [6]. B. Muruganantham et al. analyzed the parameters of Distribution Network (DN) using various load flow methods as well as various pricing methodologies for the delivered power in DN elaborately [8]. Schäfer et al. proposed a simplified cost optimal model of a future European electricity network with a high share of renewable generation using flow tracing techniques to disentangle the emerging pattern of imports and exports and assign shares of the distributed generation capacity in system [9].

II. Theoretical Overview

A. *Present Status of Energy Sector*

According to the latest annual report by Bangladesh Power Development Board on the status of electrical power of year 2016 2017; it is observed that the current installed capacity is higher than present demand of energy (Fig 2). But due to maintenance and repairing causes as well as system malfunction, the peak generation is far less than the total installed capacity as well as maximum demand. The annual increase in installed capacity is less than the annual increase in demand (Table I).

TABLE I
Electrical power status in Bangladesh of year 2016 − 2017 [1]

Particulars	Year (2015-2016)	Year (2016-2017)	% Change over previous year
Total installed capacity (MW)	12,365	13,555	9.62
Maximum Peak Generation (MW)	9,036	9,479	4.90
Maximum Peak Demand (MW)	11,405	12,644	10.86

TABLE II
ESTIMATED POWER DEMAND ACCORDING TO POWER SYSTEM MASTER PLAN 2015 [10]

Year	2015	2020	2025
Gross Peak demand (MW)	9,300	13,300	19,100
Net Peak demand (MW)	8,920	12,800	18,300

B. Estimated Power Demand

According to Survey on Power System Master Plan 2015, certain changes in daily load curve are estimated statistically (Table II). At present peak load is observed in the evening. But it is estimated that evening load will be reduced with time and there will be a gradual increase of load at the day time [10].

C. Development of Non-renewable Energy Projects

1) Coal power: Barpukuria power station is a coal fired plant located near Durgapur, Dinajpur. It consists of 2 plants; 125 MW and 275 MW capacities. Another coal fired plant is under construction financed jointly by Bangladesh and Singapores Sembcorp. Phase 1 of the plant has 700 MW capacity located in Matarbari of Coxs Bazar and is expected to start operating from June 2023 [11].

2) Nuclear power: A nuclear based power plant is under construction in Rooppur of Ishwardi upazila, Bangladesh. Russian Rosatom State Atomic Energy Corporation is building the plant which will consist of 2 units; each of 1200 MW capacity. The first unit will operate from the year 2023 [12].

III. PRESENT SCENARIO OF RENEWABLE ENERGY

Bangladesh has a tropical monsoon climate such that heavy rainfall, high temperatures and humidity are observed. There are 700 rivers generally flowing towards the south. There is a great amount of feasible hydro energy. As the country straddles the tropic of cancer it receives sufficient solar irradiance throughout the majority of the year. This provides enormous potential of solar energy. Being an agricultural country there is ample scope of biomass and bio-gas energy.

A. Solar Power

Bangladesh Latitude ranges from 20.86° to 26.33° north and longitude from 88.16° to 92.30° east. The solar irradiance is in the range of 4-5 $kWh/m^2/day$ on about 94% of the area [15].

IDCOL aims to install 6 million SHS of 220 MW capacity by 2021. Up to May 2017 4.12 Million SHS has been installed. Total capacity installed till now is 151.067 MW [16].7 Mini grid projects of total 966 kW capacities by IDCOL are operating. 11 more mini grid projects of total 1.8124 MW are under construction. 4 solar park projects are under construction with total capacity of 258 MW [17].

B. Hydro Power

Karnafully hydro power plant located at Kaptai, Chittagong has a capacity of 230 MW. A small hydro power plant is located at Barkal with a capacity of 50 kW. Two other rivers are being studied for hydro power plant installation. There is feasibility of 140 MW power on the Sangu River. 75 MW feasible hydro power is estimated on the Matamuhuri river.
Some rivers carry high discharges during the monsoon season and very small during the dry season [18]. The potential annual power output of these rivers is estimated at 35 MW and the annual energy production at 307 GWh [19].

C. Wind Power

A grid connected 900 KW wind power plant is being operated at Muhuri dam, Feni. Hybrid power plant using wind battery of 1000 kW is operating at Kutubdia Island. Total 15 MW of capacity wind power plants are being constructed across country's coastal regions. Recently, Bangladesh signed an agreement with US DK Green energy (BD) Ltd for installing the country's largest ever wind power plant of capacity 60 MW at Cox's Bazar [18].

D. Biomass Power

Two rice husk gasification power plants (250 kW and 400 kW) financed by IDCOL are in operation [13]. 1.5 MW biomass plants are being installed by private sectors through IDCOL [20].

E. Biogas Power

Fourteen cogeneration biogas power plants are already installed in the sugar mills that can generate 38.1 MW electricity [13]. In Bangladesh average amount of crushed cane can generate up to about 12.75 MW of electricity. Thus a total of 178.5 MW of electricity can be produced from 14 mills. Estimated potential of biogas power using cattle waste is 350 MW [21].

F. Geothermal Power

The geothermal gradient of Bangladesh is mostly controlled by the Tectono stratigraphic setup of the Bengal Basin [22]. Countrys first geothermal energy based plant of 200 MW capacity has been initiated by a private company named Anglo MGH.

TABLE III
INSTALLED RENEWABLE ENERGY TECHNOLOGIES IN BANGLADESH [13]

Technology	Off grid (MW)	On grid (MW)	Total (MW)
Biogas to electricity	5	-	5
Biomass to electricity	1	-	1
Hydro	-	230	230
Solar PV	184	1	185
Wind	1	0.9	1.9
Total	191	232	423

TABLE IV
FEASIBLE RENEWABLE ENERGY POTENTIAL IN BANGLADESH [14]

Technology	Resource	Capacity (MW)	Annual Generation (GWh)
Solar Park	Solar	1400*	2,000
Solar Rooftop	Solar	635	860
Solar Home System (SHS)	Solar	100	115
Solar irrigation	Solar	545	735
Wind Park	Wind	637**	1,250
Biomass Generation	Rice husk	275	1,800
Biogas Generation	Animal waste	10	40
Waste to Energy	Municipal waste	1	6
Small hydro power plants	Hydropower	60	200
Mini grid, Micro grid	Hybrid	3***	4
Total	-	3,666	7,010

* Case 1 (agricultural land excluded) estimate
** Case 2 (flood-prone land excluded) estimate
*** Based on planned projects only, not a theoretical maximum potential, because there is potential overlap with off grid solar systems. Either could be used to serve off grid demand.

IV. PROBLEM FORMULATION

The improvement of the economic dispatch invention for attaining least cost sharing of mandate to the generation units faces two problems due to implicit loss assumption and approximation about transmission having vast capability. Using the nodal power flow calculations for the substitution of the one power equilibrium equation the optimal power flow (OPF) recompenses for these. Line flow inequality constraints are added while retaining the inequality constraints of generating limits. Network constraints are included to study the impact of transmission on most economic distribution of generation. Linear programmed OPF is the main focus here (Fig. 3).

A. Optimum Power Flow

During linearizing the OPF, for maintaining simplicity, it is assumed that every generator offer some single-price. Thus, at the objective function, each unit is characterized by a fixed level of generation's times for that unit.

The declaration of the problem is:

$$\text{Min} \sum_{k \in (\text{generator buses})} s_k P_{gk} \quad (1)$$

Subject to:

$$P = B'\theta \quad (2)$$

$$P_B = (D \times A) \times \theta \quad (3)$$

$$-P_{B,max} \le P_B \le P_{B,max} \quad (4)$$

$$0 \le P_{gk} \le P_{gk,max}, \forall k \in (\text{generator buses}) \quad (5)$$

Where,

$$P_k = P_{gk} - P_{dk}, k = 1, ..., N \quad (6)$$

Here, k is units index.

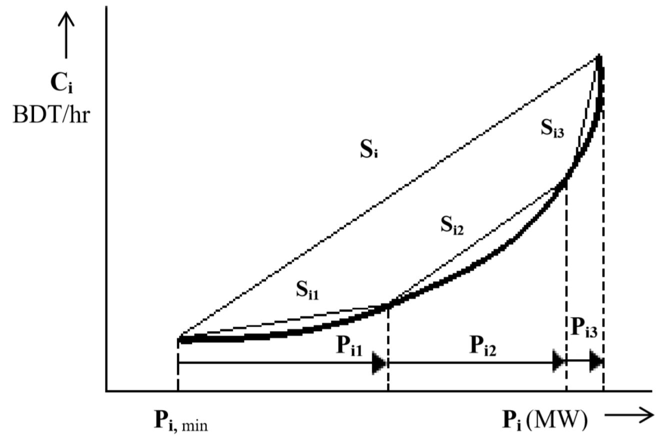

Fig. 3. Cost function for linear programmed OPF diagram of a system with 3 units

B. Locational Marginal Price

In order to find the locational marginal price (LMP) of energy all N equations are included for Lagrange multiplier for each bus which implies that all of the angles must be included as unknowns. The vector P includes the reference bus injection, the vector θ includes the reference bus angle, the matrix B' is $N \times N$ and adjacency (node-arc) matrix D is $M \times N$. The following solution vector is defined for problem of linearized OPF formulation:

$$x = \begin{bmatrix} P_g \\ P_B \\ \theta \end{bmatrix}$$

Where, P_g is the generation increments vector, P_B is the line flows vector.

The system to be solved (Fig. 4) has 7 units connected to 7 different buses in a 29 bus network supplying load at 25 different buses.

The objective function is given by: $Z(x) = 100000\times$

$$\begin{bmatrix} 2.26 & 33.3 & 13.433 & 5.391 & 6.396 & 2.26 & 0 & .. & 0 \end{bmatrix} x$$

V. RESULTS AND DISCUSSION

The simulation result provides the actual generation taken from the generating units to supply the loads at different buses. The program also provides the price of each generating units at BDT/MWh. From there, revenue and total CO_2 emission is calculated with the help of necessary data (Table V). Off peak and On peak load data are considered separately. Different results are obtained for each.

A. Case #1 (For the Year of 2018)

In the base case of the year 2018, it is found that the system at bus 1 is generating the highest amount of electricity. The operation cost of the system is low and the generating capacity is higher than the rest of the units. So, system at bus 1 is

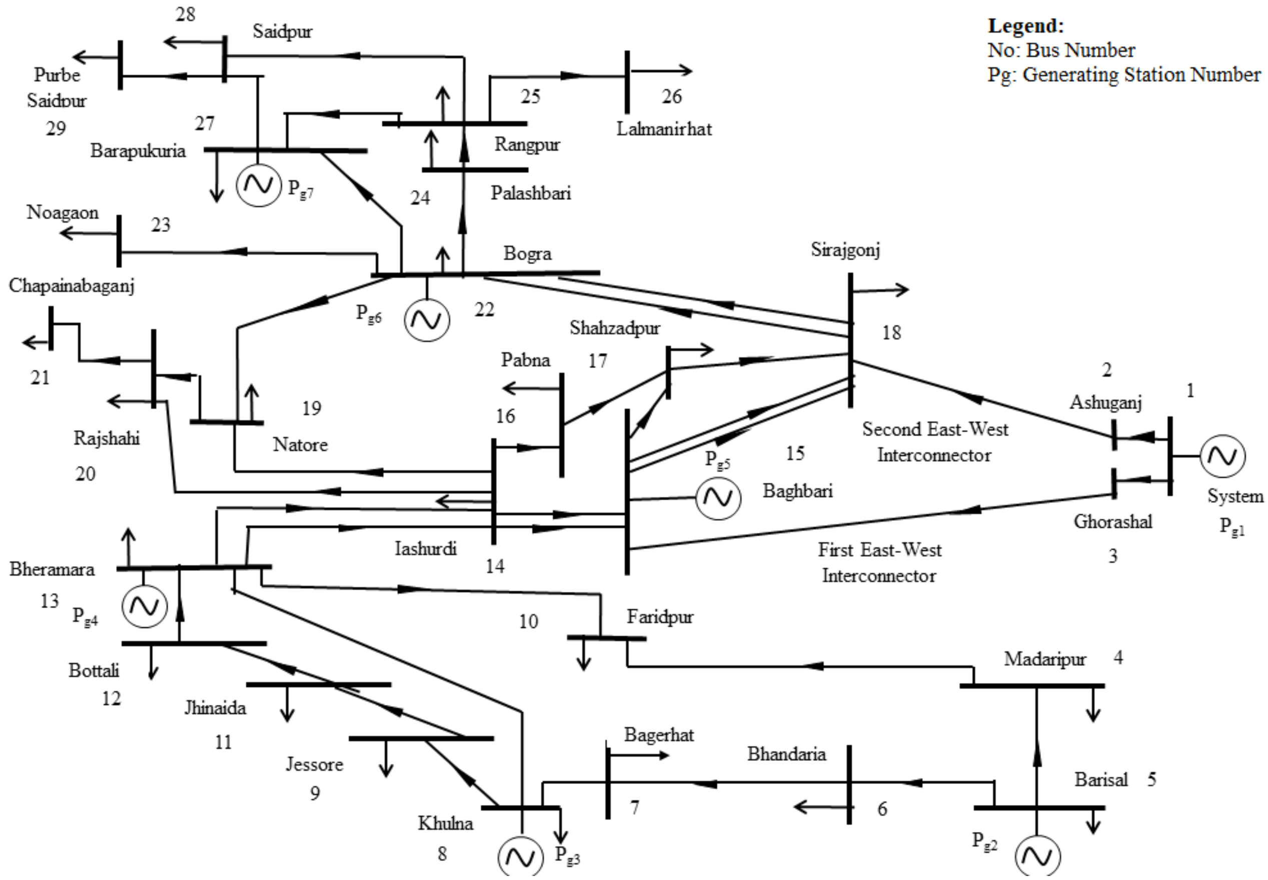

Fig. 4. One line diagram of Bangladesh west zone power network system

supplying the major part of the load at a minimum price. The second unit at Barisal contributes the lowest of all units as the cost of its generation is higher than the rest of the units. So, this unit is supplying at its lowest generation limit which is 7.5 MW. The objective function which also named as operation cost for on peak (Table VI) case is found to be greater than the off peak (Table VII) value, which is understandable as the load decreases during off peak hours.

The emission of CO_2 is found by considering the emission for each fuel type used in different generating stations and calculated in tons. The total CO_2 emission is found by

TABLE V
OPERATING CONDITIONS OF DIFFERENT GENERATING STATION (2018)

Generating Station	Bus No.	Fuel Type	Maximum Generation (MW)	Minimum Generation (MW)
System	1	Gas	3059	764.75
Barisal	5	HSD	30	7.5
Khulna	8	HSD, HFO, Gas	5100	153
Bheramara	13	HSD, Gas	456	136.8
Baghbari	15	HFO, Gas	233	69.9
Bogra	22	Gas	32	9.6
Barapukira	27	Coal	444	133.2

multiplying the generation capacity to the emission per MWh of the generating units respectively. The revenue is calculated by multiplying the price to generation capacity of the generating units respectively. During off peak hours all the generating stations produces power at least amount of cost.

TABLE VI
OPTIMUM GENERATION, PRICE AND CO_2 EMISSION FOR 2018 (ON PEAK)

Operation cost	Generating Station	Price (BDT/ MWh)	Generation Dispatch (MW)	Revenue (BDT)	CO_2 Emission (tons)
	System	2260	1898.06	4289615.6	1061.015
	Barisal	5391	7.5	40432.5	8.385
	Khulna	5391	153	824823	139.077
95452	Bheramara	5391	230.34	1241762.94	178.974
	Baghbari	4901	69.9	342579.9	48.16
	Bogra	4823	32	154336	17.888
	Barapukira	4823	133.2	642423.6	185.148

B. Case #2 (For the Year of 2021)

At the year of 2021 there will be an increase in load and new power stations will be made. 500 MW Solar Panel is now being built in Bogra. It will be fully ready to add power at

TABLE VII
OPTIMUM GENERATION AND PRICE FOR THE YEAR OF 2018 (OFF PEAK)

Operation cost	Generating Station	Price (BDT/ MWh)	Generation Dispatch (MW)	Revenue (BDT)	CO_2 Emission (tons)
	System	2260	1732.2	3914772	1061.015
	Barisal	2260	7.5	16950	8.385
	Khulna	2260	153	345780	139.077
86661	Bheramara	2260	136.8	309168	106.29
	Baghbari	2260	69.9	157974	48.16
	Bogra	2260	32	72320	17.888
	Barapukira	2260	133.2	301032	185.148

national grid by 2021. By then total load will be increased by 1.2 times.

At the year 2021 one new energy resource of 500 MW solar power will be added to Bogra generating station. Consequently the generating dispatch changes to 532 MW (maximum) and 159.6 MW (minimum). Due to that the total revenue and revenue of each station increases for both on peak (Table VIII) and off peak (Table IX) hours. Overall CO_2 emission also increases.

TABLE VIII
OPTIMUM GENERATION, PRICE AND CO_2 EMISSION FOR 2021 (ON PEAK)

Operation cost	Generating Station	Price (BDT/ MWh)	Generation Dispatch (MW)	Revenue (BDT)	CO_2 Emission (tons)
	System	2260	1898.91	4289616.6	1060.373
	Barisal	7162.9	7.5	53721.75	8.385
	Khulna	7162.9	153	1095923.7	139.077
134850	Bheramara	7162.9	456	3266282.4	354.312
	Baghbari	6396	222.59	1423685.64	153.36
	Bogra	6272.7	159.6	1001122.92	18.86
	Barapukira	6272.7	133.2	835523.64	185.148

C. Case #3 (for the Year of 2025)

2025 would be a revolutionary year. There will an addition of 1200 MW power in national grid. A nuclear power plant

TABLE IX
OPTIMUM GENERATION AND PRICE FOR THE YEAR OF 2021 (OFF PEAK)

Operation cost	Generating Station	Price (BDT/ MWh)	Generation Dispatch (MW)	Revenue (BDT)	CO_2 Emission (tons)
	System	2260	1892.95	4278067	1058.16
	Barisal	5391	7.5	40432.5	8.385
	Khulna	5391	153	824823	139.077
116650	Bheramara	5391	301.37	1624685.67	234.16
	Baghbari	4901.2	69.9	342593.88	48.16
	Bogra	4822.5	159.6	769671	18.86
	Barapukira	4822.5	133.2	642357	185.148

TABLE X
OPTIMUM GENERATION, PRICE AND CO_2 EMISSION FOR 2025 (ON PEAK)

Operation cost	Generating Station	Price (BDT/ MWh)	Generation Dispatch (MW)	Revenue (BDT)	CO_2 Emission (tons)
	System	2260	1808.32	4086803.2	1010.85
	Barisal	3786.8	7.5	28401	8.385
	Khulna	3786.8	153	579380.4	139.077
137200	Bheramara	3786.8	136.8	518034.24	106.3
	Baghbari	3458	1008.98	3579861.04	120
	Bogra	3509.6	159.6	560132.16	18.86
	Barapukira	3509.6	133.2	467478.72	185.148

TABLE XI
OPTIMUM GENERATION AND PRICE FOR THE YEAR OF 2025 (OFF PEAK)

Operation cost	Generating Station	Price (BDT/ MWh)	Generation Dispatch (MW)	Revenue (BDT)	CO_2 Emission (tons)
	System	2260	1836.13	4149653.8	1010.85
	Barisal	3786.8	7.5	28401	8.385
	Khulna	3786.8	153	579380.4	139.077
124410	Bheramara	3786.8	136.8	518034.24	106.3
	Baghbari	3548	630.98	2238717.04	74.89
	Bogra	3509.6	159.6	560132.16	18.86
	Barapukira	3509.6	133.2	467478.72	185.148

in Rooppur, Pabna district of the country is expecting to distribute electricity through grid. The load demand will also be increased. So, there will be a great reduction in price. The nuclear power input will be added to the Baghbari generating station. As a result the generating dispatch of the station changes to 1433 MW (maximum) and 429.9 MW (minimum). The total revenue and revenue of each station decreases for both on-peak (Table X) and off peak (Table XI). Decrement on On-peak revenue is far less than off-peak. Overall CO_2 emission also decreases.

VI. CONCLUSIONS

This paper presents secure and sustainable energy supply by minimizing operation cost and CO_2 emission. The LMP of electricity owing to different generating conditions has been found out using LOPF formulation simulation. Three different cases for three different years of 2018, 2021 and 2025 have been considered. In 2021, 500 MW solar panels are added to Bogra considering 20% increase in load. As a result it can be seen that there will be an increase in cost per unit, overall CO_2 emission will be decreased. The year 2025 must be the revolutionary era in the power sector of Bangladesh. As 1200 MW generating station is considered based on nuclear fuels to meet the increasing demand in load, the results obtained shows that the cost per unit will drastically reduce while minimizing the amount of CO_2 emission.

It can be concluded that long term planning and implementations are needed to shift to more clean and sustainable energy condition. There are huge potential of renewable energy in the country beside the regular solar, hydro power. These sectors must be considered for optimal energy mixing. Thus cost effectiveness of electric power generation can be obtained while a better environment for sustainable development can be ensured.

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