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Performance Analysis of Different Grid Substations with Demand-Side-Management-Based Optimal Power Usage

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Abstract— This study is centered on analyzing the performance of two power grid stations in the southern grid zone of Bangladesh. Additionally, it encompasses the effect of a demand-side management simulation of grid line operation. Firstly, this paper briefly discusses the grid circle's interconnected grid system and the serving districts' generation capacity. An analysis of schematic diagrams and an examination of the current substations and transmission cables in place has been conducted. The maximum load research has been addressed at several significant grid sub-stations, examining the capacity of a specific grid zone and determining the necessity for expanding the corresponding grid infrastructure. This study presents a comprehensive analysis of the DSM employed in the grid substation, as well as an examination of the various possibilities of renewable energy installations within it. Additionally, this study encompasses the investigation of power transmission and the accompanying structures employed for transmission, as well as the analysis of the estimation technique and any other interconnected domains.

Keywords: *Power grid, Simulation, and Renewable energy.*

1. INTRODUCTION

The Power Grid Business of Bangladesh (PGCB) is a government-owned electric utility business based in Dhaka, Bangladesh. It is one of the largest entities in the field of Power Transmission utilities. The Power Grid is crucial in facilitating the expansion of Bangladesh's power sector by establishing a strong and integrated national grid. Additionally, it is actively involved in the government's flagship initiative aimed at ensuring universal access to electricity. Advancement in the field of Technical and management has led to the synchronized progress of power transmission networks and the efficient operation and management of regional and national grids. POWERGRID, in its capacity as the Central Transmission Utility of the nation, is significantly contributing to the development of the power sector in Bangladesh and facilitating Open Access to its inter-state transmission system. POWERGRID has formulated a strategic plan to establish a robust and dynamic national grid throughout the country, implementing it systematically and gradually. This approach aims to maximize the efficient exploitation of generating resources, preserve environmentally sensitive areas along the transmission route, and handle the inherent unpredictability associated with power generation facilities. The enhancement of the National Grid is being strategically implemented through a systematic approach that involves the consolidation of the inter-regional link architecture [1].

In this scholarly article, the authors introduce a novel metric referred to as the power grid transmission performance index (PI) [2]. This index facilitates the explanation of several conventional power grid transfer issues, including the assessment of transfer capabilities, coordination among power plants, power grid and loads, and the evaluation of power grid capacity margin. This article addresses the issue of electricity transmission systems in the Chattogram Zone, as discussed in reference [3]. This discussion briefly addresses the

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interconnected grid system within the Chattogram circle and the generation capability of the Chattogram districts. We have conducted an examination of schematic diagrams, pre-existing sub-stations, the protection mechanism, and the current transmission lines. We have also examined the maximum load analysis conducted on significant sub-stations, as well as the peak hour demands seen in various grid sub-stations. To showcase the capabilities of the Simulink transmission line simulator, we will now examine a number of renowned instances [4]. The phenomena encompassed in this category consist of the propagation of waves and the dependence of velocity on the numerical values of the elements.

Furthermore, we shall examine the concept of reflection occurring at a linear terminating impedance. The phenomenon of pulse dispersion will be demonstrated. In this section, we will now discuss the concept of reflection occurring at a nonlinear terminating impedance. In this thesis, titled "Study of Patna 400/220 KV Substation," the focus is on the Power Grid Corporation Of India Limited [5]. This work introduces a MATLAB/Simulink model of a multiagent system designed to automate transmission utilities in order to mitigate grid outages. The model is presented in [6]. This study introduces the design and modeling of a Distance relay using the MATLAB/SIMULINK software, as documented in reference [7]. A transmission line network has been constructed, and fault voltages and currents resulting from both symmetrical and unsymmetrical faults have been graphed. During fault conditions, the transmission line network experiences an input voltage and current that comprise DC offset values and higher-order harmonics.

Demand-side management is a crucial component of power delivery networks' energy management systems, as it enables users to exercise control over their load consumption patterns [7]. The alteration of the electric load consumption profile can be achieved by one of four approaches. The impact of energy efficiency extends beyond peak usage periods, as it leads to a decrease in overall energy consumption. The analysis of efficiency improvement is further examined in the studies conducted by Chowdhury et al. (2018) [8] and Tronchin et al. (2018) [9]. The concept of time of use refers to a billing strategy that involves charging consumers varying rates based on their energy usage habits during different periods of the day [10],[11]. The proposed approach consists of the segmentation of fixed utility prices into several temporal intervals spanning a 24-hour duration. The utilization of differential tariffs for electricity units can potentially mitigate the effects of peak load rates and seasonal fluctuations in pricing tariffs. Rebours and Kirschen (2005) [12-16] posit that in instances where there is an unanticipated decline in electricity generation, the spinning reserve of the electric grid system can be mobilized by the distribution network operator (DNO) to compensate for the disparity between consumption and generation. Demand response, in the context of the electricity wholesale market, occurs when end-user consumers deviate from their typical load consumption patterns in response to changes in unit tariffs over time or as a result of incentivized programs aimed at reducing load consumption. This phenomenon is particularly relevant during periods of high tariffs or when grid stability is compromised [17-19].

2. PROBLEM FORMULATION

It is imperative to accurately simulate each regular load utilized by residential, semi-industrial, and industrial consumers in order to enhance the efficiency and reliability of the power grid system. Following the process of load-modeling and categorization, there exist two distinct methodologies for determining the load combination.

The top-down approach is a methodology that involves starting with a broad perspective and then gradually narrowing down to specific details or components.

The bottom-up technique is a methodology that involves starting with specific details or elements and gradually building up to a more extensive, more comprehensive understanding or conclusion.

Top-down methodologies are employed with the fundamental objective of consolidating all power consumption units inside a given unit. Consequently, this strategy only provides information on the overall energy consumption of a specific geographical region [14]. In contrast to the top-down approach, the bottom-up methodology examines the individual power consumption of each appliance in isolation. The regular load curve for a base station or multiple base stations can be easily obtained by aggregating the consumption of all devices [15]. In order to determine the hourly energy usage, historical data is utilized employing a bottom-up technique for various appliances over the course of a whole day.

2.1 Illustrations of Load Profile

The load consists of residential, industrial, and commercial components under typical user-defined conditions. To facilitate load modeling, extraneous parameters are omitted in order to establish a streamlined calculation model. In the context of load analysis, template base shapes are typically employed for nonlinear loads, while linear loads are represented by regular shapes that incorporate the power factor. For example, an industrial inductive load such as a ventilation system exhibits a power factor variation distinct from that of resistive loads inside the power grid. The home load has a consumption profile characterized by a certain power factor.

The proposed methodology involves conducting a periodic survey to assess the bottom-up load calculation approach for various customer types. The appliances are categorized based on their ability to be shifted and further divided into three groups: 1) Thermostatically controlled loads (TCL), which are specifically related to air conditioning units for base stations; 2) Lighting loads (LL), which can be adjusted to different periods based on comfort and economic factors; and 3) Household loads (HL), encompassing appliances such as washing machines, cookers, pumps, and monitoring computer terminals, which are essential for providing basic services.

2.1.1. Calculation by Demand Side Management

There are two stages of DSM energy calculation in the Grid Network. At first, the system energy calculation includes three factors: the load profile of used loads by the users, the class of the users covered by the system model, and the environmental and timing issues that affect the uses of the load data. Secondly, a simplified model of the grid model is used to produce electrical power calculation with and without DR following a linear relationship with the load models. The output calculation expressed the power saving of a grid network using the bulk amount of load in a particular test grid system. Different test grids like six, fourteen and higher number of nodes with IEEE test bus system are utilized to get the system output.

For a typical load modeling scenario, Considering N_T samples in a capture period, the acquired samples are sequences of length N_T as shown in (1) and (2).

$$v_{load} = \{v_{load}(n)\}_{n=1}^{N_T} \tag{1}$$

$$i_{load} = \{i_{load}(n)\}_{n=1}^{N_T} \tag{2}$$

The energy consumption for any load number can be obtained from

$$P_{load} = \frac{1}{N}\sum_{n=1}^{N} v_{load}(n) i_{load}(n) \tag{3}$$

For load modeling purposes, assuming the temperature control loads (TCL) as a different category. As these loads depend on temperature for consuming power. 'P_{TCL_load}' suitable modeling equation can be expressed as,

$$N_{TCL\_load} = \begin{cases} 0 \quad temp \leq lower\_threshold \\ 1 \quad temp \geq upper\_threshold \\ N_{TCL\_load} = condition\ of\ TCL\ load \end{cases} \tag{4}$$

and

$$P_{TCL\_load} = \frac{1}{N}\sum_{n=1}^{N} N_{TCL\_load} * v_{load}(n) i_{load}(n) \tag{5}$$

Shiftable loads can be considered as loads that can be shiftable to another time period, like washing machines, water pumps, telecom rectifiers, etc. As a result, the energy demand at this time will be reduced by the energy that would have been consumed by it. These loads depend on the time period for consuming power 'P_{FL_load}' suitable modeling equation can be expressed as,

$$N_{FL\_load} = \begin{cases} 0 \quad time \leq lower\_threshold \\ 1 \quad time \geq upper\_threshold \\ N_{TCL\_load} = condition\ of\ TCL\ load \end{cases} \tag{6}$$

and

$$P_{FL\_load} = \frac{1}{N}\sum_{n=1}^{N} N_{FL\_load} * v_{load}(n) i_{load}(n) \tag{7}$$

Thus, considering base load as ‘P_{BL_load}’ and thus total active power ‘$P^k_{Total\_load}$’ can be calculated for ‘k’ time period,

$$P^k_{Total\_load} = P^k_{BL\_load} + P^k_{FL\_load} + P^k_{TCL\_load} \tag{8}$$

Similarly, we can consider ‘$Q^k_{Total\_load}$’ as total reactive power for ‘k’ time period,

$$Q^k_{Total\_load} = Q^k_{BL\_load} + Q^k_{FL\_load} + Q^k_{TCL\_load}$$
(9)

If any aggregator is responsible for coordinating at ‘l ‘number of loads in a power network then,

$$P^k_D = \sum_{L=1}^{l} P^{k,L}_{Total\_load} \tag{10}$$

and

$$Q^k_D = \sum_{L=1}^{l} Q^{k,L}_{Total\_load} \tag{11}$$

The standard version of AC optimal power flow, the power balance equation expressed as functions of the voltage angles $'\theta^{k'}$ and magnitudes ‘V^k_m’ and generator injections ‘P^k_g’ and ‘Q^k_g’, where the load injections are assumed constant and given:

Here, the objective function for the power grid network with n_g generator is

$$minmize \quad \sum_{i=1}^{n_g} f_P^{i,k}\left(P_g^{i,k}\right) + f_Q^{i,k}\left(Q_g^{i,k}\right) \tag{12}$$

Subject to

$$g_p\left(\theta^k, {V_m}^k, {P_g}^k\right) = P_{bus}\left(\theta^k, {V_m}^k\right) + \; P^k_D - C^k_g P^k_g = 0 \tag{13}$$

$$g_p\left(\theta^k, {V_m}^k, {Q_g}^k\right) = Q_{bus}\left(\theta^k, {V_m}^k\right) + \; Q^k_D - C^k_g Q^k_g = 0 \tag{14}$$

Where ‘$f_P^{i,k'}$ and $'f_Q^{i,k\prime}$ are the cost functions of real and reactive power injections in a sparse (*nb* ×*ng*) generator connection matrix *Cg* can be defined such that its (*i, j*) th element is 1 if generator *j* is located at bus *i* and 0 otherwise. Also subject to the inequality constraints *h* ($\theta^k, {V_m}^k$) are the branch flow limits and the minimum and maximum values. Bounding condition includes reference bus angles, voltage magnitudes and generator injections.

3. METHODOLOGY

The proliferation of electrical and electronics loads in residential dwellings, commercial complexes, and office spaces has experienced a significant surge within the last two decades. These particular categories of loads have contributed to an improvement in the overall quality of life and have resulted in an increased use of electrical power. Both electrical and electronic equipment require higher power supplies as they are designed for decentralized networks. With the growing demand for energy, there is a need for stricter infrastructure support to accommodate the supply of electrical energy. The majority of power supplies are engineered to fulfill requirements related to regulated output, isolation, and compatibility with diverse grid systems. The load type and electricity usage exhibit variability across different localities. The usage of domestic energy has experienced a steady increase throughout time. The predominant portion of home electrical energy is utilized for the purposes of illuminating spaces and operating cooling fans. The majority of residential loads have a single-phase characteristic and receive power from single-phase mains. By utilizing load templates, it becomes feasible to assess the influence of various categories of residential loads on a distributed system. By employing template-based load modeling, it becomes feasible to ascertain the system's power consumption, voltage, power factor (PF), and energy need for any given number of loads within a feeder [18].

The calculation of an output load is possible for user-defined load combinations, which can then be applied to the node bus of various bus systems, such as the six or fourteen-test bus system provided by the Institute of Electrical and Electronics Engineers (IEEE). Figure 1 illustrates that when the system load is substituted with a percentage, there is a reduction in output consumption. Ultimately, the diminished computed load is employed to obtain an optimal power flow (OPF) solution for the system.

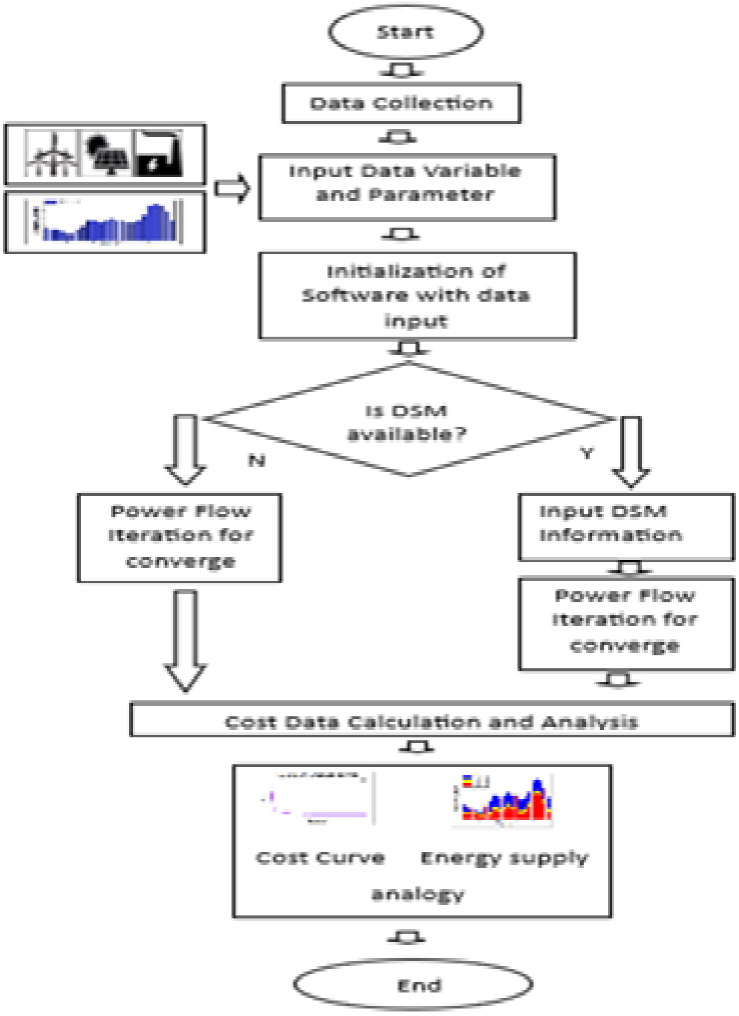

Figure 1: Flow chart of the proposed system

4. RESULT AND DISCUSSION

A comparison analysis was conducted to examine the power consumption of individuals within 24 hours, measured in megawatts (MW), for the grid system under investigation. The general pattern exhibits fluctuations with a small upward trajectory toward the conclusion of the observed timeframe. The electricity consumption in the considered region initially begins at a level just below 140MW and fluctuates within a range of approximately 140MW to 120MW throughout the subsequent eight hours. The consumption demand experienced significant fluctuations, reaching a peak of 180MW at 20:00. Subsequently, there was a decline in power utilization throughout the early hours of the night, namely during four hours, resulting in a reduction of 160 megawatts.

However, it should be noted that the power consumption demand remained slightly below 80MW within the specified timeframe. Subsequently, there was a marginal decrease in the consumption of load demand within the subsequent 8-hour period. Subsequently, there was a gradual increase in the load demand, with a progressive decrease and subsequent increase to a maximum of 18.30 below 100MW. Ultimately, the level of consumption had a consistent decline, reaching a value of 80MW.

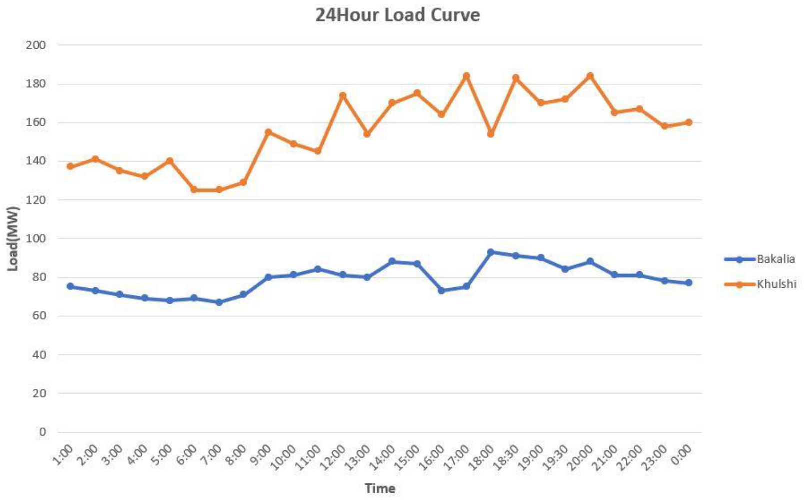

Figure 2: Load curve of the nodes collected from PGCB

The line graph of Figure 3 illustrates the power consumption of the monthly load curve, measured in megawatts (MW). The entire demand for power consumption exhibited significant fluctuations and experienced a drop.

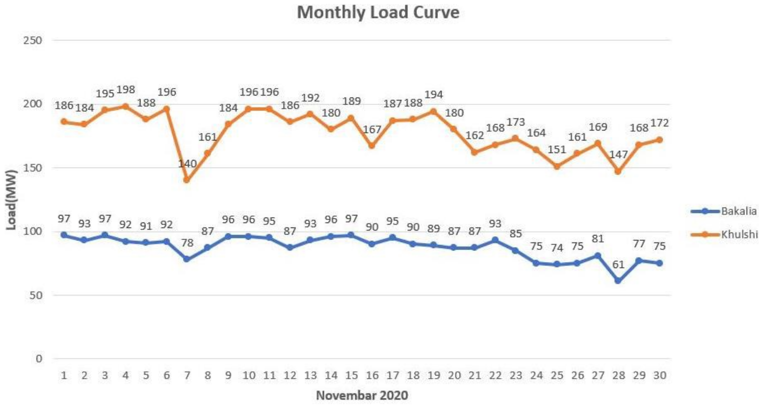

Figure 3: One-month load curve for the considered system

The initial power output at Khulshi was recorded at 186MW, followed by minor fluctuations over the subsequent five days, reaching a peak of 196MW and seeing tiny increases and decreases over this period. Subsequently, the load demand exhibited a sharp increase, reaching a value of 140 during the subsequent two days. Following a period of continuous growth in 196, the data subsequently stabilized in the subsequent days. The demand for consumption exhibited significant fluctuations during the whole day, reaching a peak of 172MW.

On the contrary, the consumption load commenced at 97MW within the specified time period. Subsequently, the load demand exhibits a consistent decrease over a period of seven days, reaching a value of 78MW. Subsequently, there was a gradual increase in the load demand, which eventually stabilized over a period of 22 days at a level of 93 MW. The load saw a gradual decrease and afterward exhibited fluctuations, reaching a maximum of 75MW in recent days.

The production cost of the test grid system is consistently decreased for all levels of load demands. Figures 8 a, b, c, and d display the hourly production of the Distributed Energy Resources (DERs) for the schemes with 5% Demand Side Management (DSM), 10% DSM, and 15% DSM, respectively. It is important to acknowledge that the hourly output of the grid heavily impacts the decrease in grid production costs. The implementation of grid control mechanisms results in a reduction in production expenses associated with power usage.

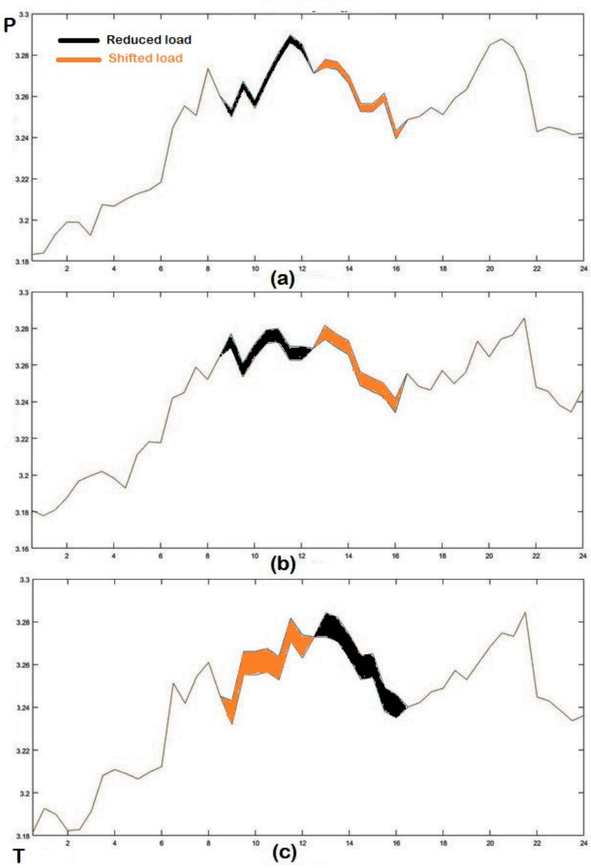

Figure 4: Load shifting for DSM (a 5%, b 10%, c15%)

The implementation of time-of-use (TOU) energy market pricing, which incentivizes aggregators to sell electricity to customers while offering certain compensation, is believed to have an impact on grid demand. The remaining distributed energy resources (DERs) will be adequate to modify the overall load demand of the test grid system inside this specific hour.

In order to examine the impact of the FL load shift, the calculation of the minimum generation cost is conducted without accounting for LL and TCL. The omission of the Firm Load (FL) in the grid system results in a substantial escalation in the expenditure associated with generating one hour's worth of production. The cost experiences a reduction when the aspect of moving is taken into account. As a result of the evolving role of the grid and the examination of cost generation across four separate Demand-Side Management (DSM) strategies, it is deemed unnecessary for the grid to get energy from high-cost production sources.

TABLE I: DEMAND CHARACTERISTICS

	Without DSM	5% reduction	10% reduction	15% reduction
Peak	3.2843	3.272	3.271	3.267
AVG	2.2421	2.2420	2.2417	2.2416
Peak Reduction (%)		0.09	0.27	0.65
Load factor	0.6826	0.6828	0.6831	0.6838

On the other side, Figure 4's b and c depict the possibility of an alternative peak, which might raise the cost of production in comparison to Case 1. The grid's best strategy for transferring grid users is to utilize a TOU-based power market pricing model, according to a comparison of prices in Figure 10. In this case, the grid controls the market price of power, allowing customers to maintain their standard of living while perhaps lowering prices overall.

5. CONCLUSION

In summary, enhancing active grid involvement is crucial for mitigating the generation costs of the system. The costs associated with electricity generation exhibit similarity when compared with the implementation of Demand Side Management (DSM), resulting in a cost reduction ranging from 15% to 31% compared to the costs obtained without DSM. Moreover, DSM offers several advantages, such as reducing peak demand and increasing the load factor while simultaneously managing the total load and average load of the demand. The efficiency of demand-side management (DSM) relies on the incorporation of both time-of-use (TOU) and incentive-based power market pricing. Consequently, the cost of energy must vary on an hourly basis in accordance with the prevailing demand. The influence of the fixed electricity price on demand-side management (DSM) load modeling is minimal. The costs associated with the generation of the system increase when the grid price is decided.

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