Reduction in Weighted Average Cost of Generation by Utilizing ToU Pricing Models: A Study from Pakistan

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***Abstract*— During the last few decades, Pakistan experienced an energy shortage as well as a surplus. Pakistan had previously undergone shortages of up to 7,000 MW but today has a surplus of 12,000 MW, after meeting peak demand. One of the key causes of the industrial sector's slump is a supply shortfall that slowed GDP growth. On the other hand, the current oversupply is producing a steady rise in electricity costs as well as circular debt. Intelligent demand management has the potential to decrease circular debt buildup while simultaneously reducing electricity prices. Demand Side Management (DSM) technologies provide intelligent load management by providing energy distribution companies with distinct incentives to lift the load from peak hour to off-peak hour by reducing the weighted average cost of generation (WACG). This research develops a DSM-based tool that allows for data analytics to evaluate the impact of demand variations on an hourly basis. While calculating its findings, the tool considers the rates of all Pakistani generation units, as well as other financial variables like required capacity and energy payments from IPP agreements. With only a 5% shift in demand from peak hour to off-peak hour, the utility will save significantly. Furthermore, the developed tool assesses the environmental impact of different operational sets of generating units.**

Keywords—WACG, DSM, ToU pricing, CO_2 emissions, Circular debt

I. Introduction

The electricity demand is steadily increasing due to increased population and industrialization. To prevent any disruptions in the supply, it is imperative that the supply and demand be in perfect equilibrium with one another [1]. At any particular time, the load in the system fluctuates. As a result, the supply side must be adaptable to this fluctuating load requirement. There are usually two peak load times in Pakistan: one during the day around noon and another during the evening at dusk. The energy demand in peak hours can be fulfilled by additional power plants. Compared to existing power plants that operate during off-peak hours, the newly added power plant has a high generation cost. As a result, the cost of generation per kWh rises during the day's peak hours. The generation per unit (kWh) cost contains costs for generation, transmission, distribution, cross-subsidies, and government levies. Energy and capacity payments are included in the cost of generation. Fig. 1 shows an example of one-unit cost in the industrial sector. The cost of capacity is a significant component of the unit cost, as seen in fig. 1. But it has been fixed for over a month in Pakistan.

Pakistan's energy consumption changes significantly on a daily and seasonal basis, exacerbating the capacity mismatch between demand and generation. The weighted average cost of generation (WACG) has increased significantly over the past few years as a result of a significant proportion of idle surplus generation capacity. So, the basket price of energy in Pakistan is rising due to increased capacity payments [2]. It is vital to develop techniques for lowering WACG value. For this purpose, using idle capacity during off-peak hours is a realistic alternative [3]. In order to do this, as illustrated in fig. 2, a variety of non-seasonal flexible loads that may be used for the interval of off-peak hours must be introduced to balance the demand and generation capacity mismatch. This practice is known as demand-side management (DSM) [4,5]. According to the findings in [6], the annual savings may range from USD 5 to USD 10 billion if the annual peak demand in the United States was reduced by just 5%. Peak-load curtailment often benefits the environment by reducing emissions as peak demand is typically fulfilled by fossil fuel-based power sources having good ramping rate. Additionally integrating intermittent renewable energy sources into the energy mix is made possible by minimizing the peak load [7].

To encourage the utilization of idle power capacity during an off-peak hour, a reward in the form of a plan of temporally varying tariff rates is essential. Customers and companies in the power sector benefit from this kind of variable pricing. By using idle power capacity during off-peak hours, the power sector increases its load factor while customers benefit from lower WACG rates.

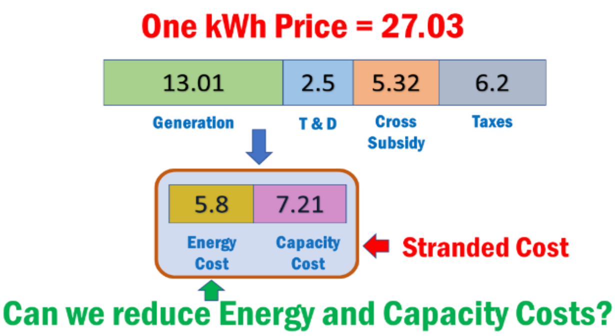

Fig. 1. Illustration of One kWh of energy cost (PKR) in Pakistan

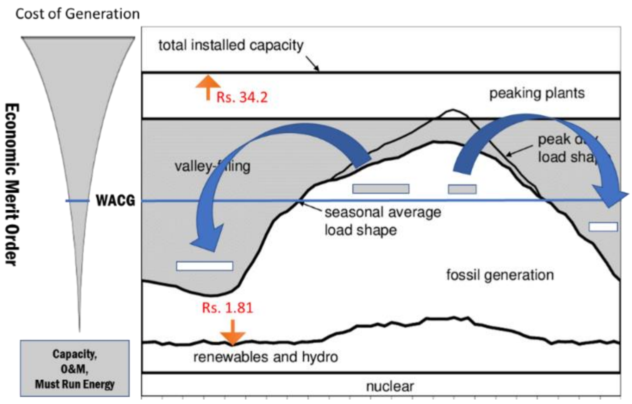

Fig. 2. Valley filling using flexible loads in Pakistan's Case

In Pakistan, there is no system in place to provide variable tariff prices to consumers. In this article, a dynamic dashboard-based ToU pricing model for the utilization of idle generation capacity during off-peak hours is developed and presented. The ToU models in this research are evaluated using a variety of flexible loads. According to our analysis, customers would pay lower tariff rates thanks to the ToU pricing mechanism, and utility companies and other stakeholders in the power sector will preserve their revenues.

This paper is organized into five sections. Section II discusses the methodology used in the tool's development. The developed tool's insights and findings are presented in Section III. Section IV presents some recommendations based on the tool that was developed. Section V concludes the article.

II. Methodology

WACG is calculated via a comprehensive data modelling exercise that concludes in a dashboard interface. To extract useful information for WACG calculation, the obtained data is processed through several steps. Below is a detailed description of each step.

A. Data Collection from Power Sector Entities

Access to hourly-granular real-time generation and demand information is collected from the Power Information Technology Company (PITC). All relevant information on machine loading, reactive power supply, active power supply, load management, forced and scheduled outages, peak power supply, and daily log sheets with the hourly resolution are included in the data. National Power Control Centre (NPCC) and National Transmission and Despatch Company (NTDC) have provided the required data for the merit order of utilized generation sources for the fiscal year of 2020-21. The presented merit order includes the price of power generation from each generation source and the accompanying capacity payment process. Central Power Purchasing Agency (CPPA) provided information regarding energy and capacity payments for each power plant. This analysis utilized the provided data sets, which include hourly generation and demand data, monthly capacity, and energy generation costs for the fiscal year 2020-21. In addition, reported data on emissions was utilized to compile emissions for various power-producing facilities [8]. Based on the amount of energy produced by various power plants, the corresponding carbon emission cost has been calculated.

B. Data Synthesis

Data analysis is a process that examines, cleans, transforms, and modelling data to determine facts, draw conclusions, and aid in the decision-making process. In order to accomplish this, the R programming language (RPL) was used to create an automated data cleaning tool. The tool cleans data and gets essential information. The following is a complete and thorough description of the data synthesis process.

1. Data pre-processing utilizing a combination of RPL and MS Excel provides a framework for data synthesis.

2. Outlier anomalies are identified and eliminated from the raw data.

3. Missing values are estimated using mathematical procedures as a remedial measure.

4. Data unification from multiple formats is undertaken to ensure standardization after the data sets have been cleaned and missing data has been verified.

5. A validity analysis is done to determine the justifiability of data to eliminate unreasonable values.

6. An exploratory data analysis is carried out, which entails a preliminary qualitative and quantitative data depiction.

No matter how much data is entered, all processed data is saved in a single file. It has hourly generation data for each generation source.

C. Demand Data Analysis

For load analysis, synthesized data is used for the fiscal year 2020-21. Fig. 3 illustrates the generation profile for the fiscal year. Seasonal classifications of generation patterns are identified by data analysis. This categorization is based on generation utilization and enables the National Electric Power Regulatory Authority (NEPRA) to establish variable tariff models.

Statistics show that hydroelectric power plants are one of the most economically viable sources of generation, which is why these are frequently used as baseload power sources [9]. These sources are also employed as peaking generators to meet peak demand because they have a high ramping rate. The study also shows that power plants run by furnace oil and diesel are necessary to meet peak demand. However, their generation costs are higher than those of other sources of energy [10].

D. Flexible Loads

One of the most critical aspects of this research is finding flexible loads. The term "load flexibility" refers to the ability

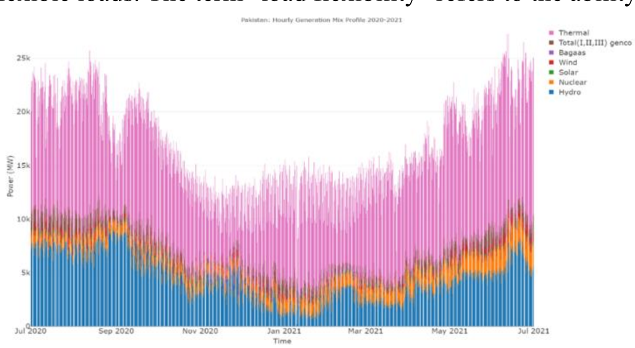

Fig. 3. Hourly Generation Pattern of Pakistan for the year of 2020-21

to change the scheduling energy consumption in order to decrease stress during peak hours. Many loads may be moved to off-peak hours. Tube wells, freezers, EV charging, dishwashers, washing machines, water pumps, heating and cooling systems and several other industrial activities are among these flexible loads [11], [12]. The goal of this section is to identify all available flexible loads for Pakistan while considering that such loads do not raise load peaks daily.

The annual category-wise load data has been collected from various power sector entities, that data includes domestic, commercial, agriculture, industrial, public lighting, and bulk consumer load profiles.

The data indicate that the total amount of energy consumed in 2020-2021 was 132,299 GWh. Agricultural tube wells contributed 10,115.32 GWh to the overall energy consumption. Furthermore, for the year 2020-2021, the industrial load share was 24,664.95 GWh [9]. Over time, the proportion of renewable energy sources in the energy mix increases. In 2025, solar capacity will rise from 569 GWh in 2021 to 1,916 GWh [8].

According to collected data, agricultural tube wells and soft industrial loads are the most flexible loads in Pakistan. The energy consumption of tube wells is 10% of overall energy consumption [9]. The tube wells are the best candidate for load switching from peak to off-peak hours. It is worth noting that the power sector is already subsidizing the electricity tariffs for tube wells to help the agriculture sector through government subsidies. If an incentive is offered to operate their tube wells during off-peak hours, this subsidy would become irrelevant. This will save the government money on subsidies while providing farmers with subsidized tariff during off-peak hours. Furthermore, industrial load accounts for 5% of the overall load. Our calculations show that 5% of the industrial demand is a soft load that can easily be switched to off-peak periods.

E. WACG Modelling

The WACG considers two variables: the capacity payment (CP) and the energy payments (EP). Details are provided by

$$WACG = \frac{CP + EP}{EU} \tag{1}$$

Where EU is energy utilization.

Eq (1) is a general representation of the WACG. CP must be made regardless of EP in Pakistan's case. Eq (2) shows the modelled equation for computing WACG.

$$WACG = \frac{CP + \sum_{x=1}^{n} EP_x}{\sum_{x=1}^{n} EU_x}, n \leq z \tag{2}$$

Here, n denotes the number of operating power plants at a given hour, while z represents the total number of power plants available. x is the plant number in merit order. Equation (3) depicts the WACG using an hour-to-month approximation for one month.

$$WACG = \sum_{h=1}^{720} \frac{CP + \sum_{x=1}^{n} EP_p}{\sum_{x=1}^{n} EU_x}, n \leq z \tag{3}$$

For each month, the CP for the available generation plants is fixed. The WACG will decrease if energy consumption is raised. Therefore, it is suggested that the load must be shifted to the valleys of the load and generation profile, where the difference between demand and available generation capacity is significant. Fig. 4 depicts the fluctuation in WACG for the fiscal year 2020-21.

III. Result and Discussion

The WACG was calculated with the help of the RPL. The tool determines the appropriate WACG value at a one-hour granularity by analyzing the provided data set. Each power plant's generation cost is seen in proportion to its utilization at different times of the day. The emissions corresponding to each power plant are also calculated. The analysis is elaborated on below:

A. Energy Analytics: Visualisation in Dashboard

The generation cost is composed of two components. One is the cost of energy, which is determined by the available and operational power plants. The second component is the capacity cost, which is based on the contracted cost of power plant capacity over the available period. Both the energy and capacity components are subject to hourly and monthly variations. Both components are incorporated into the developed tool. The WACG is derived from these two components. The designed tool informs us of the cost of generation on the generation bus. Figure 5 demonstrates the designed dashboard. Multiple tabs are present on the tool. Figure 5 depicts the hourly cost of generation on the generation bus. At 11 a.m. on July 1, 2020, the cost was 8.78 Rs/kWh, with an energy cost of 4.56 Rs/kWh and a capacity cost of 4.22 Rs/kWh. At that exact hour, the 20,86 GWh of energy sold by the DISCOs for 95,06 million rupees indicates the cost of energy generation. The capacity payments go under a separate category. Consumers can view all power plants used to meet the current demand by hovering over the pointer, as well as the amount of energy each plant supplies and its associated cost.

The WACG is calculated from the data sets. Many cases and scenarios can be built using the developed tool. But in this paper, we will focus on one case, which includes two scenarios depending on the load profile and switching of peak demand to off-peak hours. The paper computes and presents the hour shifting for the sake of simplicity. On the other hand, the tool may convert a multi-hour input to a multi-hour output. The following section depicts the load lifting benefits from peak to off-peak hours.

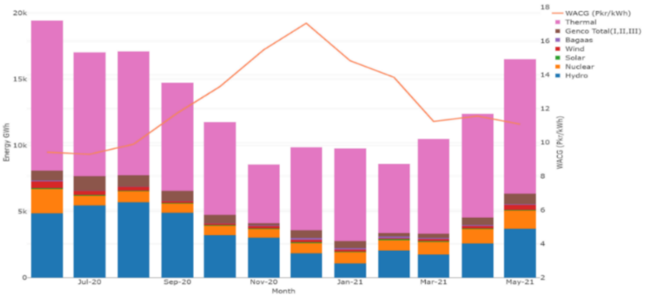

Fig. 4. Changes of WACG during FY 2020-21

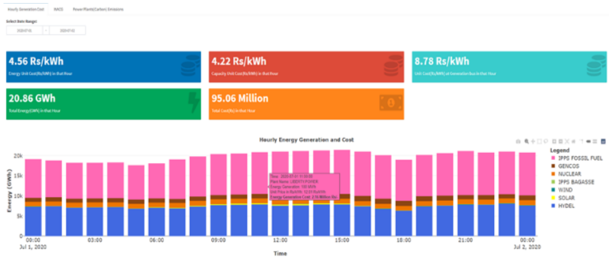

Fig. 5. Dashboard interface that shows the energy payments, capacity payments, total energy utilization, and its total cost

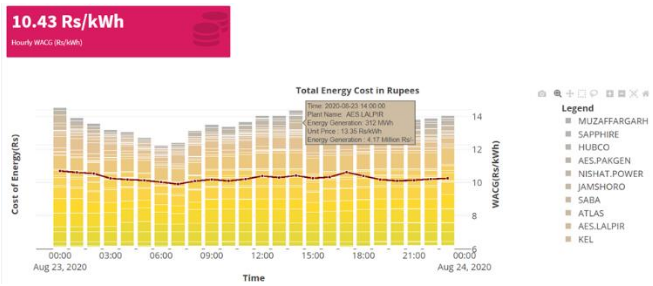

Fig. 6. Generation cost for each power source and associated WACG of each hour

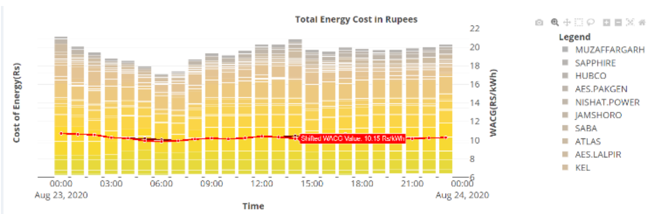

Fig. 7. Total Energy Cost after load shifting and associated changes in WACG

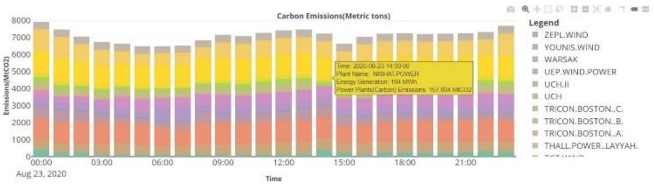

Fig. 8. Impact of load shifting on the emission profile for various Power Plants

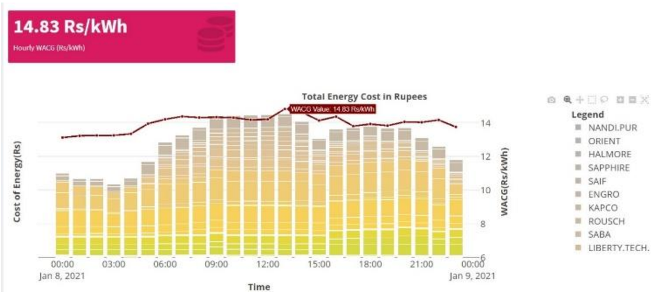

Fig. 9. Generation cost for each power source and associated WACG of each hour

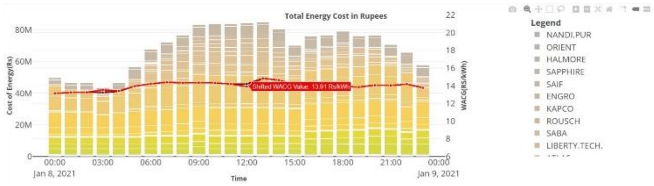

Fig. 10. Total Energy Cost after load shifting and associated changes in WACG

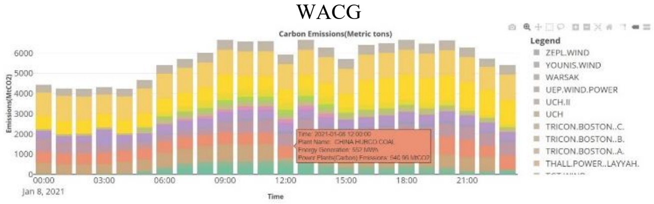

Fig. 11. Impact of load shifting on the emission profile for various Power Plants

B. Case A: 5% change in Demand from Peak hour to off-Peak hour

Case A shows a 5% load shift from peak to off-peak times. The overall energy cost savings and emission reductions due to load shifting are analyzed in depth below for two distinct scenarios. The subsequent subsections go through each scenario in detail.

1) Scenario 1- Peak Load Month

The yearly peak for the 2020-21 year occurred on August 23, 2020. At 2 p.m. on a peak day, the WACG was 10.43 Rs/kWh. Fig. 6 shows the total energy cost for all power plants operated on this day. The red line represents the WACG values throughout the day on the bar graph.

The power sector might save 17.18 million rupees on a single event by shifting 5% of its demand from peak hour to off-peak hour. As indicated in fig. 7, the electricity sector will save 514.41 million rupees if this load is relocated for a month. After switching load from peak hour to off-peak hour, the new WACG can be 10.15 Rs/kWh, down from 10.43 Rs/kWh.

The power sector may lose or earn carbon credits when energy is moved from peak to off-peak hours. The power sector releases 7,679.17 metric tons of CO_2 during peak hours, but when the load is relocated by 5% to off-peak hours, CO_2 emissions drop to 7214.92 metric tons. Fig. 8 depicts the carbon emissions of all power plants operating at that time.

2) Scenario 2- Lowest Load Month

The lowest demand for the year 2020-2021 was reported on January 8, 2021. The WACG was 14.83 Rs/kWh at 1 p.m. on this day. The overall energy cost for all power plants utilized on that day is depicted in Fig. 9. WACG per hour is shown in the red line over the bar graph during the day.

The power sector may save 1.78 million rupees on a particular event by switching the 5% load from peak hour to off-peak hour. The power sector can save 53.48 million rupees if this load is relocated for a month, as indicated in fig. 10. After switching the load from peak hour to off-peak hour, the new WACG can be 13.91 Rs/kWh, down from 14.83 Rs/kWh.

If power plants are shifted from peak hour to off-peak hour in January, the power sector might earn 27.52 million rupees per month due to emission trading. The power sector released 6586.73 metric tons of CO_2 during peak hour, but when load transfers by 5% to the off-peak hour, CO_2 emissions fall to 5915.99 metric tons. The emissions from each power plant utilized on this day are illustrated in fig. 11.

Pakistan can save a significant amount of money by simply shifting the load from peak to off-peak hours. Additionally, Pakistan may easily meet the emission targets specified in the sustainable development goals (SDGs) because of the reduction of CO_2.

IV. Recommendations

The following recommendations should be considered based on the literature review, research findings, and gathered data and analysis to create the basis for shifting load from peak hours to off-peak hours in Pakistan and attaining success in this strategy. The recommendations are solely based on the current scenario in Pakistan.

A. Smart Meters

In order to control peak load, smart meters must be placed to provide demand-side management and to track the load at any given time. USAID has launched a pilot project to implement smart meters in Multan Electric Power Company (MEPCO) and Peshawar Electric Supply Company (PESCO) for agricultural purposes. Electricity consumption is recorded in near-real-time via smart meters. The meters automatically transmit the electricity consumption pattern to the distribution company. Customers may be provided tailored rates depending on price signals during peak hours. The demand response (DR) will reduce power-producing costs by decreasing peak demand at regular times.

B. Tariff Offering for Bulk and Industrial Consumers

After the pilot mentioned above projects in the MEPCO and PESCO regions have been completed successfully, Bulk and Industrial consumers should be the next target consumers. This technique will provide dynamic tariffs to industrial and bulk consumers via price signals. The marginal cost of the generating unit will determine the variable tariff rates. This cost should be lower than the previously quoted tariff rate. Both the participants and the utility will gain from this. The DISCO's handling of the participants' information will determine the success of this strategy. The WACG can be significantly lowered when industrial and bulk users are provided with ToU-tariff rates.

C. Identification of New Flexible Loads

After including industrial and bulk users, the ToU pricing regime may be expanded to include a variety of newly found flexible loads. This stage will include flexible municipal loads, such as water pumps and tube wells. At specific loads, smart meters must be installed for singling pricing. Smart meters will provide consumers with variable tariff rates via smart meter communication protocols and App development. Tariff rates that are favorable to consumers might be provided to reward them. By decreasing peak demand and raising the load factor, the success of this DR strategy will benefit both municipalities and DISCOs.

D. Community Awareness and Inclusion

A wider variety of loads can be introduced at this phase to improve flexibility. A broader spectrum of consumers might benefit from these ToU-tariff rates. The price will be monitored and signalled via smart meters. Smart meters will enable real-time pricing and monitoring of power usage. The DISCO's management is critical to the success of this DR strategy. By decreasing the utility's peak demand and providing incentives to people who participate; this initiative will benefit both the consumer and the power sector entities.

V. Conclusion

Multi-dimensional and multi-sectoral challenges hamper Pakistan's energy and power sector. These problems need a multi-pronged strategy for a total solution, which may be impossible to achieve in the short to medium term. On the other hand, a few unorthodox solutions for traditional problems may prove to be highly effective in easing the stress on the power sector. We conceived and built a tool for giving temporally variable-tariff rates to shift various flexible loads to off-peak hours. Load shifting to off-peak hours boosts the use of idle generation capacity, reduces reliance on costly fossil fuel-based peaking power plants, increases R.E utilization, and lowers the WACG cost. Combining these variables has resulted in a decline in Pakistan's power sector's circular debt. According to our calculations, switching just 5% of the flexible load to an off-peak hour can significantly save the national exchequer. We are confident that the finding of this research work will serve as a valuable recommendation for introducing ToU-pricing in Pakistan.

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