The Power Sector Of Pakistan; A Brief Review

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Abstract: The power sector of Pakistan is a complex structure, comprising of different entities for various functions. This paper is a brief overview and understanding of the electricity provision in Pakistan. The city of Karachi and some parts of Balochistan are under the vertically integrated company of KE (Karachi Electric), whereas the rest of the country is served by the national grid, the two are interconnected and form a wide synchronous area. The process of regulation and license provision to all the companies for generation, transmission, and distribution is done by NEPRA (National Electric Power Regulatory Authority). Such a compound system faces several problems in the process of electricity provision to the residents of Pakistan. Supply-Demand gap, T & D losses, and power breakdowns are some of the major problems; many steps have been taken such as HVDC (High Voltage Direct Current) transmission projects, increased inter-area transaction between KE and NTDC, Transmission capacity enhancement through commissioning of new transmission lines and rehabilitations of existing lines, efficiency enhancement and improvement in protection schemes.

Keywords: NTDC, KE, NEPRA, Cascaded blackouts, HVDC.

I. INTRODUCTION

In Pakistan, the electric power is transmitted across the country by two entities namely: National Transmission & Despatch Company (NTDC) and Karachi Electric (KE) which is a privately owned vertically integrated utility. NTDC supplies electricity to all areas of Pakistan except the zone of KE [1] including the city of Karachi and some parts of Balochistan namely: Hub, Vinder, Uthal and Bela. The systems of NTDC and KE have two interconnections which allow for KE to import power from the national grid at the time of need [2].

The power flow starts at the power generating stations owned by various entities. Referring to Sources of Power Generation in Pakistan-A feasibility study [3], the different modes of electric power generation in Pakistan, prior to the amount of energy generated, are: thermal, hydel, nuclear and generation through renewable(wind and solar) energy. Thermal power and nuclear power are bulk power sources; however, the emissions from these generating units cause severe environmental pollution. Consequently, the countries of the world are switching towards green energy generation through wind and solar power. Pakistan has a high potential for hydel generation [3]; however, the need of large land areas, the concern of relocating people, very high initial cost and environmental limitations have hindered the construction of hydel power plants.

In Pakistan, The Water and Power Development Authority (WAPDA) has the control of the Hydel Generation from the country's major dams [4]. The Generation Companies GENCOs including (GENCO I, GENCO II, GENCO III and GENCO IV) are state owned entities. Similarly, KE owns few thermal power plants in its network. The rest of the generated power is obtained from private Independent Power Producers IPPs, Special Power Producers SPPs and Captive Power Producers CPPs which sale their excess electricity to NTDC and KE.

The generated power is than transmitted towards the load centers via High Voltage (500, 220 or 132 kV) Transmission lines [9]. KE being a vertically integrated utility possess its own transmission system whereas the National Transmission & Despatch Company NTDC operates the primary transmission network for the rest of Pakistan. The IPPs, SPPs, and CPPs are connected to same transmission networks of NTDC and KE; thus, adding power to the national and KE grid.

Finally, distribution of electric power is done at voltage level 11 kV or below. For the consumers, apart from KE, there are ten publically owned Distribution Companies DISCOs (PESCO, TESCO, IESCO, GEPCO, FESCO, LESCO, MEPCO, QESCO, HESCO, and SEPCO) which are responsible for electric power distribution in their respective areas and perform their function under the License of NEPRA which regulates the electric power supply in Pakistan [1].

The paper [3] also sheds light on the power losses encountered during the process of transmission and distribution of electric power. The major power losses are due to inappropriate equipment sizing, faulty metering, power factor losses and power theft which require immediate attention of stakeholders for these problems to be resolved. The research suggests that Pakistan would need to increase its generating capacity and improve the system's reliability to timely cater to the increasing demand.

According to the State of the industrial report by NEPRA, the generation capacity of Pakistan is not properly utilized [5]. As analysis and forecasting of electricity demand are essential for planning and development.

Paper [6] suggests that linear regression models can come in handy to find the relationship between energy demand and factors like population, energy usage, and fossil fuel consumption. The same model can be used to predict the energy demand for future years of Pakistan's power sector..

II. THE POWER SECTOR OF PAKISTAN

The power sector of Pakistan can be divided into three sectors i.e., Generation, Transmission, and Distribution.

A. Generation

The total installed generation capacity of Pakistan is 38,719MW which comprises both renewable and non-renewable resources. Renewable resources include Hydro, wind, solar, and bagasse while thermal and nuclear lie under the non-renewable resources. As of 2020, from the total installed capacity is 38,719 MW. 24,817 MW is thermal (GENCOs, IPPs, and KE), 9,861 MW hydroelectric, 1,248 MW wind, 530 MW solar, 369 MW bagasse, 1467 MW nuclear, and 427 MW SPPs/CPPs [5]. In the following Figure 1 represents the contribution of different sources of generation in the form of percentages:

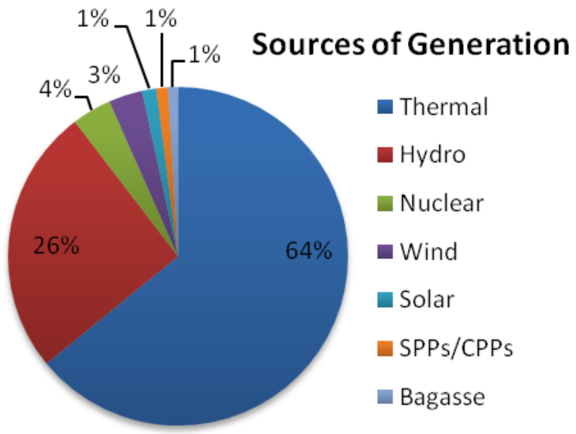

Figure 1: Sources of generation.

Table 1: Generations of the plants during the fiscal year 2019-20 [5]

Plant Type	Generation (GWH)	Installed Capacity (MW)
KE SYSTEM (Total)	13,101.68	2984
KE's own	10,358	2294
IPP's	1862.68	366
SPP's/CPP's	535	87
KANUPP (Nuclear)	193	137
Solar	153	100
CPPA-G SYSTEM (Total)	121,643.99	35735
WAPDA Hydel	37,425.41	9389
IPPs Hydel	1562.55	472
GENCO's	7907.91	4881
IPP's	60,720.33	17276
SPPs/CPPs	170.99	340
Nuclear	9704.89	1330
Wind	2882.48	1248
Solar	704.97	430
Bagasse	564.46	369

Table 1 shows the generation of the country for the year 2019-20 and the installed capacity for the same year as obtained from [5]. The total installed capacity for the CPPA-G system is 35,735 MW (Mega Watts) and for KE is 2984MW, whereas the peak hour demand for NTDC and KE is 26,252MW and 3604MW respectively [5].

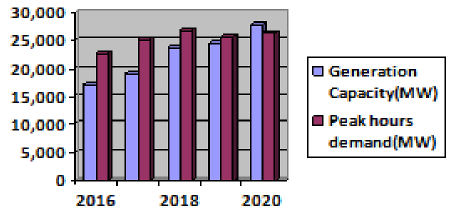

Figure 2: Comparision of generation and demand of NTDC. [5]

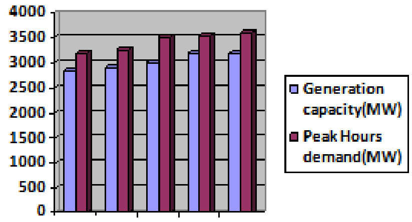

Figure 3: Comparision of generation and demand of KE. [5]

The data of generation and demand for NTDC grid and KE grid was collected from 'State of Industrial Report 2020' by NEPRA [5] and converted into graphs (Figure 2 and Figure 3). It was found that the generation of the NTDC is higher than the actual demand of the region, whereas KE is undergoing a power deficit and is unable to meet its demand. As deducted by the report [5], KE has a total installed capacity of 2984 MW and for the NTDC system is 35,735 MW. Karachi plays an important role in providing for the country's economy but unfortunately, the city is unable to meet its total demand for power. As of the year, 2020 NTDC is supplying KE with 650MW under power purchase and energy agreement between the two and NTDC [7]. In addition to the aforementioned power schematics of the country, it also imports 104MW through 132KV (Kilo volts) transmission line from Iran. [8]

B. Transmission

The step after generation is the transmission, this system is also divided into two entities, and KE again is the sole network for transmitting power to the metropolitan capital and some surrounding regions whereas the rest of the country relies on NTDC which is the national grid for this step. NEPRA has also issued licenses to SPTL (Special Purpose Transmission Licenses) to some provincial dispatch companies but so far only Sindh has established a PGC (Provincial Grid Company). The Table 2 and Table 3 are the tabular representation of transmission systems data of NTDC and KE as derived from [5].

Table 2: NTDC transmission network [5]

Voltage Level (KV)	Transmission Line Length (KM)	No. of Grid Stations	Transformer Capacity (MVA)
500	5970	16	22350
220	11322	45	31060

Table 3: KE Transmission Network [5]

Voltage Level (KV)	Transmission Line Length (KM)	No. of Grid Stations	Transformer Capacity (MVA)
220	365	11	6951
132	801	68	4580

C. Distribution

The distribution of power in the country is performed by the region-wise DISCO's under the license by NEPRA; these companies are responsible for the maintenance of the systems below or at 132KV. In Karachi, KE is the sole organization that handles distribution. The main drawback in Pakistan's distribution system is that of T&D (Transmission and Distribution) losses; these losses account for the energy units for which the consumer is not billed. The T&D losses for the DISCO's during the year 2019-20 were recorded to be 20.21% (average) whereas for KE they were recorded to be 19.73% [5]. Another problem that is faced by the distribution system is that of overloading of distribution and power transformers. Almost all the transmission in the country takes place in the form of HVAC (High Voltage Alternate Current), such a method of transmission causes much higher AC loss which is the loss of energy in the form of heat due to the resistance of transmission wire and are not feasible for transmission over longer distances [9], an HVDC (High Voltage Direct Current) line of 660KV has also been introduced in the country under the contract of CPEC (China Pakistan Economic Corridor). [10]

Figure 4: Grid Network of Pakistan [5]

Figure 4 shows the 500 KV and 220 KV grid network of Pakistan. The figure was obtained by plotting approximate locations for the different grid stations as acquired from [5] using Google Maps.

III. PROBLEMS FACED BY THE POWER SECTOR OF PAKISTAN AND STEPS TAKEN

A. Cascaded Blackouts

Whenever there is an overloading of a transmission line; this can be either due to an increase in the load or due to a decrease in generation, if the voltage is kept constant at the generating end and a decrease occurs in the impedance it causes the current to significantly increase. Now in the protection system of the lines distance relays are used, they measure the line impedance and if it drops significantly it trips the circuit breaker off that line to protect it from a short circuit. Once a line shuts down the rest of the lines rapidly increase their current to overcome the load that was on the tripped line, now this again overloads the lines that acted to compensate for the tripped line and as a result, they undergo tripping as well. This whole phenomenon creates a chain reaction for the whole system and results in a cascaded blackout.

Pakistan has faced multiple blackouts over the past years. The most recent one was on 9th January 2021, which started at 11:40 PM, according to the inquiry report submitted by NEPRA [1]. This report mentions that this blackout was a cascading effect of a bus bar protection fault at the Guddu powerhouse which was not initially rectified by the authorities on time. The fault began on the 8th of January 2021; the fault affected the 220 as well as the 500 kV systems. When the Guddu station underwent fault the load of the subsequent station shifted to the later far end grids i.e. Shikarpur, Dera Ghazi Khan, Muzaffargarh, Guddu 747, and Multan. The aforementioned stations after sometime underwent tripping due to the protection coordination mechanism of the time relays. This cascaded tripping caused islanding of the North and South region that was connected (Shikarpur, Dadu, Jamshoro, Karachi, Mitiari, Moro, Rahimyar Khan) and this ultimately resulted in a power swing i.e. Over voltage/ Over speed/ Over frequency in the South and an under frequency power swing in the North. The power swing occurred because at the time of the cascade the South was providing North with 3000MW of power and due to the tripping of the far end stations this export significantly dropped.

This whole phenomenon caused a nationwide blackout, but luckily no instrument or people were harmed during the unfortunate event.

Observing the whole situation, some events could have been avoided and a considerably large area could have been protected from shutting down.

- **A.** There should have been a timely and proper response to the bus bar protection fault at the Guddu station and proper power backups should have been present at the stations.
- B. The presence of a black start mechanism; (it is a mechanism that provides the external auxiliary load to the system until the system generates enough power to synchronize with the main grid) at all the stations should be ensured.
- C. The islanding of the South and North could have been prevented by using the PSB (Power Swing Blocking);

it distinguishes a power swing from a fault and prevents the picking up of the relay in case of a power swing.

D. By using the OOS (Out Of Step) relaying mechanism; (it detects an unstable power swing and an out of step condition, it then send a trip signal to the breaker to separate the system before a large area is affected), the shutdown of the South-North island could have been prevented.

B. Demand and Supply Gap

The total installed capacity for electricity generation in Pakistan is 38,719 MW as of 30th June 2020 according to the State of Industry Report by NEPRA. Out of 38,719 MW of Installed Capacity of CPPA-G, the system supplies 35,735 MW of electricity whereas KE (K-Electric) supplies 2984 MW [5]. The Peak hour demand for NTDC is 26,252 MW which is a lot lesser than its installed capacity of 37,735 MW. On the contrary, the peak hour demand of KE is 3604 MW which is considerably higher than its installed capacity of 2984 MW. The gap in energy supply and demand leads to several major issues like:

A. Due to lack of regulation, the whole power sector undergoes T&D losses that lead to higher tariff rates. Permissible Transmission and Distribution Losses in Pakistan's power sector are about 17% whereas the actual figures are much higher. [11]

B. There is an excess of power that is being generated by the NTDC and KE is facing an energy deficit. This Uneven transmission and distribution of power results in an electricity outage across the country that ultimately results in overloading and shutting down of the system. To restart the system a mechanism called the "Black start mechanism" is used which utilizes much more power.

C. The city of Gwadar serves as a major seaport for Pakistan and it has been facing a challenge of 12-14 hours of load shedding daily. The current power supply to the region is about 142.5 MW out of which 104MW is imported from Iran [12]. The supply from Iran has high tariff rates and a different technical structure than the National grid of Pakistan. This causes unstable and unreliable results in a power crisis for the region.

The steps that have been taken so far to overcome these issues are:

A. KE has taken multiple steps to reduce T& D losses by upgrading its transmission system, making the technology investment, and campaigning against energy pilferage. KE has so far been successful in reducing the number 39.5% in FY 2009 to 20.4% in FY 2018. [13]

B. To minimize the Black Start Mechanism, we can provide the grids with proper contingency to have a backup supply through auxiliary loads. NEPRA approved an additional supply of 150MW to KE to meet its energy demand according to the order [7]. This step can provide KE enough Power to meet the demand of its consumers.

C. To meet the Power demand of Gwadar, CPEC is working on a 300 MW (two units of 150 MW) Imported Coal based Power plant [14]. The plant is projected to be in service from 2022.

D. Karachi Nuclear Power Plant (KANUPP) has been working to expand its capacity to 2.2 GW by installing two 1.1 GW pressurized water reactors (PWR). Both Kanupp-2 and Kanupp-3 have a gross electrical output of 1100 MWe and gross thermal output of 3060 MWt [15]. According to "The News" [16], Fuel loading at Kanupp-2 has started on December 2, 2020, after the permit of the Pakistan Nuclear Regulatory Authority (PNRA). After Fuel loading, various tests have been performed on KANUPP-2 to verify the safety regulations on basis of the International Atomic Energy Agency (IAEA) to begin the plant operation and connect it to the national grid [16]. The commercial operation of Kanupp-3 is scheduled for 2022 [17].

C. AC Transmission Losses

The transmission and distribution system of Pakistan also faces multiple losses; these losses are collectively termed as T&D (Transmission and Distribution) losses. While transmitting electricity the AC (Alternating Current) power experiences relatively higher losses than the DC (Direct Current) power. There are two types of T&D losses; technical and non-technical. Technical losses are of two types fixed and variable technical losses. Some of the fixed technical losses for AC (Alternating Current) transmission system include; corona losses (occurs due to the ionization of the surrounding air molecules of the transmission line), leakage current losses, losses caused by the load of the measuring and control elements connected in the system. The variable losses are mostly the energy losses in the form of heat. Higher impedances, longer length of the wire, placement of the transformers far from the grid station are mostly the causes of variable losses. These losses are a part of the AC transmission system.

Due to the lesser number of transmissions through the HVDC system, there is a significant amount of loss in power transmission over long distances. An HVAC transmission is feasible for power transmission over the area of 600KM or below, over the distance of 600KM power transmission through HVAC is not feasible [9] and results in much higher losses; furthermore, through HVDC the frequency is more controllable and has better voltage regulation.

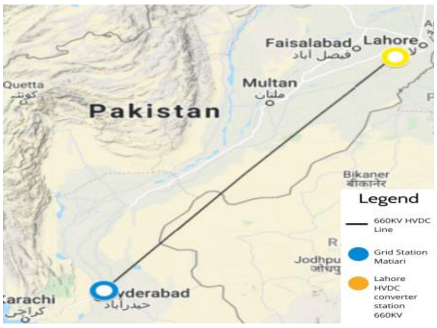

Figure 5: 660KV HVDC Line map [5]

Figure 5 is an approximate visualization of Matiari to Lahore HVDC transmission line. The figure was produced by joining the start-point and end-point locations of the line as obtained from [14].

The 886 KM (Kilometers) long HVDC line project of 4000 MW and 660KV has been established (as shown in figure 5) under CPEC (China-Pakistan economic corridor) from Matiari to Lahore Pakistan [14]. This project will be taking power from the coal-based power plants at Thar, Port Qasim, and Hub Baluchistan. There are also 500KV HVAC transmission lines provided at the end of both stations. This can prove to be a very crucial step in transmitting power from the area where there is a comparatively higher generation to the area where the power is required, without AC losses.

According to the recent news source [18] the Mitiari to Lahore HVDC project has delayed its operations due to outstanding work; this will further delay the process of bringing grid stability and affordable energy to the network. According to the source the project will now start its operations in September 2021.

IV. CONCLUSION

The Power market of Pakistan is a very complex structure. Being a large synchronous area it faces many problems, the quest of the power sector to achieve stability in terms of frequency, protection and adequate provision is still in process. Multitudes of steps have been taken by the concerned authorities so far, but the system is yet to achieve complete stability. There needs to be a market where the consumers have more options and healthy competition among the utilities which will result in lower tariff rates and freedom of choice for the consumers. More renewable energy power plants should be introduced especially those which provide frequency-stable power to the system.

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