High voltage Direct Current (HVDC) Transmission; Future expectations for Pakistan

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***Abstract*—HVDC transmission system for bulk power transfer over longer distance offers numerous advantages over alternating current (AC) transmission system, such as direct integration of networks operating at different frequencies, comparatively low line losses on account of constant current and absence of reactance. This paper presents details about HVDC power transmission systems and power converter technologies. Issues concerning integration of electrical power generated by alternate sources i.e. wind (onshore and offshore) into national grid of Pakistan using HVDC technology are also discussed. Research work revealed that energy crisis of countries like Pakistan can be mitigated to a larger extent with the use of HVDC transmission system.**

***Index Terms*— HVDC, Wind Energy, Renewable energy, Transmission systems.**

I. INTRODUCTION

Energy has been the most important source for the continuous development of human civilization. Global energy consumption has increased tremendously after the start of industrial revolution and growth around two centuries ago. Nowadays per-capita energy usage is a major parameter for a nation's growth and prosperity. United States of America accounts for the highest living standard having only 5 percent of world population; it consumes 25 percent of total global energy [1].Pakistan strongly depends on fossil fuels and conventional energy sources for the production of electricity. As per energy mix of Pakistan reported in [2] oil, coal and gas shares are almost 86.6 % where as 12.71% is supplied by hydro generation. In order to meet energy demands huge quantity of oil is imported every year which put extra burden on the economy of Pakistan. Due to fluctuations in oil prices at international market and poor state of economy, oil imports are gradually falling every year which results in a mismatch between demand and supply of electricity generation as evident from Fig.1 [3]. However this graph does not include the renewable energy sources which will be inducted in future as per energy policy.

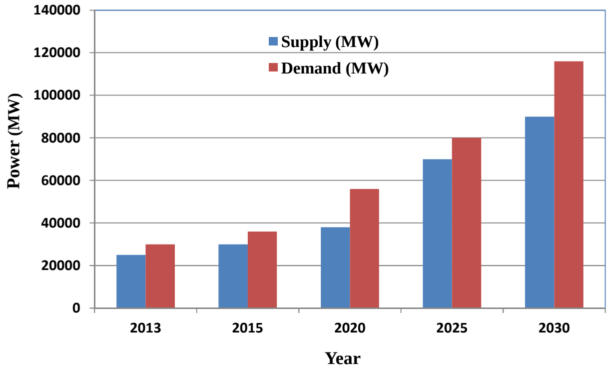

Fig.1 .Peak electrical energy demand vs.supply projections for pakistan

The following issues are also responsible for the less generation of electrical power [4]:

- Ageing of existing power transmission and distribution networks and its capacity.
- Power generation is mostly centralized and is more dependent on the availability of fossil fuels.
- The power system network is highly Longitudinal with respect to regional location. Hydro generation is only available in the northern part of country where as thermal generation is concentrated in the southern part located away from big load centers.
- Hydro generation is usually affected by the availability of water during summer and winter seasons.
- Presence of fewer shares of renewable energies in over all energy mix of Pakistan.

In order to overcome the energy shortage, exploration of alternate energy resources such as renewable is much needed. Pakistan is blessed with all types of alternate energy sources including wind and solar offering great potential for generating electricity and bridging the gap between supply and demand [5-6]

Electric Power Production using wind energy around the world

This paragraph of the first footnote will contain the date on which you submitted your paper for review. It will also contain support information, including sponsor and financial support acknowledgment. For example, "This work was supported in part by the National Natural Science Foundation of China (No. xxxxxxx) .

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has total l installed capacity (both offshore and onshore) of 121 GW. It is the fastest growing renewable energy source and many European countries are getting nearly 10% of their total energy demand from wind energy. Pakistan has good potential for generating electricity from wind in different regions and along the coastline of Sindh province. The country's first Renewable energy policy was announced in 2006 which set mid-term and long-term targets that include generation of 9700MW of electricity from renewable energy resources by the year 2030 [7] .However only 10 MW of wind energy has been installed so far at different locations in the country. There is a great wind potential at Gharo–Keti Bandar corridor which is 60 km long located along the coast belt of Province Sindh [8]. According to Pakistan Metrological Department (PMD), after analyzing the wind data at 20 different sites in the coast belt, the favorable area for wind power generation is 9700 km² with estimated wind power potential of 43,000 MW [9].

Electric power transfer capability is restricted by different constraints like thermal loading of conductors, voltage and transient instabilities emerging in a power system [10]. As Power grids around the world are continuously changing due to rapid interconnection of large wind farms into transmission systems. Wind energy sources located at far off areas and variable nature of wind are two major challenges faced in its integration to national grid [11].To integrate energy from renewable sources to the main centers of power grid; existing capacity of transmission systems needs to be enhanced and modified so that the HVDC links could be used effectively for the transfer of electric power produced by the renewable energy source to the main centers [12].

This paper provides information about HVDC and HVAC systems; updated Power converters technology .It also highlights the potential and benefits of use of HVDC systems in countries like Pakistan.

II. HVDC SYSTEMS AND POWER CONVERTERS

In the beginning (19^{th} century) transmission and distribution of electricity were based on direct current (DC) technology, on account of low voltage (110v) generation at that time. With the growing demand for higher voltages, AC became popular as it could be easily converted to higher voltages, with fairly less power loss. However, after the invention of thyristor valves by General electric motors in 1950's and development of power electronics, HVDC transmission proved to be technically attractive. To transmit power over longer distances, high voltage alternating (HVAC) line needs reactive power compensations at regular intervals. The frequency and the intermediate reactive components are major concerns pertaining to stability problems in Alternating current line. Whereas HVDC system lacks stability problem due to absence of frequency and it is not dependent on distance as well [13]. A comparison between HVAC and HVDC overhead lines is presented in Table .1 below [14]:

TABLE I

HVAC and HVDC Comparison

Characteristics	HVAC	HVDC
Power Losses	HVAC systems losses signify with distance.	High voltage DC transmission line has fewer losses compared with an AC circuit for the same amount of power transferred .Converter terminals and substations have power losses.
Investment cost	HVAC land acquisition costs are higher as more conductors are used to transmit power.	HVDC land acquisition costs are lower as two conductors are used to transmit power. The operating and maintenance expenditure is less in HVDC system.
Asynchronous connection	HVAC systems cannot be used to connect asynchronous ties.	HVDC is the only option to establish link between two different frequency networks.
Environment	The visual impact and right of way management (ROW) of HVAC systems is high.	Right of way management (ROW) expenses for the High voltage DC overhead system is less than the AC line of system. Converter stations have issues such as: noise level, electromagnetic compatibility and use of ground / sea return circuit of electric current in mono polar mode of operation.
Fault performance	In HVAC, when a fault occurs, a circuit breaker is used to interrupt the current and extinguishes the arc, which is formed during the breaking and opening of contacts.	In HVDC systems the current value does not change making a DC line short-circuit difficult to extinguish by itself until the current is lower down to zero value and the arc is extinguished.
Short-circuit currents	HVA C transmission line contributes towards the short-circuiting current of the AC/DC system interconnected.	High voltage DC transmission makes no contribution towards the short-circuiting current in the interconnected AC/DC system.

Power converters are needed (AC/DC/AC) to embed DC link in AC transmission system. The power conversion process is completed using electronic devices (switches) like diodes transistors and thyristors. HVDC technology based on current sourced converters (LCC-HVDC) was first implemented 50 years ago. This technology uses thyristors as switching device. The voltage source converters (VSC-HVDC) based on Insulated Gate Bipolar Transistors (IGBT) was developed later has the advent of self commutation i.e. switch turn on and off is controllable. As switching Frequency is low in LCC-HVDC systems, so power losses are less compared with VSC systems where switching frequency is high due to pulse width modulation method which is used to control gate signal. To increase power rating of VSC technology more series connected devices (IGBT's) are needed as stacks, which add difficulty in control mechanism. Another approach to get higher power rating of a converter is to implement it as a multilevel topology. These have inherent problems of less number of levels which put restrictions on their voltage levels. Modular multilevel converter (MMC) is a promising technology based on multilevel topology .It implements two-level converter (IGBT devices) sub modules in cascade to get the desired output voltage .Switching frequency is less so losses are also lower. However high voltage dc breakers are still in the development stage, making dc line fault clearance difficult in MMC based converters. VSC-HVDC technology made with extruded DC cables is called HVDC Light. This technology is more suitable for offshore environment and interconnection of different networks. An HVDC system shown in Fig.2 comprises of three major components [15-19]: 1) Rectifier terminal to convert AC to DC. 2) Transmission line 3) Inverter terminal to convert back to AC.

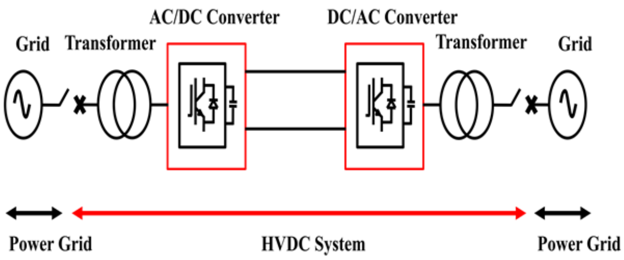

Fig. 2 HVDC System

A comparison between different types of power converters are given in Table. II [20].

TABLE II

Types Of Power Converters

Attributes	Classical HVDC	VSC-HVDC	MMC-HVDC
Convertor Technology	Thyristor valve, grid commutation	Transistor valve (IGBT), self commutation	Sub-modules (IGBT),
Reactive power demand	Yes	No	No
Independent control of active and Reactive power	No	Yes	Yes
Multi-terminal configurations	Complex	Simple	Medium
Control System	Simple	Medium	Complex

III. Future Development of HVDC Systems in Pakistan

Power transmission system of Pakistan consists of 40 grid stations and the total length of high voltage AC lines is 12, 436 km. Out of which 5,077 km is of 500 KV Transmission lines. It is estimated that almost one third of the population has no access to electricity Grid due to remote locations of the settled areas and scale of the country. The country total installed capacity (hydro+thermal) is around 11,300 MW. Details about main hydro and thermal units are mentioned in Table III. Big Hydro plants are located in the northern areas of Pakistan while thermal plants are in the south as evident from power plant map shown in Fig.3 [21].

TABLE III

Hyrdo/ Thermal Units

Name of Power Station	Province	Type of Power station	Capacity(MW)
Tarbela	KPK	Reservoir	3700
Mangala	AJK	Reservoir	1200
Ghazi Barotha	Punjab	Canal	1450
Muzaffargarh	Punjab	Thermal	1300
Guddu	Punjab	Thermal	1600
Jamshoro	Sindh	Thermal	800

The majority of electricity consumers are located in the middle of the country, where wind energy potential is minimum. In the Southern region, wind energy potential is available for future electricity production.

Fig.3 Major Power Plants

Pakistan needs to produce around 3000-4000 MW electricity per annum according to demand as reported. To increase capacity and efficiency, Transmission system needs up gradation [22].The idea to initiate the usage of HVDC technology in Pakistan comes from the proposed CASA-1000 (Central Asia-South Asia electricity transmission and trade) project which will interconnect Tajikistan , Afghanistan and Pakistan through Bi-polar 500 kV HVDC link. It consists of 500 kV, 750 km bipolar HVDC interconnection link with conversion capability of 1300 MW at Sangtuda (Tajikistan), 300 MW at Kabul (Afghanistan) and 1300 MW at Peshawar (Pakistan) [23]. Another 600 kV HVDC line is under construction between Matiari (Sindh) and Nankana Sahib (Punjab), which will transmit up to 4000 MW of power produces by Thar coal power plants. Existing AC grid located nearby has limited transfer capacity. More HVDC stations will be required to transmit power produces from wind energy sources as predicted in fig.4 [24].

The purpose of installing current HVDC links in Pakistan is to transfer electric power between two distant regions. However for future development, HVDC system has great potential for Integrating wind energy sources, Asynchronous connections and system stability improvement.

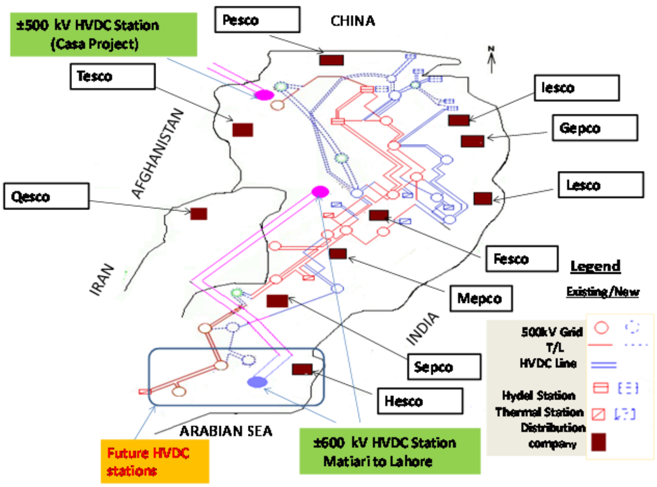

Fig.4 HVDC Grid Map of Pakistan

As explained earlier Geographical locations and infrastructure limitations are two major constraints for the transmission of wind power to the load centers .If shore is located near in any country then Off shore wind energy farms makes a good choice to generate power [25]. Normally the existing transmission system capacity is designed for the conventional fossil fuels and thermal based generation systems and to interconnect large wind energy system from one region to another existing setup has capacity limitations [26].

HVDC system has proved to be more attractive for large offshore wind farms located away from the main grid. Specifically, VSC-HVDC is a favorable technology for interconnecting big offshore wind energy farms to the terrestrial AC grids due to its advantages over conventional HVDC based line commutated converters .It can control power flow direction easily without altering the polarity of the DC voltage [27]. Furthermore VSC technology can operate with weaker ac grids, no reactive power demand at the converter stations and reduced harmonics. However its disadvantage is the less power and voltage ratings of converter [28].Interconnection of off shore wind farms to a common ac bus system, point-to-point HVDC transmission link has a difficulty in controlling each wind energy farm independently .Multi terminal (MT-HVDC) Systems can overcome this problem. The VSC-based MT-HVDC technology for connecting doubly fed induction generator based off shore- wind farms has shown better performance in the power oscillations damping and transient stability during fault conditions [29].Interconnection of wind power (on shore and offshore) generated along the coastline of Pakistan to the national grid, HVDC transmission technology will be the right choice in near future. Where LCC-HVDC systems will be the right choice for high power applications and VSC –HVDC main role would be to interconnect offshore wind energy farms to the electricity grid. A possible layout scheme of offshore wind energy farms linked to the major grid is shown in fig.5 [30].

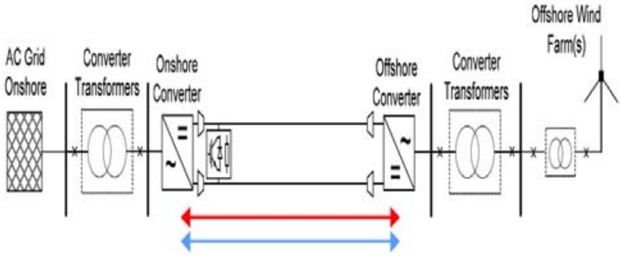

Fig.5 Offshore wind farms linked to the major grid

IV. Conclusion

This paper has highlighted the need for exploring wind energy as a potential source to overcome the deficit between demand and supply of electrical power in Pakistan. It also emphasizes the challenges and issues related to the penetration of electric power in to the national grid of Pakistan. HVDC technology comes out to be a good choice in future for the possible transmission of electrical power (wind energy source) generated along the coastline of Sindh and Baluchistan province to the city centers. This paper also provides details about updated HVDC converter technologies and the benefits of HVDC systems for the future expansion of existing transmission lines.

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