Economic Analysis for HVDC Transmission System in Pakistan

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Abstract

Electricity is being generated from mega sized power plants based on conventional and non-conventional sources of energy, located in remote areas. Two possible choices are high voltage dc (HVDC) and high voltage ac (HVAC) to transmit bulk power from the remote generation sites to the load centers. This paper aims to present techno-economic comparison of both transmission systems for 4000MW power plants installed 878km far from load centers. Discounted cash flow (DCF) technique is employed for techno-economic comparison. A soft mechanism is devised in Excel/Microsoft to study the vision in the discrepancy of input factors.

1. Introduction

Renewable energy development authority has estimated that the most of transmission lines are over loaded within Pakistan. Energy demands are increasing day by day. Currently, Pakistan is facing energy crises and thus to meet the load demands new proposals for power generation are being suggested like; coal, wind and nuclear plants in southern areas of Pakistan. Coal power plants include Engro Thar Coal (2×330MW), SSRL Thar Coal (2×660MW), Port Qasim (1320MW), Thal NOVA (330MW), Oracle (600MW), Lucky Energy (660MW) , Siddique Sons Energy (330MW) and Hub power company's Thar coal based plant (300MW) [1]. Wind based plants are being installed in coastal areas (UEP 100MW wind Farm, Jhimpir, Sindh). Nuclear power plants are under construction such as: KANUPP-II (1100MW) and KANUPP-III (1100MW) and proposed to complete till 2022 [2], [3]. Nuclear Power Complex of 1000MW is proposed in Muzaffargarh with Chinese collaboration [4]. By 2025, thousands of megawatts would be the part of Pakistan's power system. To reinforce the power system, new transmission lines are mandatory. A new transmission network is required in south as most of the power generation projects are planned in the south under the vision of China Pakistan Economic Corridor (CPEC).

Typically, power transmission to the national grid is achieved through high-voltage alternating current (HVAC) [5]. Corona, skin effect and presence of capacitance in the event of no load cause power losses in ac systems, respectively. So, more insulation, big size of conductors and external reactive power supports are required. Thus, HVAC is not suitable to transmit bulk power over long distance. High voltage direct current (HVDC) technology is proposed for bulk power transmission. Reactive power support, black start

capability, small filter sizes, and the ability to change the power direction without altering the polarity of the dc link voltage make voltage source converter (VSC) based HVDC a viable candidate to transmit the power from south to Punjab with reduced investment than HVAC [6], [7].

Location of the proposed bipolar 878km VSC-HVDC transmission line from Matiari to Lahore is shown in Figure 1. To fulfill the government objectives of diminishing global warming till 2030, offshore WFs are considered as crucial solution. Europe set a target to produce 120GW of electrical power from offshore wind energy by 2030. Integration of offshore WFs to mainland grids, to transmit generated power, causes environmental and techno-economic challenges both for transmission system operators (TSO)s and utility[8]-[10]. Thus, HVDC technology either based on VSC or LCC is viable alternative than high voltage alternating current (HVAC) to integrate offshore WFs to onshore grids. Possible choices for power transmission are presented in Figure 2. In dc transmission, charging current on transmission distance with reduced number of conductors and controlled power flow. Transmission planning involves various parameters such as: technical, economic and legal considerations. This paper deals with the economic planning considering the technical and legal aspects. Installation of such a giant transmission network needs as accurate, precise and economic planning as possible.
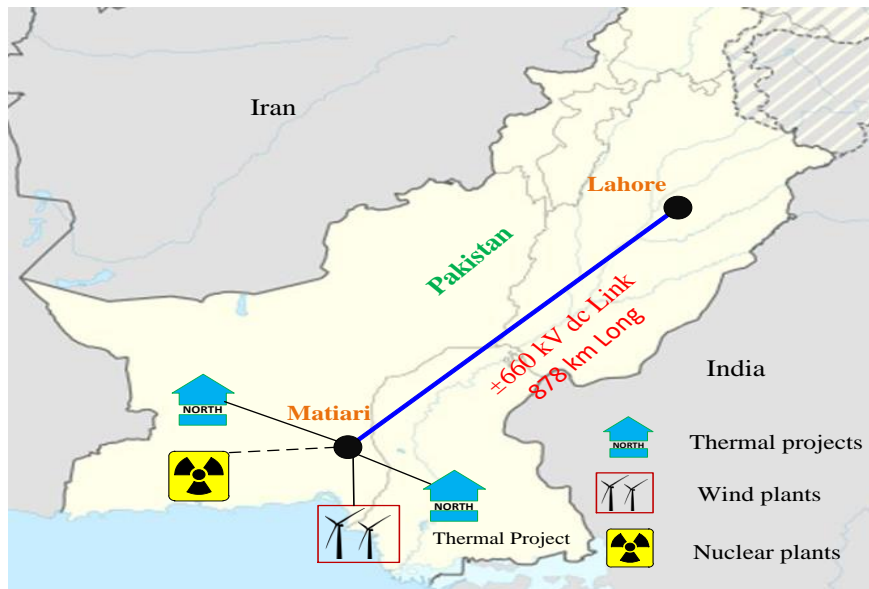

Figure 1. 4000MW Project of South of Pakistan

Appropriate choices regarding technology and line routing is adapted to achieve proper cost optimization. The study conducted is based on the economic factors like; cost comparison, net present value, initial capital cost, annual cost, taxation rate, discounted factor and annuity factor. DCF is proposed for analysis of VSC based HVDC bipolar transmission system [6], [11]. Discounted cash flow technique is a reliable tool to make decisions about capital budgeting of project [12], [13].
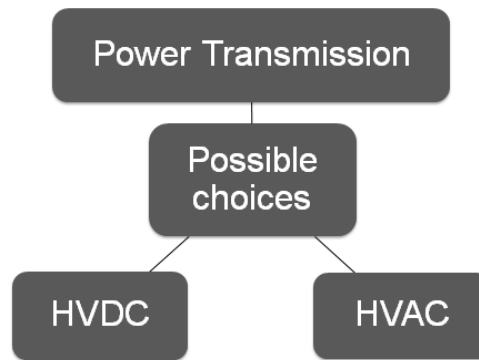
Figure 2. Possible Choices For Electrical Power Transmission

Both the technologies are techno-economically analyzed through DCF which gives the discrepancies in annual costs (AC) and total investment costs (IC). An annual cost consists of losses within transmission system and both preventive and, maintenance costs. But, insurance amount and reliability of system has not been considered in this study. Initial amount (IA) covers the price of grid stations, overhead (OH)-lines, switchgear, poles and land. For HVDC technology, the estimated costs of converter station of 4000MW, overhead system for 1000km (lines and poles), cost of land and annual maintenance are 800M\$, 915M\$, 70M\$ and 60M\$, respectively. For 500kV HVAC transmission systems, the costs of substation (SS), OH lines, static compensators and of land are 282.872M\$, 1357.8M\$, 141M\$ and 70M\$, respectively, while maintenance cost is considered 90 M\$ [14].

This paper is organized as follows; general comparison between HVAC and HVDC is presented in section II. Adopted methodology is described in section III. CSF outcomes are presented in section IV. Finally, conclusions are drawn in section V.

2. Comparison between HVAC and HVDC

A typical techno-economic comparison of HVAC and HVDC is depicted in Figure 3, which shows that HVDC is economical than HVAC beyond the knee point [15]. Power transmission standards and conducting medium, atmospheric circumstances and relative cost statistics affects the distance of the break-even point. Figure 4 depicts a comparison of the losses in 1200MW overhead (OH) transmission line using HVDC and HVAC [16]. A vital factor to find in economic comparison of two systems is to determine the better alternative. Subsequent section provides the insight to this question as in Figure 5 for a 4000MW over 787km long OH transmission line. HVDC system requires low capital cost because of two conductors for distribution and it has ability to transmit large power over long distances with reduced power losses as 3% per 1000km [17]. HVDC system gives better voltage regulation in the absence of inductance and capacitance than HVAC system [18]. The HVDC grids are employed for [19]:
  i. Interconnection of offshore wind power plants with the existing ac networks
 ii. Inter-continental transfer of large quantities of power, *i.e.* an overlay grid
iii. As the main transmission system: opportunity when no or very weak ac transmission system exists, to actually reinforce the transmission system with dc Example: the African power transmission system.
iv. As a distribution grid for power storage
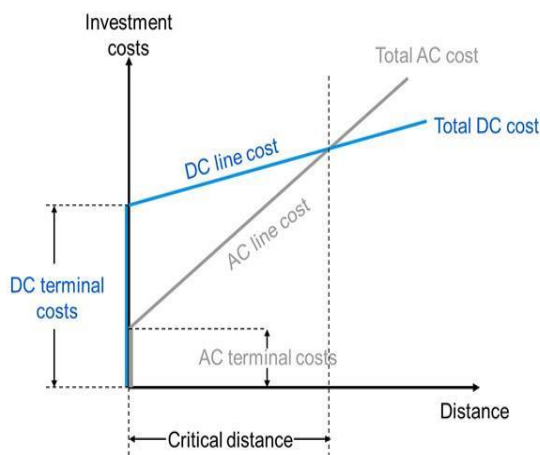 In the above applications, the dc transmission will have following advantages over HVAC:
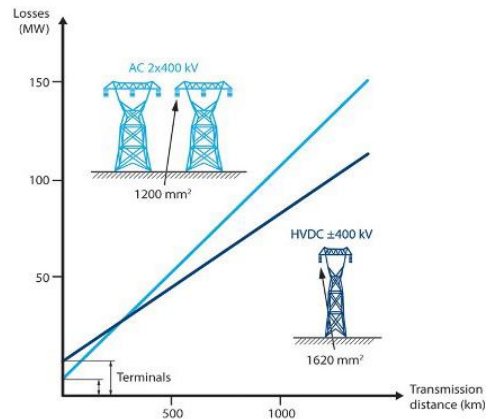
Figure 3. Cost comparison of HVAC and HVDC
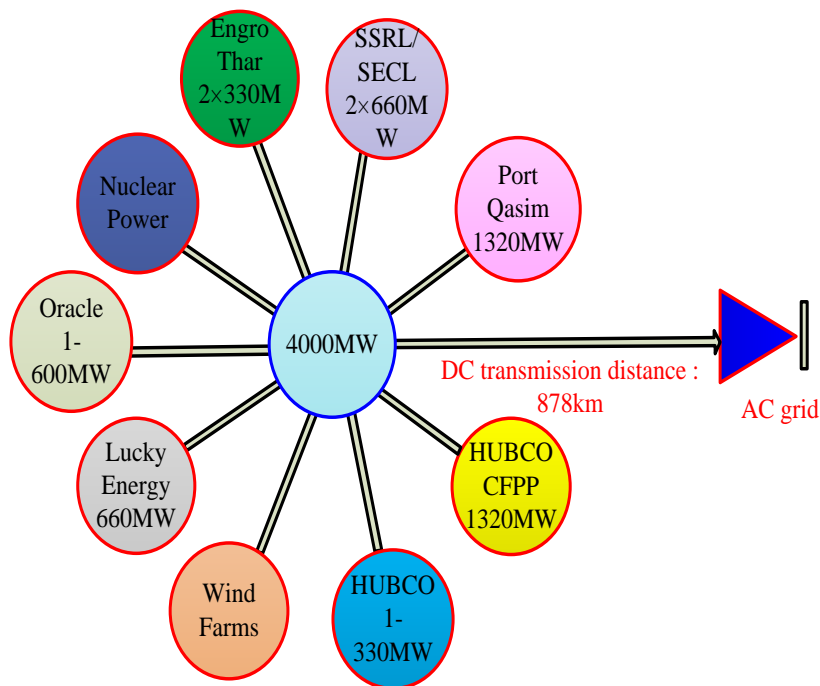

Figure 4. Comparison of the Losses in OHTL

Figure 5. A Scenario for Economic Comparison

   i. Number of conductors is reduced for transmission of same quantity of power
  ii. Allows power exchange between asynchronous networks
 iii. Reduce the long distance losses
 iv. More compact overhead line towers, less visual impact
  v. Controlled input and output power
 vi. The ac fault-ride through capability

Another drawback of HVAC system is the production of charging current as:

$$I_C = \left(\frac{V}{\sqrt{3}}\right)^2 2\pi f C$$

HVDC technology is of two types: line commutated converters (LCC) and voltage source converters (VSC). LCCs are in need of external source to push off the switches while VSCs do not need, during HVDC applications.

VSC-HVDC offers numerous advantages than LCC-HVDC and some of them are listed in Table I [20]. VSCs also do not require interface transformer and harmonic filters *i.e.* reduce cost. These are the reason to be ousted from LCC to VSC.

Table I. Comparison between LCC-HVDC and VSC-HVDC

	LCC-HVDC	VSC-HVDC
Power Reversal	Mechanical switches for voltage reversal as current cannot change direction	Change of current in the converter. No need for mechanical switches
AC disturbances	Commutation failure: short circuit of the HVDC Grid for some time	No influence other than some loss of active power transfer. Fault ride through capability.
AC connections	Limited to medium and high short circuit capacity networks	Connection to electrically weak AC-network or even "black" AC network.
AC voltage support	Always consumes ~50% reactive power (which is compensated by breaker switched AC filters)	Provides reactive power support
DC short circuit	DC Grid breaker needed in overlay HVDC Grid	DC Grid breaker needed in overlay HVDC Grid
Typical system losses	0.7 %	1.1 %
Typical delivery time	36 months	24 months

Various generalized methods to perform the economic comparisons are shown in Figure 6. Discounted cash flow (DCF) is selected in this paper, where all forthcoming cash flows are calculated and discounted to obtain net present values (NPV) [6].
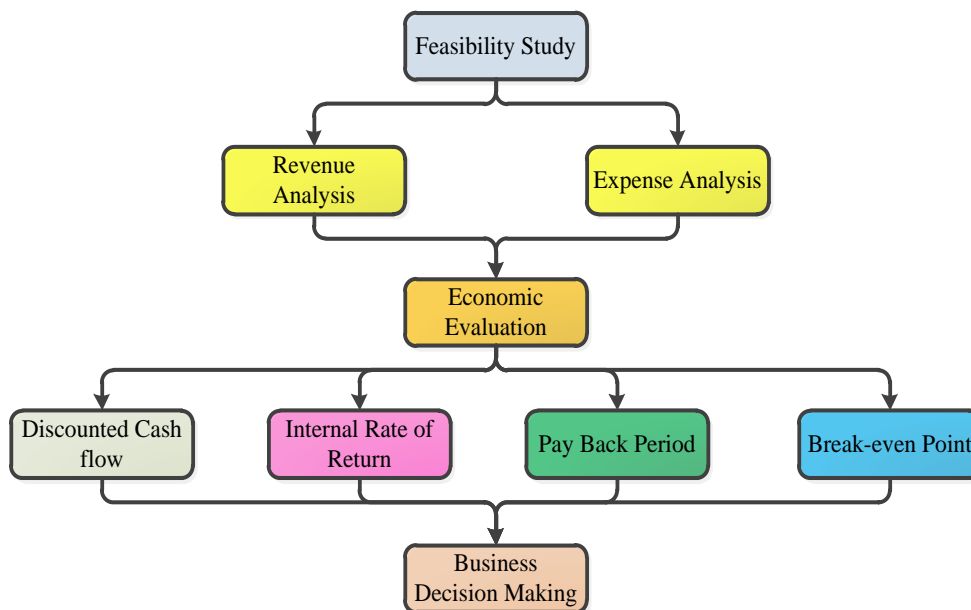

Figure 6. A Typical Procedure for Making Business Decisions

3. Methodology

DCF analysis [11] is employed for comparison between VSC-HVDC and HVAC transmission system. Its outcome is the variance of NPV of two described transmission technologies. Discounted cash flow integrates the discounted annual and original investment costs for each technology. 30 years life spam is considered for the proposed HVDC transmission system. Taxation rate and discounted factors are 17% and 5.5%, respectively, in Pakistan. Investment cost of both the systems is given in Table II. The employed mathematics is described as:

   i.   Total invested Amount for HVDC Systems = Cost for Substation + Cost for land (poles and lines) + Cost for overhead Transmission system
   ii. Total invested Amount for HVAC Systems = Cost for Substation + Cost for land + Cost for overhead Transmission system (poles and lines) + Cost for Q compensation
   iii. Annual Cost = Cost for running losses within system + Cost for maintenance
   iv. NPV = Total Investment + Discounted annual cost
   v. $AF = [1 - (1 + DF) \wedge (-L) / DF]$
   vi. $DAC = PCF \times [YC \times (1 - T) - D \times T]$

Where

AF	Annuity Factor
DF	discount factor
L	Lifetime
DAC	Discounted annual cost
PCF	Present cost for AF
YC	Yearly costs
TR	Taxation
D	Depreciation value

AF can also be found by using annuity standard factor Tables [21].

Table II. Investment Comparison of HVAC and VSC-HVDC Technologies

No.	Components	VSC-HVDC	HVAC
1	Substation	800	282.872
2	Overhead system	915	1357.8
4	On shore land use	70	70
5	STATCOM	-	141
	Total	1785	1851.67

4. Transmission System Investment Cost

The choice between HVDC and HVAC greatly influences the economy of the project. VSC-HVDC is relatively new technology and offers several technical advantages over HVAC as described in section I.

In this perspective, techno-economic comparison is conducted between HVAC and VSC-HVDC technologies for 4000MW power transmission over 878km long OH lines. The proposed dc system consists of bipolar ground return transmission lines at 660 kV with cross-section of 4×1250 mm^2 [1]. Two 660kV SS are required to install in Matiari and Lahore, respectively. The requirements for the ac transmission system are different. Only one 500kV grid need to construct as the existing 500kV Matiari grid station can be used to connect the load centers. Transmission system's cost is presented in Table II for both HVDC and HVAC networks based on their respective components: substations, transmission line conductors, installation and land expenses. Under the same circumstances, the cost of HVAC and VSC-HVDC SS are 800M\$ and 282.8M\$,

respectively. Cost of VSC-HVDC stations may reduce with the advancements in power electronics. By giving the due attention to the cross-sectional area and distance of lines, the total investment required for the 878km HVAC line is about 1.484 times that of VSC-HVDC. Aggregated ac line cost is 1357.8M$ for 878km, taking 1.54M$ per km. 1.04M$ per km is the installation cost for dc transmission. VSC-HVDC is cheaper than HVAC, with an aggregate distinction of roughly 66.67M$. VSC-HVDC costs 1785M$, compared with 1851M$ of HVAC to transmit 4000MW over 878km.

5. Annual Cost

Two components are defined for economic comparison: maintenance (both preventive and corrective) and system losses. The losses in the transmission system are important economic indicator.

The losses in the VSC based HVDC transmission grid originate from the VSCs (*e.g.,* filters, HVDC station transformers and IGBTs,) that are roughly 7.4% (1.8% for every station), and line joule losses [6]. Losses in the HVAC system are determined by considering the losses in ac grid station (*e.g.* transformers and compensation coils), that's 0.5% of the total power flow [6] and line losses are incorporated. The line losses are due to line conductors. 0.5% of the total components cost is assessed as the annual maintenance cost [22] and transmission line cost is not included in it. 2.06M$ and 4.11M$ are the annual maintenance costs for HVAC and HVDC systems respectively. The cost of HVDC is higher because of the complexity of VSC stations. However, to cope with the charging current produced in HVAC line STATCOM is required. Hence, resulting in increased maintenance cost for HVAC transmission system. Thus, total estimated annual cost for VSC-HVDC is 60M$ and for HVAC is 90M$.

6. Results of DCF Analysis

Methodology (DCF) presented in section III is used to obtain the comparative results for HVDC and HVAC transmission systems, as in Table III. VSC based HVDC technology is cheaper than HVAC based on the investment cost considering lifetime. Higher annual costs result in higher difference of NPV values for HVAC or VSC-HVDC than the differences in investment costs [6]. This can be seen in Figure 7.

However, continues evolution of power electronics shall result in further reduction in cost of VSC stations, making it more economical option for bulk power transmission.
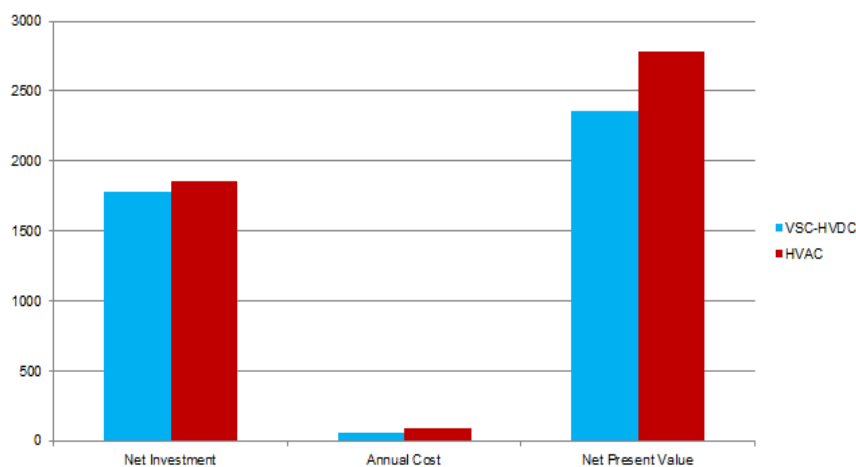

Figure 7. Cost for HVDC and HVAC (M$)

Table III. NPV Cost for HVDC and HVAC (M$)

No.	Components	VSC-HVDC	HVAC
1	Net Investment	1785	1851.67
2	Annual Cost	60	90
3	Net Present Value	2361.77	2784.84

7. Conclusion

Economic comparison between HVAC and HVDC is presented in this paper for the connection of large coal, nuclear wind based plant in the south of Pakistan to load center, Lahore. VSC-HVDC bipolar transmission system is proposed for 4000MW power transmission over 878km long distance using OH transmission line based on discounted cash flow analysis. VSC-HVDC net present value result is 2361.7M$, less than HVAC. Thus, VSC-HVDC offers cost effective and efficient transmission network with black start capability than HVAC system.

HVDC got tremendous scope within Pakistan's power system with the inauguration of CPEC to meet the load demands.

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