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The Role of HVDC Technology in Transmission Planning with Renewable Energy Integration: A Case of Wind Energy

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Abstract: Renewable sources of energy have particular characteristics which make grid integration and long-distance transmission onerous. For one, the existing transmission infrastructure cannot, at its present state, accommodate features of RE for reliable integration with the grid and subsequent transmission. Wind, for example is very unpredictable – the ripple effect of this unpredictability is that the availability of power output will also fluctuate so much so that without auxiliary support, secure, reliable and quality power cannot be dispatched. Another set of complexity is the location of RE power plants that are significantly miles away from the intended Point of Use (PoU) centers. This makes VSC-HVDC the most appropriate technology that can harmonize the challenges of RE integration and transmission in one-fold. The VSC-HVDC transmission link was simulated in a MATLAB environment for offshore wind integration and results reveal the need to adopt VSC-HVDC as the most compatible technology for integrating and transmitting RE.

Key Words:* *Renewable Energy Integration (REI), Renewable Energy Transmission (RET), Location of RE, Cost of RE, Voltage Source Converter (VSC), Wind Energy

I. INTRODUCTION

Despite the enviable ubiquity and lesser cost of electricity generation from renewable sources of energy several challenges, nonetheless, still come to the fore if RE is to share its electrical energy with the grid [1]. For large-scale accommodation of RE into the electrical grid to see the light of day with near-zero dependence on electricity generation from fossil fuels – energy sources that emit toxic greenhouse gases (GHG) into the environment – unpredictable availability, locational specificity and a variability that cannot be easily managed are the immediate set of complexities and challenges that ought to be solved. The choice of Renewable Energy Technology (RET) on the other hand, involves taking into consideration several elements that in the long-run make RE Integration (REI) a challenge. First, some RES are not available in each region. Second, distance between RE plants and the grid is a major aspect in terms of cost and efficiency. Lastly, RES availability depends on weather, climate, and geographical location [2]. Location plays a crucial role in the total for they require transfer of power via transmission lines that depend on the voltage level.

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Thus, whether it’s designing a new transmission and distribution infrastructure or upgrading an existing one a forward-looking RET will become a necessity for REI.

This paper investigates REI to the grid by taking advantage of the ongoing effort on RE generation. The conventional transmission networks are in dire need of modernization for instance, HVAC corridors located near sites with an abundance of wind could be converted to HVDC – a technical solution that is sensitive and consistent with present and future trends of meeting electrical energy demand – a solution set of RET which can be effectively and efficiently executed within the context of HVDC.

Paper Organization: The rest of the paper is organized as follows: Background and Related Work, Methodology, Results, Conclusion and Future Work and lastly References.

II. BACKGROUND AND RELATED WORK

Accommodating large-capacity RE generation requires large-scale transmission grid expansion and reinforcement for the following reasons [3]:

i) Grid expansion and inter-regional connection are needed to transmit the energy generated by large-capacity RE sources, which are generally located far from load centers and the existing grid.
ii) Through grid expansion, the geographic diversity of RE generation can be exploited to smooth out their aggregated variability and uncertainty and to reduce the RE power forecast error.
iii) Grid expansion and reinforcement can support interconnection between balancing areas, hence facilitating their cooperation or consolidation to share flexibility resources.

Related works have addressed REI but a healthy number of this undertakings have been developed built from concept to commissioning, an approach that is currently being least explored due to complex and bureaucratic protocols, land acquisition that is expensive and right-of-ways. To this end, HVAC corridor conversion is still an under estimated alternative, only discussed theoretically. Key indicators why HVAC corridor conversion to DC is an overlooked alternative:

i) Stability from the impact of using non-renewable sources cannot be solved by harnessing RE generation alone;
ii) Quite a number of people are still without access to reliable electricity despite the abundance of RES. A transmission bottleneck not a generation one;
iii) Most viable RE rich sites are miles away from metropolitan and urban centers which poses a threat on how demand for energy will be met against a population that is constantly growing;

Figure 1 is a typical representation of wind energy integration to the electrical grid.

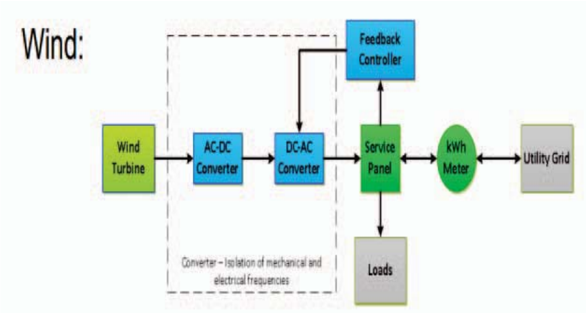

Figure 1 Wind Energy Integration

Key projects worldwide that have been undertaken using VSC HVDC technology with a bias on renewable energy integration are summarized in Table 1. This demonstrates the gradual maturity of VSC HVDC technology, which is also available for medium scale power transmission useful for towns and urban centers that in the long-run supports RE prevalence.

Table 1: Worldwide VSC HVDC Projects with REI

Project Name	Purpose	Year
Gotland, Sweden	WPI*	1999
Tjæreborg, Denmark	WPI**	2000
Nord E.ON Germany	WPI**	2009
Shanghai Nanhui, China	WPI**	2011
Barsoor&Lower Sileru, India	AC to DC	Ongoing

WPI = Wind Power Integration
WPI* = Onshore WPI** = Offsore

A. Problem Formulation

Reducing the cost of energy through cutting dependence on non-renewable sources of energy on one hand; whilst, integrating renewable energy to the electrical grid on the other hand; are multi-nodal challenges requiring complex multi-nodal energy management strategies. The growth of RE on the electric grid is increasing so as to contribute towards de-carbonization of the energy system and also expand the access to energy. This shift in generation requires a shift in how electrical energy is also transmitted as well.

B. VSC HVDC Transmission Link

Figure 2 is a schematic representation of the fundamental concept of a dual terminal VSC-HVDC transmission link.

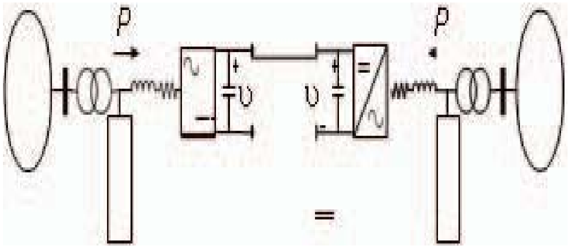

Figure 2: Dual Terminal VSC-HVDC Transmission Link [4]

VSC independently creates an AC voltage from a DC voltage source for the exchange of active and reactive power between the AC and AC components. The connection point of the phasor reactor or point of common coupling (PCC) – connecting the VSC to the converter transformer – is where the exchange of power is initiated. The output voltage content of the VSC and the phasor reactor harmonics is minimized by the AC filters during the switching processes. Therefore, in order to obtain a steady direct voltage from the AC voltage generated from the converter on the AC side, the DC side capacitors smoothen the voltage ripples/spikes [4]. These capacitors play a vital role as the converter's provisional energy storage devices so as to absorb and maintain power balance during the transient moments. Table 2 is a summary of the major system and control components of a VSC HVDC.

Table 2: Major VSC HVDC System Components

System Component	Main Function
AC Side Transformer	Join converter station to AC system
Phase Reactor	For active/reactive power transfer
AC Side Filters	Sinuisoidal smoothening
DC Side Capacitors	Voltage Stabilization
DC Lines	Power Transmission between VSC

The maximum power that can be transmitted from the sending end to the receiving without loss of synchronism is what determines the limit of the steady state. Analyzing the AC voltage control can be described mathematically as:

$$P_{VSC} = [(U_{cabc}U_{abc}) / X] \sin \delta \quad (1)$$
$$Q_{VSC} = [(U_{cabc}U_{abc}) \cos \delta - U^2_{abc}] / X \quad (2)$$

Where P_{VSC} = Active power transmitted by the VSC-HVDC link and Q_{VSC} = Reactive power transmitted by the VSC-HVDC link , X = the reactance given by ωL, U_{cabc} =

this is the RMS value of line to line voltage at the converter output, U_{abc} = RMS value of line to line voltage at the AC bus, δ = Phase angle difference between U_{cabc} and U_{abc} which are negligible such that $\sin \delta = \delta$ and $\cos \delta = 1$ Equations (1) and (2) thus yield

$$P_{VSC} = ((U_{cabc}U_{abc}) / X)\ \delta \qquad (3)$$

$$Q_{VSC} = (U_{abc}(U_{cabc} - U_{abc})) / X \qquad (4)$$

Equation (3) regulates the active power for it to be proportional to the phase angle difference whereas equation (4) regulates the voltage.

III: METHODOLOGY

The simulation of the VSC HVDC Link Simulation conceptualized a wind power plant that was fed into an AC network after being converted from DC to AC via a Wind Energy Conversion System (WECS). This is summarized in Figure 3.

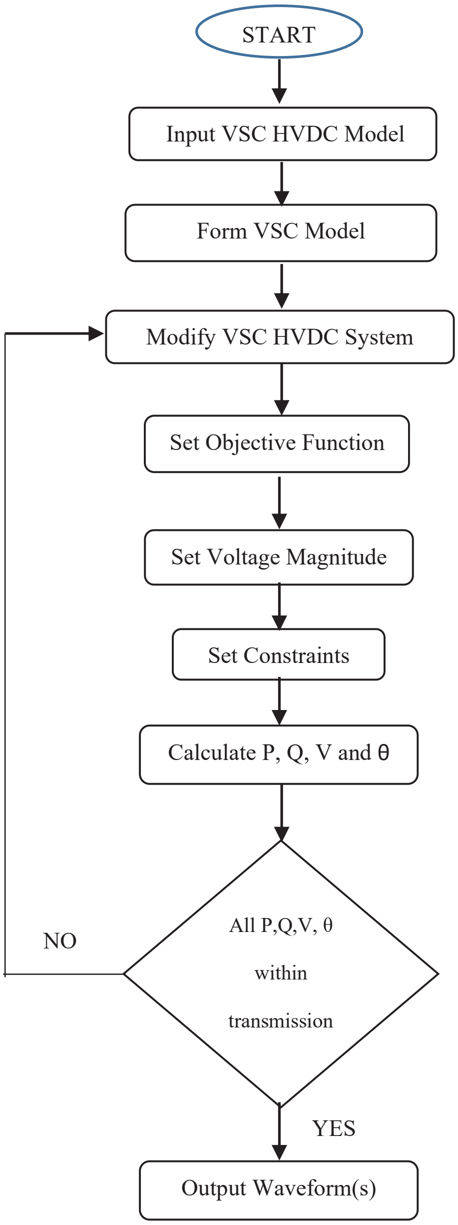

Figure 3 Simulation Flowchart Steps

At this juncture, conversion to DC took place for ease of transmission over extended distances to the marked substations and intended points of use. The inversion from DC was to make the supply consistent with most industrial, commercial and domestic appliances.

III. RESULTS

The graphical representation of various simulation results is as shown in Figures 4 ,5,6,7, 8 and 9. Figures 4 to 6 belong to the Rectifier side while Figure 7 to 9 are for the Inverter. The discuss and analysis is contained in Section IV.

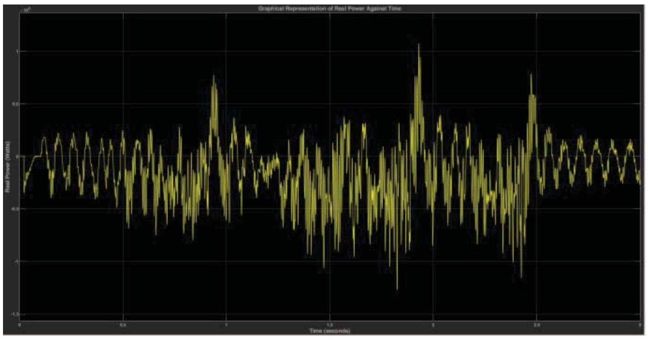

Figure 4 Graphical Representation of Real Power of VSC HVDC Against Time

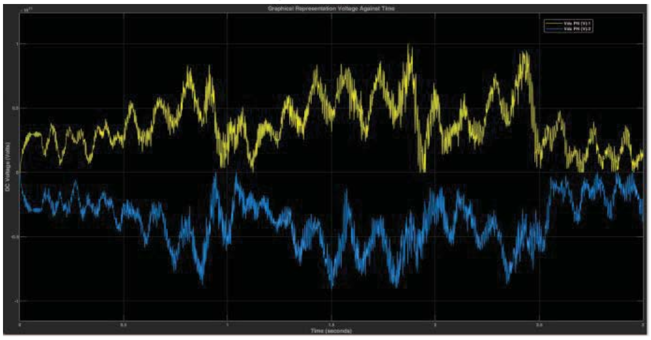

Figure 5 Graphical Representation of Real and Reactive Voltage Against Time

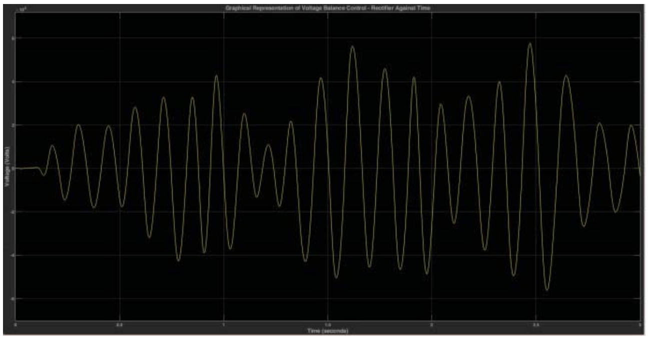

Figure 6 Graphical Representation of Voltage Balance Control Against Time

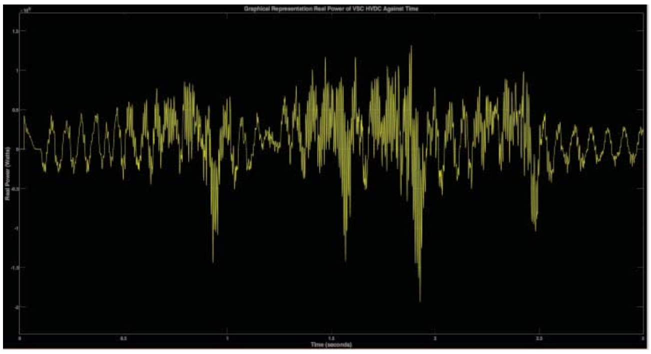

Figure 7 Graphical Representation of Real Power of VSC HVDC Against Time

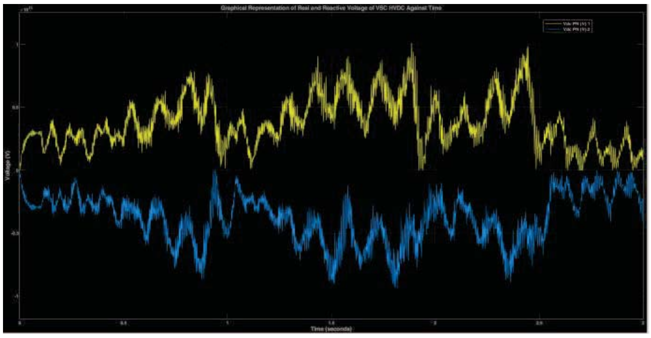

Figure 8 Graphical Representation of Real and Reactive Voltage Against Time

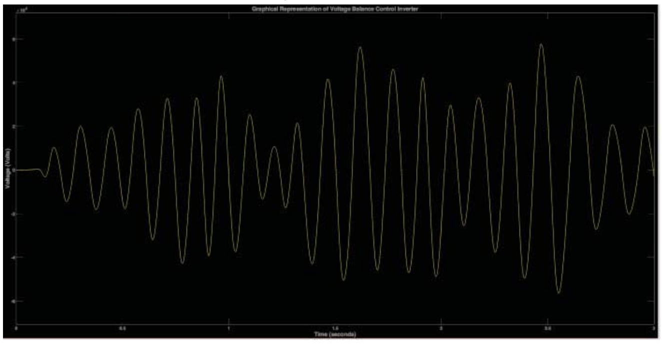

Figure 9 Graphical Representation of Voltage Balance Control Against Time

IV. DISCUSSIONS

The converter switching frequency (f_{CS}) was set 2 kHz from this value we derive the mean converter time delay (T_{mean}) from the following expression:

$T_{mean} = (2 \text{ x } f_{cs})^{-1} = (2 \text{ x } 2*10^3)^{-1} = \mathbf{250\ \mu s}$ (5)

Using a time constant, τ = 3ms alongside the system description, the DC-link capacitance is calculated using the following expression:

$C = (2\,\tau\, P_{vsc}) / (U^2_{cabc}) = [2 \text{ x } (3*10^{-3}) \text{ x } (10*10^3) \;/\; (120*10^3) = \mathbf{500\ \mu F}$ (6)

We observe from equation 6 that the calculated DC link capacitance indeed corresponds to the simulated capacitance of the transmission link. Thus, effective total capacitance is 1000 µF and grounded at their respective junction nodes. Base parameters helps in simplifying how complex power is analysed. These parameters often expressed per unit (p.u) also aid in simulating the design of VSC transmission link.

The determination of base parameters is as expressed in equation 7:

Quantity (p.u) = Base Parameter Quantity / Value of Base Parameter Quantity (7)

The base parameters converted per unit for modelling were as indicated in Table 3.

Table 3: Base Parameter and Description

Base Parameter	Base Parameter Description
$V_{d,b}$ & $V_{q,b}$	Voltage in the dq coordinate system
$I_{d,b}$ & $I_{q,b}$	Current in the dq coordinate system
Z_{DC}	DC side impedance
S_{DC}	Apparent power DC side
I_{DC}	DC side current
Z_n & S_n	Rated impedance & apparent power
V_n & I_n	Representation of rated voltage & current
V_{DC}	DC side voltage
Z_{DC}	DC side impedance

V. CONCLUSION

RET is an issue everywhere for both technical and regulatory reasons. An inability to solve the transmission problem jeopardizes the achievement of RE goals, and drive up the cost to reliably integrate these new resources into power systems. The VSC-HVDC was evaluated in terms of flexibility, reliability, stability and security in the REI. Simulated results revealed the merits of HVDC on one hand, whilst on the other hand it demonstrated the plausibility of integrating wind power – a type of RES – over a long distance. The rationale of expanding transmission using existing infrastructure is a least-cost approach to meeting the demand of power with fewer environmental constraints in comparison to new line constructions.

VII. REFERENCES

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