Comparative evaluation of power loss in HVAC and HVDC transmission systems

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Yew Ming Yeap
Agency for Science, Technology and Research (A*STAR)

Abhisek Ukil
University of Auckland

Comparative Evaluation of Power Loss in HVAC and HVDC Transmission Systems

Thu Win May, Yew Ming Yeap, *Student Member, IEEE*, and Abhisek Ukil, *Senior Member, IEEE*

***Abstract*—Researches on renewable energy sources have been carried out and ways to reduce energy consumption and energy wastage have been discussed and studied to tackle the world's power shortage problems. Wind farm, one of the prominent renewable sources, is usually remotely far from onshore and needs long transmission to bring generated power to populated areas. This paper covers the analysis of the traditional high voltage alternating current (HVAC) transmission system and comparison of the aforementioned system with high voltage direct current (HVDC) transmission in terms of power loss. In this paper, the converter that used in HVDC transmission system is voltage source converter (VSC). To observe and evaluate the power losses, the HVAC and HVDC transmission models are simulated in PSCAD. It is seen that cable contributes to large portion of losses in HVAC system, increasingly so with longer transmission distance. Whereas for HVDC system, converter loss is found to outweigh cable loss.**

***Index Terms*—HVDC system, HVAC system, VSC-HVDC, power loss, converter loss, cable loss, PSCAD/EMTDC.**

I. Introduction

In power systems, a substantial amount of power is lost in distribution and transmission, especially when the power is delivered over long distance. Therefore, it is important to evaluate the power loss in transmission and distribution systems. The reasonable power loss in transmission of bulk electric power greatly reduces overall power consumption.

The major constraint of transmission lines in high voltage alternating current (HVAC) transmission systems is that they tend to generate large amounts of reactive power [1]. High voltage direct current (HVDC), on the other hand, has relatively lower transmission loss . However, there are several drawbacks of HVDC transmission such as the need of additional conversion equipment, maintenance difficulties and less reliability of the system. The AC-DC conversion process (1-2 kHz) using voltage source converter (VSC) introduces dominant portion of the overall loss [2], [3]. Therefore, it is essential to understand the pros and cons of both transmission system and carry out detailed research on power losses of both systems over a range of transmission distances and basic components.

A miniature amount of differences in transmission losses could produce significant difference in output energy for long-term projects that stretch over 20 years [1]. Hence, the evaluation of transmission loss is essential in power transmission systems and it is important to design a transmission system with minimal power loss. Evaluation of power loss in transmission system can contribute to optimization of the overall system performance by assessing the technical and economic benefits of the system and understanding the components that contribute to maximum power loss. That being said, it is reported in [4]–[6] that the benefits of HVDC outweigh that of HVAC when the HVDC overhead line transmission reaches a breakeven distance.

The structure of this paper is organized as follows. Section II and III describes the simulation of HVAC and HVDC transmission system, respectively. The comparison of loses between these systems is presented in Section IV. Finally, the conclusion is given in Section V.

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T. W. May and Y. M. Yeap are undergraduate and PhD student, respectively, and A. Ukil is Assistant Professor in the School of Electrical & Electronic Engineering, Nanyang Technological University (NTU), Singapore (Email: maythu001@e.ntu.edu.sg, yeap0022@e.ntu.edu.sg, aukil@ntu.edu.sg).

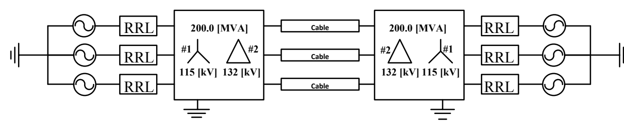

Fig. 1: HVAC transmission model in PSCAD/EMTDC.

II. HVAC transmission system

Alternating current is usually used to transfer electricity in high-tension power lines. The voltage level can be increased and decreased by using transformer. The combination of transformers, reactors and HVAC transmission lines are the basic building blocks for constructing different schemes and configurations of HVAC transmission system.

A. HVAC transmission model

The HVAC transmission system rated at 117 MW is modeled and simulated in PSCAD/EMTDC [7] to study the power loss of HVAC transmission system as shown in Fig. 1. The specification of HVAC transmission model can be found on Table I.

TABLE I: Model Specification of Simulated HVAC Transmission System

Parameter	Value
Steady state frequency	50 Hz
Rated power	117 MW
Rated AC voltage (L-L RMS)	115 kV
Transformer ratio	115 / 132 kV
Cable length	50 km, 100 km, 150 km

B. Loss calculation

Power loss calculation for Transformer T1, Cable and Transformer T2 can be expressed and constructed in PSCAD/EMTDC program as follows:

$$P_{loss,T1} = GenP - P_{bfTransmission}, \quad (1)$$

$$P_{loss,ACcable} = P_{bfTransmission} - P_{AfTransmission}, \quad (2)$$

$$P_{loss,T2} = P_{AfTransmission} - RevP, \quad (3)$$

$$\text{Total power loss} = P_{loss,T1} + P_{loss,ACcable} + P_{loss,T2}, \quad (4)$$

where $GenP$ is generated output power, $P_{bfTransmission}$ is the power measured at the transmitting end, $P_{AfTransmission}$ is the power measured after passing through the cable, $RevP$ is the power measured after passing through the transformer, T2.

Loss Distribution in terms of generated power can be calculated as follow:

$$P_{loss,i}\% = (P_{loss,i}/GenP) \times 100\%, \quad (5)$$

where $P_{loss,i}$ represents the losses at the i component [8].

C. Simulation result

The voltage level at the generator is 115 kV. The power generated is set to be 117 MW. For long distance transmission, the voltage level is step up to 132 kV using transformer. The cable length is 100 km. The power at generator, before and after transmission cable and receiving side are simulated using PSCAD/EMTDC. Using (1)-(5) in Section B, the power loss for each component is shown in Fig. 2. The transmission loss in cable is around 4% higher than the loss at each station. Therefore, it can be said that the highest share of the total transmission losses in HVAC transmission system comes from cable.

The power loss for transmission cable for different cable lengths is represented in Fig. 3. Based on the simulation results, the cable loss increases sharply with longer transmission length. The relationship between cable length and loss appears to be rather non-linear.

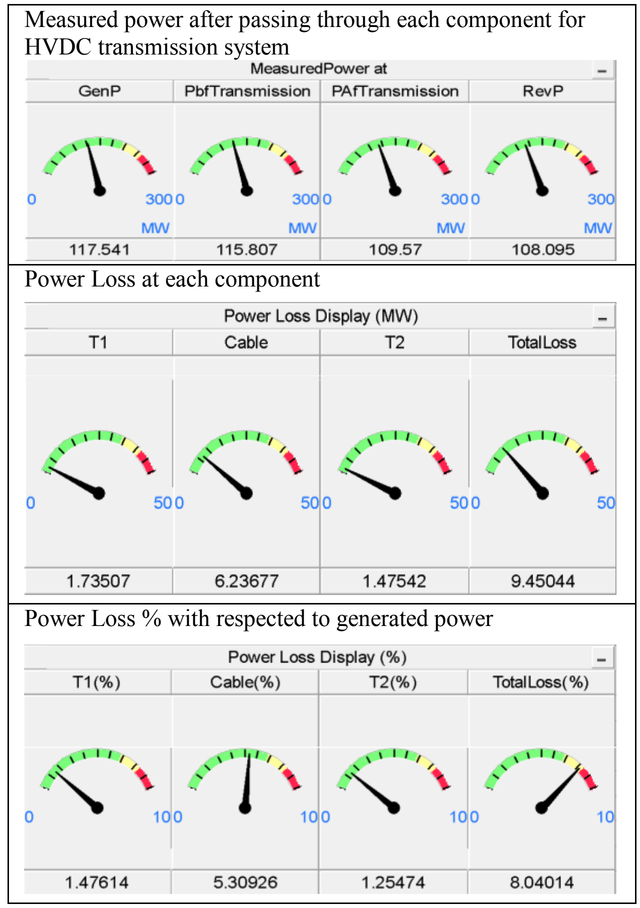

Fig. 2: Output interface of HVAC transmission model for generated power 117 MW for 100 km cable length.

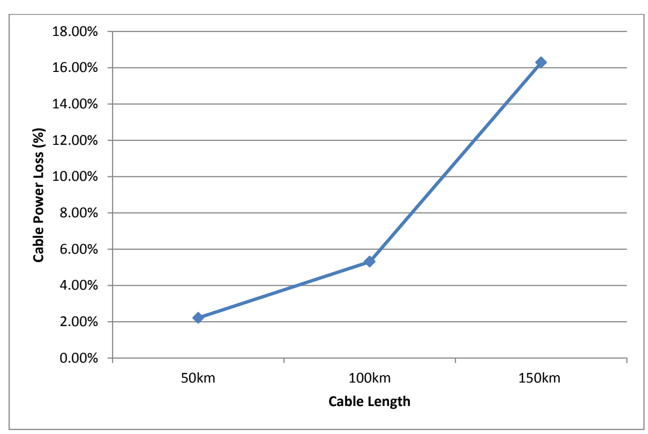

Fig. 3: Power loss % of cable with respect to generated power 117 MW for different cable length.

III. HVDC TRANSMISSION SYSTEM

A HVDC transmission system uses direct current for bulk electrical power transmission. The basic components in the system are rectifier, converter transformer, transmission line and inverter.

A. HVDC transmission model

The VSC-based HVDC system is modeled in PSCAD/EMTDC using IGBT power semiconductors as a rectifier as well as an inverter [9]. Four measurement points are of interest in the system, such as power generated at the sending end, power at the rectifier, power at the inverter and power obtained at the receiving end [10]. On the DC side of converter, the DC-link capacitor is used to reduce ripple

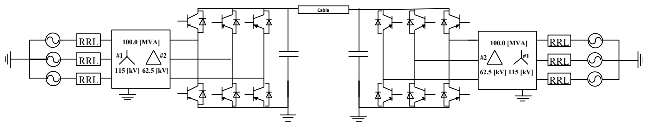

Fig. 4: HVDC transmission model in PSCAD/EMTDC.

voltage and provide the energy storage for controlling the power flow.

The nominal dc voltage to transmit is 110 kV.The HVDC transmission system rated at 117 MW is modeled and simulated in PSCAD/EMTDC to study the power loss of HVDC transmission system as shown in Fig. 4. The parameter of HVDC transmission model can be found on Table II.

TABLE II: Model Specification of Simulated HVDC Transmission System.

Parameter	Value
Steady state frequency	50 Hz
Rated power	117 MW
Rated AC voltage (L-L RMS)	115 kV
Transformer ratio	115 / 62.5 kV
Cable length	50 km, 100 km, 150 km
DC-link capacitor	500 μF
Switching frequency	1650 Hz

B. Loss calculation

$$P_{loss,CS1} = GenP - P_{bfTransmission}, \tag{6}$$

$$P_{loss,DCcable} = P_{bfTransmission} - P_{AfTransmission}, \tag{7}$$

$$P_{loss,CS2} = P_{AfTransmission} - RevP, \tag{8}$$

$$\text{Total power loss} = P_{loss,CS1} + P_{loss,DCcable} + P_{loss,CS2}, \tag{9}$$

where $GenP$ is generated output power, $P_{bfTransmission}$ is the power measured after passing through converter station1(CS1) $P_{AfTransmission}$ is the power measured after passing through the transmission cable, $RevP$ is the power measured after passing through the converter station2(CS2). The power loss % is calculated using (5).

C. Simulation result

The measurement results from simulation are shown in Fig. 5. The total loss of converter stations is 4.3 MW while the cable loss is 1.2 MW.

In Fig. 6, the power losses (%) are calculated with respective to the generator power, for different cable length. The cable loss slightly increases by 0.5% going from 50 km to 150 km, which is still significantly lesser than converter loss. The converter is seen to be the main contributor of power loss in the HVDC transmission system.

IV. Comparison of HVAC and HVDC transmission system

In Table III, the power loss of HVAC and HVDC transmission systems are simulated and analyzed based on components and distance.

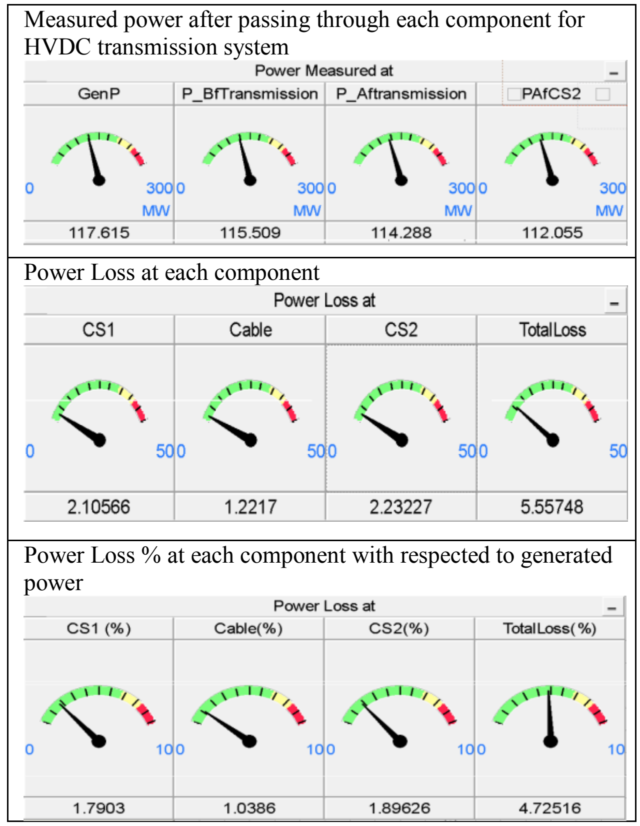

Fig. 5: Output Interface of HVDC Transmission Model for generated power 117 MW with 100 km cable length.

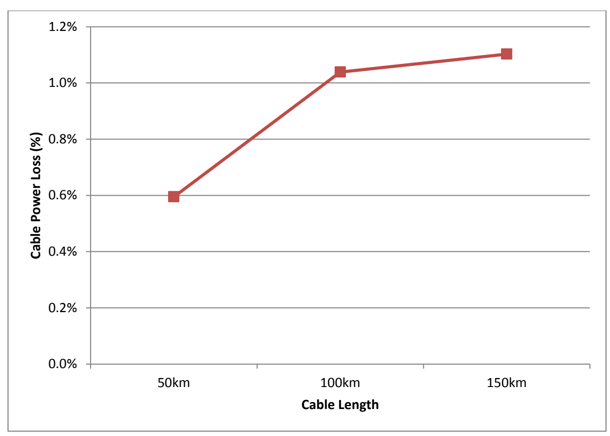

Fig. 6: Power loss % of cable with respect to generated power 117 MW with different cable length.

A. Loss contribution of components

The power loss contribution of each component in the overall HVAC and HVDC transmission systems is illustrated in Fig. 7. Cable has the highest participation of power loss for HVAC transmission system. For HVDC transmission system, converter stations result in the most of overall system loss.

B. Effect of changing cable length

Comparison of the power losses of HVAC and HVDC transmission systems based on different cable length is presented

TABLE III: LOSS % COMPARISON OF EACH COMPONENT FOR HVAC AND HVDC.

	117MW							
	HVAC				HVDC			
%	Components			Total Loss	Components			Total Loss
Cable Length	T1	Cable	T2		CS1	Cable	CS2	
50 km	1.6	2.21	1.49	5.3	1.77	0.59	1.93	4.26
100 km	1.61	5.31	1.25	8.04	1.79	1.04	1.9	4.73
150 km	1.62	16.28	1.1	19	1.78	1.1	1.89	4.77

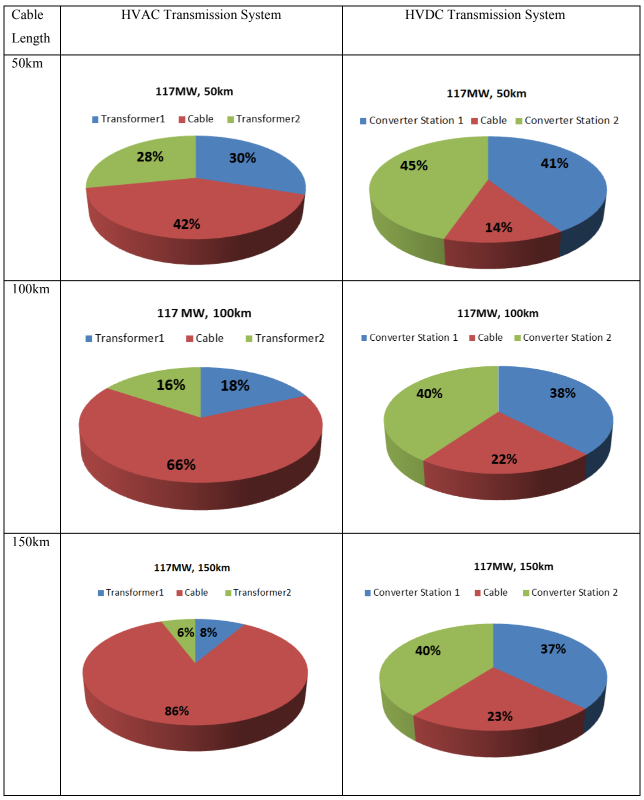

Fig. 7: Power loss distribution of each component to overall HVAC and HVDC system.

in Fig. 8. The power loss is calculated with respect to the generated power. When the transmission distance is longer, the resistance of cable becomes larger. The higher resistance leads to the greater losses in the transmission cable. Furthermore, it can be observed that the power loss of HVAC transmission system progressively increases from 8% at 100 km to around 19% at 150 km while the power loss of HVDC transmission system is still around 4%. Therefore, the HVDC transmission system has greater advantage in term of cable length. It is the optimal solution with lower loss for transmissions over long distance.

V. Conclusion

This research project aims to evaluate the different types of power losses for power transmissions through HVAC and HVDC systems. The conclusions drawn from the experiments done in this project are as follows.

The power losses of HVAC transmission system and HVDC transmission system are evaluated under different scenarios.

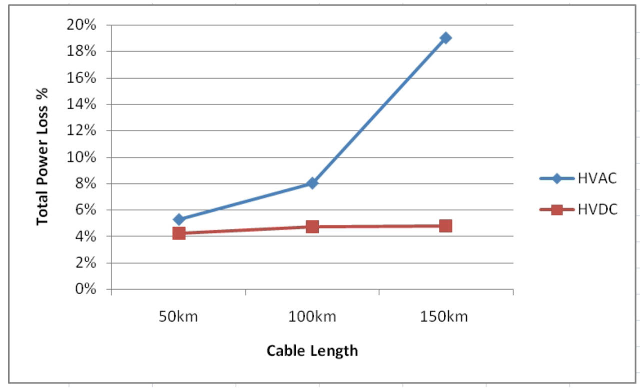

Fig. 8: Total power loss % of HVAC and HVDC transmission system for different cable length.

These experiments assist the users in analyzing HVAC and HVDC transmission efficiency. With the help of information on power loss in each component of these two transmission systems, evaluation of transmission efficiency can be done easily and the optimal transmission strategy can be decided accurately and straightforwardly.

In HVAC transmission system, the loss mostly occurs in transmission line whereas in HVDC transmission system, converters contributed the greatest amount of loss. There is no limitation to transmission distance to HVDC system due to the absence of reactive power loss. Thus, it motivates researchers to be more interested in HVDC system and to carry out further analysis on HVDC system.

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