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Future Generation of “HTS VSC-HVDC” Power System with PSCAD Application

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Abstract

This paper explained application of VSC-HVDC transmission system by using HTS DC cable for efficient power transmission [1]. Voltage source converter based high voltage direct current (VSC-HVDC) is feasible. Due to the use of pulse width modulation (PWM) concept in VSC-HVDC has number of potential advantages as compared with classic HVDC, such as short circuit reduction, rapid and independent control of active and reactive power, etc., and also with the advantages of high current capability, zero resistive loss, lowering voltage levels [2], and efficient system behavior by implementing HTS DC cable technology is evaluated through the PSCAD/EMTDC modeling and analysis. With those advantages HTS VSC-HVDC will likely be widely used in future transmission and distribution. Simulation results show that the proposed connection types of HTS VSC-HVDC are feasible and the characteristics of them are verified. The characteristic Analysis of HTS DC conductors are plotted using MATLAB and it’s comparison with respect to conventional copper conductor are studied.

Keywords: HTS VSC-HVDC, PSCAD/EMTDC Modeling, voltage source converter (VSC), (HTS) High temperature superconductors, HTS superconducting cables, MATLAB.

Introduction

HVDC was developed from technologies used in industrial drive systems. In order to obtain ideas on how HVDC can be developed, it is important to follow what is happening in that area. In industrial drives, the PCC (Phase Commutated Converter) technology that is presently used in HVDC has now almost totally been replaced by VSC technology. The fundamental difference between these two technologies is that

VSC requires additional components that can switch off the current, and not only turn it on as is the case with the PCC. As in a VSC, the current can be switched off, and there is no need for a network to commutate against it. In HVDC applications it could also be of interest to use VSC technology in order to supply “dead” networks, which are areas that lack rotating machines, or “weak” power systems that have excessively low short circuit power.

In 1956 forecast of WBI proposed that the 21st century is demanded by the high T_c superconductor (HTS) cables. This technology not for dedicated applications, already major countries like China, Germany, USA, Japan have been manufacturing Bi-HTS tapes for a few kilometers with a single length using the process of mechanical distortion and heat treatment. Power cables based on high temperature super conducting material have been developed for making of DC power transmission with the high transport current capability and low resistivity loss [1] as compared to conventional cables, so this is an alternative option to previous technical problems[2]. The comparison of HTS cable and conventional cables, and a virtual HTS VSC-HVDC system model presented in this paper. Comparison of transmission power characteristics are studied through MATLAB.

HTS VSC-HVDC Transmission System

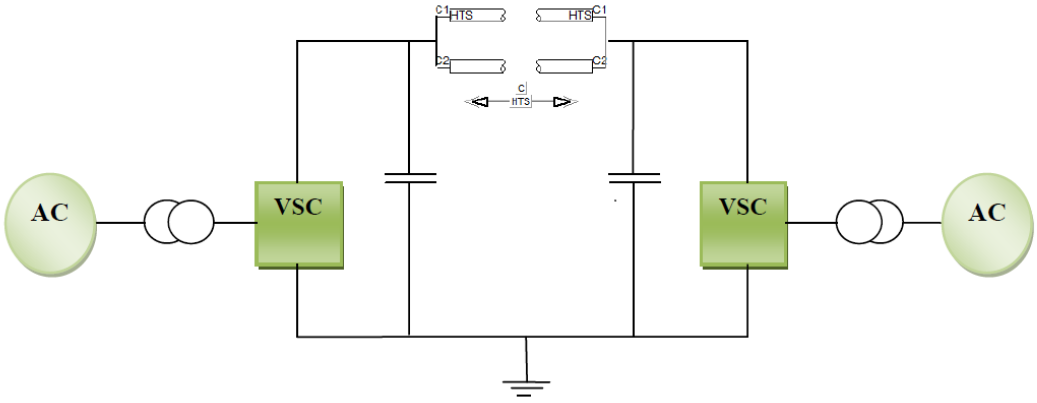


Figure 1

In Fig 2 represents the PSCAD/EMTDC equivalent model of power system interconnection. HTS VSC–HVDC is a mono polar system, which consist of equivalent 3-phase voltage sources, filters, 3-phase transformers, DC line, two 6-pulse converters which play a role of Rectifier or Inverter.

AC power system

Both side AC system is represented by 3-phase voltage source, which is described as equivalent voltage source and equivalent impedance. Therefore, we can reflect the characteristics of AC system that will be connected with HVDC system by properly inputting parameters like equivalent impedance, voltage magnitude, phase and frequency.

Converter

The VSC based HVDC mono polar transmission system mainly consisting of two 6-pulse converter stations connected by a DC cable (see Fig 2). Usually the magnitude of AC output voltage of the converter is controlled by pulse width modulation (PWM) without changing the magnitude of DC voltage [3]. However, the three level converter topology considered here, can also achieve the goal by varying the dead angle *B* with fundamental switching frequency. A combination of multi-pulse and three level configuration is considered for both VSC's to have 12-pulse converter with 3-level poles. Here the real power can be controlled by changing the phase angle of the converter AC voltage with respect to the filter bus voltage, where as the reactive power can be controlled by changing the magnitude of fundamental component of the converter AC voltage with respect to filter bus voltage. By controlling these two aspects of converter voltage operation in all four quadrants is possible [4]. This means that converter can be operated in the middle of the reactive power range near unity power factor to maintain dynamic reactive power reserve for contingency voltage support. It also means that the amplitude and phase angle of the converter AC output voltage can be controlled simultaneously to achieve rapid, independent control of active and reactive power in all four quadrants. The detailed three phase model of converter is developed by modeling the converter operation by switching functions.

DC transmission Line

Provided that DC transmission line is an overhead transmission line using superconducting cables, we use an overhead transmission line model in EMTDC library.

Transformer

In this study, 3-phase Y-Δ transformer is used as the converter transformer and saturation of transformer is not considered.

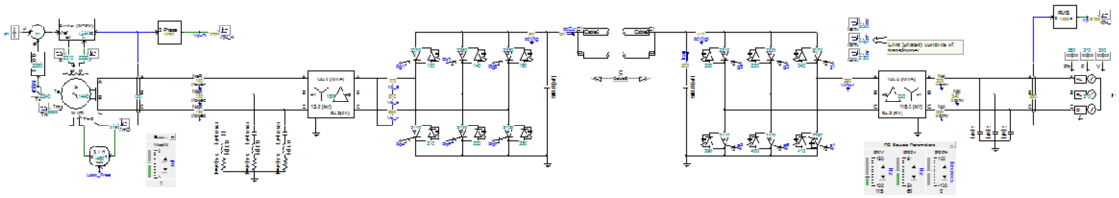


Figure 2: PSCAD/EMTDC HTS VSC-HVDC Transmission System Model.

Steady-state Characteristics of HTS VSC-HVDC Transmission

According to the PSCAD/EMTDC HTS VSC-HVDC system model shown in Fig 2. The pu current versus time characteristics and power characteristics in its steady state analysis shown in Fig 2(a & b), with the sending end and receiving end real power of

DC transmission system. Here the front segment of real power characteristics in Fig 2(a) is a ramped start-up and the next segment is the resuming process.

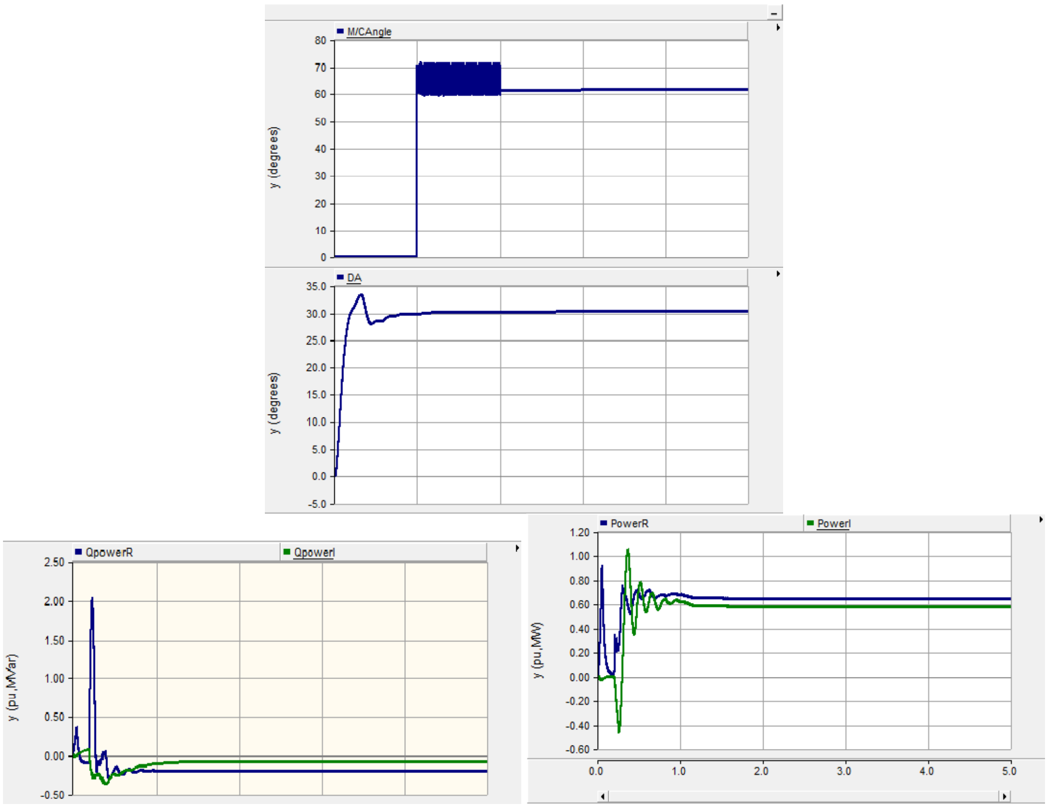
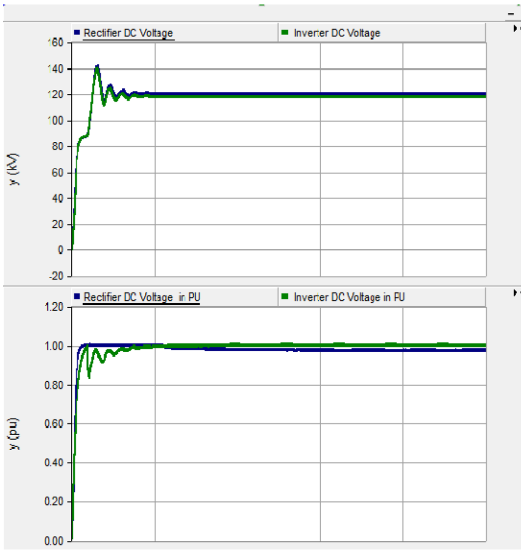


Figure 2(a): HTS VSC-HVDC (power & angle) Characteristics.



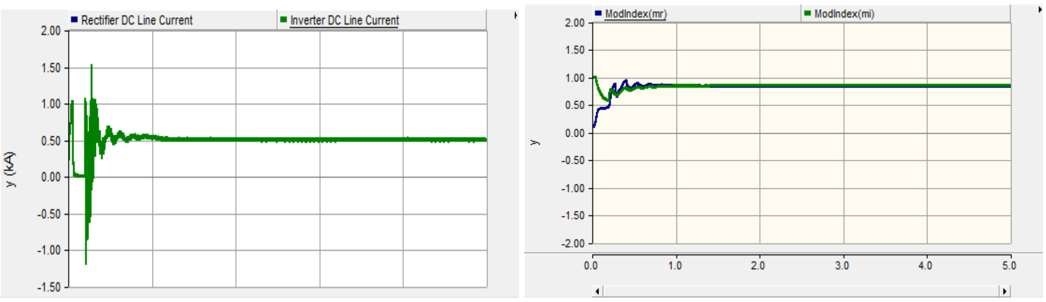


Figure 2(b): HTS VSC-HVDC (current & voltage) Characteristics.

The power obtained in the simulation process is the active power at the sending end (rectifier side) of AC system and receiving end (inverter side) of AC system. Normal voltage and current taken in the analysis and calculation and here from the output power curve, loss is obtained by subtracting sending end power and receiving end power of the system. The total power losses which include the loss consumed by the transformers, filters, converters and transmission lines.

HTS Cable System Principle Architecture Concept & It's Advantages

At present there are two principal types of HTS cable. The simpler design is based on a single conductor, consisting of HTS wires stranded around a flexible core in a channel filled with liquid nitrogen coolant. This cable design as in Fig 3(a) employs an outer dielectric insulation layer at room temperature, and is commonly referred to as a "warm dielectric" design. It offers high power density and uses the least amount of HTS wire for a given level of power transfer.

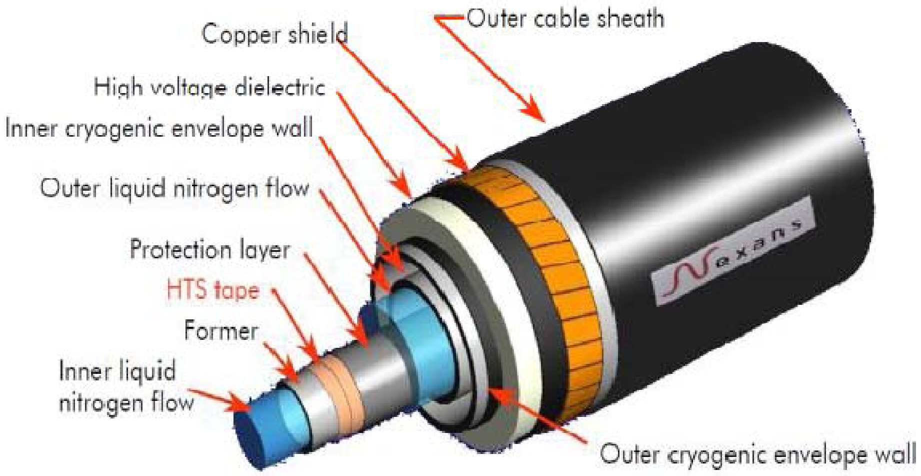


Figure 3(a): Single Phase warm dielectric Cable.

Drawbacks of this design relative to other superconductor cable: It is a ideal choice when electromagnetic stray field can be tolerated and a slightly lower transmission capacity than that of cold dielectric cable and higher electrical losses (and therefore a requirement for cooling stations at closer intervals), higher inductance, required phase separation to limit the effects of eddy current heating and control the production of stray electromagnetic fields (EMF) in the vicinity of the cable. This kind of warm dielectric HTS design is more desirable for medium voltage installation. a higher inductance when compared to a cold dielectric, it has it's place in applications where conventional cables have reached their limits but not all the features of a cold dielectric design are necessary, in such situations it can be the choice that makes the best economical sense, owing to it's simpler overall design, cheaper manufacture cost, reduced superconductor length.

An alternative design Fig 3(a) employs concentric layer's of HTS wire and a dielectric material, providing electrical insulation, compatible with cryogenic temperatures. Liquid nitrogen coolant flows over and between both layers of wire, providing cooling and contributing to the dielectric insulation between the center conductor layer and the outer shield layer.

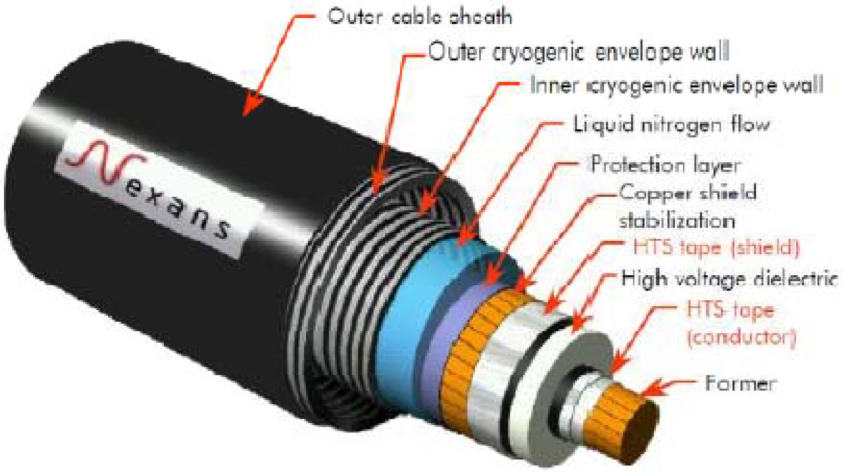


Figure 3(b): Single Phase Cold dielectric Cable.

As the dielectric material remains at about-200°C, this cable architecture is commonly referred to as a coaxial, "cold dielectric" design. The inner, high voltage layers of superconductor tapes are transmitting power while the outer layer's are grounded. In the outer layers, currents equal in magnitude but opposite in phase to the inner layer are being induced. these individual currents completely cancel the electromagnetic fields of the inner layers, so that a cold dielectric HTS power cable has no stray electromagnetic fields outside the cable, no matter how high it's current (and thus transmission power) rating. This is one of the key benefit of cold dielectric design. The fact that the electromagnetic field is contained inside the superconducting screen also significantly reduces the cable inductance, another important benefit of

HTS power cables. Such a cables including higher current carrying capacity, reduced AC losses, low inductance and the complete suppression of stray electromagnetic fields (EMF) outside of the cable assembly. The reduction of AC losses enables wider spacing of cooling stations and the auxiliary power equipment required to assure their reliable operation.

HTS Cable System Present Development

The growing availability of second generation high temperature superconductors (2G HTS) revolutionary are now being Considered. Today, the manufacture of high performance 2G HTS wire is underway. The fabrication technologies for 2G HTS materials have been progressing dramatically in the past few years with remarkable advancements in the metrics of the high current-carrying capability of 2G HTS wire, combined with its low cross-sectional area results in high J_c values compared to other available wires. In-magnetic-field performance and production throughput and costs. In order to function properly over the lifetime of the application, the 2G HTS wire must maintain its current carrying capability under the winding, thermal and magnetic stresses the coil experiences during fabrication and operation. The 2G HTS wire fabricated has the inherent advantage of a built-in structural element with its Hastelloy C276 substrate, eliminating the need for added external reinforcement. This has the added advantage of keeping the engineering current density high.

Power Loss Analysis (Copper & Bi-2223)

Conventional conductor are usually made of copper material and typical applications are cables, transformers etc,. Suppose we take a copper tape of 1-meter length and its resistance = 0.195Ω, dimensions are height and width as 0.22mm, 4mm respectively. So It's resistivity at room temperature is calculated by using the formula

$$\rho = [RA/L]- \tag{10}$$

Where R = Resistance, A = Area of cross-section, L = Length of copper conductor The resistivity ρ of a copper at a operating temperature 'T' are represented as

$$\rho(T) = \rho_0(1+\alpha(T- T_0))- \tag{11}$$

Where T is operating temperature, 'α' is the coefficient of temperature and ρ_0 is the resistivity at temperature T_0

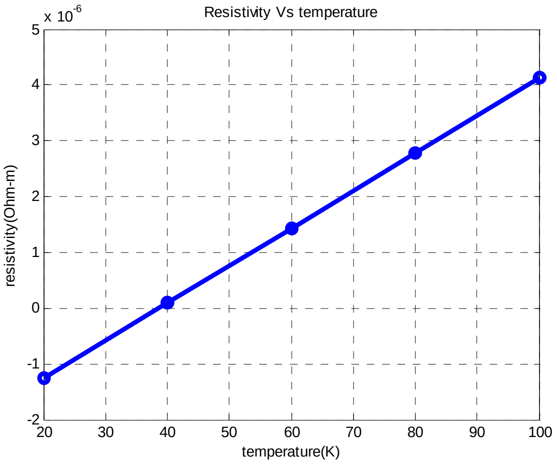


Figure 4(a)

The linear characteristics, resistivity versus temperature for a conventional copper conductor of 1-meter length are shown in above Fig 4(a). The power loss of this conductor based on resistivity measurement and it is expressed as ‘P_{cu}’, the conventional copper conductor power loss per meter length is

$$P_{cu} = \rho(T)\ J_c\text{-}[mW/m]\text{-} \qquad (11)$$

with the current density ranges from 1-4 A/mm^2. And the power loss characteristics are shown below Fig 4(b).

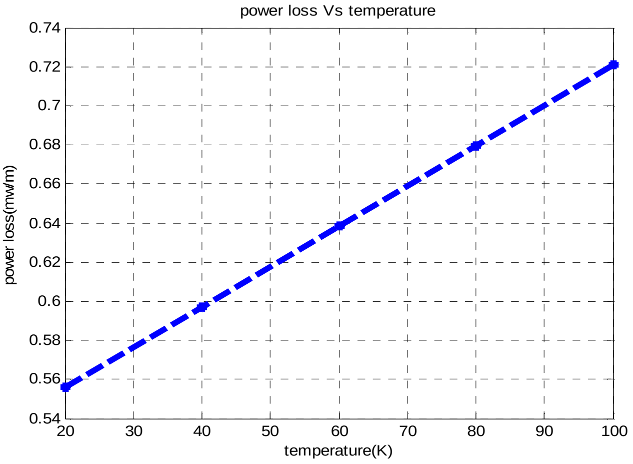


Figure 4(b)

The purpose of using Bi-2223 HTS cables as transmission conductors in HVDC system is to reduce the power loss on transmission side. The energy loss in a dc HTS conductor is negligible, if it is operated under its high critical current but it should not be a practical case, there should be some negligible loss (compared to other losses) exists. Here we consider

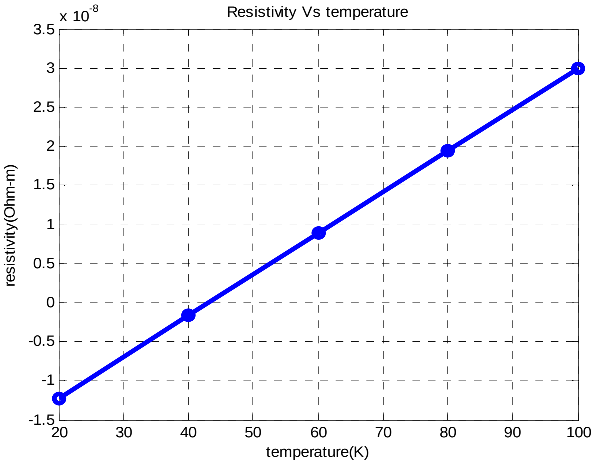


Figure 5(a)

Bi-2223 HTS tape of 1-meter length with the same dimensions of conventional copper conductor and resistance as 0.0015Ω. The loss of a HTS conductor is dependent on resistivity at a operating temperature T, and it's resistivity, power loss characteristics as shown above Fig 5(a), Fig 5(b)

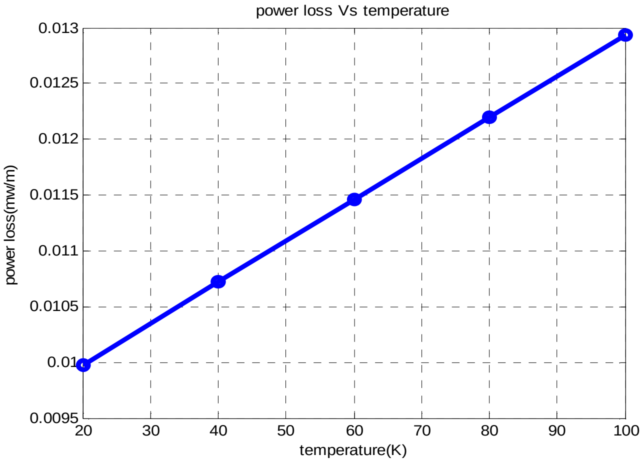


Figure 5(b)

And also it will produce some extra energy losses when it is exposed to an AC magnetic field. The AC magnetic field generated by a high transport current or some other external nature activities like radiations, atmospheric temperature etc. so generally it's called as heat losses, it is essential to remove these heat losses a cooling system is employed in the use of superconductors in power system applications. The amount of cooling is used to reduce this heat loss at a operating temperature of superconducting cable is based on cooling penalty factor and it is represented as 'η_{cp}' and is given by

$$\eta_{cp} = (\eta_{carnot}/\eta_{cooling})- \tag{12}$$

Here $\eta_{cooling}$ & η_{carnot} is the efficiency of cooling device and carnot factor. The variation of cooling penalty factor with respect to operating temperature is shown in below characteristics Fig 6. We observe that the characteristics cooling penalty factor increases with the operating temperature from right to left that is from 77K to 60K. We know that critical current density for HTS conductor increases much more in this interval.

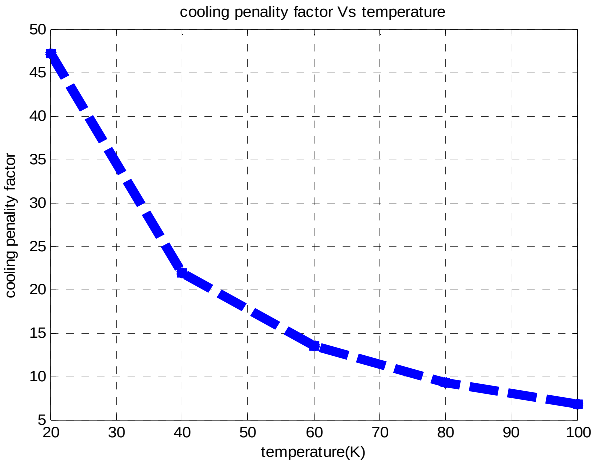


Figure 6

Power Loss Comparison

Energy loss for both conductors, HTS conductor and conventional copper of meter length as shown in Fig 8. We observe that the fig power loss of HTS conductor has several times of copper conductor with the same transport current capability. Power loss comparison of conventional conductor and HTS conductor are shown below Fig 7.

The first dashed line represent the energy losses in conventional conductor and 2ed dashed line represent the acceptable energy losses in HTS conductor those energy losses comparison has been represented from 2% of conventional energy loss with the same transport current capability.

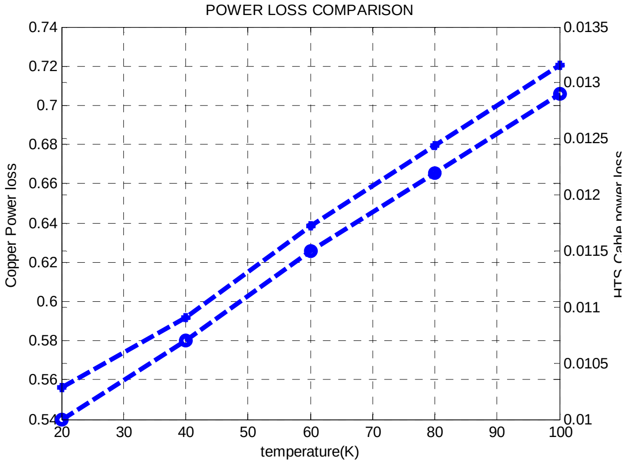


Figure 7

Conclusion

Here in this paper both real and reactive power controlling using PWM concept In VSC technology, HTS cable used for DC power transmissions has supreme electricity performance identified by analyzing the virtual DC power transmission system model using PSCAD/EMTDC and it's analysis. And also analyzing the comparison of both 1-meter length of conductors (copper & Bi-2223 HTS).

Future Work

The world wide average survey report on 2020, the initial phase of a HVDC transmission network is put into place. Development of long distance HVDC links underway.

The world wide average survey report on 2030, a number of transmission interconnectors have been converted to HVDC, providing significant reduction in losses. The construction of a national power grid's is underway, consisting of a series of HVDC interconnectors linking large scale solar stations across the country. Smart grid technologies are fully implemented.

The world wide average survey report on 2030+ Most large scale transmission interconnectors are High Voltage Direct Current (HVDC), providing significant reduction in losses. National HVDC grid connecting east and west coast allows major solar and geothermal plants to supply the country. Development of HVDC links to South East Asia allow export of renewable electricity.

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