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Compensation of Low Frequency AC Overhead Transmission Lines Using STATCOM

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Abstract- Voltage instability is one of the major issue in HVAC power network operating at 50 Hz frequency due to limited power transfer capability and distance limit. The stable operation of power system must be kept within limits to increase the efficiency of power transmission system. In this research Low Frequency AC (LFAC) transmission system has been proposed as a new power transmission technology to reduce the losses of transmission network and controlling the reactive power using Flexible AC transmission device. A LFAC Transmission lines operates at 16.7Hz frequency for transmission of power from source to load and use two Frequency converters at source and load side. The normal operation of power system depends on the reactive power flowing through the power transmission lines, which can be adjusted by a flexible AC transmission device; Static synchronous compensator. LFAC transmission lines with STATCOM controller improve the Power system voltage stability under various disturbances and enhance the power transmission capability as compare to HVAC transmission. The simulations are done in Matlab Simulink 2017a .The Output of Matlab Simulink model shows that voltage will become Stable and reactive power is compensated for best performance for power system.

Keywords-*Low Frequency AC (LFAC) Transmission, Power System Analysis, Back to Back Frequency Converter, Static Synchronous Compensator (STATCOM)*

I. Introduction

Power system is a multi-part system comprise of generators, transformers, transmission lines and diverse types of active and passive loads. Due to the increase in need of electrical power loading of HVAC transmission lines is increases and problem of voltage stability arises. Conventional HVAC transmission system with frequency 50 Hz is commonly used to transmit the power from generating station to consumer using three phase system [1].

The major drawback of HVAC transmission is that due to reactive components of transmission lines large reactive power is generated which raise the losses and reduce the power carrying capacity of power lines. High voltage AC transmission is well proven transmission system with high reliability and easy to transform voltage levels, but the cost of transmission increases noticeably as the distance expands, and stability problem [2]-[3]. So HVAC transmission is suitable for short distance power transmission. Due to limitations of HVAC, High Voltage DC (HVDC) transmission line operating at 0 Hz frequency is suggested as a new substitute technology for power transmission to long distance. HVDC is cost effective to transmit power over long distance. Due to zero frequency of transmission system reactive losses are removed and power carrying capacity of line is increased over long distance but the transmission cost increases for short and medium Distance [4].

In this paper LFAC system working at 16.7 Hz has been proposed as a substitute to HVDC and HVAC for the renewable energy sources and medium distance transmission in terms of reliability, economy and power loss. The idea of LFAC transmission system was first proposed by Funaki in [5].A low Frequency Transmission system reduces the losses of transmission lines, expands the power transfer capability and small amount of reactive power compensation required. Furthermore, HVAC transmission technology can be applied to LFAC framework straightforwardly excluding circuit breakers and transformers. LFAC transmission system combines the best of HVAC and HVDC to transmit power at a frequency, lesser than 50Hz with the advantages of high stability and power transfer capacity [6].The power electronic frequency converters are used in LFAC transmission system to decrease the frequency at generation side and also to convert low frequency to normal HVAC 50 Hz frequency at grid side shown in figure.1. Mainly, the frequency converter must be able regulate the frequency, voltage, reactive and real power, while working in abnormal conditions, While also operating under abnormal conditions [7]-[8].

For Reactive power compensation STATCOM is used along with low frequency transmission lines to increase the controllability, stability and power transmission ability of power system for best performance of existing power network [11]. Fixed synchronous compensator (STATCOM) is an emerging FACTS controller; connected in parallel to transmission lines deliver the necessary reactive power according to the requirement of power system for optimum performance. This device is attached mostly at center of the transmission lines through coupling transformer because voltage variations at center of transmission lines are more. This model uses the voltage source converter and STATCOM consist of voltage source inverter, coupler transformer, and control unit and dc energy storage element. VSI is the core element of the STATCOM based on three phase IGBT which is utilized to transform the DC voltage into AC. The output voltage of voltage source Inverter decides whether the re-active power is consumed or generated by the device.

The simple block representation of the LFAC system with compensation device is shown in figure 1.

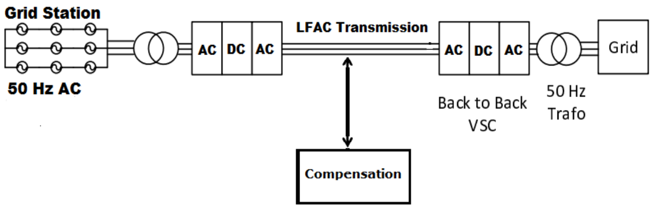

Figure 1. Block Representation of LFAC transmission with STATCOM

II. LOWFREQUENCYACTRANSMISSION SYSTEM

LFAC transmission system is used to decrease the inductive losses of transmission network and enhance the power system reliability and stability. The impedance is proportional to the frequency of the power transmission lines, so by the use of lower frequency reactive power losses also drop off [9]. By using a lower frequency, the reactive power is proportionally minimized.

$$V_r = V_s Cos\delta - \frac{X}{Vs} Q_L \tag{1}$$

$$P = \frac{V_S \times V_R}{X} Sin(\delta) \tag{2}$$

Equation (1) shows Voltage stability depends on reactive power when load increase reactive power Demand increase and receiving end circuit breakers. By using a lower frequency, the reactive power is proportionally minimized.

$$X_L = 2\pi f L \tag{3}$$

Where total inductance of the line is L, declining the frequency of the transmission will increase the transmission capability proportionally.

The main components of LFAC system are Ac source, AC-DC-AC frequency converter, control system and AC GRID as shown in figure 1. The power electronic frequency converters are used in LFAC transmission system to decrease the frequency at generation side and also to convert low frequency to normal HVAC 50 Hz frequency at grid side.

Two back to back frequency converters are essential to transform the frequency to LF and back to 50Hz. For LFAC transmission line power loss calculation two bus system is considered where impedance and Admittance is given by z and y, the π-model parameters for 200 km long lines are:

$$Z' = Z_c \sinh(\gamma l) = \sqrt{\frac{z}{y}} \sinh(\gamma l) \tag{4}$$

$$Y'/_2 = \left(1/_{Z_c}\right) \tanh\left(\frac{\gamma l}{2}\right) = \sqrt{\frac{y}{z}} \tanh\left(\frac{\gamma l}{2}\right) \tag{5}$$

Assuming the grid side voltage is $V_S = V_S\angle 0$, the receiving side voltage is $V_R = V_R\angle\theta$ and supplies to load is S = P +jQ. Thus Power loss of transmission line depends of load condition and operating frequency, when frequency is reduced voltage profile of power system improved. Design procedure of LFAC transmission scheme and stability analysis is verified by using MATLAB /Simulink. Thus, for medium transmission lines LFAC system seems to be a viable solution.

III. FREQUENCY CONVERTER FOR LFAC TRASMISSION

Low frequency high voltage transmission works at a low frequency 16.7 Hz thus require frequency converters to step up and down the frequency to and from the typical HVAC frequency. The power electronic frequency converters are used in LFAC transmission system to decrease the frequency at generation side and also to convert low frequency to normal HVAC 50 Hz frequency at grid side. The investigation of power electronics frequency converters for the LFAC transmission is concentrated on its feasibility, instead of considering the high efficiency in power transmission system. There are different types of frequency converters suggested for the LFAC transmission application include matrix frequency converter, cycloconverters, and Back to back frequency converters discussed in [6]. Mainly, the frequency converter must be able regulate the frequency, voltage, reactive and real power, while working in abnormal conditions.

A usual configuration of a back to back (BtB) converter is presented in Fig. 2. It consists of two back-to-back connected converters that convert AC into DC and DC into AC through a mutual DC connection with the desired output frequency. A Pulse width modulation (PWM) technique is utilized to adjust the output of the converter by sending the signals to the correspondent electronics switches. The key advantages of BtB converter are freedom to regulate the frequency, voltage of power transmission, regulate the real and reactive power, size is small and high reliability as compare to others.

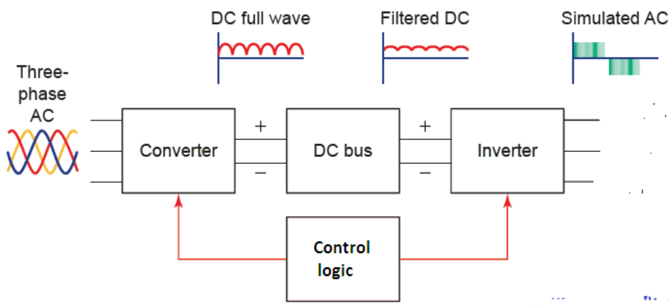

Figure 2. Block Representation of back to back converter

Based on primary analysis, BtB converters have enhanced performance due to efficient control of transmission voltage, frequency, power flow and ability to synchronize the low frequency transmission system with traditional 50 Hz AC grid. The input AC to DC converter is built with a diode rectifier, whereas the output circuit consists of transistor inverter. This solution is dedicated to high power systems. Back to back converter arrangement with its equivalent capital costs, better reliability, small filter required and less necessity of reactive power compensation makes the Back to back frequency converter a better option for LFAC as compare to other converters.

In LFAC transmission system Output of frequency converter at receiving end side needs to be synchronized with AC grid in reference of voltage magnitude, frequency, and phase. To synchronize the fluctuating output of frequency converter with AC grid Phase lock loop (PLL) technique is utilized for matching the voltage magnitude, phase-angle of grid and low frequency transmission system. A PLL is a closed loop control system consists of low pass filter, phase detector, and voltage controlled oscillator which is used to adjust the phase and frequency with respect to reference input signal.

IV. COMPARISON OF BETWEEN CONVENTIONAL AND PROPOSED MODEL

Modern HVAC power system is become more and more difficult due to load changing and other symmetrical and unsymmetrical faults. So the present power system is facing challenges. Due to the complexity of power system it's difficult for existing transmission lines to support the growing power demand. To satisfy the increasing power demand power system needs to retain the voltage stability and reactive power flow over the transmission line.

The Low Frequency transmission lines with STATCOM controller is used to operate the power system within limits to meet the power demand, reduce the inductive losses of transmission lines under faults conditions and increase the power transfer capability of the system. The comparison between conventional and proposed model is shown in table 1.

TABLE I. COMPARISON OF HVAC AND LFAC

Fault Type	Voltage stability Analysis		
	Rated voltage	HVAC	LFAC
P-G	1 pu with 5 % tolerance	0.85 pu	0.96 pu
P-P	1 pu with 5 % tolerance	0.66 pu	0.76 pu
3 P-G	1 pu with 5 % tolerance	0.30 pu	0.48 pu

From the simulation results of LFAC transmission it can be seen that when frequency reduce voltage approximately stable to rated value when fault occurs in the transmission line and current increases as compare to 50hz transmission. Therefore, LFAC transmission method is an innovative methodology for enhancing the power transmission capability, the findings shows that as the frequency becomes smaller, the fault currents increase dramatically and Power system stability is better as compare to 50 Hz transmission system.

V. SIMULATION DESIGNS

Simulation of 50 Hz AC and 16.7 Hz low frequency AC transmission system with FACTS controller is done using MATLAB SIMULINK Power Systems Analysis Toolbox software. These simulations and results are used for stability analysis and performance of power system during normal and fault conditions. Fixed synchronous compensator (STATCOM) is an evolving FACTS controller, connected in parallel with transmission lines; provide the necessary reactive power according to the requirement of power system for optimum performance. This device is attached mostly at center of the transmission lines through coupling transformer because voltage variations at center of transmission lines are more. Power generating station generates 50 MW, which is transmitted to 200km distance grid station. The rated voltage of transmission line is taken as 132kV. The rated voltage of grid station is 18kV line to line. Simulation results are shown for the 16.7Hz LFAC transmission system.

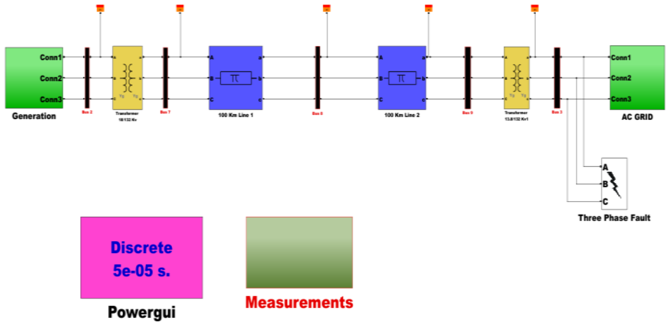

Figure 3. Simulink model of HVAC system at 50 Hz

Low frequency high voltage transmission works at a low frequency 16.7 Hz thus require frequency converters to increase and decrease the frequency to and from the typical HVAC frequency. The power electronic frequency converters are used in LFAC transmission system to reduce the frequency at sending end side and also to step up back to typical frequency of the grid station.

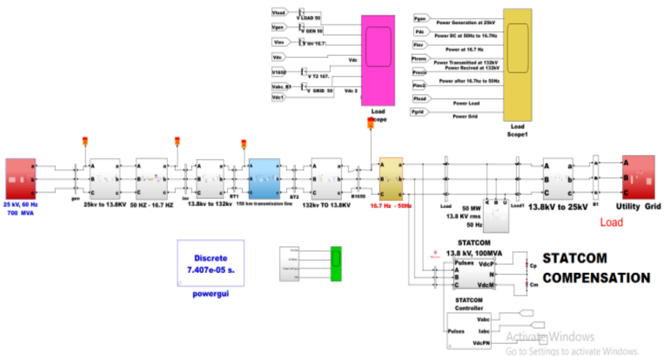

Figure 4. Simulink model of LFAC system at 16.7 Hz

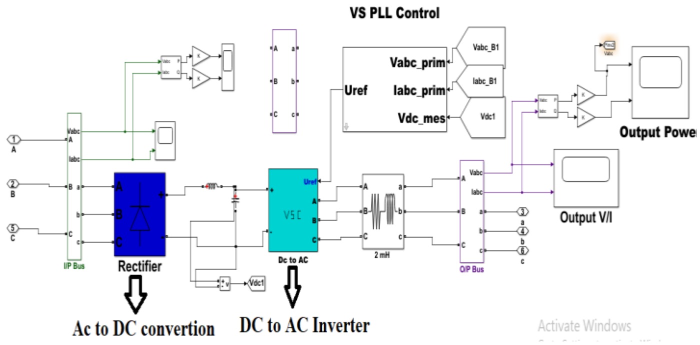

Figure 5. Simulink model of receiving side frequency converter with PLL control

Following are simulations results of the HVAC and proposed model LFAC transmission system with power compensation device in MATLAB software. The simulation is carried out and result is analyzed for voltage stability of power system.

Results of HVAC transmission shows that during load changes or faults in power system receiving voltages are reduced and current increases that are not acceptable in power system and affect the stability of power system. Under normal conditions line voltage and current waveforms at receiving side and the grid side of the frequency converter side and at 50Hz grid station under normal circumstances are shown in figure 6 and 7.

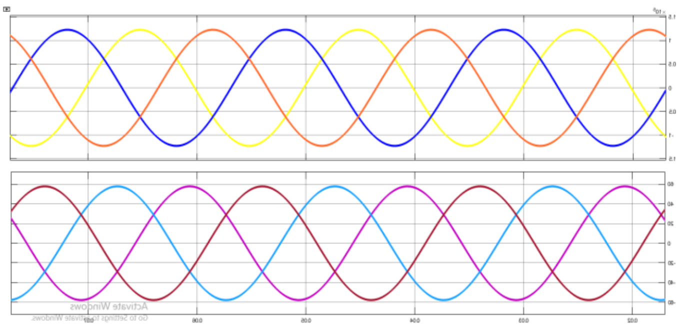

Figure 6. At grid side Voltages and currents of HVAC system

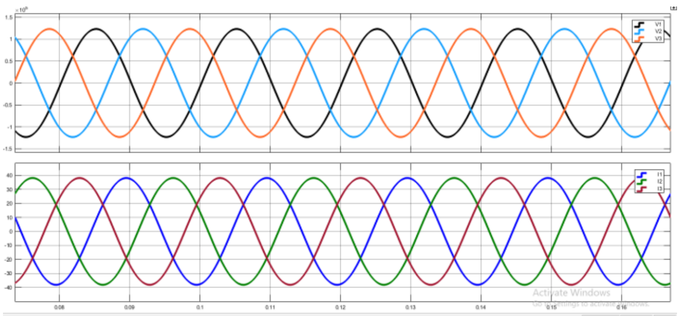

Figure 7. At receiving end side 132 KV voltages and currents of HVAC system

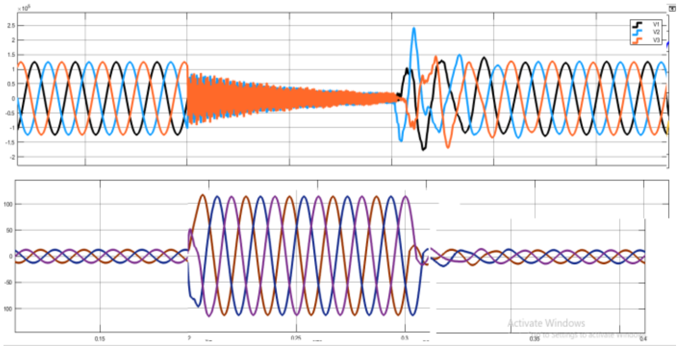

Figure 8. Voltages and currents of HVAC during three phase fault

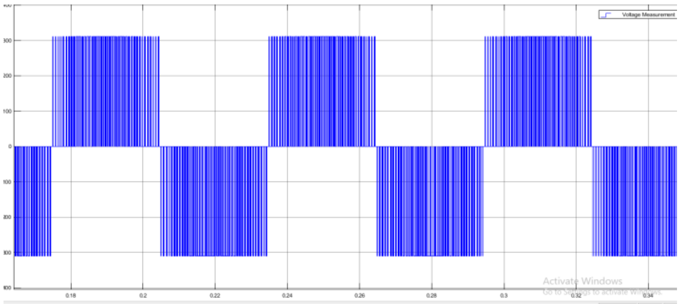

Figure 9. Sending side Frequency converter output voltages and currents without filters of LFAC

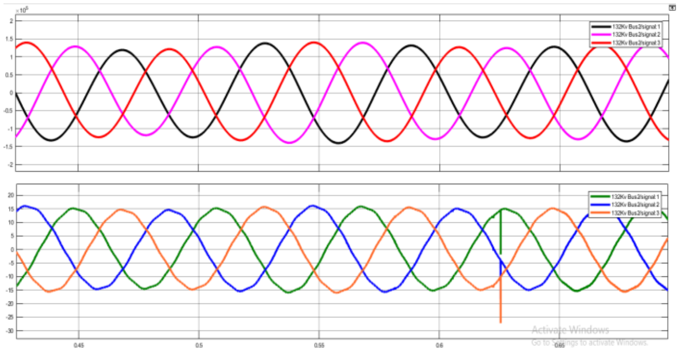

Figure 10. Sending side Frequency converter 132Kv output voltages and currents with filters of LFAC

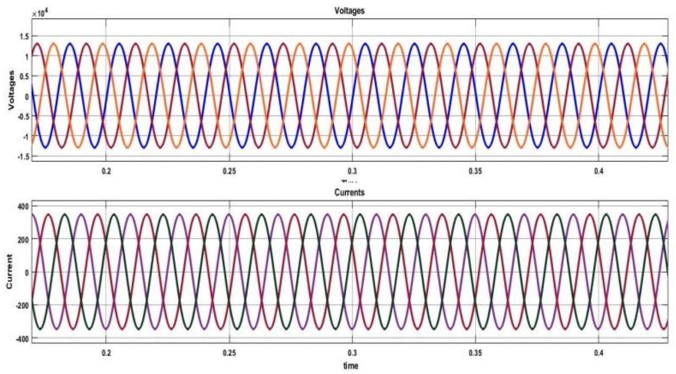

Figure 11. Receiving side Frequency converter output voltages 13.8 KV and currents of LFAC

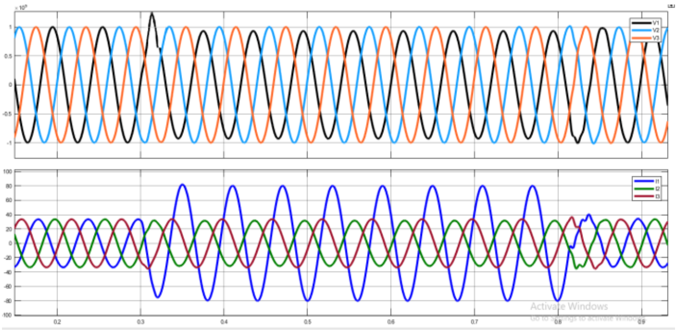

Figure 12. Phase to ground fault in LFAC transmission network

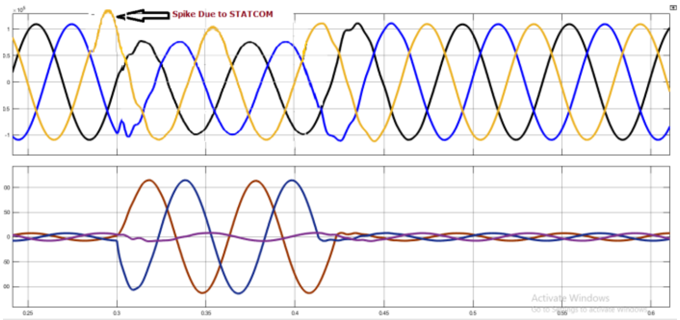

Figure 13. Phase to ground fault in LFAC transmission network

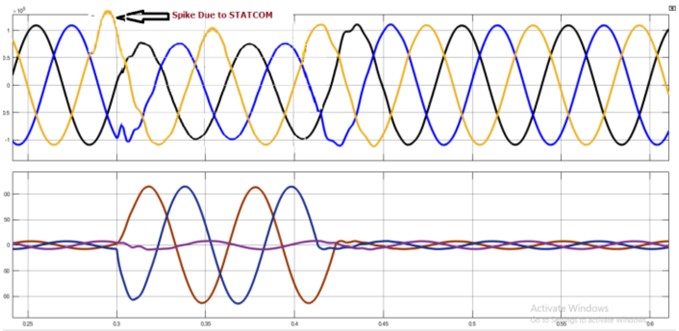

Figure 14. Phase to Phase fault in LFAC transmission network

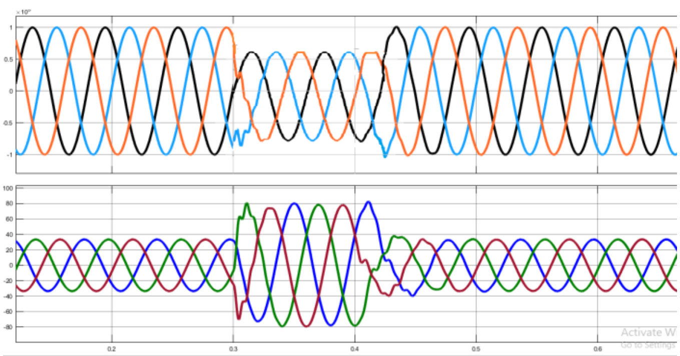

Figure 15. Three Phase fault in LFAC transmission network

From the above voltage and currents waveforms of LFAC transmission it can be seen that when frequency reduce voltage approximately stable to rated value when fault occurs in the transmission line and current increases as compare to 50hz transmission.

When the load demands increase, which makes total load in the system to increase, the voltage magnitude in the 50 Hz system is dropped to 0.9450 Pu below the lower limit. The 16.7 Hz system is less sensitive, or more stable, with load variation when the voltage magnitude is 0.9784 pu. LFAC transmission system increases the power transfer capability over long distance and more robust compared to the 50 Hz transmission system in terms of voltage stability as shown in figure 16.

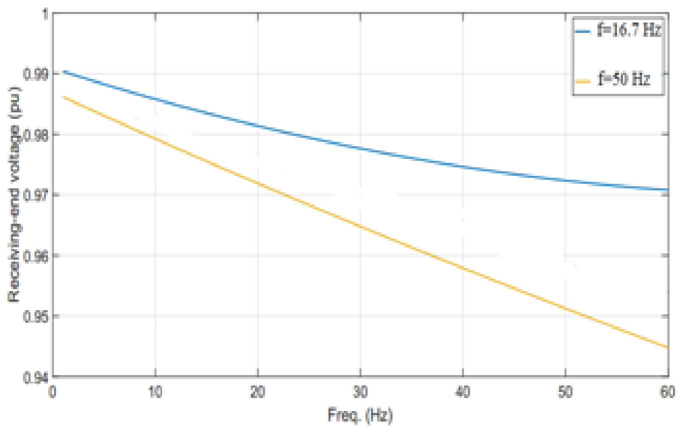

Figure 16. Voltage Stability Comparison of HVAC and LFAC AC transmission under load changing

VI. Conclusion

Low Frequency AC transmission working at 16.7 Hz is new alternative technology to HVDC and HVAC in terms of efficiency, power loss, and economy for medium distance transmission and renewable energy sources. Compensation of low frequency ac transmission using STATCOM device is used to decrease the transmission line losses and boost the power transmission capacity of transmission network to sustain the stability of power system. FACTS devices are supportive for sustaining voltage stability during load deviation. Simulation and analysis of LFAC network and its elements are confirmed by using MATLAB Simulink software. Simulation results have shown that the LFAC has superior performance compared to the 50 Hz system in terms of reactive and real power transfer capability. LFAC transmission system also reduces the operational and installation cost, and shorter maintenance time is required.

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