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Analysis of Fractional Frequency Transmission System

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Abstract— The fractional frequency transmission system (FFTS) is a newly developing concept in power transmission system. In this system, electrical power is transmitted at a reduced frequency i.eOne third of the rated frequency.This approach would be effective in long- distance transmission system . Transmitting power at a reduced frequency reduces the electrical length of the transmission line (i.e., more amount of electrical power can be transmitted using the same length of the line at reduced frequency than at rated frequency).This paper introduces the basic concept of FFTS and primary results.The simulation model of FFTS and conventional 50 Hz system is developed in Simulink platform of MA TLAB and stability is assessed under different contingencies. The results show that, rotor swings of FFTS are compatible with conventional 50 Hz system. Lastly, comparative analysis of design parameters of FFTS and conventional one is presented. Synthesis approach is used for evaluation of design parameters.

Index Terms—fractional frequency transmission system (FFTS), frequency converters, long-distance power transmission.

1 Introduction

Increasing power transfer capability and improving voltage profile of the line is always the motivation for power system engineer [2]. In the history of ac transmission system, increasing line capacity mainly depends upon raising voltage level of the transmission line. At present, the highest voltage level of ac power transmission line is 750 KV Further upgrade encounters difficulties of material and environment issues. The High-Voltage Direct Current (HYDC) transmission that has no stability limit was once became another approach to increasing electricity transmission capacity. However, the current converters at two ends of the HYDC are very expensive. In addition, up to now, the HYDC practices have been limited to the point-to-point transmission. It is still to operate a multi terminal HYDC system.

As population of India is 1.34 billion this is almost 17.86% of world population. India's installed generation capacity is 330.26 GW (as on 31st May 2017). Generation capacity fail to feed required demand of power. Hydro power is the largest renewable energy source due to large availability at north-east region. To fulfill power requirements, generating power in north-east region and transmitting it to large load areas like, metro cities is good solution. But again, increasing power transfer capability and improving voltage profile of the line is challenging to the power system engineer. The AC electricity supplied by utilities has two basic parameters: voltage and frequency. After the invention of transformer, different voltage levels could be used flexibly in generating, transmitting and distributing electricity to guarantee efficiency for different segments of the power system. Before the inventions of modern electronic techniques, it is difficult to transform frequency than to transform voltage. As new materials and power electronic techniques continuously advance, different kinds of large frequency changes are developed rapidly. This trend may possibly lead to more reasonably selecting different frequencies for electricity transmission and utilization. For instance, the lower frequency electricity can be used to transmit larger power for longer distance, and the higher frequency electricity can be used more efficiently to drive the electric tools.

The fractional frequency transmission system (FFTS) is a very promising long-distance transmission approach, which uses lower frequency (50/3 Hz) to reduce the electrical length of the AC power line, and thus, its transmission capacity can be increased several fold.

2 Principle of FFTS

For the long-distance AC transmission, the thermal limitation is not a significant hindrance. Its load ability mainly depends on the stability limit and voltage drop limit. The active power transmitted via the AC transmission line is given by,

$P_{max}=\frac{sVR}{x}\sin\delta$…. (1) Where,

Pmax= Maximum Power Transmitted

VS = Sending end voltage

VR = Receiving end voltage

δ= Transmitting angle

X = Transmission line reactance = 2πfL

L = Total inductance of transmission line

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F = Transmission Frequency The stability limit of an AC transmission line can be approximately evaluated by equation (1). We can see from above equation that transmission capacity is proportional to the sending and receiving end voltages and inversely proportional to the reactance of transmission line. Therefore, in order to raise transmission capability, we can either increase the voltage level or decrease the reactance of transmission line. Since reactance of transmission line proportional to the transmission frequency, voltage level and transmission frequency are the two fundamental factors that affect the transmission capacity. Hence decreasing the electricity frequency f can proportionally increase transmission capability.

The voltage drop of a transmission line can be evaluated by

$$\Delta V \% = \frac{Qx}{V^2} \times 100 \dots (2)$$

Where,

Q = Reactive Power flow of transmission line

According to the equation (2), the voltage drop of the transmission line is proportional to the reactance of the transmission line. Reducing the transmission frequency will obviously improve the voltage drop. In the FFTS, the transmission frequency is usually chosen to be 1/3rd of the standardfrequency, and the reactance of the transmission line also correspondingly reduces to1/3rd of the original one. Consequently, the capacity of active power delivered throughthe AC transmission line will increase three times. Besides, the voltage drop of thetransmission line can be decreased to 1/3rd of voltage drop in the standard ACtransmission line.

3 Case Study

The line performance equations in terms of sending end and receiving complex power.

Based on the flowchart shown in figure 1, code is written in MATLAB and executed for frequency 50Hz and 50/3 Hz with the system given below.

Voltage=220kV
Length of Transmission Line= 250 km r= 0.05Ω/ph/km
l= 1.294mH/ph/km
c=8.942nF/ph/km
Pr=50MW

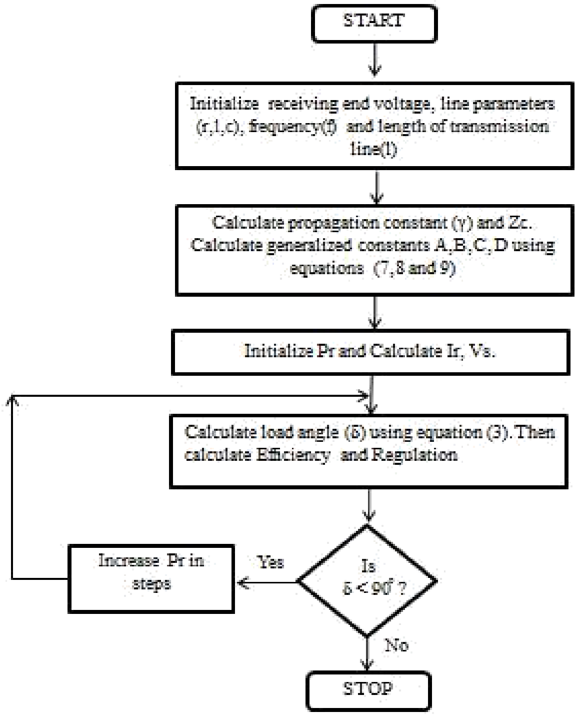

Fig.1: Flowchart for evaluation of performance oftransmission Line

1. **Power Transfer Curves:**

The Power angle curves of FFTS and conventional 50Hz line is as shown in fig.2From curves it can be seen that, power transferred across the line is more for FFTS line than conventional 50 Hz line for any operating condition.

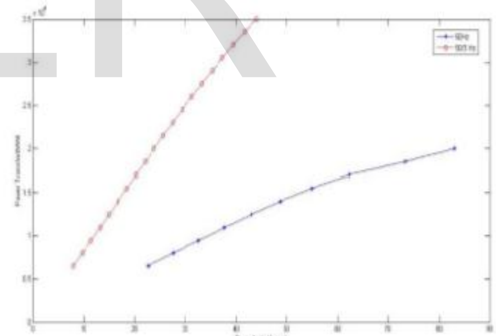

Fig.2: Power Angle Curves of FFTS and Conventional 50 Hz Line

2. Efficiency Curves:

The efficiency curves of FFTS and conventional 50Hz line is as shown in fig.3. From curves it can be seen that, efficiency of FFTS line is more than conventional 50 Hz line for any operating condition.

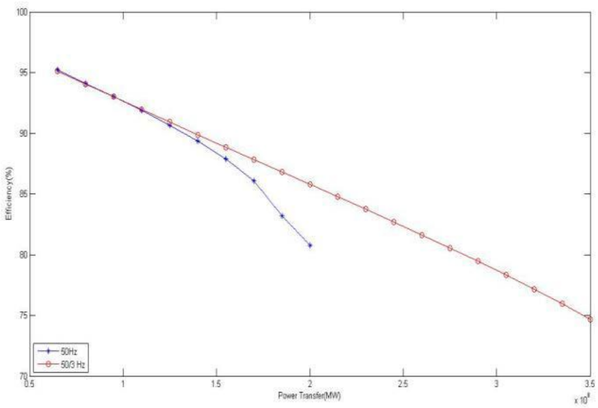

Fig.3: Efficiency Curves of FFTS and Conventional 50Hz Line

3. Regulation Curves:

The regulation curves of FFTS and conventional 50Hz line is as shown in fig.4. From curves it can be seen that, regulation of FFTS line is better than conventional 50 Hz line for any operating condtion.

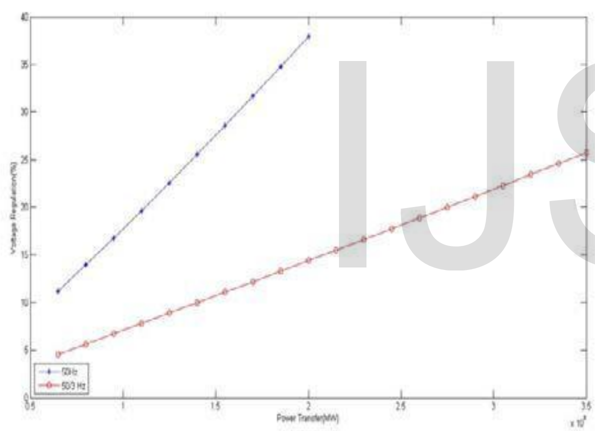

Fig.4: Regulation Curves of FFTS and Conventional 50 Hz Line

4. CASE STUDY II:

We know that, all the systems connected in an interconnected power system have to maintain synchronism with one another under contingencies. In this section stability study of FFTS is carried out under different contingencies and the rotor swings are compared with the conventional system to investigate the feasibility of FFTS.

The rating of phase shifting transformer and frequency changing transformer assumed for the development of simulation model is given in Table 1.Simulation model of FFTS is developed in the simulink platform of MATLAB as shown in figure 5.

Table 1: Rating of phase shifting transformer and frequency changing transformer

Component	Rating
Phase-Shifting Transformer	3 Phase transformer, 250MVA, 230kV/230kV. zig-zag star/star R=0.02pu, L=0.001pu, Rm= 500pu, Xm= 500 pu, f= 50/3 Hz
Frequency Changing Transformer	Units of 3 single phase transformer Each of rating 100MVA,132kV/132kV, Star/Delta R = 0.002pu, L=0.001pu, coreless resistance=300pu, Saturation characteristics [0,0;0.0024,0.8;1.0,1.2;1.5,1.4]

Table 2: Ratings of various power system components

Components	Ratings
Hydro-generator	3-phase,187 MVA, 13.8kV, r=0.02pu, x= 0.3pu, p=4, f=50/3Hz, H=3.7se, kd=32.5
Station Transformer	3-phase, 250MVA, 13.8/230kV,r=0.02pu, L=0.08pu, rm=300pu,xm=300pu,f=50/3Hz
Transmission Line	250km, r=0.050ohm/ph/km, L=1.29 mH/ph/km, C= 8.942 nF/ph/km
Infinite Bus	220kV,50Hz

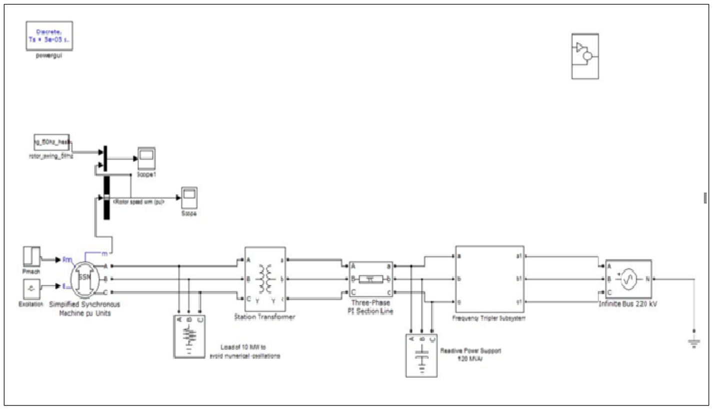

Fig. 5: Simulation Model of FFTS

Stability study is assessed neglecting speed governor and excitation control, so expecting a pessimistic result. So the mechanical input and excitation to the generator are assumed constant. A small 3-phase load is connected across the generator to avoid the numerical oscillation. Due to the flow of harmonic current in the system there is harmonic voltage drop and hence the voltage is found to collapse and this in turn reduces the required power transfer. To keep the voltage profile constant and to have a required power transfer a proper reactive power support is given at the end of the transmission line.

Stability Study is assessed under two contingencies as below;

A] Sudden Change in Mechanical Input:

Sudden change in mechanical input is simulated by step input block, which change the state from 1. 068 p.u to 1.4 p. u. in zero time at 2 sec from the simulation run. Due to sudden change in the state of the system it drives into transient condition and rotor swing obtained is as shown in Fig. 7.Excitation is kept constant. In similar manner the transient stability of conventional 50 Hz systemfor sudden change in mechanical input is performed and the result is shown in Figure 6.

The result shows that, the FFTS is stable for sudden change in mechanical input and is compatible with the conventional 50 Hz system.

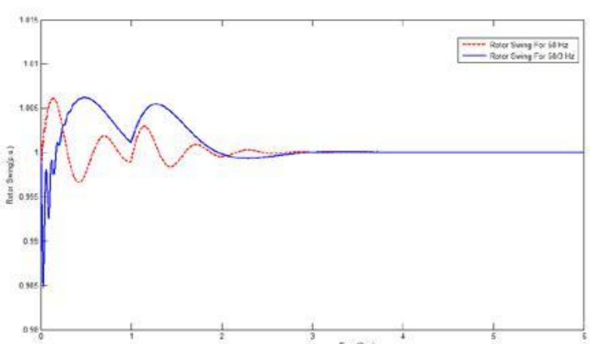

Fig. 6: Rotor Swing of FFTS and Conventional 50 Hz system for sudden change in mechanical Input

B] Introduction of Different Types of Faults:

Different Faults are introduced at the sending-end of the line at 2 sec from the simulation run and open at 2.05 sec. Due to change in the state of the system it drives into oscillation and the rotor swing obtained. Respective rotor swings for different types of faults as shown below;

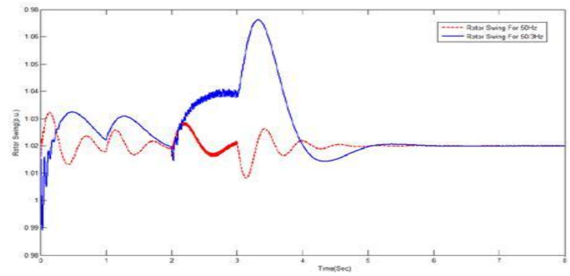

Fig. 7: Rotor Swing Curve of FFTS and Conventional 50 Hz System for LLLG Fault at the sending end

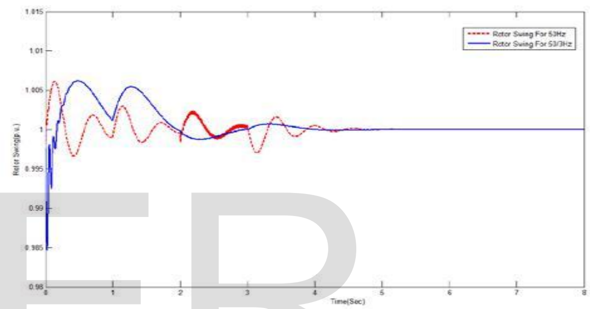

Fig. 8: Rotor Swing Curve of FFTS and Conventional 50 Hz System for LLG Fault at the sending end

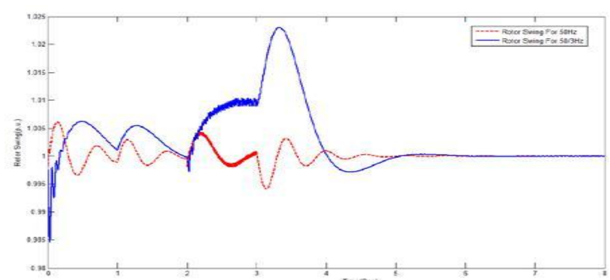

Fig. 9: Rotor Swing Curve of FFTS and Conventional 50 Hz System for LG Fault at the sending end

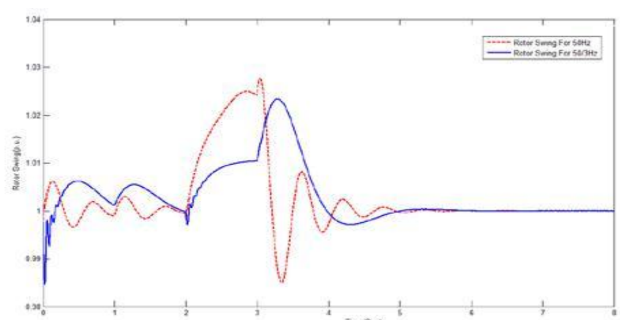

Fig. 10: Rotor Swing Curve of FFTS and Conventional 50 Hz System for LL Fault at the sending end

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The power loss in FFTS is less as compared to the normal transmission system .This can be proved by following formula

Where,

V=Phase voltage (rms Value)

Vd=disruptive critical voltage (rms value)

r=radius of conductor in meter

d=spacing between conductors in meter

f=frequency in Hz

From above equation corona loss is directly proportional to frequency. Hence, as frequency reduces the corona loss also reduces which in turn minimizes the power loss.

The result shows that, the FFTS is more stable for ground faults than line to line faults and is compatible with conventional system.

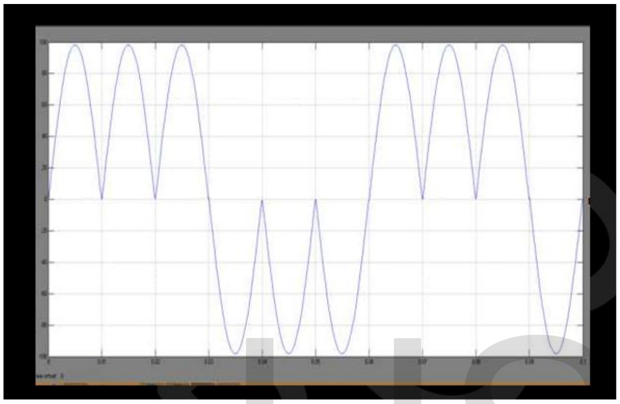

Fig.11: MATLAB Simulation of down-conversion (50/3Hz)

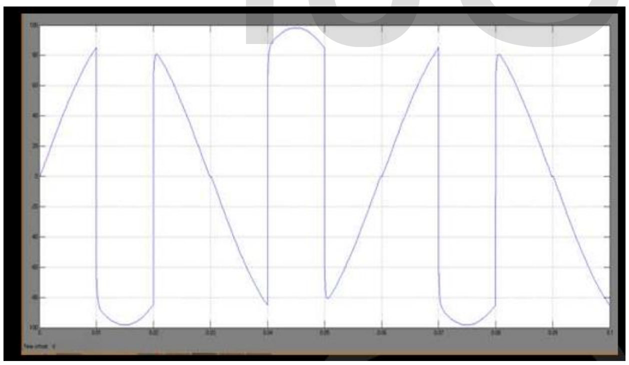

Fig.12: MATLAB Simulation of up-conversion (50Hz)

5 Conclusion

The 50Hz and 50/3 Hz system is studied in this paper. From results obtained we can say that power transfer capability, efficiency and voltage regulation characteristics are better for FFTS line than 50Hz system. Thus, this approach will be best alternative for the EHVAC or HVDC transmission system. Voltage profiles also get improved. In FFTS the receiving end voltage and power factor are within limits. From case study 2, it is concluded that, the FFTS can maintain synchronism in an interconnected power system and can be a part of it as conventional system

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