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Performance Analysis of Fractional Frequency Transmission System

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***Abstract* -- In this paper comparative analysis is done for power transmission on line length of 1200 km at 50Hz and 50/3Hz. Test system of 765kV is selected as transmission voltage level. Simulation is done on test system over Matlab/Simulink. Result shows that, efficient power transfer without compensation is not possible in 50Hz system, but by using FFTS, it is possible to transmit 2.5 to 3 times the rated power without any compensation.**

***Keywords*—Efficiency, FractionalFrequency Transmission System (FFTS), frequency converters,long distance power transfer capacity, Voltage regulation.**

I. INTRODUCTION

Increasing power demand, switching to Non-conventional energy resources (India ranks 4th in 2016 Global Wind Power Installed Capacity) located at remote areas and increasing the transmission distance and capacity is always the motivation to advance power industry technologies. In ac transmission system, increasing distance and capacity mainly depends on raising voltage level of transmission lines. At present, the highest voltage level of the ac power transmission line in India is 765 kV [1]. The high-voltage direct current (HVDC) transmission is another approach to increase electrical power transmission capacity. It has no stability limit. However, the current converters at two ends of HVDC are very expensive and the HVDC practices have been limited to point to-point transmission.FACTS (Flexible Alternating Current Transmission System) exploits power electronic techniques to regulate the parameters of the ac transmission, which can raise transmission capacity to some extent like Series compensation, Shunt compensation etc. The Fractional Frequency Transmission System (FFTS) proposed in the literature [2] is another promising approach to increase transmission line capacity without any compensation.In this system, generation and transmission is done at fractional frequency of 50/3 Hz. Cycloconverter circuit is used at grid side to step up the frequency from 50/3 Hz to 50 Hz and power is fed back to grid. Due to reduction in frequency, line reactance is decreased and hence the transmission capability is increased.A laboratory level experiment performed on FFTS shows that, FFTS can be easily synchronized with the grid and the transmission capability can be increased by 2.5 times than conventional 50 Hz system [3].

The efficiency of FFTS is determined analytically to investigate its feasibility and shown that the efficiency is around 95% [4].

II. PRINCIPLE OF FFTS

The ac electricity supplied by utilities has two basic parameters: **voltage and frequency**. With the help of transformer different voltage levels are used easily in transmitting and consuming electricity to define efficiency for different elements of the power system. In the history of electricity transmission, besides 50–60 Hz, many frequencies were used, such as 25, 50/3, and 133 Hz.However, 50–60 Hz was selected as the standard frequency later. The reason behind fixed frequency transmission system is that to transform frequency is more difficult than to transform voltage. After introducing power electronic techniques, it is possible to introduce different frequency levels by the help of different types of power electronic converters. For instance, the lower frequency electricity can be used to transmit larger power for longer distance.

There are three factors limiting transmission capability, i.e., the thermal limit, stability limit, and voltage drop limit. For long-distance ac transmission, the thermal limit is not of significant impediment. Its load ability mainly depends on the stability limit and voltage drop limit [5]. The stability limit of an AC transmission line can be approximately evaluated by

$$P_{max} = \frac{V^2}{X} \;.......(1)$$

Where V is the nominal voltage, and X is the reactance of the transmission line. We can see from the above equation that transmission capacity is proportional to the square of the nominal voltage and inversely proportional to the reactance of the transmission line. The percentage voltage drop can be evaluated by

$$\Delta V = \left(\frac{QX}{V^2}\right) \times 100 \;....(2)$$

Where Q is the reactive power flow of transmission line. Thus, the voltage drop is inversely proportional to the square of voltage and proportional to the reactance and reactive power flow of the transmission line.

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Therefore, in order to raise transmission capability, we can either increase the voltage level or decrease the reactance of the transmission line. The reactance is proportional to power frequency f

$$X = 2\pi f L \ldots\ldots (3)$$

Where L is the total inductance of the transmission line. Hence, by decreasing the frequency of the supply, we can proportionally increase the transmission capability.

The FFTS technique uses fractional frequency to reduce the reactance of the transmission system; thus, its transmission capacity can be increased several fold.

We can also look the principle of FFTS from another perspective. It is well known that the velocity of electricity transmission is approximately equal to the velocity of light i.e., 3000000 km/s. When supply frequency is 50 Hz, the wave length is 6000 km; for 50/3 Hz supply frequency, the wave length enlarges to 18000 km. Thus, when frequency is 50 Hz, a transmission line of 1200 km corresponds to one fifth of the wave length; for the 50/3 Hz case, this transmission line corresponds to one fifteenth of the wave length. Therefore, the "electrical length" decreases to one third. This is the essential reason why FFTS can increase transmission capability several fold and remarkably improve its performance. The basic structure of FFTS is illustrated in Fig.1

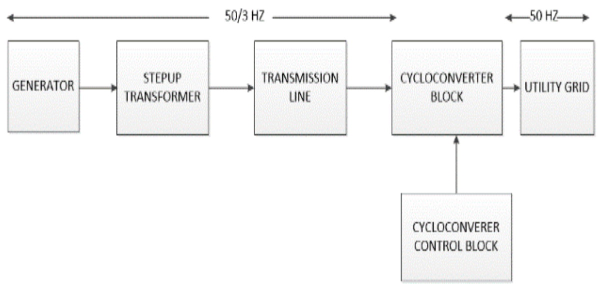

Fig.1 Structure of FFTS

The generation and transmission of electric power is done at 50/3Hz frequency. Wind power plant produces lower frequency due to non-uniform speed of wind. A cycloconverter bank of 36 GTO is added at receiving end to convert fractional frequency (50/3Hz) to 50Hz.

III. Model Of Transmission System At 50 Hz

Transmission system, for EHVAC i.e. 765kV transmission voltage at 50Hz is built in MATLAB for transmitting power through 1200 Km.

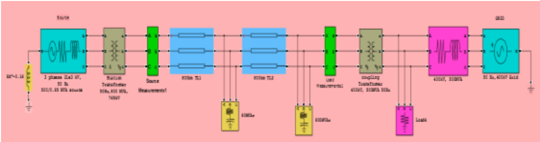

Fig.2 Matlab model for 50Hz transmission system

The three phase transmission line modeled in MATLAB is constructed by the composite conductors of 6 sub-conductors, ACSR, moose type with the bundle spacing of 0.45 m, phase spacing of 15.4 m and ground clearance from phase conductors is 15 m. The line parameters for 1200km are shown below in table 1:

Table 1:
Transmission Line Parameters

Resistance per unit length [r0 r1]	[0.042753 0.18573]
Inductance per unit length [l0 l1]	[0.0010351 0.0033749]
Capacitance per unit length [c0 c1]	[$11.257*10^{-9}$ $8.1154*10^{-9}$]

IV. Model Of Transmission System At 50/3 Hz

The simulation model for 50/3Hz transmission system is shown below-

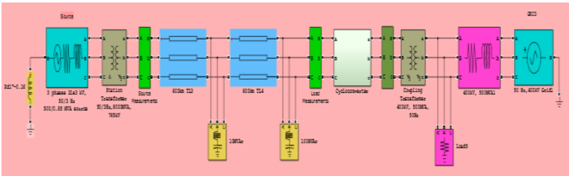

Fig.3 MATLAB model with cycloconverter at receiving end of transmission line to synchronize with grid frequency

Three phase to three phase bridge cycloconverter, also called a step up cycloconverter [6] is shown below to convert frequency from 50/3Hz to 50Hz –

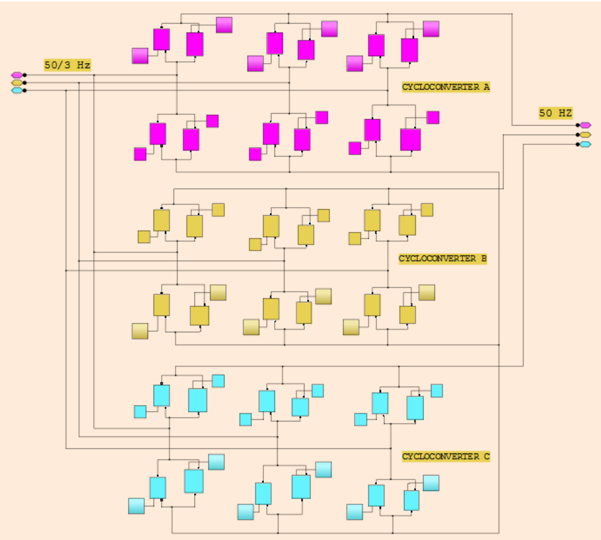

Fig.4 3-phase to 3- phase cycloconverter

Fig.4 employs 36 - GTOs and is called 3-phase to 3 phase cycloconverter. In this circuit, each phase group consists of 12 GTOs. Each group gives R, Y and B phase respectively.

V. Result And Analysis

The voltage waveform of cycloconverter is shown below-

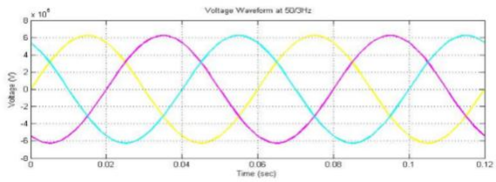

Fig.5 voltage waveform for 50/3Hz

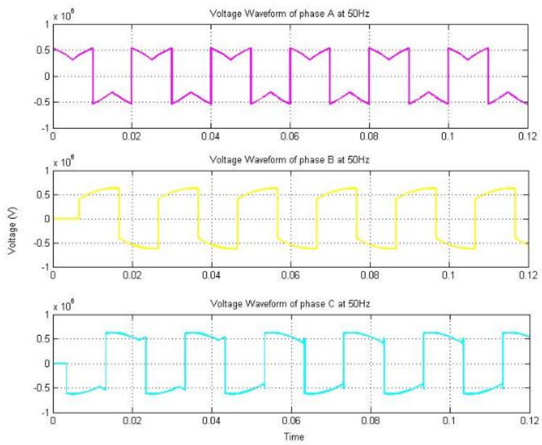

Fig.6 voltage waveform after cycloconverter at 50Hz

The respective voltage regulation and efficiency for 50Hz is given by-

$$\boldsymbol{Voltage\ Regulation} = \left[\frac{\left(\frac{V_s}{A}\right) - V_r}{V_r}\right] \times \mathbf{100\ .\ .\ .\ .\ .(4)}$$

$$Voltage\ Regulation = \left[\frac{\left(\frac{596.39}{1.3}\right) - 447.37}{447.37}\right] \times 100$$

$$\boldsymbol{Voltage\ Regulation} = \mathbf{2.547}\ \%$$

$$\boldsymbol{Efficiency} = \left(\frac{P_{out}}{P_{in}}\right) \times \mathbf{100\ .\ .\ .\ .\ .\ (5)}$$

$$Efficiency = \left(\frac{655.33}{778.99}\right) \times 100$$

$$\boldsymbol{Efficiency} = \mathbf{84.13}\ \%$$

Voltage regulation and efficiency at 50/3Hz frequency is given below-

$$Voltage\ Regulation = \left[\frac{\left(\frac{656.21}{1.089}\right) - 602.08}{602.08}\right] \times 100$$

$$Voltage\ Regulation = 0.08318\ \%$$

$$Efficiency = \left(\frac{1751.4}{1827.4}\right) \times 100$$

$$Efficiency = 95.84\ \%$$

Table.2
Voltage profile and receiving end power of 50Hz and 50/3Hz system

Transmission System	V_{in} (kV)	V_{out} (kV)	P_{in} (MW)	P_{out} (MW)
50 Hz	596.39	447.37	778.99	655.33
50/3 Hz	656.21	602.08	1827.4	1751.4

Comparative analysis of power transfer capability, voltage regulation, and efficiency for 50Hz and 50/3Hz is given below –

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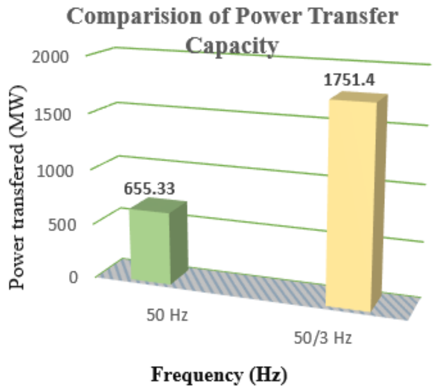

Fig.7 Comparative analysis of power transfer capability at 50 Hz and (50/3) Hz frequency

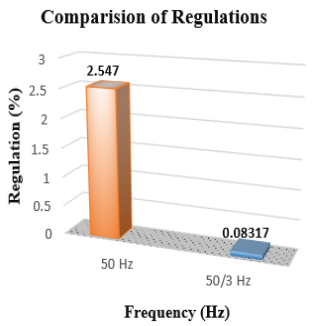

Fig.8 Comparative analysis of power transfer capability at 50 Hz and (50/3) Hz frequency

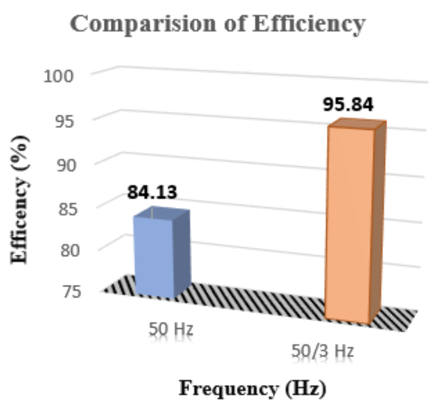

Fig.9 Comparative analysis of power transfer capability at 50 Hz and (50/3) Hz frequency

VI. CONCLUSION

From table 2 and comparative analysis of different Bar graphs, it is seen that power handling capacity gets increased after implementing fractional frequency transmission system without any compensation. It can also be seen that efficiency and voltage regulation of FFTS is much better than the conventional 50Hz transmission system.

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