Modelling and Simulation of Fractional Frequency Transmission for S of Power Systems

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ABSTRACT

The fractional frequency transmission system (FFTS) is a very promising long-distance transmission approach, which uses lower frequency (50/2 Hz, 50/3 Hz, 50/4 Hz) to reduce the electrical length of the ac power line, and thus, to increase its transmission capacity by several fold. The simulation uses the phase-controlled cyclo-converter as the frequency changer. The system step down the grid frequency of 50 Hz to 50/3 Hz etc. and being tested for the harmonics and distortion in the propagating wave. The same frequency will act as an input frequency to the WPDAN system. The transmission capabilities, transmission length, and resonant frequency have been tested and demonstrated.

1. Introduction

Increasing transmission distance and capacity is always the motivation to advance power industry technologies [1]. In the history of the 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 operation is 750 kV. To further upgrade, the voltage level encounters difficulties of material and environment issues. The high-voltage direct current (HVDC) transmission that has no stability limit problem once became another approach to increasing electricity transmission capacity. However, the current converters at two ends of HVDC are very expensive. In addition, up to now, the HVDC practices have been limited to the point-to-point transmission. It is still difficult to operate a multiterminal HVDC system. From 1982 to 2003, the total HVDC transmission capacity in the world was only 70 GW.

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The flexible ac transmission system (FACTS) has been used to improve power system performance and has become a very challenging research field. This paper introduces the experimental installation of FFTS and primary experiment results. The experiment uses the phase controlled cycloconverter as the frequency changer, stepping up 50/3 Hz electricity to 50 Hz and supplying it to the utility grid. Thus, a new FACTS device is successfully established in this paper and also illustrates that there is no essential difficulty to realize FFTS in engineering practice.

The AC electricity supplied by utilities has two basic parameters: voltage and frequency. After the transformer was invented, different voltage levels could be used flexibly in generating, transmitting, and consuming electricity to guarantee efficiency for different segments of the power system. In the history of electricity transmission, besides of 50–60 Hz, many frequencies were used, such as 25, 50/3, and 133 Hz. A 25-Hz electric system had been chosen as the winning design [5]. However, since 50–60 Hz was selected as the standard, changing frequency apparently became taboo. The reason for this might consist in that to transform frequency is more difficult than to transform voltage. As new materials and power electronic techniques continuously advance, different kinds of large-frequency changers 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 [3], [4].

Design of Three phase to three phase (50/3 Hz to 50 Hz) step up cycloconverter based on FFTS to increase electricity transmission capacity is the central subject of this paper. The paper starts with an introduction in chapter 1 about history of FACTS advantages and a brief survey of long distance power transmission system in literature.

The theory of power system transmission, FACTS and its various controls are presented in next section. The further section presents the principle and structure of FFTS, generation and synchronization of 50/3 Hz, the phase controlled cycloconverter, the simulation for the three phase to three phase cycloconverter and its waveforms are presented, and finally the contribution of this paper and future research in this area are presented in the last section of the paper.

2. Working Methodology

2.1 Principles of FFTS

To transform frequency is more difficult than to transform voltage. As new materials and power electronic techniques continuously advance, different kinds of large-frequency changers 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.

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

$P_{max} = V2/X$

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 normal voltage and inversely proportional to the reactance of the transmission line. The voltage drop % can be evaluated by

$\Delta V\% = QX/V2 * 100$

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 of the transmission line. 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

$X = 2\pi fL$

Where L is the total inductance of the transmission line. Hence, decreasing the electricity frequency f can proportionally increase transmission capability. The FFTS uses fractional frequency to reduce the reactance of the transmission system; thus, its transmission capacity can be increased several fold. For instance, when frequency is 50/3 Hz, the theoretically transmission capability can be raised three times.

We can also look through the principle of FFTS from another perspective. It is well known that the velocity of electricity transmission is approximately equal to the light velocity, 300 000 km/s. When electricity frequency is 50 Hz, the wave length is 6000 km; for 50/3 Hz, the wave length reaches 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 only corresponds to one fifteenth of the wave length. Therefore, the “electrical length” decreases to one third. This is the essential reason why the FFTS can increase transmission capability several fold and remarkably improves its performance.

2.2 Basic Structure of FFTS

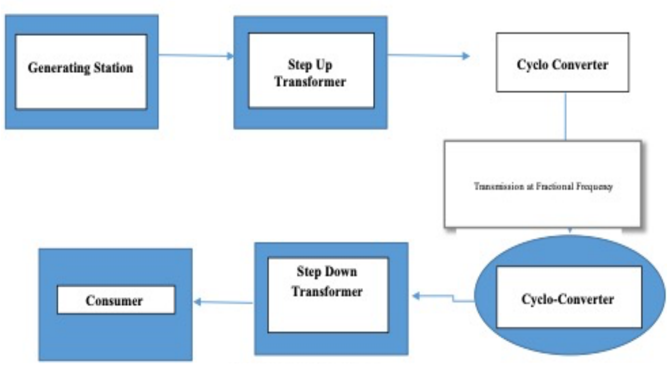

Fig. 1- Basic structure of FFTS

The basic structure of FFTS is illustrated in Fig. 1. The power generator in the figure generates ac power which is then stepped up by a transformer and transmitted to the receiving end of the transmission line where the fractional frequency ac power is stepped up to the normal frequency. The frequency changer is the key equipment in FFTS, which can be either the saturable transformer [7] or the power electronic ac–ac frequency changer, such as the cycloconverter [8]. The ferromagnetic frequency changer has advantages of simpler structure, lower cost, and more reliable operation, while the electronic type is superior in higher efficiency and more flexible in installation.

2.3 Input Source 50/3 Hz Generation

The control system of the cycloconverter consists of three parts: the fraction frequency generator, synchronizing circuit, and cycloconverter control circuit as shown in Fig. 3.3. The Generated voltage is fed to the three phase transformer and to the three phase transmission line.

2.4 Operation of Frequency Synchronizer

The IGBT based (frequency synchronizer) step up cycloconverter is shown in Fig.2 A fixed frequency (50/3 Hz) AC voltage source is applied to the primary of the transformer. Using mid-point transformer the input AC voltage is splitted into two voltages. These voltages are converted in to variable output frequency (50 Hz) using pair of IGBT switches. Each pair of IGBT switch consists of two anti parallel connected IGBT's. Using two pulse generators the triggering pulses given to switches. Now we are getting the required output voltage with frequency 50 Hz, across Ro. The time period can be calculated from the output frequency. The output voltage is shown in Fig.3.

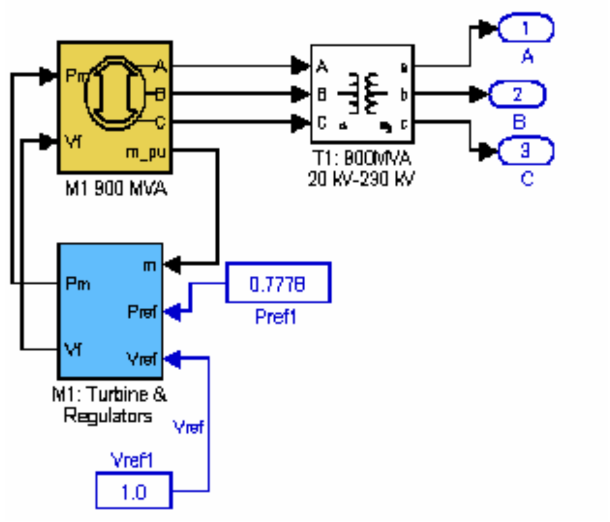

Fig.2 50/3Hz Source Generation

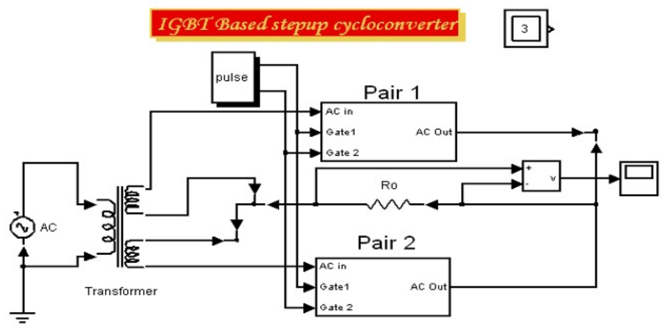

Fig.3 IGBT based (frequency synchronizer) step up cycloconverter

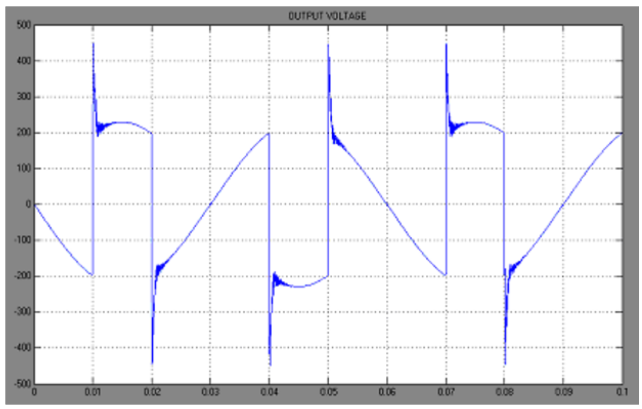

Fig.4 Output voltage of frequency synchronizer

2.5 Configuration of Cycloconverter in FFTS

A Cycloconverter is a Frequency changer that converts AC power at one input frequency to output power at a different frequency with a one – stage conversion process. The three phase to three phase cycloconverter configuration is shown in Fig.5.It consists of two three phase bridge converters connected in anti-parallel and is built up by 36 thyristors (K200A/1600 V).

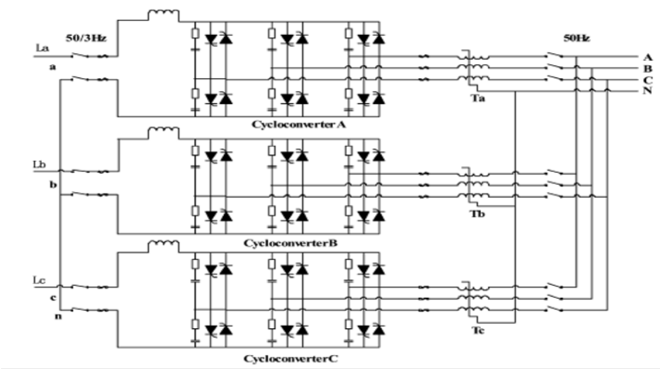

Fig. 5 Configuration of Cycloconverter in FFTS

Traditionally, ac-ac conversion using semiconductor switches is done in two different ways: 1- in two stages (ac-dc and then dc-ac) as in dc link converters or 2- in one stage (ac-ac) cycloconverters (Fig. 1). Cycloconverters are used in high power applications driving induction and synchronous motors. They are usually phase-controlled and they traditionally use thyristors due to their ease of phase commutation. The single phase to single phase converter consists of back-to-back connection of two full-wave rectifier circuits. Fig 6 shows the operating waveforms for this converter with a resistive load. The input voltage, vs is an ac voltage at a frequency, fi as shown in Fig. 6a. For easy understanding assume that all the thyristors are fired at a=0° firing angle, i.e. thyristors act like diodes. The firing angles are named as P for the positive converter and N for the negative converter.

Consider the operation of the cycloconverter to get one-fourth of the input frequency at the output. For the first two cycles of vs, the positive converter operates supplying current to the load. It rectifies the input voltage; therefore, the load sees 4 positive half cycles as seen in Fig.6b. In the next two cycles, the negative converter operates supplying current to the load in the reverse direction. The current waveforms are not shown in the figures because the resistive load current will have the same waveform as the voltage but only scaled by the resistance. Note that when one of the converters operates the other one is disabled, so that there is no current circulating between the two rectifiers. The frequency of the output voltage, vo in Fig.6b is 4 times less than that of vs, the input voltage, i.e. fo/fi=1/4. Thus, this is a step-down cycloconverter. The frequency of vo can be changed by varying the number of cycles the positive and the negative converters work. It can only change as integer multiples of fi in 1f-1f cycloconverters.

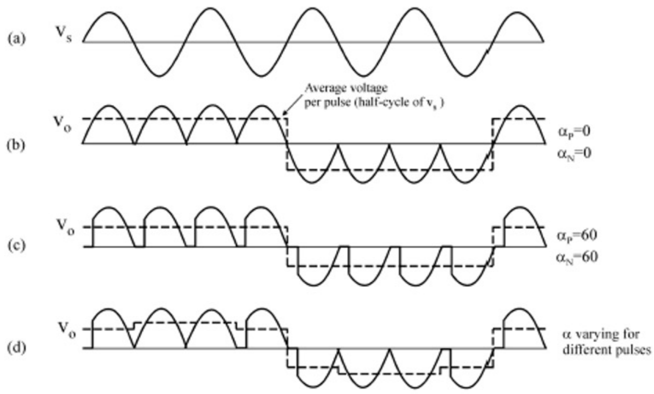

Fig.6. Single-phase to single-phase cycloconverter waveforms a) input voltage, b) output voltage for zero firing angle, c) output voltage with firing angle p/3 rad, d) output voltage with varying firing angle.

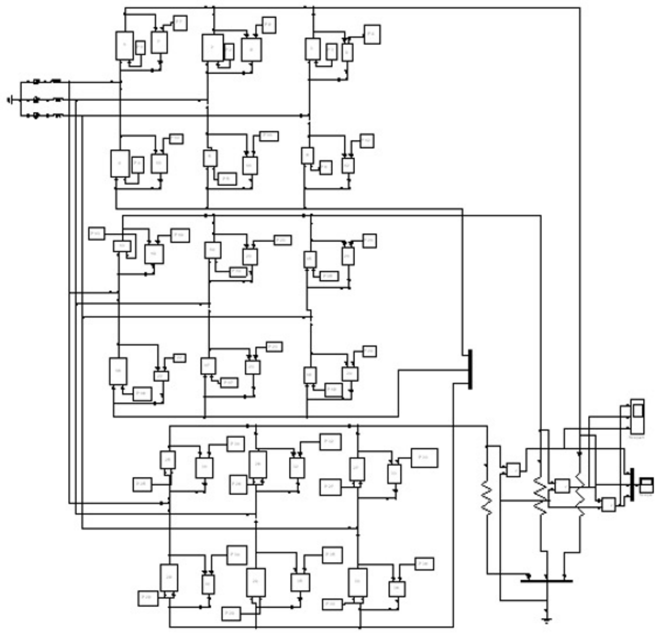

Fig.7. Simulation diagram of 3 phase to 3 phase cycloconverter

3. Results and Discussion

The three phase to three phase cycloconverter is used to convert the input source frequency 50/3 Hz to the required output frequency 50 Hz. The operation of phase A is given below. The simulated results of phase A, B, C are shown in Fig.5.1 to 5.7 respectively.

Phase A operation: The output frequency is three times higher than that of the input frequency. The model input and output wave forms are given below.. From figure the time axis is separated by electrical degrees with respect to input voltage.

0<ωt<30º : The most positive phase is C and the most negative phase is B. Hence the entering switch is 3 and leaving switch is 5.

30º<ωt<60º: The most positive phase is A and the most negative phase is B. Hence the entering switch is 1 and leaving switch is 5.

60º<ωt<90º: In this period the output voltage is in negative cycle. So the download switch is operated to get the negative cycle. The most positive phase is A and the most negative phase is B. Hence the entering switch is 10 and leaving switch is 8.

90º<ωt<120º: The most positive phase is A and the most negative phase is C. Hence the entering switch is 10 and leaving switch is 9.

120º<ωt<150º: During the period the output voltage is in again positive cycle. So the upward switch is to be operated to get the positive cycle at the load. The most positive phase is A and the most negative phase is C. Hence the entering switch is 1 and leaving switch is 6.

150º<ωt<180º: The most positive phase is B and the most negative phase is C. Hence the entering switch is 2 and leaving switch is 6.

180º<ωt<210º: The most positive phase is B and the most negative phase is C. Hence the entering switch is 11 and leaving switch is 9.

210º<ωt<240º: The most positive phase is B and the most negative phase is A. Hence the entering switch is 11 and leaving switch is 7.

240º<ωt<270º: The most positive phase is B and the most negative phase is A. Hence the entering switch is 2 and leaving switch is 4.

270º<ωt<300º: The most positive phase is C and the most negative phase is A. Hence the entering switch is 3 and leaving switch is 4.

300º<ωt<330º: The most positive phase is C and the most negative phase is A. Hence the entering switch is 12 and leaving switch is 7.

330º<ωt<360º: The most positive phase is C and the most negative phase is B. Hence the entering switch is 12 and leaving switch is 8. Similarly the other phases B, C are switched upward / down ward corresponding to the positive and negative cycles. The phase A, B and C (three phase input) / Output voltage wave forms are given below.

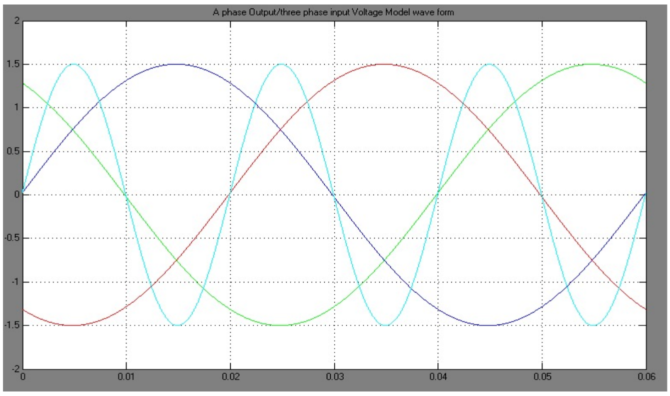

Fig. 8 Three phase input Voltage Model wave form for phase - A

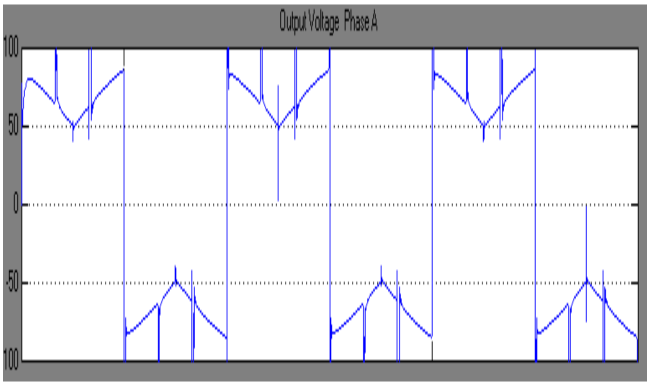

Fig.9 A - phase Output Voltage

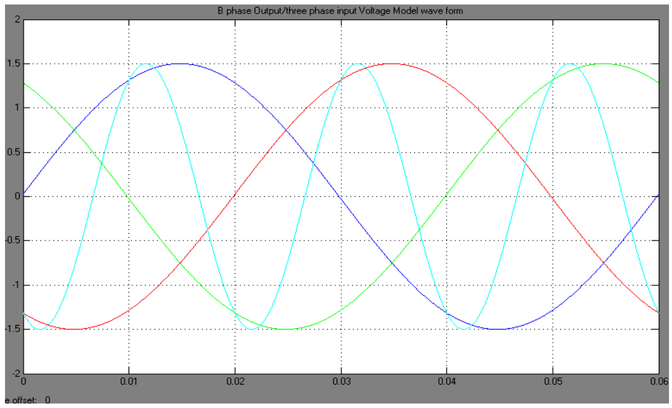

Fig. 10 Three phase input Voltage Model wave form for phase – B

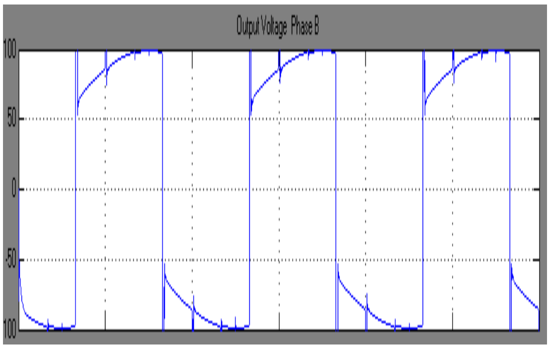

Fig.11 - phase Output Voltage

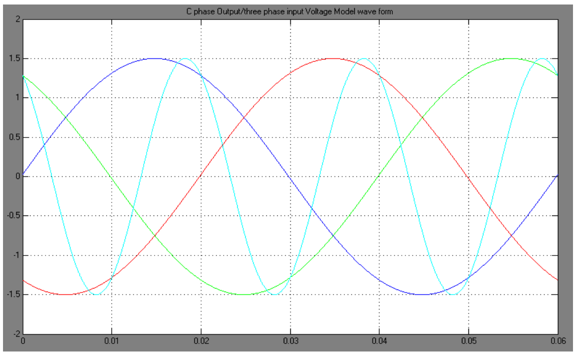

Fig .12 Three phase input Voltage Model wave form for phase – C

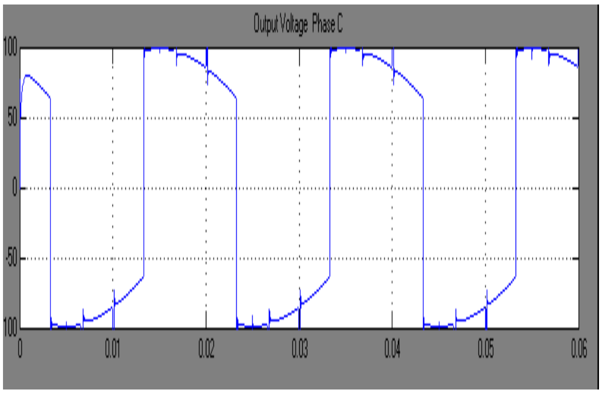

Fig.13 B - phase Output Voltage

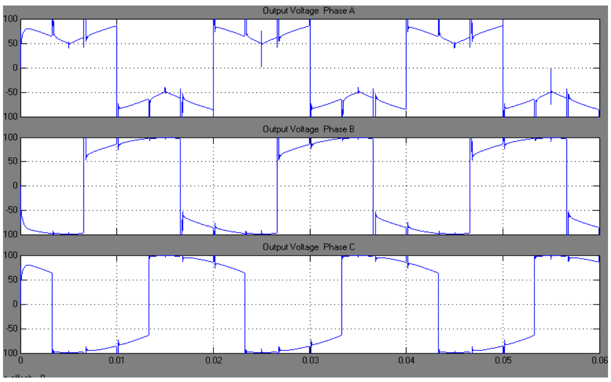

Fig.14 Combined output voltages of Phases A, B, C

4. Conclusions

The paper discusses the simulation that employs the cycloconverter as the frequency changer to step up 50/3 Hz power to 50 Hz power. The step up frequency of desired voltage is to be supplied to the utility grid with the 1200 km/500 kV transmission line. The transmission line can transmit electric power to 2000 MW by using FFTS. Comparing with the 50-Hz ac transmission line, the transmission capability increases 2.5 times. It demonstrates the great potential of applying this new FACTS device. Comparing with HVDC, the FFTS can save an electronic converter terminal, thus reducing investment. In addition, usually HVDC can be used only for point-to-point transmission, but FFTS can easily form a network-like conventional ac system. Nowadays, it is mature to transform power frequency by the electronic converter (e.g., the cycloconverter). Therefore, FFTS on/under 750 kV can be completed without any special technical difficulty.

Further the scope of the works to be done, such as a study on economic feasibility, analysis of transient and dynamic stability, optimal control of the cycloconverter, improvement of transmission efficiency, and restraint of harmonics.

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