

Application of LFAC $\{16\frac{2}{3}\text{Hz}\}$ for electrical power transmission system: a comparative simulation study

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Abstract

Transmission of electrical power for long distance is one of the major challenges for electrical engineers over the years. The first and foremost target it is to ensure the transport of electric power with minimal losses over the distance. This paper proposes to employ the low frequency alternating current (LFAC) with $(16\frac{2}{3}\text{Hz})$ instead of the traditional frequency (50Hz) for electrical power transmission based on a simulation study. Two transmission systems have been constructed using MATLAB/Simulink software namely: 50Hz transmission systems and $(16\frac{2}{3}\text{Hz})$ transmission systems. In addition, three different distances of transport lines have been used to compare the efficiency of the two systems namely: short (50km), medium (150) and long (300km). The result demonstrated that the use of LFAC with $(16\frac{2}{3}\text{Hz})$ is better than the traditional frequency (50Hz) in term of energy saving.

Keywords: electric power system, electrical power transmission, HVAC, LFAC, simulink

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1. Introduction

Direct current (DC) was the typical in 19th Century form of electrical power production at the starting of electricity transport and distribution, However, high load currents and low operating voltages from increasing demand caused poor voltage profile (difference between the sending and receiving end voltages) and high transmission losses. Devices for HVDC transmission is impractical and costly. With the introduction of HVAC. HVAC power system take place to outstrip HVDC power systems that for using due to significant reduction in better voltage profiles and transmission losses [1]. Low Frequency AC Electric power transmission system, The used of LFAC Electric power transmission system has been suggested that different studies as an alternative to HVDC Electric power transmission system [2]. The modern ways, the AC system (LFAC) and DC in transport, distribution grid [3]. To put the ability of the devices insulation withstand under the system's voltage, frequency and power the apparatus is subjected to test [4].

The low-frequency AC $16\frac{2}{3}\text{Hz}$ currently depends on five European countries (Germany, Austria, Sweden, Norway and Switzerland), which is equivalent to one-third the normal frequency of a 50Hz single-phase AC. In the United States, the electrical distribution system operates at 60Hz, so they have a 25Hz low frequency AC. Spicily power stations in these countries rely on the production of low-frequency current called Traction Current Converter Plants, where the electric power of these stations is converted into an appropriate form of voltage and frequency for the processing of vehicles or electric buses (Street Cars) Low frequency. These systems can be used to convert a three-phase 50Hz or 60Hz alternating current to equip low-frequency single-phase AC power systems as currently used by many old electric traction systems [5-7]. The traction switching stations are generally decentralized where the station is supplied with one line of direct lines, ie without direct supply to the electric traction network. Or centralization of the electric traction current network, as well as the direct supply of overhead lines. Central traction switching stations are located in Germany, Austria, Switzerland. While decentralized traction stations in Norway and Sweden [8-9].

National network that transmits power from generating stations, the electrical energy produced from the generator needs to be converted for convenience [10-13]. The idea of transferring the electric energy produced from an electric power station 50km away from the electrical grid was studied by adopting low frequency instead of the normal 50Hz frequency via a transmission line (ground cable, using the cycle converter to switch the frequency from 50Hz to generating power generated from the generating station, and to demonstrate the economic feasibility of using this frequency in the transmission of power from the generating station to the electrical grid, we adopted a low frequency power transmission cable). The amount of losses in the line was calculated and compared with the losses achieved on the same line but at 50Hz frequency and other benefits that would emerge from our search. In the generating station we need a frequency switch that changes the frequency to low frequency and then the power is transferred to a distance of 50Km where another station near the electrical grid to convert the frequency to normal frequency 50Hz.

2. Electric Power System

In Figure 1 and Figure 2 shows the model of simulation electric power system , it has three principals component electric generation, electric transmission and electric distribution. Electric Generation, the voltage 11kv r.m.s, frequency 50Hz called normal electric generation in 3ph Ac power system. It has, firstly steps up voltage by transformer 11kv to 132kv. Electric transmission, it is carrying 132kv in primary electric transmission. Second, steps down voltage by transformer 132kv to 33kv. Electric transmission, it is carrying 33kv in secondary electric transmission. Electric distribution, It has, firstly down voltage by transformer 33kv to 11kv. Electric transmission, it is carrying 11kv in primary electric distribution. Second, steps down voltage by transformer 11kv to 400v that connected to 3ph or 1ph load [14-16].

3. Power transmission lines

Power transmission lines, The transfer of electric power from generation plants to the consumer is the main objective of the construction of transmission lines and the value of electrical voltage at different points should be maintained at certain limits[17]. The electrical transmission lines are characterized by four constants: resistance-reactivity-capacitance-conductivity. Connectivity is usually neglected for small amounts [18]. Transmission lines are divided according to their lengths to the following groups:

- 1) Short lines with a length of less than 80 km
- 2) Medium length lines with lengths ranging from 80 to 240 km
- 3) Long lines with a length exceeding 240 km.

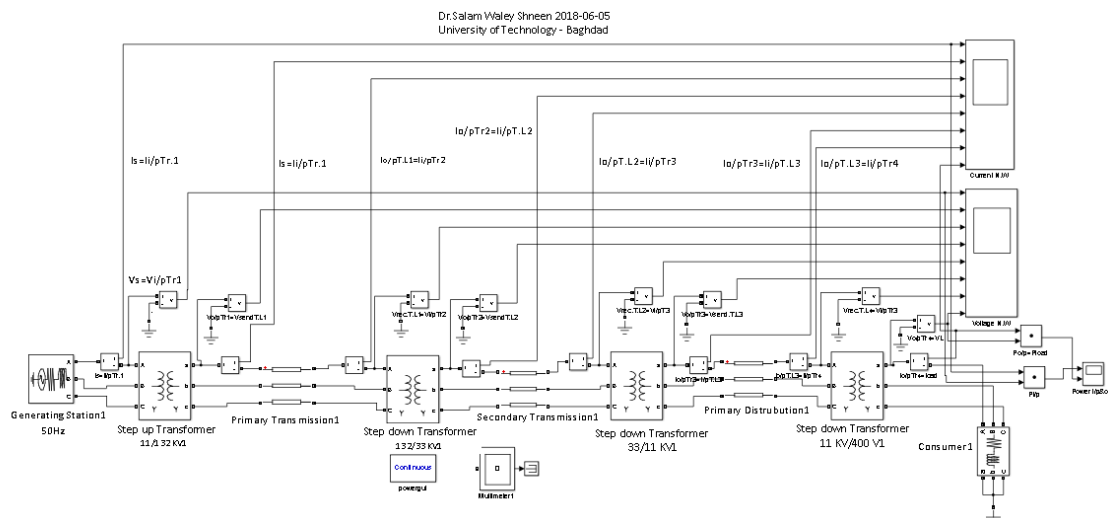


Figure 1. Simulation model with 50 Hz

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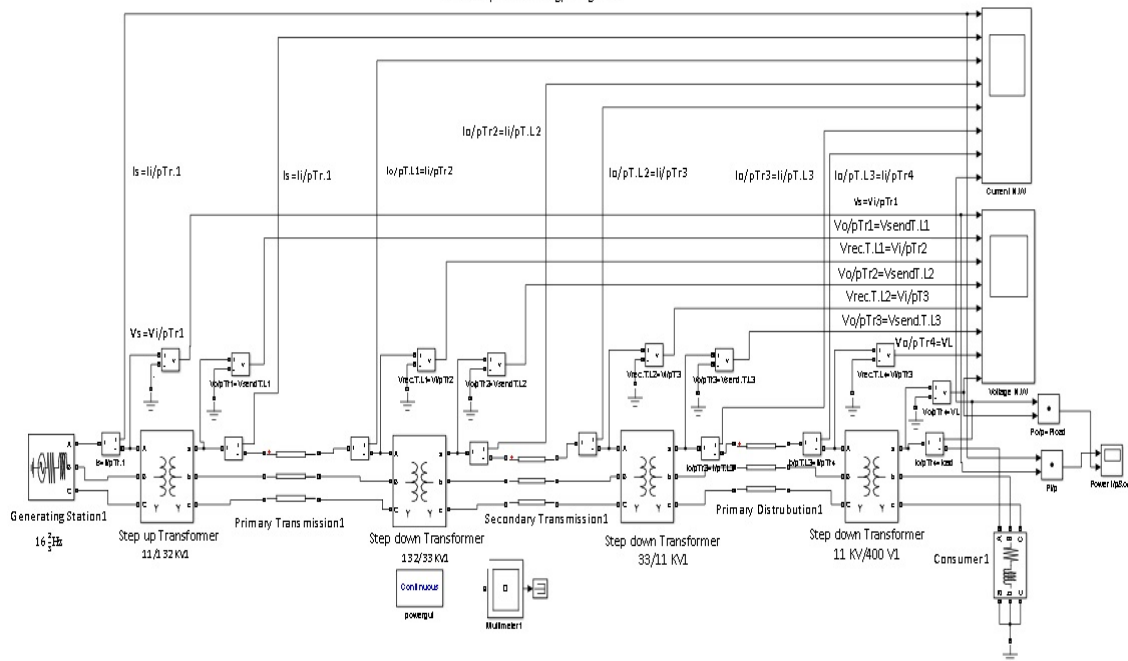


Figure 2. Simulation model with $16\frac{2}{3}$ Hz

Figure 3 shows the equivalent circuit of the line represented by resistance (R) whose value is equal to the total resistance of the line and the X reactive value is also equal to the total reactivity of the line, and neglects the conductivity and amplitude. In this case, the current at the alternator in the transmitter is equal to the current at the load I_r and the relationship between current and voltage is as follows [19-21].

$$I_s = I_r = I \tag{1}$$

$$V_s = V_r + I_s(R+jX) = V_r + IZ \tag{2}$$

Where Z is the line impedance. The transmission lines transfer the electrical power from the sending end to the receiving terminal where the line is fed into the transmitter and the loads are processed at the reception. The transport lines have four constants that are resistance. (Reactance), Capacitance (Leakage Conductance) where the inductive resistance and reactivity are in series and form the series impedance (Z) of the line and the capacitance and continuity are in parallel and form the secondary extension of the Shunt line admittance [22]. Line constants are distributed along the line as shown in Figure 3. Where R, L, C, and B respectively represent the resistance, reactivity, amplitude and continuous rotation of each unit length of the line.

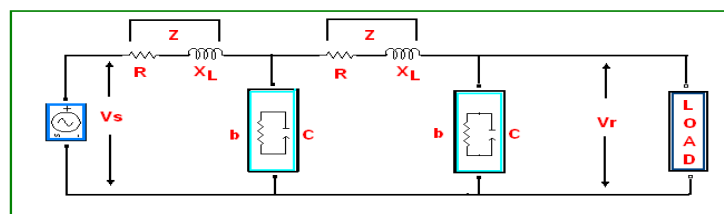


Figure 3. Constants of transmission lines

The capacity of the transmission line causes the flow of a charger current in the line even in cases where the line is not loaded. As the current power factor in the capacitor is an advanced power factor, it will cause an increase in voltage, For this reason, in the case where the line is not loaded, the receiving voltage is higher than the sending voltage and the phenomenon of high receiving voltage is called the transmission voltage when the line is not loaded with the Ferranti effect [23-25].

In this research, we studied the possibility of transmitting electrical power through a short 50 km long transmission line at $16\frac{2}{3}$ Hz low frequency. The power transmission line is called short if its C capacity can be discarded permanently because the transport voltage is relatively little 33Kv and its length is less than 80 km, In this case, the properties of this transmission line can be calculated by taking the successive R resistance and the XL induction only as in Figure 4. where the equivalent circuit of a single-phase transmission line of resistance, respectively, with inductance His plan is as evolutionary as in Figure 5.

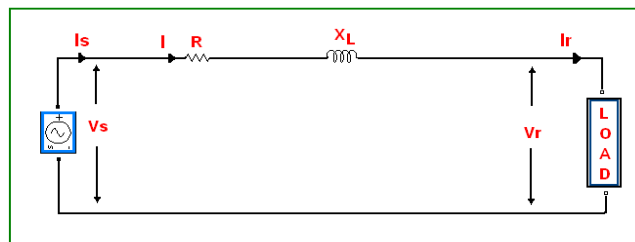


Figure 4. Equivalent circuit of a single phase transmission line

For the three balanced phases, the calculations are made for a single phase using the current of the line (I) and the voltage between the line and the neutral (L) as in Figure 6.

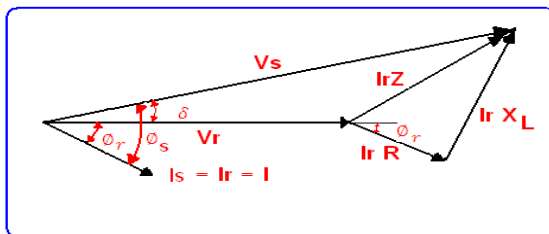


Figure 5. The phase diagram of a short transmission line

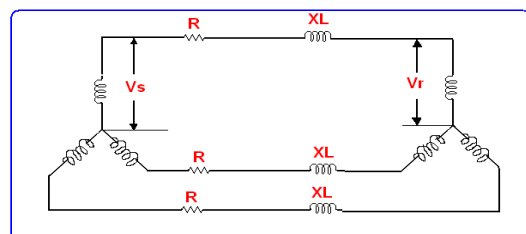


Figure 6. Three-phase transmission line circuit

4. Simulation Results for HVAC and LFAC

The simulation results of power (I/p&o/p) and frequency (50Hz& $16\frac{2}{3}$ Hz) that results for the system network with simulation / matlab by using the models in Figures 1 and 2. In Figure 5 show the input and output powers network system(-500 to 1500=2000VA), it has wide 0.02sec in the first part at Figure 7(a) that used 50Hz but the input and output powers network system (-250 to 3750=3500VA), it has wide 0.06sec in the first part at Figure 7(b) that used $16\frac{2}{3}$ Hz. The output power that used $16\frac{2}{3}$ Hz beast than that used 50Hz its mean the different losses (3500-2000=1500VA).

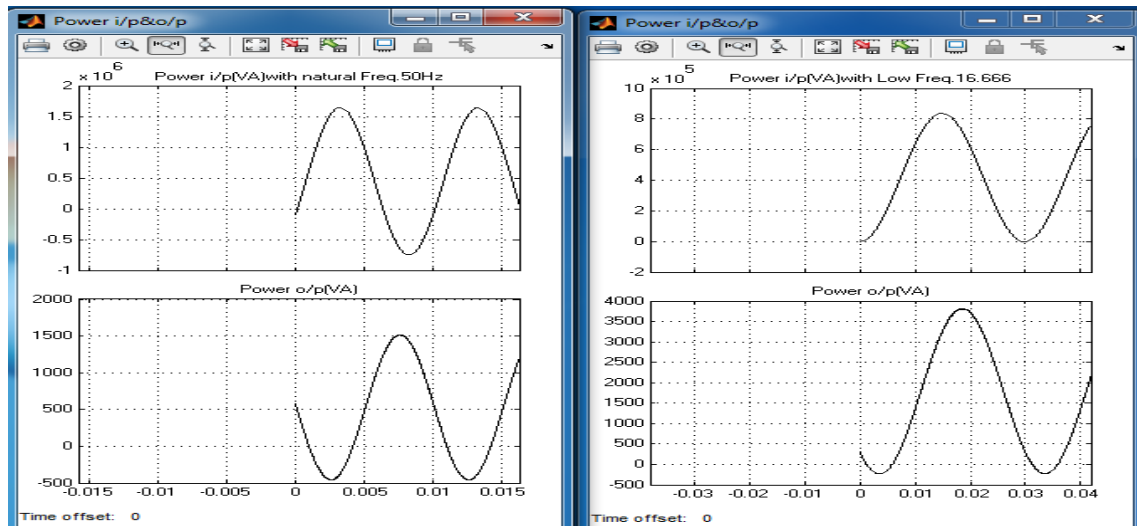
4.1. Simulation Results for HVAC with 50Hz

Simulation results with natural frequency 50Hz, the results for the system network system (N.W.S.) with simulation / matlab by using the models in Figure 1. In Figure 7, part one

current (N.W.S.) show in Figure 8(a), part two show the Voltage (N.W.S.) in Figure 8(b) and part three Power (N.W.S.) show in Figure 8(c).

4.2. Simulation Results for LFAC with $16\frac{2}{3}$ Hz

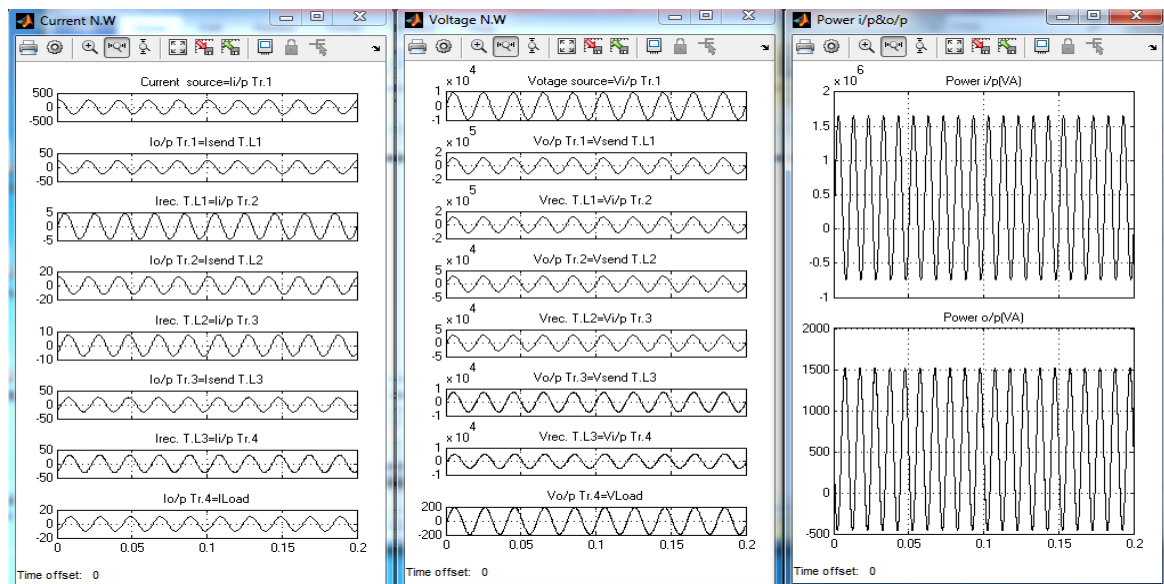
Simulation results with natural frequency $16\frac{2}{3}$ Hz, the results for the system network system (N.W.S.) with simulation/matlab by using the models in Figure 2. In Figure 8, part one current (N.W.S.) show in Figure 9(a), part two show the Voltage (N.W.S.) in Figure 9(b) and part three Power (N.W.S.) show in Figure 9(c).



(a) Power (I/p&o/p) with (50Hz)

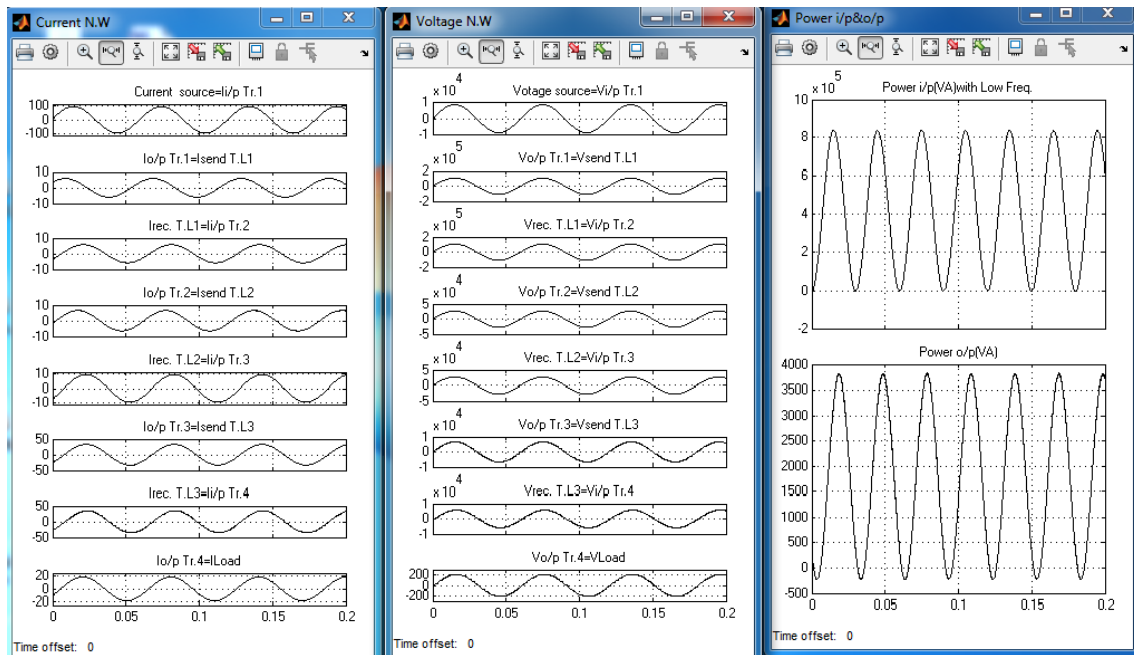
(b) Power (I/p&o/p) with ($16\frac{2}{3}$ Hz)

Figure 7. Simulation results Power (I/p&o/p) and Frequency (50Hz& $16\frac{2}{3}$ Hz)



(a) current N.W.S.(b) Voltage N.W.S. (c) Power N.W.S.

Figure 8. Simulation results with natural frequency 50Hz



(a) current N.W.S.

(b) Voltage N.W.S.

(c) Power N.W.S.

Figure 9. Simulation results LFAC with $16\frac{2}{3}$ Hz

5. Conclusion

In this research, a new technology was not previously adopted, namely the use of low-frequency AC $\{16\frac{2}{3}$ Hz} to transfer electrical power from remote generation sources to distribution networks. The results of the study and calculations showed that this technique has positive returns on energy saving by reducing losses. Where the study was carried out using computational equations for the transfer of electric power on three types of electric transmission lines which are short, medium and long transport lines. The method of low frequency AC is used in five European countries not to transfer electric power but to electric traction vehicles by using electric traction switching stations.

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Appendix

A. High voltage alternating current (HVAC)

HVAC Electric power system, in this work by used 50Hz. In this section the system parameters with 50Hz, it has many parts as following:

Note:the Number of phases [N]:3 that for all parts

Part one : Generating Station

Phase-to-phase rms voltage (V): $11 \times 10^3 = 11 \text{ kv}$

Frequency (Hz): $50 = 50 \text{ Hz}$

3-phase short-circuit level at base voltage(VA): $44 \times 10^6 = 44 \text{ MVA}$

Part two : Step up Transformer 11/132 KV

Nominal power and frequency [Pn(VA) , fn(Hz)]:[250×10^6 , 50]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]:[11×10^3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]:[132×10^3 , 0.002 , 0.08]

Part three : Primary Transmission

Line length (km):50

Frequency used for rlc specification (Hz):50

Resistance per unit length (Ohms/km) [NxN matrix] or [r1 r0 r0m]:[0.01273 0.3864]

Inductance per unit length (H/km) [NxN matrix] or [l1 l0 l0m]:[0.9337×10^{-3} 4.1264e-3]

Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]:[12.74×10^{-9} 7.751e-9]

Part four :Step down Transformer 132/33 KV

Nominal power and frequency [Pn(VA) , fn(Hz)]:[250×10^6 , 50]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]:[132×10^3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]:[33×10^3 , 0.002 , 0.08]

Part five :Secondary Transmission

Line length (km):150

Frequency used for rlc specification (Hz):50

Resistance per unit length (Ohms/km) [NxN matrix] or [r1 r0 r0m]:[0.01273 0.3864]
 Inductance per unit length (H/km) [NxN matrix] or [l1 l0 l0m]:[0.9337e-3 4.1264e-3]
 Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]:[12.74e-9 7.751e-9]
 Part six : Step down Transformer 33/11 KV
 Nominal power and frequency [Pn(VA) , fn(Hz)]:[250e6 , 50]
 Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]:[132e3 , 0.002 , 0.08]
 Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]:[33e3 , 0.002 , 0.08]
 Part seven:Primary Distribution
 Line length (km):300
 Frequency used for rlc specification (Hz):50
 Resistance per unit length (Ohms/km) [NxN matrix] or [r1 r0 r0m]:[0.01273 0.3864]
 Inductance per unit length (H/km) [NxN matrix] or [l1 l0 l0m]:[0.9337e-3 4.1264e-3]
 Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]:[12.74e-9 7.751e-9]

B. Low Frequency AC Electric power transmission system

LFAC Electric power system, in this work by used $16\frac{2}{3}$ Hz. In this section the system parameters with $16\frac{2}{3}$ Hz, it has many parts as following:

Note:the Number of phases [N]:3 that for all parts

Part one : Generating Station

Phase-to-phase rms voltage (V):11e3=11kv

Frequency (Hz): $16\frac{2}{3}$ Hz

3-phase short-circuit level at base voltage(VA):44e6=44MVA

Part two : Step up Transformer 11/132 KV

Nominal power and frequency [Pn(VA) , fn(Hz)]:[250e6 , $16\frac{2}{3}$ Hz]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]:[11e3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]:[132e3 , 0.002 , 0.08]

Part three : Primary Transmission

Line length (km):50

Frequency used for rlc specification (Hz): $16\frac{2}{3}$ Hz

Resistance per unit length (Ohms/km) [NxN matrix] or [r1 r0 r0m]:[0.01273 0.3864]

Inductance per unit length (H/km) [NxN matrix] or [l1 l0 l0m]:[0.9337e-3 4.1264e-3]

Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]:[12.74e-9 7.751e-9]

Part four :Step down Transformer 132/33 KV

Nominal power and frequency [Pn(VA) , fn(Hz)]:[250e6 , $16\frac{2}{3}$ Hz]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]:[132e3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]:[33e3 , 0.002 , 0.08]

Part five :Secondary Transmission

Line length (km):150

Frequency used for rlc specification (Hz): $16\frac{2}{3}$ Hz

Resistance per unit length (Ohms/km) [NxN matrix] or [r1 r0 r0m]:[0.01273 0.3864]

Inductance per unit length (H/km) [NxN matrix] or [l1 l0 l0m]:[0.9337e-3 4.1264e-3]

Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]:[12.74e-9 7.751e-9]

Part six : Step down Transformer 33/11 KV

Nominal power and frequency [Pn(VA) , fn(Hz)]:[250e6 , $16\frac{2}{3}$ Hz]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]:[132e3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]:[33e3 , 0.002 , 0.08]

Part seven:Primary Distribution

Line length (km):300

Frequency used for rlc specification (Hz): $16\frac{2}{3}$ Hz

Resistance per unit length (Ohms/km) [NxN matrix] or [r1 r0 r0m]:[0.01273 0.3864]

Inductance per unit length (H/km) [NxN matrix] or [l1 l0 l0m]:[0.9337e-3 4.1264e-3]

Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]:[12.74e-9 7.751e-9]

C. Mathematical and calculation

Power relationship, active Power (ΔP), reactive Power(ΔQ) and useless VA(ΔS):

$$\Delta Q = \Delta S - \Delta P \quad (3)$$

$$\Delta S = 3I^2 Z \quad (4)$$

$$\Delta P = 3I^2 R \quad (5)$$

$$Z = \sqrt{R^2 + XL^2} \quad (6)$$

$$XL = 2\pi f l \quad (7)$$

$$P = \sqrt{3}IV \cos\theta \quad (8)$$

$$I = \frac{P}{\sqrt{3}V \cos\theta} \quad (9)$$

$$XL_{50Hz_{50km}} = 2 * 3.14 * 50 * 0.9 * 10^{-3} * 50 = 14.13ohm$$

$$XL_{50Hz_{100km}} = 2 * 3.14 * 50 * 0.9 * 10^{-3} * 100 = 28.26ohm$$

$$XL_{50Hz_{150km}} = 2 * 3.14 * 50 * 0.9 * 10^{-3} * 150 = 32.39ohm$$

$$XL_{16\frac{2}{3}Hz_{50km}} = 2 * 3.14 * 16\frac{2}{3} * 0.9 * 10^{-3} * 50 = 4.7ohm$$

$$XL_{16\frac{2}{3}Hz_{100km}} = 2 * 3.14 * 16\frac{2}{3} * 0.9 * 10^{-3} * 100 = 9.4ohm$$

$$XL_{16\frac{2}{3}Hz_{150km}} = 2 * 3.14 * 16\frac{2}{3} * 0.9 * 10^{-3} * 150 = 14.12ohm$$

$$Z_{50Hz_{50km}} = \sqrt{(0.12)^2 + (14.13)^2} = 14.13ohm$$

$$Z_{50Hz_{100km}} = \sqrt{(0.12)^2 + (28.26)^2} = 28.26ohm$$

$$Z_{50Hz_{150km}} = \sqrt{(0.12)^2 + (32.39)^2} = 32.39ohm$$

$$Z_{16\frac{2}{3}Hz_{50km}} = \sqrt{(0.12)^2 + (4.7)^2} = 4.7ohm$$

$$Z_{16\frac{2}{3}Hz_{100km}} = \sqrt{(0.12)^2 + (9.4)^2} = 9.4ohm$$

$$Z_{16\frac{2}{3}Hz_{150km}} = \sqrt{(0.12)^2 + (14.12)^2} = 14.12ohm$$

Test by using matab: First test at P=44MVA & V=132KV. Simulation first test by using matlab as shown in Figure 10.

$$I = \frac{P}{\sqrt{3}V \cos\theta} = \frac{44 * 10^6}{\sqrt{3} * 132 * 10^3 * 0.8} = 245Ampere$$

Second test at P=200KVA & V=33KV. Simulation second test by using matlab as shown in Figure 11.

$$I = \frac{P}{\sqrt{3}V \cos\theta} = \frac{20 \cdot 10^4}{\sqrt{3} \cdot 33 \cdot 10^3 \cdot 0.8} = 7.575 \text{ Ampere}$$

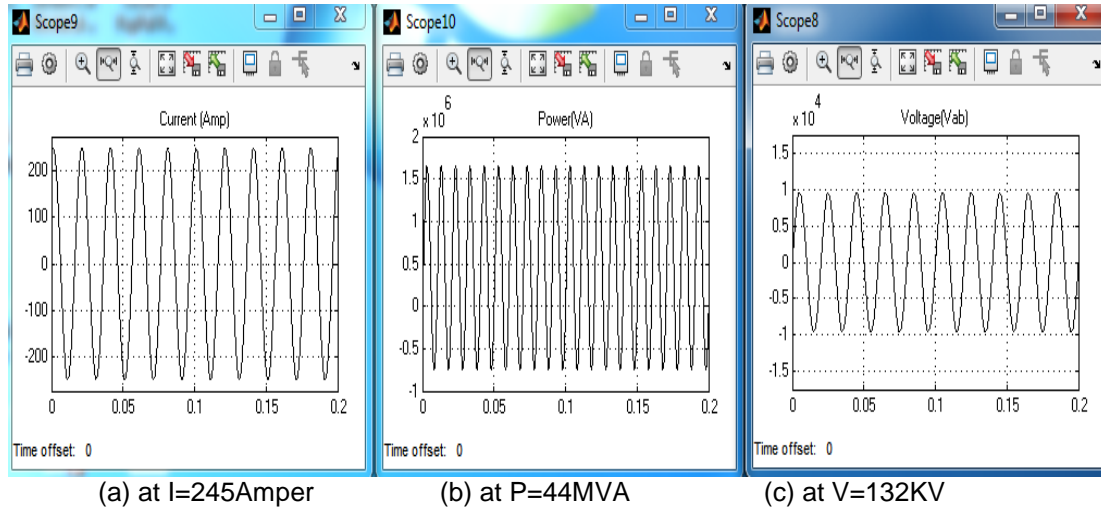


Figure 10. Simulation first test by using matlab

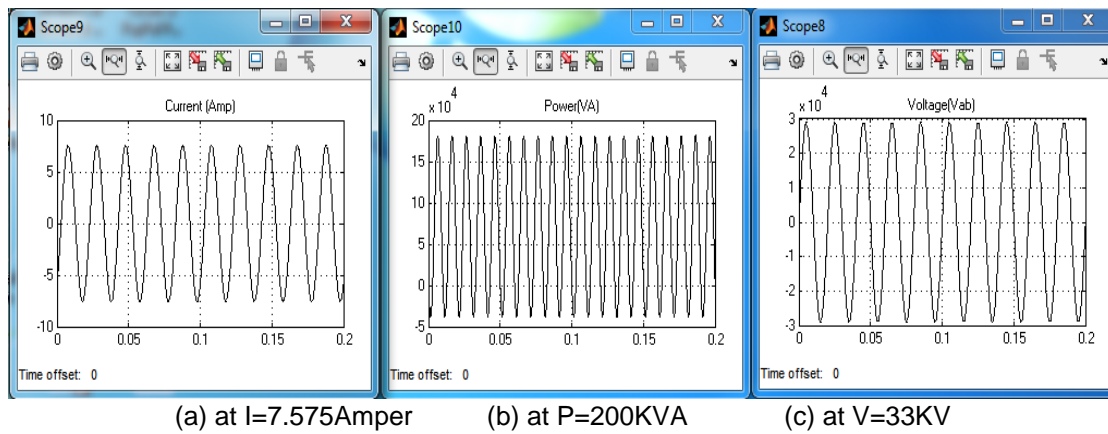


Figure 11. Simulation second test by using matlab