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Nine-Phase Transmission Line Design: Implementation using Matlab/Simulink

Abstract. *This paper presents the design and the study of a nine-phase transmission line system. Two lines (400 kV over 200 km and 400 kV over 600 km) are implemented using Matlab/Simulink to solve problems of environmental damage caused by several lines located in the same place, the multiplicity of electric faults and the poor power capability transmitted of the three-phase systems. The results obtained show that nine-phase line system could connect up to 9.6 times more load than that of a three-phase line system.*

Streszczenie. *W artykule zaprezentowano projekt i analizę dziewięciofazowej linii przesyłowej. Analizowano dwie linie 400 kV – 200 km i 400 kV 600 km. Stosując Matlab/Simulink analizowano zakłócenie środowiska, możliwości powstawania błędów i możliwości przesyłania mocy. Wykazano że sieć dziewięciofazowa pozwala na obciążalność 9.6 razy większą niż sieć trójfazowa.* ***Projekt dziewięciofazowej linii przesyłowej z wykorzystaniem oprogramowania Matlab/Simulink***

Keywords: Power transmission line, Three-phase, Nine-phase system, High voltage
Słowa kluczowe: dziewięciofazowa linia przesyłowa, przesyłanie energii

Introduction

In the beginning, humans used their physical force to perform any activity to generate an income. Then, came the first industrial revolution which entailed the mechanization of tasks [1, 2, 3]. The first industrial revolution remained difficult for humans because physical force was still required even if the impact of this revolution was clearly visible. The second industrial revolution introduced the utilization of electrical motors [1, 5, 6]. Electricity joined mechanics to become the new research area. Since the advent of electricity, daily human work has become less painful, whether in agriculture, transport or in manufacturing. However, the use of electricity is subject to many difficulties such as its area of production which is in the majority of the cases far removed from the consumption point. This means electricity needs to be conveyed [7, 8, 9, 10]. The next difficulty lies in the consumers continued increase in demand. The world energy council published a study in 2013 entitled “Global energy scenarios by 2050”. This study shows that the energy supply will increase from 152000 TWh in 2010 to 244000 TWh in 2050, which represents an increase of 61% and electricity consumption will increase by 111% per person [11]. The question to be answered is how such an amount of energy will be transmitted to the consumers? The third difficulty is the permanent distribution of the electricity to all consumers in time and with regular frequency [12].

The nine-phase transmission line was studied to anticipate the growing need for energy in our modern cities and to increase the power density transmitted. Much research that has been conducted in the last 30 years started in the USA and good results have been obtained. Several studies covered multi-phases greater than three phases and fewer than six phases [4]. A literature review of multi-phase systems identified various publications.

In 2002, Liu and Yang [13] demonstrated that a four-phase system could increase 33.3% of the transmission capacity. The aim of the study in Mustafa et al. [14] was to simulate a six-phase line using PSCAD/EMTDC in several fault types. Many faults were studied using the symmetrical components methodology and it emerged from this study that the current flow in each phase is higher when fault to ground are conducted on the six-phase transmission lines compared to the ungrounded fault. In the continuation this researcher [15] in 2006 demonstrated that the four bus, two generators test system with six-phase single circuit could have a good stability versus a three-phase line. In 2010, Takani et al. [16] compared the efficiency of a multi-phase auto-reclosing against a single-phase and a three-phase auto-reclosing. They concluded that in multi-phase auto-reclosing the current differential relay avoids interruption of the system between the line terminals. Ibe et al.[17] presented a mathematical model of a multi-phase line algorithm to locate faults for a three-phase system that has a 400 kV line to line voltage with a length of 150 km and is analysed using partial differential equations called Telegraph’s equations. It emerges from this study that the complex matrix could be simplified using nodal analysis, the rest is the straightforward analysis.

The limitation in the above literature is that none of the researchers shows how to design a line that has more than three-phases using actual software; how to evaluate the power transmitted at both sides of the line to determine whether this phase increase could be useful or not; and there is no research on nine-phase line design.

In general, this study of a nine-phase line is the first that shows step by step how to use actual software called Matlab/Simulink to design an electrical line and to evaluate the power transfer at the sending and receiving end of the line. A nine-phase transmission line has many advantages compared to the existing three-phase, such as a high power transmitted capacity and a reduced number of faults. Other researchers demonstrated that the corona effect, noise, electric and magnetic fields that negatively impact on the environmental system might be reduced at equal power compared to the existing three-phase line system [13, 18].

The increase in the world's population has an impact on the amount of electricity produced daily and that must be transported, which is the reason why the three-phase electrical system was developed. However, this three-phase line has demonstrated its limitations. That is why many companies working with transmission lines build other lines in parallel either to increase the energy capacity available for consumption or to troubleshoot the main transmission line. In case of default, this solution is subject to several disadvantages such as the cost to the company to build a new line, the environmental impact, the complexity of the maintenance because of many lines close to each other to cite a few [19], [20]. To preserve existing investments, the study of new ninephase lines having the same characteristics with the actual three-phase system, but that can supply more load, is necessary.

A transmission line with the same characteristics (type of cable, type of pylon) as a three-phase network has been

studied. It is called a nine-phase line. The main aim of this study is to implement a new way to convey electricity that will supply more load than the existing three-phase system. The specific objectives are firstly to use Matlab/Simulink software to design such a system, secondly to determine the most important parameters in transmission line design such as R, L, C parameters and finally to compare what we have in terms of load connected to the nine-phase transmission line system and the three-phase system to reach the 100 MW threshold power remaining in the grid before starting the load shedding. The contribution of the results of this research can be used to reduce the cost for the same amount of power in threephase; to reduce the negative environmental impact of power transmitting; to increase the amount of power transmitted; to reduce the time used by the companies to maintain their network system; to reduce the troubleshooting time; and to achieve the global world energy requirements by 2050.

The structure of this paper is as follows: Section 2 introduces the parameters of a transmission line; Section 3 will explain the use of the Simulink software in nine-phase implementation; Section 4 will present the results and discussion and Section 5 contains the conclusion.

Parameters of Power Transmission Lines

In this section, the mechanical and the electrical parameters of the general transmission lines are studied. Parameters such as the maximum sag of the cable and the types of high voltage cable as well as the characteristics of the cable utilized in this study and used by ESKOM Ltd., the main South African electricity supplier, are given. Various equations are utilized to determine the electrical parameters such as the inductance, the capacitance and the resistance of the line as well as the power angle of the line.

0.1 Mechanical parameters

High voltage overhead transmission lines are hooked to insulators which are also fixed on pylons. The distance in meters between two phases depends on the admissible sag value in the line. In general, 1 meter is taken between two pylons for every 1000 volts [21, 22]. The vertical phase gap (X_{ph}) as shown in Figure 1 for a circuit depends on the nominal voltage and the length of the insulators.

$$X_{ph} = \frac{U_N}{150} + K\sqrt{Sag_{max} + L_i} \qquad (m) \tag{1}$$

U_N: nominal voltage; K: coefficient depending on the nature of the cable; Sag_{max}: maximal admitted (m); L_i: length of the isolator (m).

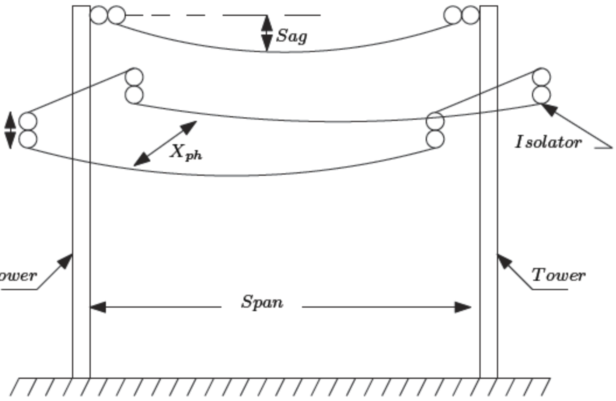

Fig. 1. Admissible Sag and Vertical Phase Gap.

The conductors used in overhead lines are in the majority of cases made from aluminum or/and copper. In alloy conductors, copper provides the mechanical strength needed to cancel horizontal and vertical strength tension which keeps the cable in balance while the aluminum ensures the conductibility of the conductor [23, 24]. The frequent utilization of the aluminum and/or its alloys in high voltage lines is due to its low weight, its lower cost and its resistance to climatic influences.

A transmission line subjected to rising temperatures might see its efficiency decrease. This rise of the cable temperature may be due to one or more phases overloading or to climate change. The temperature rise will cause the cable sag. The cable sag should not drop more than the range admitted by the regulation.

The calculations used to determine whether or not an overhead line complies with the usual safety rules, such as the height of the cable relative to the ground, are carried out following the mathematical equation of the chain as seen in Figure 2.

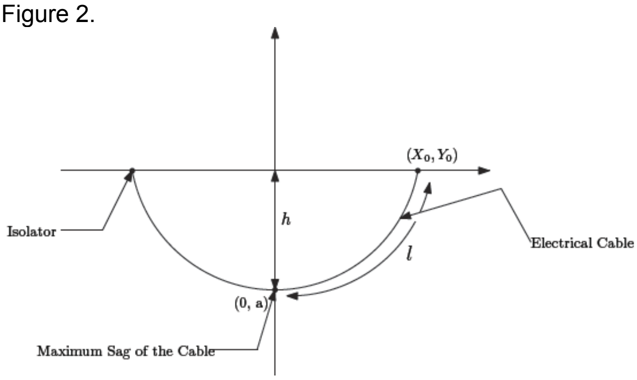

Fig. 2. Mathematics model of cable sag.

The equation of a chain could be applied either in threephase line or in nine-phase line. These equations are as follows:

$$Y(x) = aCh\frac{x}{a} \tag{2}$$

$$\begin{aligned} l &= \int_0^{x_0} \sqrt{1 + y'(x)^2 dx} \\ &= \int_0^{x_0} \sqrt{1 + Sh^2\frac{x}{a} dx} \\ l &= aSh(\frac{x_0}{a}) \end{aligned} \tag{3}$$

The sag is the height h between the two points of the cable attachment and the lowest point.

If ($\pm x_0$, y_0) the two points of the cable attachment can be stated as

$$y_0 = aCh\frac{x_0}{a} = a + h \quad \Rightarrow \quad h = aCh\frac{x_0}{a} - a \tag{4}$$

$$l = aSh\frac{x_0}{a} \tag{5}$$

$$\begin{aligned} l^2 - h^2 &= a^2 Sh^2\frac{x_0}{a} - (aCh\frac{x_0}{a} - a)^2 \\ &= 2ah \end{aligned} \tag{6}$$

$$\Rightarrow \quad a = \frac{l^2 - h^2}{2h} \tag{7}$$

where h: is the horizontal distance between the point where the sag of the cable is maximum and the origin of the cable; l: is is the curve distance between the point where the sag of the cable is maximum and the isolator; a: is the maximum sag of the cable; x_0, y_0 are the Cartesian system's co-ordinates.

It is obvious that for both three-phase and nine-phase systems the mechanical parameters are the same. These equations can be used in order to determine the conductors' sag. As the parameters of Equation 7 are not directly linked to electrical parameters, it is possible that the maximum sag will stay the same for both systems. However, the length of the isolators should be taken into consideration and this depends on the number of disc-shaped pieces of porcelain or polymer which now depend on the line voltage.

The sag of the cable in Equation 7 depends on the chemical characteristic of the cable. The most important parameters from the point of view of electrical efficiency in the study and implementation of a transmission line are the resistance, the inductance, the capacitance and their mutual values per km.

0.2 Electrical Parameters

The inductance in Equation 10 and the capacitance of the line in Equation 11 depend on the radius of the conductors and the distance between the centers of the conductors. The two wire phase inductance of a single phase is

$$L = \frac{\mu_0}{4\pi}\left[1 + 4\ln(\frac{d-r}{r})\right] \qquad (H/m) \tag{8}$$

where r: radius of the conductors; d: distance between the centers of the conductors

$$\begin{aligned} d >> r \quad \Rightarrow \quad L &= \frac{\mu_0}{4\pi}\left[1 + 4\ln(\frac{d}{r})\right] \\ &= \frac{\mu_0}{4\pi}\left[4\ln(\exp(\frac{1}{4})) + 4\ln(\frac{d}{r})\right] \\ &= \frac{\mu_0}{\pi}\left[\ln(\frac{d}{r\exp(\frac{1}{4})})\right] \end{aligned} \tag{9}$$

if $r' = r\exp(\frac{-1}{4})$ with $\mu_0 = 4\pi 10^{-7}$

$$L = \left[4 \times 10^{-7}\ln(\frac{d}{r'})\right] \qquad (H/m) \tag{10}$$

The capacitance of the line will be equal to

$$C = \frac{2\pi\epsilon_0}{\ln\left(\frac{d}{r'}\right)} \qquad (F/m) \tag{11}$$

In practice, the use of two or three conductors on a phase reduces the reactance, which will reduce conductor to ground surface voltage gradients and therefore, will reduce the corona loss and radio interference [21]. Those conductors are linked with a spacer damper as shown in Figure 3.

However, if two lines are located on the same pylon, to maintain a good performance for each of them, the magnetic interaction produced by these lines must be taken into account in the design. Then, Equation 1 should be applied to determine the distance between different phases.

Fig. 3. Spacer damper for three cables [25].

Phase voltage for a multi-phase system is

$$U = 2V\sin(\frac{\pi}{N}) \tag{12}$$

where U is the nominal voltage, V is the phase to ground voltage and N is the number of phase. From Equation 12:

$$\frac{U}{V} = 2\sin(\frac{\pi}{N})$$

If N = 3 then the ratio will be equal to √3 and if N = 9 then the ratio will be equal to 0.4 √3. In the theory the power of a transmission line (S_L) and the power angle (P_Θ) of a line can be written respectively as

$$S_L = \frac{N \times V^2}{Z_S}; \qquad P_\theta = \frac{N.V_S.V_R}{X}\sin(\delta) \tag{13}$$

where S_L is the power of a line; N is the number of the phase; V is the phase to ground voltage; V_S is the phase to ground at the sending; V_R is the phase to ground at the receiving, Z_S is the surge impedance and X is the reactance per phase.

If the number of phases increase, the surge impedance and the reactance of the line stay the same. The power of the transmission line and the line's power angle could then increase 3 times more than in three-phase.

In a nine-phase line, parameters of the line cannot be identified as they are in Equation 10 and in Equation 11 because the line has more than three phases. So, parameters of a line with more than a three-phase system are presented in terms of a matrix. Each matrix representing R, L and C will be equal to 9 ×9 dimensions for a nine-phase line. The R and C matrix will as the first row be equal to the first column, the second row equal to the second column…the ninth row equal to the ninth column (R12 = R21, R13 = R31… R19 = R91) or (C12 = C21, C13 = C31… C19 = C91). However, the resistance matrix does not have negative numerical values while C matrix has. In the inductance of the line, all the numbers in the diagonal are equals and the first row equal to the first column…the ninth row equal to the ninth column ($L12 = L21$, $L13 = L31$, … $L19 = L91$). All numbers in this L matrix are positives.

Voltage drop on power lines is common and can be caused by improper load sharing. However, even when the loads are balanced, the unsymmetrical conductor spacing results in different inductances for each phase which might create an unbalanced voltage drop. This unbalanced voltage drop will provide current and voltage in the neighbouring electrical line. To solve this issue, it is recommended to exchange the phases' position while transmitting electrical energy in the regular range to avoid induced currents three times in threephase lines as shown in Figure **4** or nine times in a ninephase line as shown in Figure 5 [23, 26].

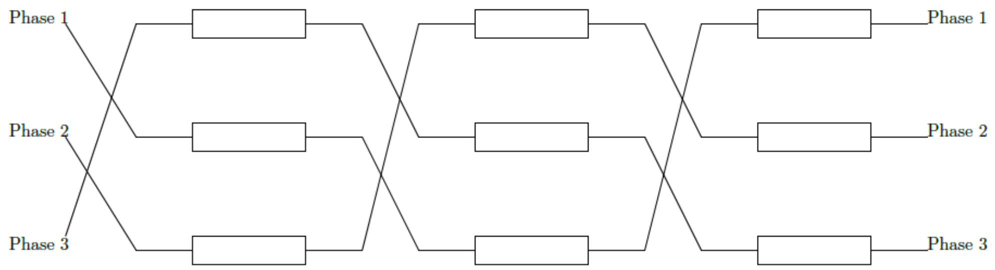

Fig. 4. Phase Transposition of a Three-Phase Transmission Line.

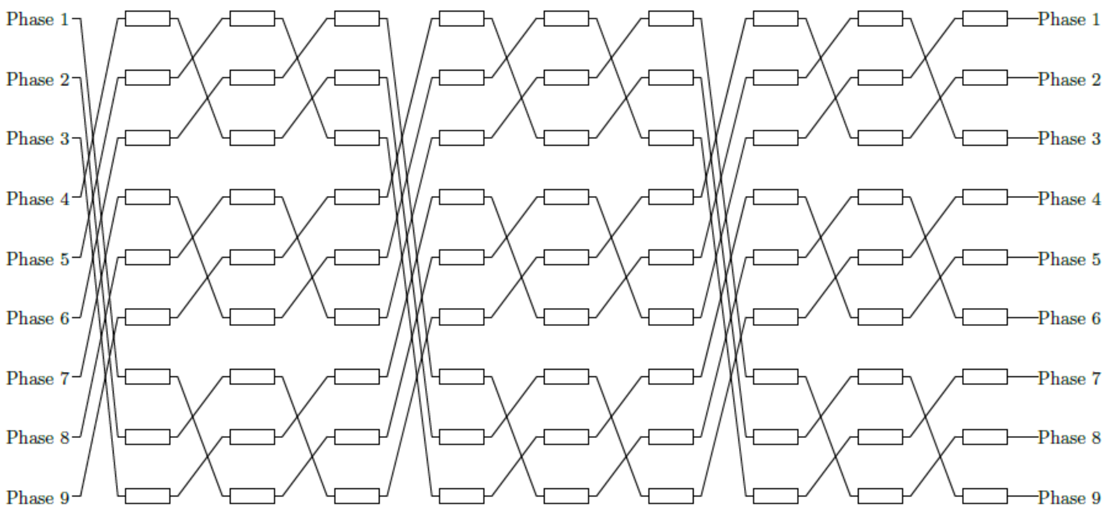

Fig. 5. Phase Transposition of a Nine-Phase Transmission Line.

This technique of phase transposition is usually made at the substation. In practice, it is difficult to exchange phases in the regular range because of the substation's location which depends on many parameters such as environmental or geographical parameters. In general, the phase transposition is equal to the number of phases of the system and it is applied to long transmission lines. Therefore, in a nine-phase system, the phase transposition could be done nine times.

Heat dissipation in transmission line is also known as Joule's losses. The Equation of the well known Joule's effect is as follow in Equation 14.

$$P_j = RI^2 \qquad (W) \tag{14}$$

where R is the resistance of the conductor, I is the current flowing and P_j is the power loss due to heat.

For lines having the same characteristics, a nine-phase transmission line will have more conductors than a threephase line so, the power loss due to heat dissipation will also be greater in nine-phase than in three-phase system and could be up to three times.

Nine-Phase Implementation in Simulink

This section presents the step by step procedures to design a nine-phase transmission line using Matlab / Simulink software.

In general, a transmission line can be simplified as shown in Figure 6 and its design is always similar either, in three-phase or in nine-phase systems. It includes towers, insulators, conductors, shield conductor, tower's foundation and grounding [23, 27].

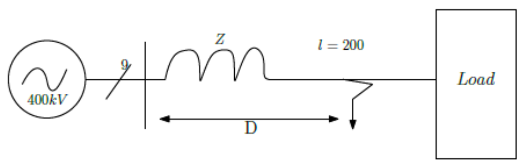

Fig. 6. A Simplified Transmission Line System.

In Simulink, all components are designed for single and three-phase. For this purpose, the designer of a nine-phase line using this software must be ingenious. All electrical equipment such as voltmeter, ammeter and wattmeter must be designed according to their operating system. Therefore, to design the nine-phase system, the three-phase system was designed beforehand and the Simulink tools used are the line, the circuit-breaker, the generator, the measuring equipment and the Powergui.

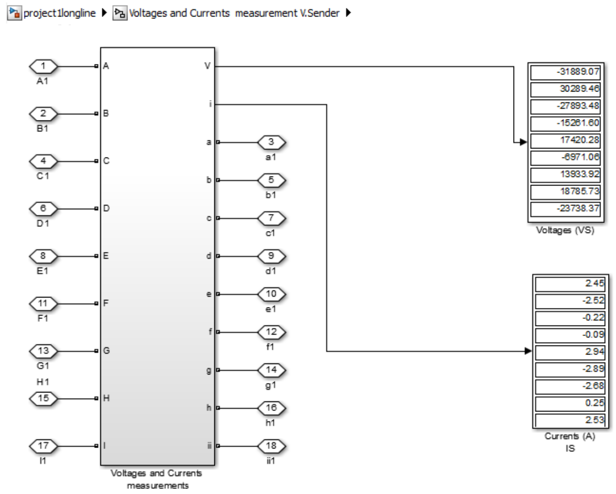

Fig. 7. Subsystem of the Voltmeter and the Ammeter.

0.3 Measurement of Network Variables

In order to measure the network variable such as the voltage and the current that flows into the line when there is a shortcircuit fault, two ammeters and two voltmeters were designed and incorporated at two distinct positions, at the beginning and at the receiving end of the line. A combined ammeter and voltmeter is designed in one circuit. Figure 7 shows the subsystem

where each value of the current and voltage can be read. Figure 8 shows the internal circuit of the measurement system. This system permits the display of the measured values in real time. If, for example, a fault occurred anywhere on the line, it is possible to see the variations of the current and the voltage at the point where the apparatus is inserted.

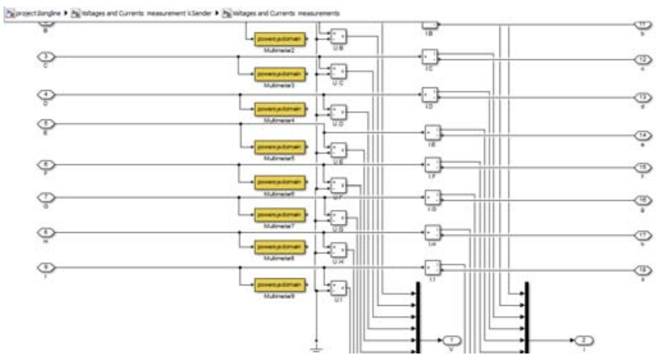

Fig. 8. Voltmeter and Ammeter internal circuit.

Similarly, to measure the total power at the beginning and at the end of the line, a wattmeter is designed and presented in Figure 9 and the sub-system which permits the reading of the recorded values is presented in Figure 10. This wattmeter was designed to measure the changing of the load, the power that flows into the nine-phase system and to compare it with the one that flows into the three-phase system.

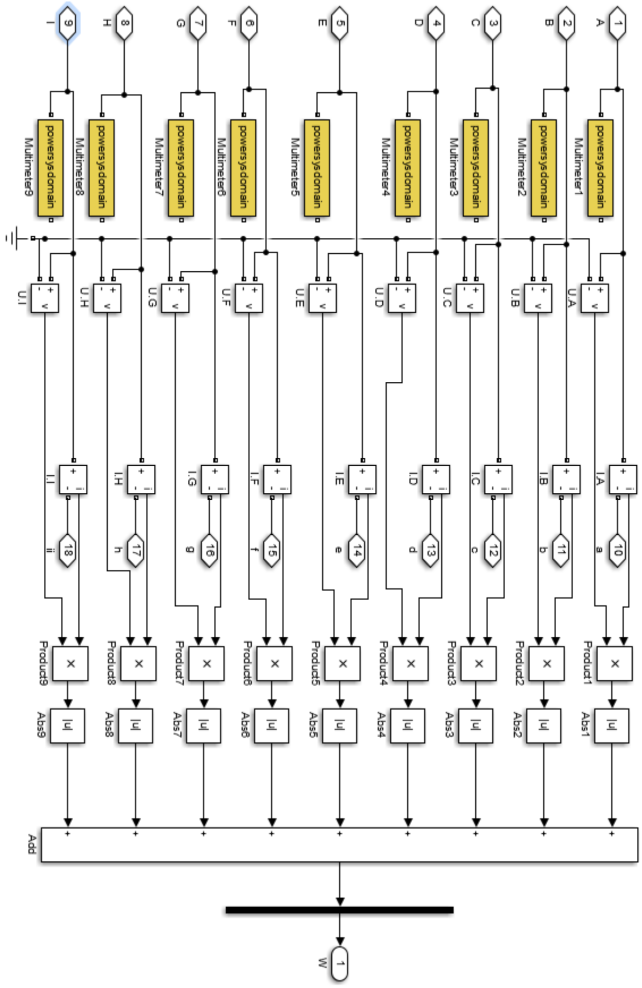

Fig. 9. Wattmeter internal circuit.

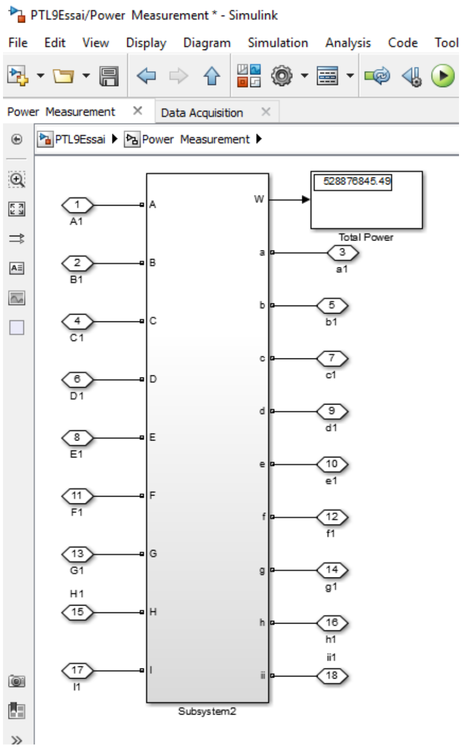

Fig. 10. Subsystem of the Wattmeter.

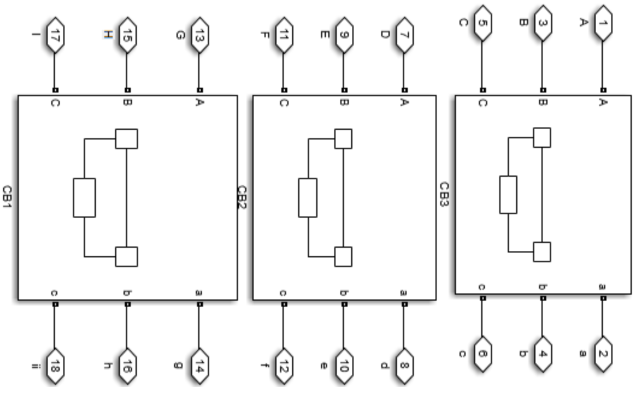

Fig. 11. Circuit Breaker for a Nine-Phase Line.

0.4 Network Protection

To protect the nine-phase line, three three-phase circuit breakers are used based on the practical principle where three single-phase circuit-breakers can be used to protect a three-phase circuit in the absence of a three-phase circuit breaker. In practical terms, the three three-phase circuit breakers may not respond to a nine-phase system considering the voltage capacity and line parameters. So, this could only work in simulation because the open time of circuitbreaker's poles are the same in case of the fault. It is recommended to use a circuit-breaker that corresponds to the number of phases of the transmission line or to use a relay that will command the opening and closing of the circuit breaker's poles, or it is also recommended to protect each phase using a single-phase circuit-breaker. Figure 11 shows the model circuit of the circuit-breaker used in the simulation. This circuit-breaker could also be used to introduce various fault types in the system such as single phase to ground and double-phase faults.

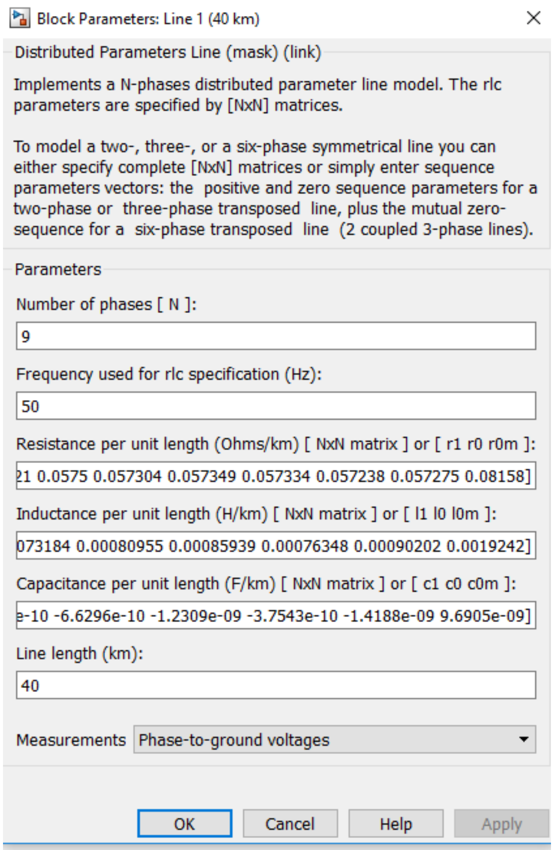

Fig. 12. Transmission Line Block Parameters.

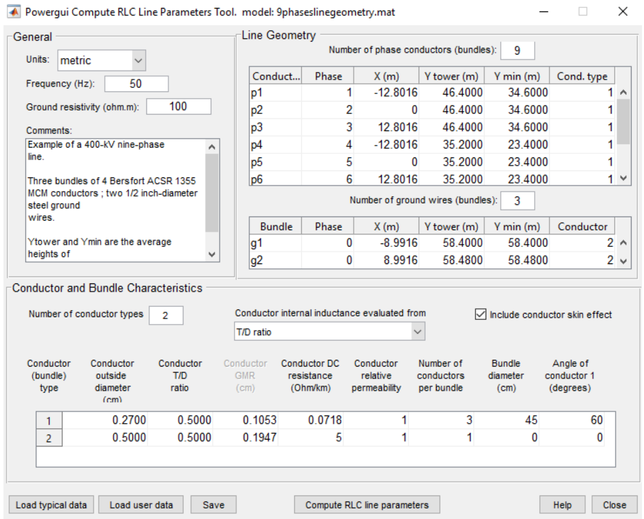

Fig. 13. Powergui Compute RLC Line Parameter tool.

0.5. Block Parameters of the Line

The line's configuration required computing parameters such as the resistance, the capacitance, the inductance and to fill the number of the phase, the frequency, the length of the line and the parameters of the cable as shown in Figure 12. In this study, the characteristics of the line were provided by ESKOM Ltd. The characteristics are presented in the Table 1. This nine-phase line is designed to compare the power capability with the existing three-phase system, but could also be used for its short-circuit current and voltage values to predict fault classifications and fault locations that may occur. The total length of the line used is 200 km divided into 5 zones of 40 km each.

Table 1. Characteristics of the cable.

Diameter (mm)	27
DC Resistance (Ω/xm0	0.0718
T/D Ratio	0.5
Number of conductors per bundle	3
Bundle diameter (mm)	450
Angle of the conductor (degre)	60

To compute the line's parameters needed, Matlab/ Simulink has a Powergui where RLC parameters are selected as shown in Figure 13.

In Table 1, T/D ratio represent the evaluation of the AC resistance where T is the thickness of conducting material which is the conductor and D is the outside diameter of the conductor.

In the top left of Figure 13 "Units"allows the choice of the unit of the distance either in meter (Metric) or in feet (English). The frequency of the system and the ground resistivity are filled in. In the top right, the line geometry can be filled in with the number of the Phase conductor. $X(m)$ and $Y\ tower\ (m)$ are the coordinates of each phase conductor and $Y_{min}\ (m)$ is the sag value of the cable. A transmission line has two types of cables such as a phase conductor and a protection conductor against lightning connected to the earth. The last box filled with "1"means that this is a phase conductor.

Also in Figure 13, the parameters of the cable type are filled in at the bottom. When all those parameters are filled in, the RLC parameters of the line can be computed by clicking on the button "Compute RLC Line Parameters". In ninephase, the sequence parameters will not be available and only RLC matrices' parameters computed will be available to be downloaded. For the case studied, the line parameters obtained are shown in Figure 14. These are the values that will be downloaded in the line. To do so, select the line on your model and click " *RLC* Matrices".

Finally, by putting together the different items of equipment as designed, we obtain Figure 15 that presents the nine-phase line.

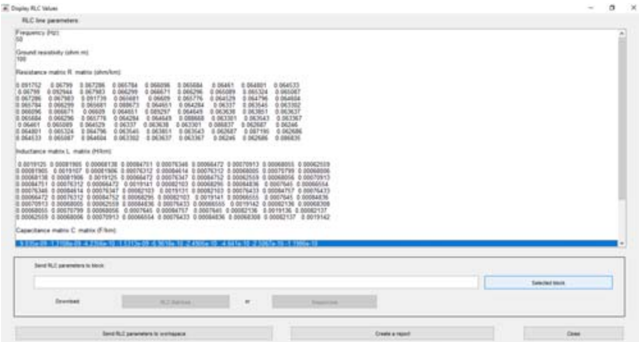

Fig. 14. RLC Line Parameters Obtained.

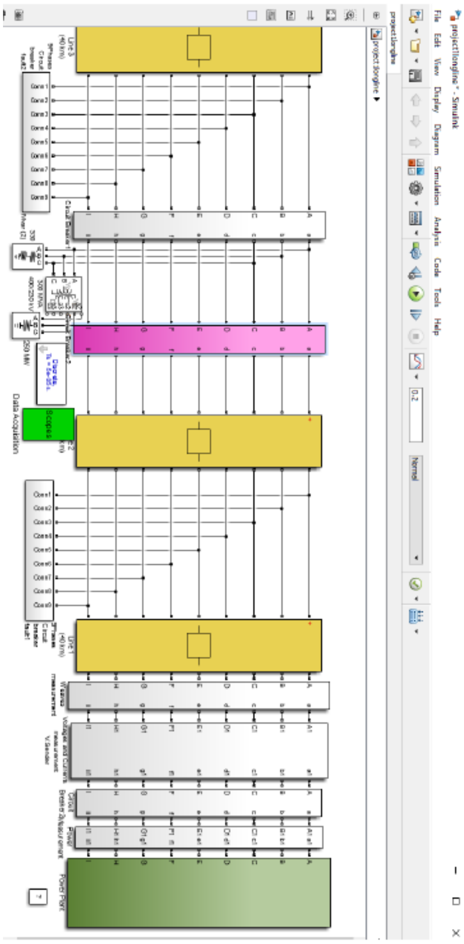

Fig. 15. Nine-Phase Transmission Line Obtained.

Results and Discussion

RLC line parameters computed by the system and downloaded in the line are the matrices which have 9×9 dimensions displayed in Figure 14. These *RLC* parameters permit the system to be simulated and the power transmitted to be evaluated and compared successfully to the obtained nine-phase circuit with the existing three-phase model.

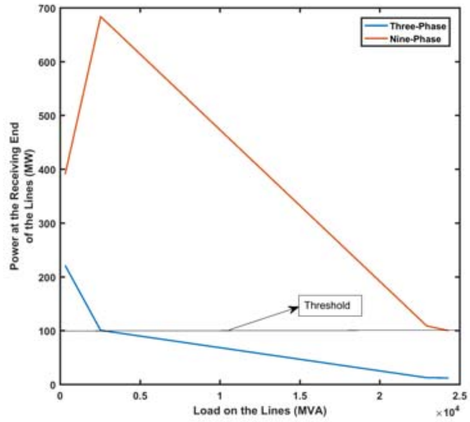

Fig. 16. Load Comparison in both Systems at the Receiving End of the Line.

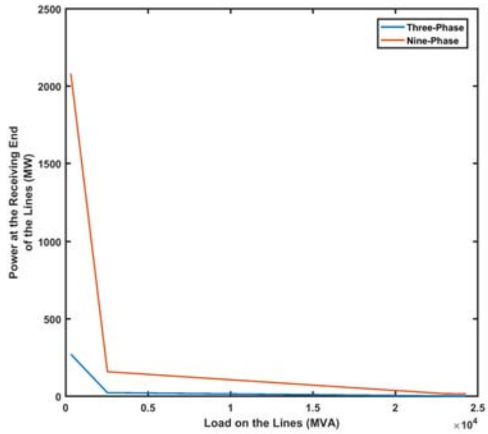

Fig. 17. Load Comparison in both Systems of 600 km, at the Receiving End of the Line.

Comparing the nine-phase circuit against the threephase shows that a nine-phase line will always have the same conception base as a three-phase line. The complexity of a nine-phase line in terms of mathematic equations used to analyse the model is the highest. Comparing the load that could be connected into the grid without load shedding in the existing three-phase line and the studied nine-phase line, shows that by using the same type of cable to transmit power in 200 km, a nine-phase system could supply a load of up to 23550 MW while a three-phase system could only supply a load of up to 2500 MW. In 600 km, a nine-phase system could supply up to 2500 MW while a three-phase system could only supply 306 MW. These values are measured using two wattmeters inserted at the beginning and at the end of the lines. If this three-phase system supplied a load while the power measured at the receiving end of the line is less than the recommended 100 MW threshold, there will be a blackout because of the line collapse. It is recommended to respect the 100 MW threshold that should be measured at the end of the line as shown in Figures 16 and 17. The nine-phase system could supply a load up to 9.6 times higher than the load connected to the three-phase system for the medium line (200 km) while in 600 km lines, the nine-phase could supply a load up to 7 times higher than the load connected to the three-phase system. Therefore, this nine-phase is more effective than three three-phase transmission lines built in parallel as is usually used in practice. However, at this distance none of them needed to be compensated as shown in Tables 2 and 3 because the power on line remains sufficient. But when the load increases, the power measured at the beginning and at the end of line in both systems is influenced and the power measured may be less than the threshold. To maintain these lines to function it is recommended to introduce a compensation system into the lines .

$$R = \begin{pmatrix} 0.0918 & 0.0680 & 0.0673 & 0.0658 & 0.0661 & 0.0657 & 0.0646 & 0.0648 & 0.0645 \\ 0.0680 & 0.0929 & 0.0680 & 0.0663 & 0.0667 & 0.0663 & 0.0651 & 0.0653 & 0.0651 \\ 0.0673 & 0.0680 & 0.0917 & 0.0657 & 0.0661 & 0.0658 & 0.0645 & 0.0648 & 0.0646 \\ 0.0658 & 0.0663 & 0.0657 & 0.0887 & 0.0647 & 0.0643 & 0.0634 & 0.0635 & 0.0633 \\ 0.0661 & 0.0667 & 0.0661 & 0.0647 & 0.0893 & 0.0646 & 0.0636 & 0.0639 & 0.0636 \\ 0.0657 & 0.0663 & 0.0658 & 0.0643 & 0.0646 & 0.0887 & 0.0633 & 0.0635 & 0.0634 \\ 0.0646 & 0.0651 & 0.0645 & 0.0634 & 0.0636 & 0.0633 & 0.0868 & 0.0627 & 0.0625 \\ 0.0648 & 0.0653 & 0.0648 & 0.0635 & 0.0639 & 0.0635 & 0.0627 & 0.0872 & 0.0627 \\ 0.0645 & 0.0651 & 0.0646 & 0.0633 & 0.0636 & 0.0634 & 0.0625 & 0.0627 & 0.0868 \end{pmatrix} (\Omega/km) \tag{15}$$

$$L = \begin{pmatrix} 0.0019 & 0.0008 & 0.0007 & 0.0008 & 0.0008 & 0.0007 & 0.0007 & 0.0007 & 0.0006 \\ 0.0008 & 0.0019 & 0.0008 & 0.0008 & 0.0008 & 0.0008 & 0.0007 & 0.0007 & 0.0007 \\ 0.0007 & 0.0008 & 0.0019 & 0.0007 & 0.0008 & 0.0008 & 0.0006 & 0.0007 & 0.0007 \\ 0.0008 & 0.0008 & 0.0007 & 0.0019 & 0.0008 & 0.0007 & 0.0008 & 0.0008 & 0.0007 \\ 0.0008 & 0.0008 & 0.0008 & 0.0008 & 0.0019 & 0.0008 & 0.0008 & 0.0008 & 0.0008 \\ 0.0007 & 0.0008 & 0.0008 & 0.0007 & 0.0008 & 0.0019 & 0.0007 & 0.0008 & 0.0008 \\ 0.0007 & 0.0007 & 0.0006 & 0.0008 & 0.0008 & 0.0007 & 0.0019 & 0.0008 & 0.0007 \\ 0.0007 & 0.0007 & 0.0007 & 0.0008 & 0.0008 & 0.0008 & 0.0008 & 0.0019 & 0.0008 \\ 0.0006 & 0.0007 & 0.0007 & 0.0007 & 0.0008 & 0.0008 & 0.0007 & 0.0008 & 0.0019 \end{pmatrix} (H/km) \tag{16}$$

$$C = 1.0e-08 \times \begin{pmatrix} 0.9035 & -0.1311 & -0.0424 & -0.1531 & -0.0696 & -0.0249 & -0.0464 & -0.0251 & -0.0120 \\ -0.1311 & 0.9350 & -0.1311 & -0.0709 & -0.1279 & -0.0709 & -0.0259 & -0.0315 & -0.0259 \\ -0.0424 & -0.1311 & 0.9035 & -0.0249 & -0.0696 & -0.1531 & -0.0120 & -0.0251 & -0.0464 \\ -0.1531 & -0.0709 & -0.0249 & 0.9409 & -0.1035 & -0.0241 & -0.1365 & -0.0597 & -0.0170 \\ -0.0696 & -0.1279 & -0.0696 & -0.1035 & 0.9667 & -0.1035 & -0.0597 & -0.1180 & -0.0597 \\ -0.0249 & -0.0709 & -0.1531 & -0.0241 & -0.1035 & 0.9409 & -0.0170 & -0.0597 & -0.1365 \\ -0.0464 & -0.0259 & -0.0120 & -0.1365 & -0.0597 & -0.0170 & 0.9522 & -0.0982 & -0.0198 \\ -0.0251 & -0.0315 & -0.0251 & -0.0597 & -0.1180 & -0.0597 & -0.0982 & 0.9694 & -0.0982 \\ -0.0120 & -0.0259 & -0.0464 & -0.0170 & -0.0597 & -0.1365 & -0.0198 & -0.0982 & 0.9522 \end{pmatrix} (F/km) \tag{17}$$

Table 2. Comparison of the two different systems of 200 km.

Load connected		Three-Phase System		Nine-Phase System	
Q (MVAR)	**P (MW)**	Power at the End of the Line (MW)	Power at the Beginning of the Line (MW)	Power at the End of the Line (MW)	Power at the Beginning of the Line (MW)
50	**306**	221.68	230.22	390.86	417.45
400	**2500**	100.86	125.68	684.01	717.68
4500	**22500**	12.83	65.47	108.99	270.51
6000	**23550**	12.3	62.58	100.38	258.26

Table 3. Comparison of the two different systems of 600 km.

Load connected		Three-Phase System		Nine-Phase System	
Q (MVAR)	**P (MW)**	Power at the End of the Line (MW)	Power at the Beginning of the Line (MW)	Power at the End of the Line (MW)	Power at the Beginning of the Line (MW)
50	**306**	272.33	291.3	2082.2	4643.44
400	**2500**	23.14	44.91	158.71	156.7
4500	**22500**	2.42	34.51	17.18	121.76
6000	**23550**	2.3	35.5	16.05	122.45

Table 4. Power losses comparison of the two different systems.

Load connected		200 km Lines		600 km Lines	
Q (MVAR)	**P (MW)**	Three-Phase System P_j (MW)	Ninee-Phase System P_j (MW)	Three-Phase System P_j (MW)	Ninee-Phase System P_j (MW)
50	**306**	8.54	26.59	18.97	2561.24
400	**2500**	24.82	33.67	21.77	2.01
4500	**22500**	52.64	161.52	32.09	104.58
6000	**23550**	50.27	167.88	33.2	106.4

By having the power at the receiving and at the sending end of the transmission lines presented in Table 2 and in Table 3, to determine the magnitude of the power loss, a subtraction can be done in absolute value and the obtained results are presented in Table 4. These results cannot well be compared in two conditions: when the line is over-loaded and under-loaded. It can be seeing in Table 4 that when the load connected has Q = 400 MVAR and P = 2500 MW, the nine-phase line has more power losses for the 200 km lines but this power loss does not equal to three times the one of the three-phase system. However for the 600 km lines, threephase power losses are higher than nine-phase power losses only because the threshold of 100 MW has been exceeded.

Conclusion

The work done in this article consists of designing two distinct nine-phase overhead high voltage transmission lines that respectively carry 400 kV over a length of 200 km and 600 km using Matlab/Simulink software. It should be noted that Matlab/Simulink software only offers one-phase or threephase electrical equipment when all electrical components that allow the smooth operation of the system such as voltmeter, ammeter, wattmeter and circuit breaker are designed. The results obtained show that, to build three transmission lines in parallel could not help transmitting an amount of power as high as a single nine-phase transmission line. According to the results in Tables 2 and 3, three transmission lines built in parallel and having the same characteristics will only supply three times the value of the load while a single nine-phase transmission line will supply up to 9.6 times the load for the medium line and up to 7 times the load for the long line connected in a three-phase transmission line system without compensation.

As the network migrated from single phase to a threephase line for increasing the power transmitted to the consumers in our cities, it is now urgent to find a system that could supply more loads than a three-phase line while preserving the existing transmission system such as the vertical spacing between phases and the phase voltage as well as the towers. By doing this, a new electrical line with a high energy efficiency in terms of cost and power transmitted could be used to supply consumers in our society. After the implementation of the nine-phase system, it is clear that this line can replace the existing system and transmit more power.

Data from a nine-phase line studied in this research could be used to classify faults and determine their location. It is also possible to determine a matrix of the Clarke's transformation which is well known in three-phase systems. Such a matrix will be used to analyze symmetrical and unsymmetrical fault locations.

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