SEMINAR NASIONAL ENERGI

Added Value of Energy Resources

AVoER

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PROSIDING

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MOCK-UP SYSTEM OF SIX PHASE POWER TRANSMISSION LINE FOR FEASIBILITY STUDY THREE TO SIX PHASE CONVERSION TRANSMISSION LINE

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ABSTRACT

Six phase transmission line theoretically is a alternative way to increase transmission line power capability to meet the increasing electrical energy demand. Several researchers was developed mathematical model and computer programming simulation of this system. However, modeling and simulation have not been carried out the actual measurement result. This paper presented the proposed mock-up system of transmission line by presenting the various representations of transmission line components such as; transmission tower, transmission line, circuit breaker, transformers and loads. Impact of conversion of three to six phase and over-voltages due to switching transient are presented.

Keywords: Transmission line, measurement, over-voltages

1. INTRODUCTION

Transmission line network is part of an electric power system. It serves to transfer electric energy from generating units located at various locations to centres the load via the distribution system. Transmission lines also interconnect neighboring utilities which permits not only economic dispatch of power within regions during normal conditions, but also the transfer power between regions during emergencies (Saadat,1999).

The increasing demand for power energy in Indonesia especially in Sumatera island, coupled with the difficulty in obtaining new rights-of-way, electric power utilities are often faced with the challenge of increasing power transfer capabilities of existing transmission lines. Beside the cost of development of new transmission line project is high, other reason responsible for the slow increase of transmission is the growing difficulty in getting permits for new lines. Hence, that reason dictates the feasibility of upgrading the capacity of existing line. In upgrading the capacity of a line, the possible options among others include installing larger conductors on existing structures, increasing the operating voltage, increasing operating temperature, increasing the reliability, or a combination of above (Rural Utilities Service, 1984). However, they typically involve one or more conditions that exceed the original design capabilities of the existing electrical and structure aspects. An upgrading that involves increased mechanical loads or electrical insulation clearance, a number of factors should be considered that can minimize the extent of modification (Simpson, 1990). One alternative to increase the power transfer capability of existing three phase double circuit transmission line is the use of six-phase single circuit transmission line (Venkata, 1982).

2. SIX-PHASE TRANSMISSION LINE

A Six-Phase Transmission System (SPTS) is characterized by number of voltages of equal magnitude and equally spaced in time. For a Three-Phase Transmission System (TPTS) this means three equal voltages spaced 120° in time. For SPTS this becomes six voltages spaced 60° in time (Kanya, 1993).

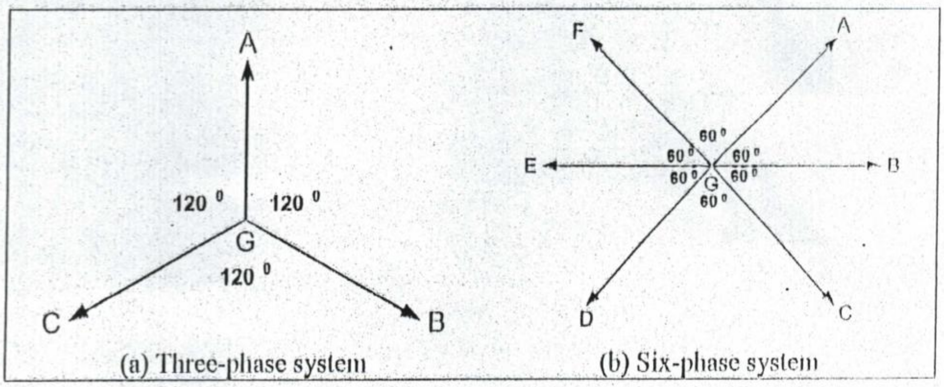


Figure 1. Phasor diagram of TPTS and SPTS

Wilson and Stewart (1984) classified the voltage system of SPTS as shown in Figure 1(b) into four discrete voltages, i.e.: phase-to-ground voltage, between adjacent phase, between phases separated by one intermediate phase, and between opposite phases. Within each group the voltages have identical magnitudes. In the group I the voltages are spaced 60°, in the group II and III the voltages are spaced 120° and 180° respectively. For example, when the six-phase transmission line is energize with a nominal phase-to-ground voltage of V kV, the phase-to-phase voltage will be V kV between adjacent phases, $\sqrt{3}\,V$ kV between phases 120° apart, and $2V$ kV between opposite phases. Hence, voltage stress on the insulators of six-phase mode will be substantially different from those in the three phase mode

Phasor diagram of phase-to-phase and phase to ground is shown in Figure 2(a) and Figure 2(b) shows phase-ground-phase DGC triangle. The equation of V_{line} and V_{phase} can derived by determining the resultant of DGC triangle.

$$V_{CD} = 2 \times V_{CG'} = 2 \times V_{CG} \cos\theta \qquad (1)$$

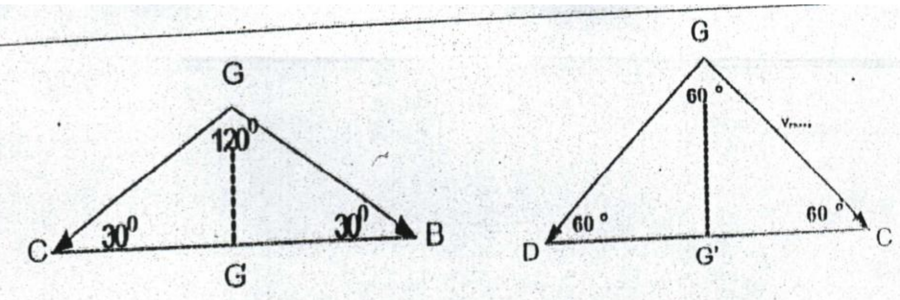
Angle θ for adjacent phase-to-phase is 60°, it can simplified that

$$V_{line\ (adjacent)} = V_{CD} = 2 \times V_{phase} \cos 60^\circ$$

(2)

Hence,

$$V_{phase(6\phi)} = V_{line\ (adjacent)} \qquad (3)$$



(a) Three-phase system (b) Six-phase system

Figure 2. Phase-ground-phase triangle

TPTS with refer to Figure 2(a) the common terminal *G* is called the neutral/Ground or star (Y) point. The voltages appearing between any two of the line terminals A, B, and C have different relationships in magnitude and phase to the voltages appearing between any one line terminal and the neutral point *G*. The set of voltages V_{AB}, V_{BC} and V_{CA} are called the line voltages, and the set of voltages are referred to as the phase voltages. The effective values of the phase voltages are shown in figure 2(a) as V_{AG}, V_{BG} and V_{CG} Each voltage has the same magnitude, and each is displaced 120° from the other two phasors. V_{line} and V_{phase} can define as:

$$V_{line\ (line\ to\ line)} = V_{AB} = V_{BC} = V_{CA} \tag{4}$$

While

$$V_{phase\ (line\ to\ ground)} = V_{AG} = V_{BG} = V_{CG} \tag{5}$$

The equation of V_{line} and V_{phase} can derived by calculate resultant of CNB triangle in Figure 2(a) :

$$V_{BG'} = V_{BG} \cos 30^0 = \frac{1}{2}\sqrt{3}\ V_{BG} \tag{6}$$

$$V_{BC} = 2 \times V_{BG'} = 2 \times \frac{1}{2}\sqrt{3}\ V_{BG} = \sqrt{3}\ V_{BG} \tag{7}$$

From equation 2.6 and equation 2.7, it can simplified, that

$$V_{line} = V_{BC} = V_{phase} \tag{8}$$

$$V_{phase(3o)} = V_{BN} = \tag{9}$$

Then the phase power is

$$P_{phase(3o)} = V_{phase} \times I_{line} \cos 0 \tag{10}$$

Because $V_{phase(6o)}$ $\sqrt{3}$ higher than $V_{phase(3\ phase)}$, hence, the main advantage of a six-phase transmission line it can carry up to 73% more electric power transfer capability compare to a three-phase system at the same operating voltage. Consequently, the transient over-voltage in high phase conversion system may differ in a low phase system under abnormal situation contributed by fault conditions or atmospheric phenomenon. Hence the development of a system to mock-up high phase conversion transmission line is useful to study the over-voltage phenomenon in that concern system.

3. THREE TO SIX-PHASE CONVERSION

There is several ways to convert three-phase to six-phase system by using power transformer phase converter regarding to transformer connection:

⇒ six unit single phase transformer

⇒ two unit three-phase transformer

A three-phase double circuit transmission line can be converted to a six-phase transmission line by using two pairs of identical delta-wye transformer connected at each end of the line/substation (Billinton, 2003). One of each pair of transformers has reverse polarity on the high voltage side in order to obtain the required 60° phase shift. Figure 3 (a) and (b) shows transformer arrangements of conversion three-phase to six-phase transmission line and phasor diagram respectively. This arrangement has the advantage of breaking the zero sequence networks.

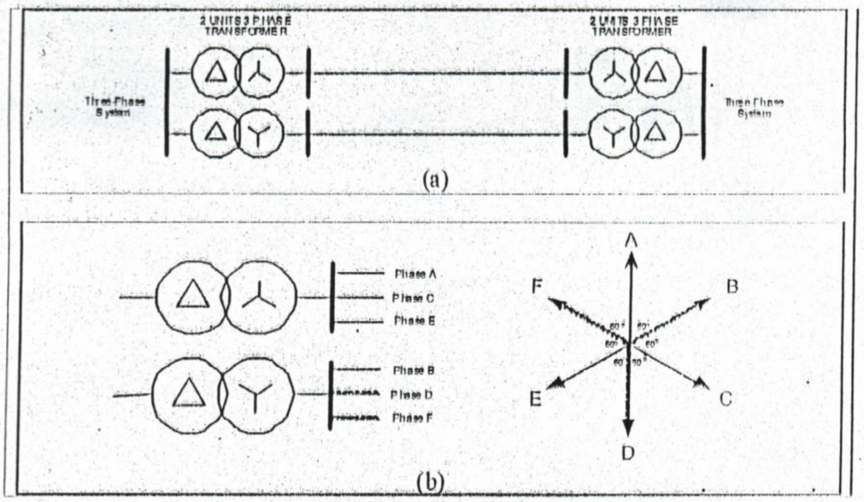


Figure 3. Transformer converter arrangement and phasor diagram

4. SYSTEM STUDIED

4.1 Design Overview

Tests on actual line settings and configuration which are needed during a study are challenges to researchers who have limited access to the lines. It will be more challenging especially reconfiguration exercises for conversion of three phase to six phase system. This is due to the fact that as the continuous and quality of supply is of utmost importance to utilities. Any changes to the actual line settings and configurations while the systems is running fine is not appreciated by power utilities who are committed to minimizing cause any interruption to their supply system. Numerous works have been carried out to examine transient behaviours emanating from conventionally designed transmission lines. Up to date there are many works done on field reductions were only based on digital simulations and calculations. Software models only provide a means for analysis of integrated system performance but cannot provide hands on experience that simulate real operational performance. This micro-model is Scaled-Down Transmission Line Laboratory Model (SDTLLM) of existing three phase double circuit transmission line with some form of sufficiently flexible feature. The flexibility feature of the SDTLM implies that it can also be converted to a six-phase system, which are consists of seven major components; Transformer, Towers, Inductors, Switching Unit, Protection Unit, Artificial Earth and Insulator.

Three phase double circuit line of Tenaga Nasional Berhad system has been chosen for the study. The chosen line is the 132kV three-phase double circuit transmission line between Gua Musang (GMSG) and Kuala Krai (KKRI), Kota Bahru Region, Kelantan which has a distance of 113.100 km in length. The one-line diagram of the system is shown in Figure 3.

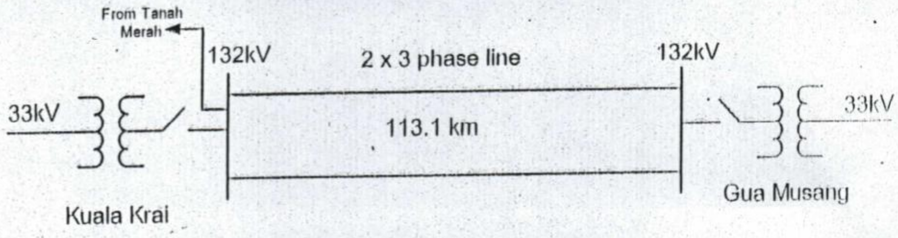


Figure 4. 132 kV double circuit line between KKRI and GMSG

4.2 Development Of SDTLLM

The solution of the development Transmission Line Laboratory Model has several different parameters requires such as: voltage, current, power. It is cumbersome task of transformation of all parameters to the actual voltage level. However, this works have derived the per-unit system of concern as such that the various quantities described before are expressed in term of base quantities. In this SDTLLM system, the different voltage levels between actual and model have been comprised to suit the laboratory model voltage energization. The transmission line parameters involving transformer and lines were reduced to a system of simple impedance. Figure 5 shows block diagram of proposed SDTLLM

a) Tower Model

The construction of the scaled down tower model were based on an actual dimensions of a transmission lines which are commonly found in Malaysia but with approximate 20 times reduction factor. Figure 6(a) shows the dimensions for the actual double circuit 132 kV transmission tower and the model. The modelled towers, including their cross arms and tower footing were made of L-shaped aluminium material 10mm 90°angle type for the purposes of insulation and means of holding the phase conductors. Jointing of each aluminium metal pieces was done by using screw and bolt. The towers were designed for a quadruple system and their dimension were 1700mm height, 100mm x 100 mm at the top, and 390mm x 390mm size at the bottom. SDTLLM consisted of 6 cross arms, each arm was 210mm length. Figure 6(b) pictorial view of the modelled towers.

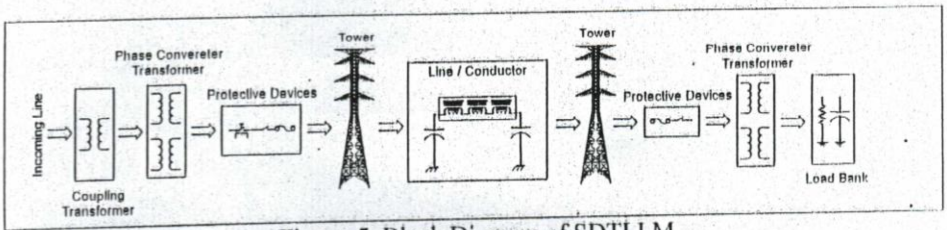


Figure 5. Block Diagram of SDTLLM

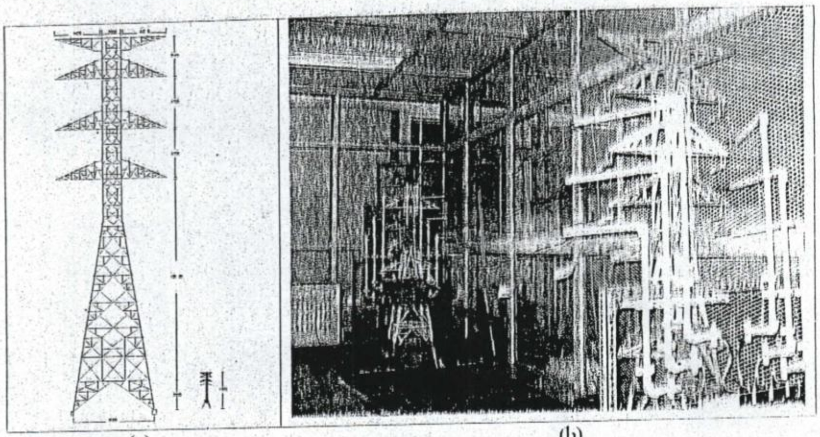


Figure 6. SDTLLM tower

b) High Phase Power Transformer Laboratory Model (HPPTLM)

HPPTLM can be use to produce six-phase system as well as a three-phase power system is shown in Figure 7. The study found that the easiest method to convert a three-phase to a six-phase system is to use a set of two-unit three-phase power transformers at the sending side. Similarly to convert a six-phase to a three-phase system is to use a set of two-unit three-phase power transformers at the a receiving side . The three-phase power is run through a delta/wye transformer that splits and converts the original three-phase voltage into two three-phase voltage sets. The first voltage set 'ACE' mirrors the original three-phase system with respect to phase. The second voltage set 'DBF' is inverted by 180 degrees with respect to the 'ACE' phase. Note that the polarities of the 'DBF' windings are reversed respect to 'ACE" windings, and the star point of the both transformer are grounded. The inverted voltage phases 'DBF' are then superimposed over the top of the first set of voltages 'ACE'. The resulting voltages are now in the form of six-phases which are 60 degrees apart, which represent a six-phase system.

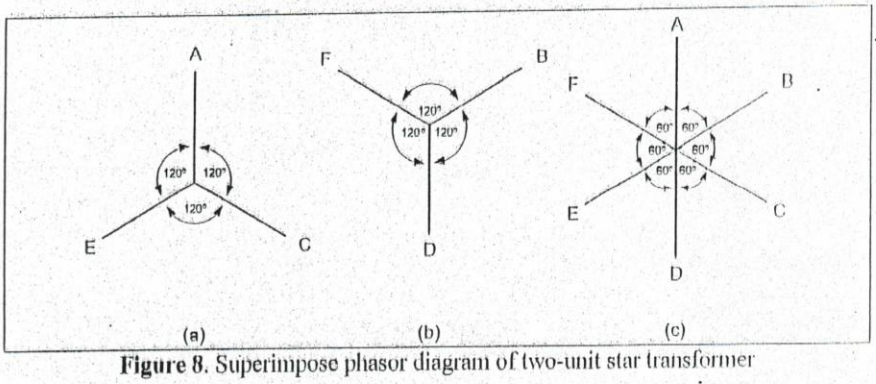


Figure 8. Superimpose phasor diagram of two-unit star transformer

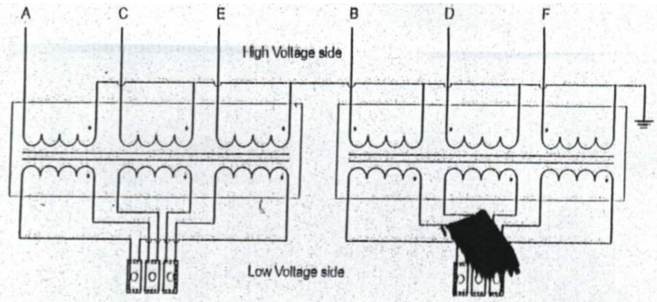


Figure 9: Wiring connection diagram of HPPTLM

c) Remotely relay-operated protection unit

A combination of relay, contactor, switch and circuit breaker is constructed with a mechanism to be controlled from a distance. With capability to be switched off and on, this contactor of concern is use for switching transient study.

d) Inductor

In SDTTLM, inductor is used as a length representation of transmission line. Base on the data from TNB, inductance of transmission line between KKRI and GMSG is about 97.3 mH or 0.861 mH/km. Two types inductor is used: single layer iron core open magnetic circuit inductor and multi-layer air gap ferrite core inductor. This inductor has capability maintaining constant inductance value at low and high frequency condition. .The inductor is made by using insulated copper wire diameter 0.8 mm. The newly constructed inductor is tested to determine the effective inductance value using R-L-C Bridge.

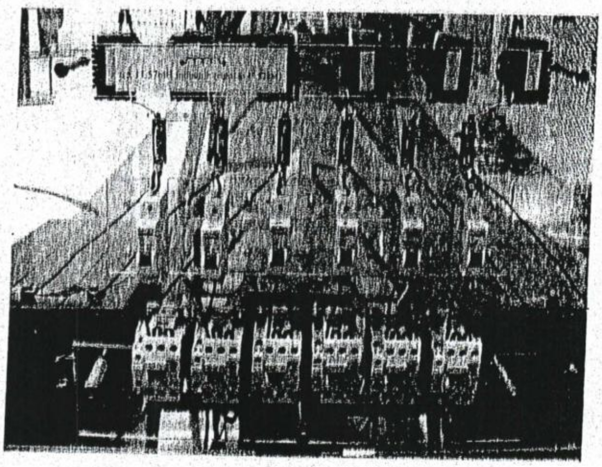


Figure 10: Pictorial view of remotely-operated protection unit

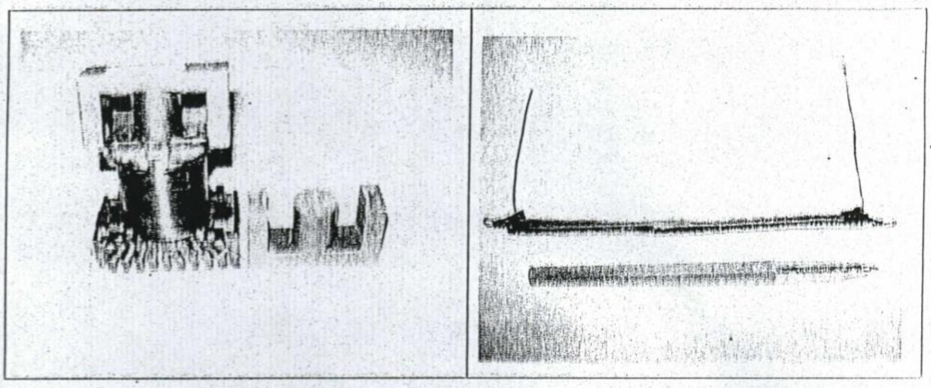


Figure 11. Pictorial view of inductor in the development stage

5. RESULT

Waveform measurement and observation of line is executed by means of LeCroy LT344L DSO. It can be connected to a PC by using GPIB interface card to facilitate PC-Based display of waveform. Figure 12 shows experimental set-up diagram. Several tests were conducted to study mock-up system response under steady state and switching transient conditions. Figure 13 shows a typical steady state waveform. While, Figure 14 to Figure 18 show switching transient waveforms when MCCB is switch-off.

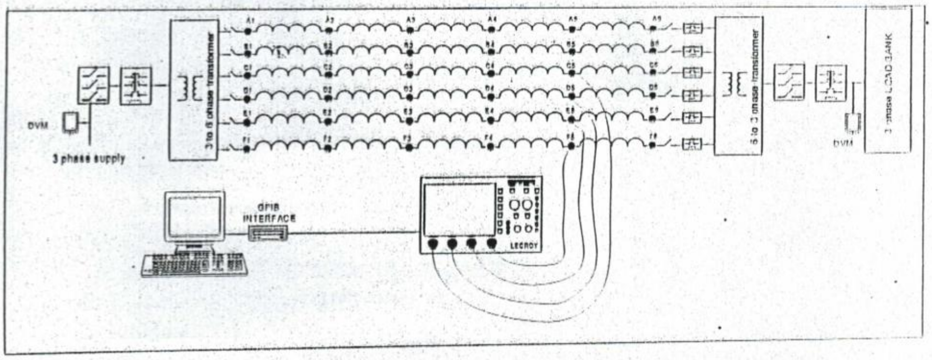


Figure 12. Circuit diagram of experimental set-up

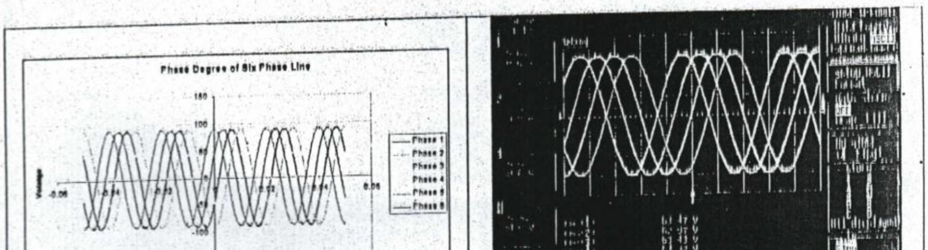


Figure 13. 60^0Phase degree waveforms observed using LeCroy LT344L DSO

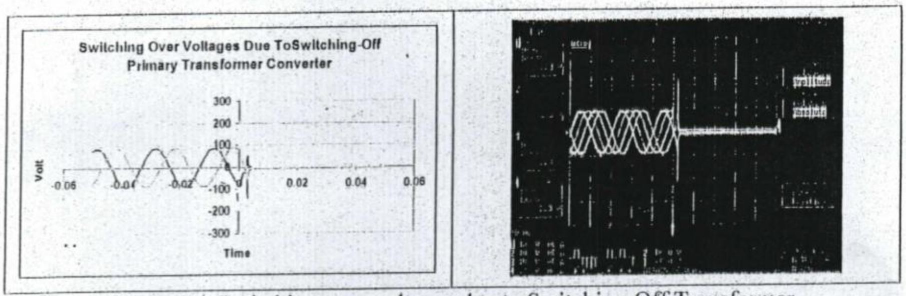


Figure 14. Switching over voltages due to Switching-Off Transformer

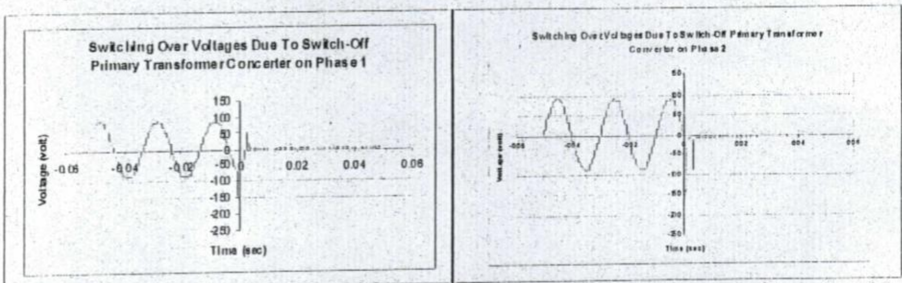


Figure 15. Switching over voltages due to Switching-Off Transformer on Phase 1 and 2

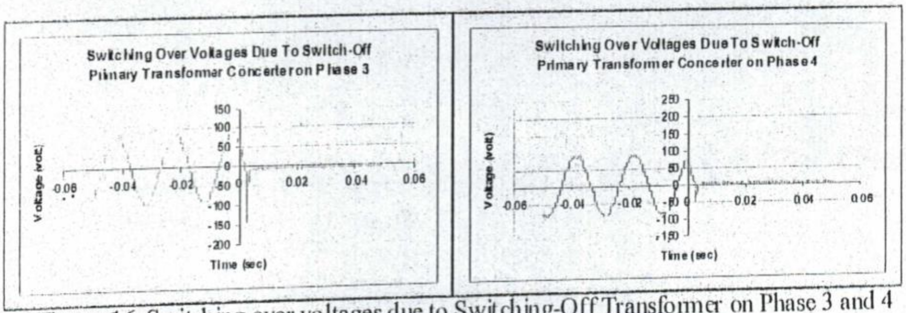


Figure 16. Switching over voltages due to Switching-Off Transformer on Phase 3 and 4

6. CONCLUSION

This paper has presented a description on the know-how in the development of a mock-up system of conversion three- phase double circuit transmission line to six-phase single circuit. It was found that the transformer can be exposed to very high repetitive over-voltages on black-out. As describe in section 2, in the 6 phase system, stress voltage between opposite phase is twice compare hase to ground. Its also the same, when switching over-voltages occurred, absolute maximum ltage of opposite phase must to be consider for BIL study.

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