Study of Insulator to Withstand Switching Surges in Conversion Three to Six-Phase Transmission Line: Computer Simulation Analysis

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Abstract

Conversion of three to six-phase transmission line an alternative method to increase the present transmission line capability to meet the increasing electrical energy demand. In realizing this concept into actuality while maintaining same physical line dimensions and the same level of, the power capacity is more than 73% higher compare to three phase system. However there may exist in the conversion some impact will occur on the insulation of tower and substation equipment (considering no new items to be added) of the power system. This impact is associated with the stress due to switching phenomenon in the networks. This paper presents findings on the study of switching surges magnitudes on six-phase system by using EMTP/ATP. It was found that the magnitude of phase-to-phase switching surges of the converted system is much higher the parent system approximately 13% for phases spaced 120^o and 65% for phases spaced 180^o.

Keywords:

Transmission line, switching transient, over-voltages

1. Introduction

In recent years, rapid growth of Malaysia's economy has caused an increased on demand of electricity supply and load currents of transmission lines. Apart from this the national utility board has been corporatized to reduce government financial burden. To date, to cut cost on new line installations, instead of double circuit transmission lines as the main power transfer lines is used to fulfill the demand. However, the utility planner still need to anticipate the increasing demand of electrical power in advance since generation projects can have long lead times for future.

In the past [1], increase in power transmission capability has been accomplished by increasing system voltages. However, increasing of transmission operating voltage will produce strong electric field at ground level with possible biological aspect and environmental effects which necessitate large Right-of-Way (ROW). In consideration of the fundamental limits on power transfer capability in a restricted ROW led to the concept of increasing the number of phases in a transmission line system circuit as known as Multiphase system or High Phase Order (HPO)
High Phase Order, is defined by number of voltages of equal magnitude, equally space in time [2]. For three phase system, this means three equal voltage spaced 120^o in time. For a 6-phases this becomes 6 voltages spaced 30^o and so on. HPO is a unique approach in increasing the power transmission capability of a overhead electric power transmission. Since Barthold and Barnes [3] was proposed HPO in 1972, the concept of six-phase transmission line (SPTL) has received great attention from researcher and it has been described in the literature in several paper and reports as 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 [4,5].

2. Impact of Phase Conversion

SPT is sometimes known as High Phase Order system is actually a system more than three-phase [7,8]. Phasor diagram of phase-to-phase and phase to ground is shown in Figure 1, and Figure 2 shows phase-ground-phase DGC triangle.

The equation of V_{line} and V_{phase} can derived by determining the resultant of DGC triangle in Figure 2 :

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

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

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

Hence,

$$V_{phase} = V_{line\,(adjacent)} \quad (3)$$

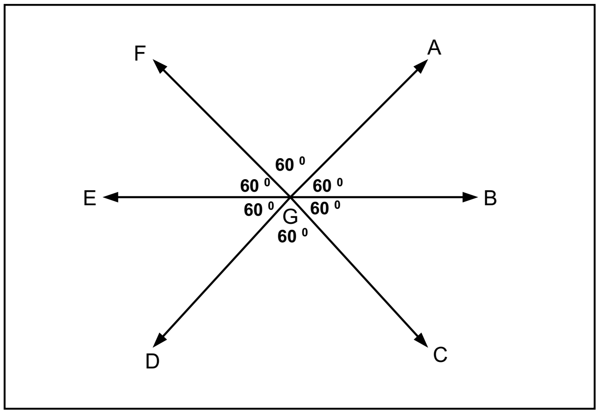

Figure 1. Phasor diagram of SPT system

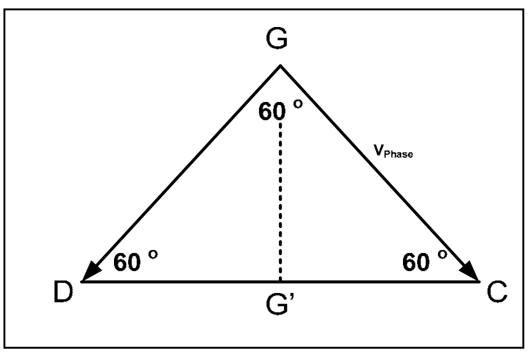

Figure 2. Phase-ground-phase triangle

Because $V_{phase\,(6\,phase)}$ $\sqrt{3}$ 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.

From Figure 1, the voltage system can be classified into four discrete voltages, i.e.: phase-to-ground voltage, between adjacent phase, between phases separated by one intermediate phase, and between opposite phases [10]. 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 93 kV, the phase-to-phase voltage will be 93 kV between adjacent phases, 161 kV between phases 120^0 apart, and 186 kV between opposite phases or in the other hand voltage between adjacent phases is the same as the ground voltage, U, but the voltage between alternate phases is $\sqrt{3}$ U and between opposite phases is 2U. So voltage stress on the insulators of six-phase mode will be substantially different from those in the three phase mode.

3. Switching Over-voltages

Over-voltages in power systems can be due to external and internal phenomena, such as faults, switching operation and lighting strokes to the tower or phase line. It is not practical to design the system equipment to withstand all type of over-voltages. In order to study insulation coordination it is necessary to analyze the different kinds of insulation levels for existing equipment before conversion three phase systems to six-phase system.

Switching over-voltages are resulted from operation of switching devices, either during normal conditions or as result of fault clearing. These transients have duration from tens to several hundreds of microsecond. The main operations that can be produce switching over-voltages are line energization and re-energization [6].

4. Modeling Requirements

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.

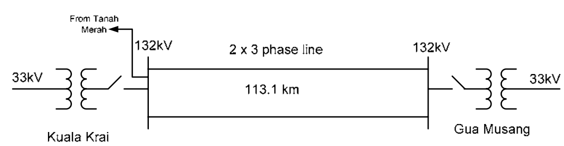

Figure 3. 132 kV double circuit line between KKRI and GMSG

The transmission line data required includes: transmission line conductor diameter, resistance per unit length, total length of transmission line, spacing between conductor on tower, shield wire, height of each conductor, sag to mid-span and tower dimensions. The selected transmission line model is distributed parameter models based on the traveling time and characteristic impedance of the line. The conductor used in the transmission line is called ACSR 300mm^2 for phase line and ACSR 80mm^2 for is used for earth wire. Two earth wires are used per tower, one on each side. Figure 4 shows phase and line arrangement at the main intake of 132kV double circuit system between KKRI and GMSG.

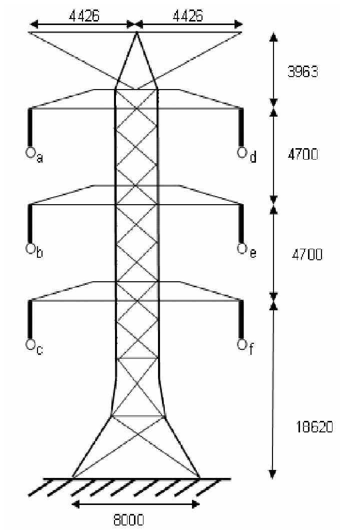

Figure 4. Phase conversion physical arrangement and tower dimension

5. Computer Simulation

The system configuration used to obtain the switching transient is illustrated in figure 5 where V_S is the supply voltage, CB is circuit breaker, and T is phase conversion transformer

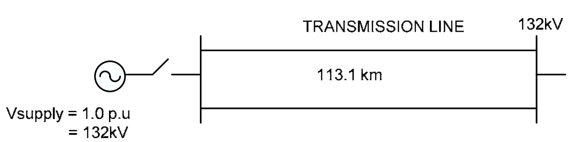

Figure 5. System Studied

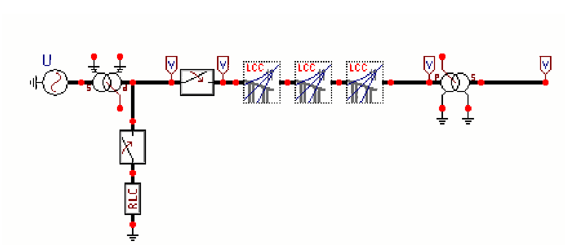

Figure 6. Three-Phase double circuit

Several modes of switching a six-phase line system is proposed i.e: single phase switching, two adjacent phases switching, three phases switching of line supplied by first transformer, and last six-phase switching. For phases "a" and phase "d" time open for circuit breaker (CB) is 0.03333 second and time closed is 10 second. For phases "b" and "e" time open for CB is 0.0361 and time closes is 10 second. For phase "c" and "f" time open of CB is 0.0388 and time closed is 10 second. Figure 6 and Figure 7 shows studied model circuit by using ATPDraw for three-phase and six-phase respectively. In this model, 113 km transmission line is divided into three mid-spans. Voltage waveform at sending-end, after CB, each mid-span and receiving-end is observed.

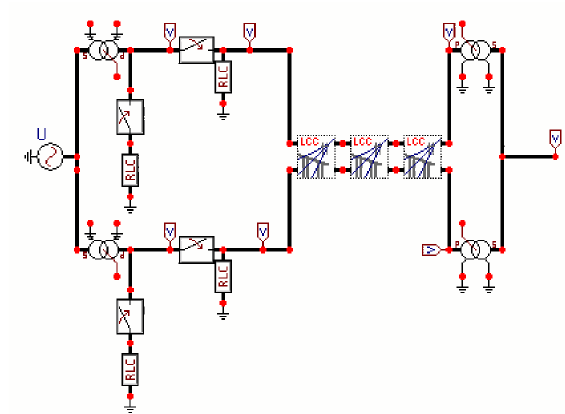

Figure 7. Six-Phase switching circuit

6. Simulation Result

Figure 8 through 10 shows switching transient simulation result of 132kV three phase double circuit system. Figure 8 typical voltage waveform obtained at upstream of circuit breaker, while figure 9 typical voltage obtained at bus bar.

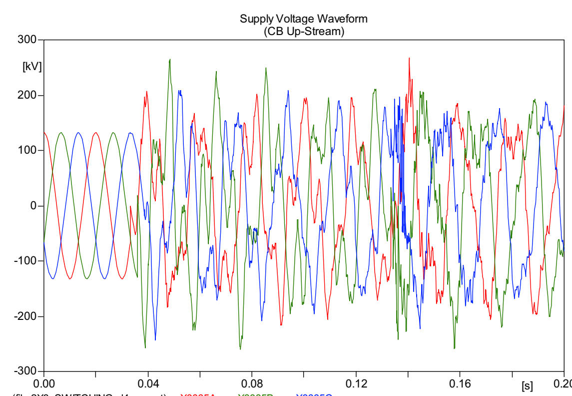

Figure 8. Three Phase Energizing voltage waveform

Table 1. Phase-to-Ground Switching Surge Magnitudes 132kV 2x3phase System

Probe	Phase A (p.u)		Phase B (p.u)		Phase C (p.u)	
Location	Cir 1	Cir 2	Cir 1	Cir 2	Cir 1	Cir 2
CB Up-Stream	2.0		1.98		1.79	
Sending-End	2.0		1.98		1.79	
Receiving-End	2.6		2.48		2.34	
37.6 km(*	2.14	2.14	2.18	2.18	2.28	2.28
75.3 km(*	2.36	2.36	2.27	2.27	2.30	2..30

Note:
(* distance from sending-end

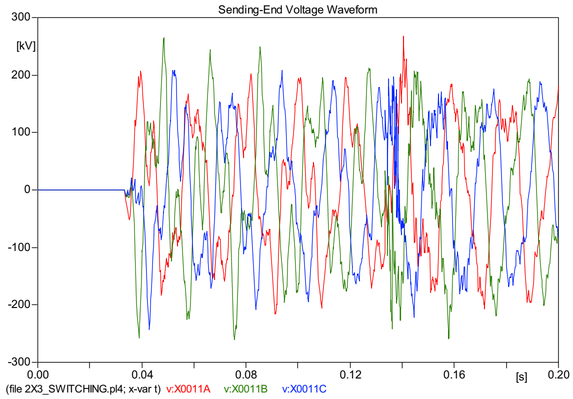

Figure 9. Sending-End voltage waveform after energizing

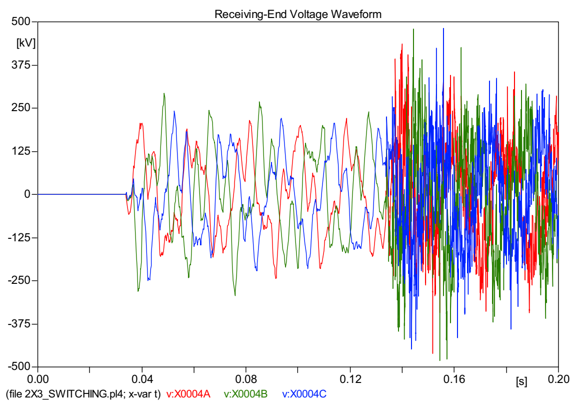

Figure 10. Receiving-End voltage waveform after energizing

Table 1 summarizes the highest value of maximum magnitude voltage obtained as described in figure 8 through 10 for the various locations.

Figure 11 through 15 shows switching transient simulation result of 132kV six-phase single circuit system with various switching condition and location. Figure 11 till figure 13 switching occurred at all line of six-phase line, while figure 14 and 15 are switching transient occurred only three phases (a-c-e) of six-phase line

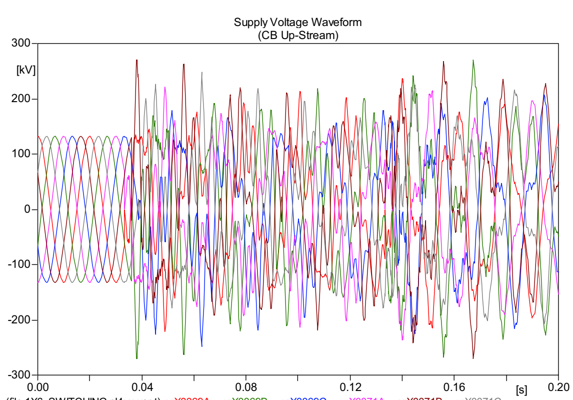

Figure 11. 6ϕEnergizing voltage waveform

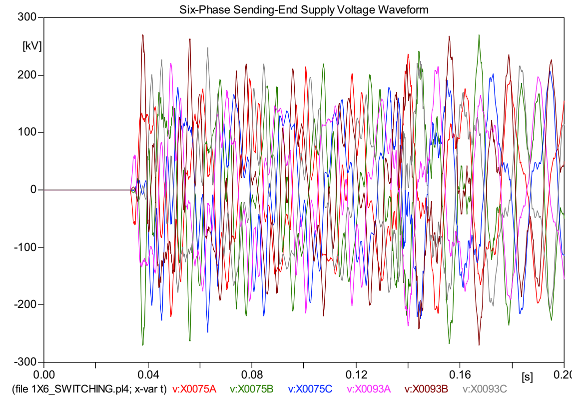

Figure 12. 6ϕSending-End voltage waveform after energizing

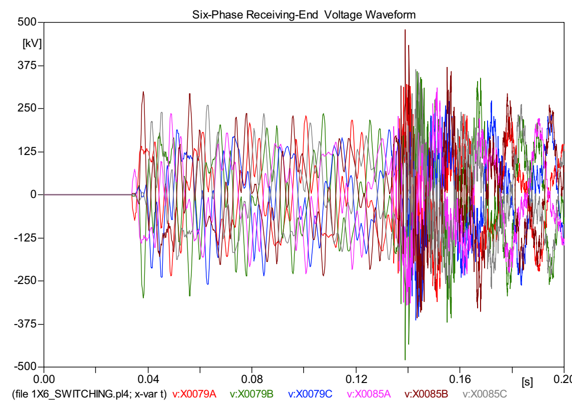

Figure 13. 6ϕReceiving-End voltage waveform after energizing

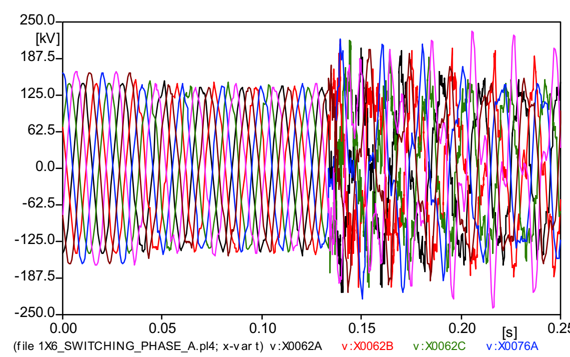

Figure 14. Sending-End voltage waveform after de-energizing phases a-c-e

In the series of simulations, line energization and re-energization are examined. Considering the above result, it can be concluded that some over-voltages are very severe. Circuit breaker and all equipment at substation need to be equipped with surge arrester.

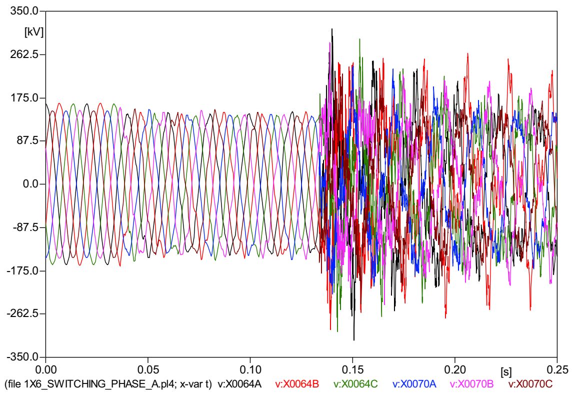

Figure 15. Receiving-End voltage waveform after de-energizing phases a-c-e

Table 2. Phase-to-Ground Switching Surge Magnitudes 132kV 1x6 phase System

	Phase Switching Magnitude (p.u)					
Location	**a**	**b**	**c**	**d**	**e**	**f**
CB Up-Stream	1.79	1.79	2.04	2.04	1.87	1.87
Send-End	1.79	1.79	2.04	2.04	1.87	1.87
Rec-End	2.36	2.36	2.72	2.72	2.48	2.48
37.66 km (*	1.98	1.98	2.27	2.27	2.47	2.47
75.32 km (*	2.23	2.23	2.51	2.51	2.29	2.29

Note:
(* distance from sending-end

Table 3. Phase-to-Ground Switching Surge Magnitudes132kV 1x6 phase System (re-energization only at phase a-c-e)

	Location	
Phase (p.u)	Send-End	Rec-End
a	1.65	2.34
b	1.52	1.81
c	1.79	2.14
d	1.66	2.18
e	1.60	2.16
f	1.57	2.25

Table 4. Phase-to-Phase Switching Surge Magnitudes 132kV 1x6 phase System

Probe Location	3 Phase System	6 Phase System		
		Phase spaced 60^o	Phase spaced 120^o	Phase spaced 180^o
CB Up-Stream	3.0	2.34	3.33	4.09
Sending-End	3.0	2.34	3.33	4.09
Rec- End	3.76	3.46	4.27	6.23
37.6 km(*	3.06	2.96	3.38	5.0
75.3 km(*	3.36	3.0	3.75	5.24

Note:
(* distance from sending-end

3 phases re-energization (phase a-c-e) of six-phase line may cause impact switching over-voltages to other 3 phases of six phase line (phase b-d-f). Per unit value of these over-voltages at any location is lower compare to six-phase energization. To simplify the comparison switching surge magnitude between 3-phase system and 6-phase system, the maximums magnitude are in per unit of the respective normal operating voltages 132kV either phase-to-ground or phase-to-phase. The phase-to-ground switching surges for the 6-phase system little bit lower than 3-phase system. However, the phase-to-phase surge magnitudes of 6-phase system as described in Table 4 are significantly higher than 3-phase system, approximately 13% for phases spaced 120^o and 65% for phases spaced 180^o.

7. Conclusions

This paper reports the studies on the switching transients caused by energization and re-energization on six-phase power transmission line. The modeling and simulation is successfully implemented in ATP-EMTP software. Computer simulation studies are presented on a 132kV under 3 phase and six-phase system with various conditions and various location of point investigation. It is possible with these results to proceed and could be considered as a reference for experimental studies in the lab.

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