Switching Overvoltage Analysis of 500 kV Transmission Line Between Nam Theun 2 and Roi Et 2

T. Keokhoungning, S. Premrudeeprechacharn, K. Ngamsanroaj

***Abstract*—This paper will investigate the overvoltage due to different types of switching in Nam Theun 2 – Roi Et 2 500 kV network. The PSCD/EMTDC is used to perform the simulation. The study presents the switching overvoltage phenomena occurring during the switching of the line circuit breaker on each side of the interconnection. The appropriate representations for the various components such as transformer, transmission line, circuit breaker, shunt reactor, surge arrestor and load have been selected. The occurrences will cover the line energization and re-energization due to single line to ground and three phases to ground faults. For each line energization, statistical switching operations are made. Switching under different load conditions is considered. In series of simulations, the maximum overvoltage will be determined. The efficiency of line terminal 444 kV surge arresters to controlled SOV along the 500 kV lines is clearly demonstrated. The maximum overvoltage from light load and three phases to ground fault are quite high. The study results are assessed, analyzed and considered as a guide line for 500 kV operation in Lao PDR.**

***Keywords*: Switching Overvoltages; Transmission line; Energization; Re-energization; Single phase line to ground; Three phases line to ground.**

I. Introduction

THE Switching overvoltage is a primary importance in insulation co-ordination for EHV lines. The objective of simulating switching overvoltage is to help for a proper insulation co-ordination and would lead to minimize damage and interruption to service as a consequence of steady state, dynamic and transient overvoltage. The level of transient overvoltage has a strong effect to power system. According to the IEC recommendations, all equipment designed for operating voltages above 300 kV should be considered under switching impulses. Switching surges have become to governing factor in the design of insulation for the EHV and UHV systems [1].

Different simulation approaches have been conducted for switching transient studies. An analysis of switching overvoltage in EGAT 500 kV system had been investigated, especially the switching overvoltages resulted from line energization and line re-energization due to faults applied to existing 500 kV systems [2]. The switching overvoltage analysis and air clearance design on the KEPCO 765 kV double circuit transmission system, it is mainly determined by the magnitude of SOV. Therefore, an accurate investigate of SOV is one of the important factors for the design 765 kV transmission system [3]. Reference [4] described the evaluation of transient switching overvoltages in Kuwait EHV network. The work investigated the voltage stress due to different types of switching in Kuwait EHV (275 kV) power network. Switching from different types of faults, fault clearing, and successful line closure are included. Transient performance of 500 kV equipment for the Chiliean series compensated transmission system had been studied [5]. The work covered several aspects such as the SOV, TOV and inrush transient due to transformer energization during various system restoration scenarios. The comparison of statistical switching results using Gaussian, uniform and the systematic are used to calculate the overvoltage distributions [6]. The three phase circuit breaker closing produces significant transient overvoltages depending on the angle on the voltage waveform, circuit breaker closing span and standard deviation. The study discussed the approaches that can be used for a statistical switch. A knowledge base for switching surge transients had been concluded in [7]. There is more specifically for transmission line switching. The work reports the case of line energization with the objective of providing practical rules and modeling suggestions of evaluating switching transient simulations.

The scope of this paper is to investigate the voltage stress due to various conditions of switching in 500 kV interconnection transmission line Nam Theun 2 and Thailand network at Roi Et 2. The study includes the switching representing single phase line to ground fault and three phases to ground fault, fault clearing, and successful line reclosing. For each line energization, the statistical switching operations are made. The switching overvoltage suppression by surge arresters is also investigated. The PSCAD/EMTDC program is used to perform the simulation. The accuracy of the model will be compared

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with the reference SOV study case in Thailand. The switching under different load conditions is considered.

II. DESCRIPTION OF THE STUDIED TRANSMISSION SYSTEM

The Lao People's Democratic Republic (Lao PDR) has estimated hydropower generation potential of more than 18,000 MW in its territory. The government of Lao PDR has planned to construct the 500 kV transmission lines and substations which will connect to the future national grid and interconnection with neighboring countries such as Thailand for export bulk power to customer. The 500 kV interconnection transmission line Nam Theun 2 (NTN2) to Roi Et 2 (RE2) substation is the first system to the national grid which connects the Nam Theun 2 hydro power project in Lao PDR with total capacity 1,080 MW to Electricity Generating Authority of Thailand (EGAT) network. The interconnection between the project crossing the Mekong River and RE2 substation consists of two 500 kV line sections as illustrated in Fig.1 [8].

- Double circuit of 500 kV Nam Theun 2 Power Plant – Savannakhet junction, using 4x795 MCM ACSR conductor per phase, a distance of 135 km, with 3x55 Mvar/525 kV line shunt reactor at Nam Theun 2 side.
- Double circuit of 500 kV from Savannakhet junction – Roi Et 2 substation, using 4x1,272 MCM ACSR conductor per phase, a distance of 169.5 km, with 2x55 Mvar/525 kV line shunt reactor at Roi Et 2 side [9].

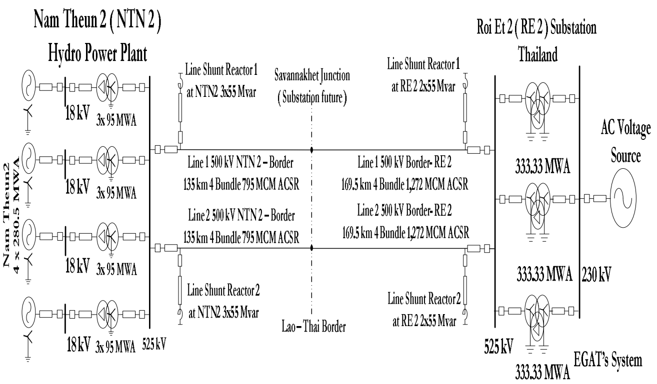

Fig. 1 500 kV Transmission line between NTN 2 and RE 2 substation

III. SYSTEM REQUIPMENTS AND MODELING

A. Transformer

Transformer models are represented with this existing information : MVA rating, wingding configuration and voltage, tap change range and normal setting, leakage reactance between windings, knee point of transformer core saturation characteristic in per unit of rate flux or voltage, and estimated saturated air core reactance [2],[10].

The 333 MVA, 500/242/22 kV, step-down auto-transformers are represented by saturable transformer models with three windings: H.T, B.T and M.T. The saturation characteristics of these auto-transformers are determined. The step up transformers are represented by saturable transformer models with two windings. All transformers are represented by one equivalent in each station. The total leakage impedance of transformers is presented in H.T winding. Saturation characteristic is represented to an internal node of the same H.T winding [3].

B. Transmission line

The transmission line represented in network, dimensions and data are required. This can be given at the tower, and include conductor sag. Shield wire dimensions and resistance are also provided. The transmission line data require includes : transmission line conductor diameter and resistance per unit length of transmission line, phase transformation data and distance between phase bundle, spacing between phases, shield wire diameter and resistance per unit length, height of each conductor and shield wire at the tower and sag to midspan, tower dimensions, and ground conductivity [2], [10].

With the reference to the PSCAD/EMTDC line model, the selected transmission line models are transposed frequency dependent phase model base on traveling time and characteristic impedance of the line [10]. The 304.5 km length of the line is divided by two parts. The 135 km the length of line from NTN2 – SVJ with 795 MCM ACSR of conductor is divided by 5 sections, the 169.5 km line from SVJ-RE2 with 1,272 MCM ACSR of conductor is divided by 13 sections.

C. Circuit breaker

The circuit breakers that will be switched are identified on the study system. Other parameters of the circuit breakers are determined: protection delay or clearing times, maximum fundamental frequency switching voltage, maximum capacitive switching capability, reclosing sequence, rated transient recovery voltage and maximum rate of rise of transient recovery voltage, mechanical closing time and variation in pole closing times, and closing resister [2],[11]. The statistical switching in closing operations are used [6].

D. Surge Arresters

Although surge arresters are complex devices, they are very important in the determination of economic insulation level. It is the best way to choose arresters with the lowest possible protective consistent with the remainder of the system [2].

The installed location and rating of surge arresters are provided. The maximum ratings, and in particular the energy absorption capability will be determined with study and characteristic V-I of surge arresters are provided [10], [12].

E. Shunt Reactors

The location of shunt reactors is identified. This will include whether they are line connected or bus connected. The shunt reactor rating is supplied along with its characteristic if it is a saturating reactor [2], [12].

The shunt reactors in the studied 500 kV system are modeled in simple lumped inductance. The saturation of these reactors is presented by two slopes. The neutral reactors are installed in the neutral of the shunt reactors.

F. Loads

Network equivalence is employed to represent the rest of the studied network especially the external network connecting with RE 2 500/230 kV substation in Thailand. The complete external network will be reduce to voltage source behind a Thevenin equivalent matrix of impedance as positive – negative sequence and zero sequence. The impedance and phase angles of all the voltage sources are found from a load flow program. Available data from the existing databank for a heavy load system condition has been chosen [7].

IV. Simulation and Results

Switching overvoltages of the 500 kV transmission system between NTN 2 and RE 2 have been analyzed with the following simulation:

- Line energization overvoltage
- Re-energization

In this series of simulation, the maximum overvoltage obtained during different line switching operation are determined. Line energization and re-energization are examined. The faults at line side are applied at different locations on the system and the transient overvoltages are recorded. Fault clearing is usually accompanied with line opening, where circuit breakers open at both ends on the faulted line to isolate the fault. Switching under different load conditions is considered. For each line energization, the statistical switching operations are applied [2]. The re-energization cases will be illustrated by the analysis of two fault cases, the single line to ground fault and the three phase to ground fault.

A. Line energization overvoltage

From the studied 500 kV system, surge arresters and shunt reactors are included in the model. The circuit breaker closes at end with another open for the weak system condition when energizing. When the line connecting with surge arresters are used, the overvoltage are reduce. For each case, the statistical operation involving 200 switching operation is used with Gaussian normal random closing orders to breaker poles as presented in Fig. 2. The maximum voltage will be recorded with each case. During line energization study, it is assumed the shunt reactors and surge arresters at both line terminals are switched on/off changing connected to line, trapped charge of 1.0 pu is set on the line being line energization in the 500 kV transmission line NTN 2 – RE 2 [2], [5], [6].

The 500 kV NTN 2 – RE 2 lines were analyzed with presence of 444 kV surge arresters at both side and 3x55 Mvar shunt reactors at NTN 2 and 2x55 Mvar at RE 2 at both side terminals. For the statistical switching, the 200 operations were simulated. The closing angle of main contract should be in normal distribution, the mean of main contract closing time is 15 ms and its standard deviation is 1 ms. The simulation result for different status of protective devices are summarized in Table I. It is obvious that highest value of energization overvoltage could be 2.193 p.u. which is the case of without arresters at both sides at no load condition. With arresters in service, the overvoltage can be reduced from 2.193 to 1.707 p.u. The shunt reactor can be also reducing the value of overvoltage, but the effect is minor from 1.754 to 1,707 p.u. The result waveform is compared with the reference studied report of EGAT [9] as illustrated in Fig.6.The maximum overvoltage at receiving end waveform during changing switched on/off protective devices at both sides as illustrated in Fig. 3 - Fig.6.

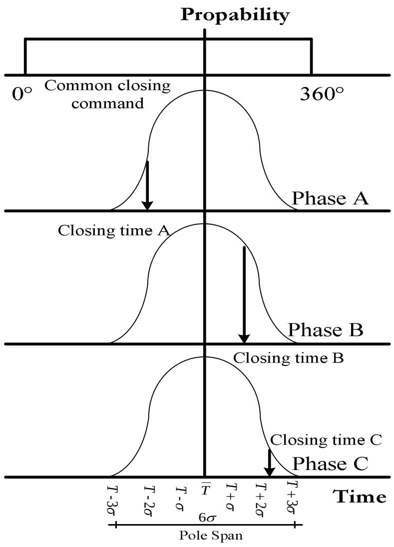

Fig. 2 Breaker pole random closing for simulation of SOV during line energization

TABLE I
SWITCHING OVERVOLTGES OBTAINED FOR SYSTEM SIMULATION BY LINE ENERGIZATION

No.	Shunt Reactor		Surge Arrester		Overvoltage at receiving end (p.u)
	NTN2	RE2	NTN2	RE2	
01	yes	yes	yes	yes	1.707
02	yes	yes	yes	no	2.027
03	yes	yes	no	yes	1.743
04	yes	no	yes	yes	1.735
05	no	yes	yes	yes	1.727
06	yes	yes	no	no	2.193
07	no	no	yes	yes	1.754

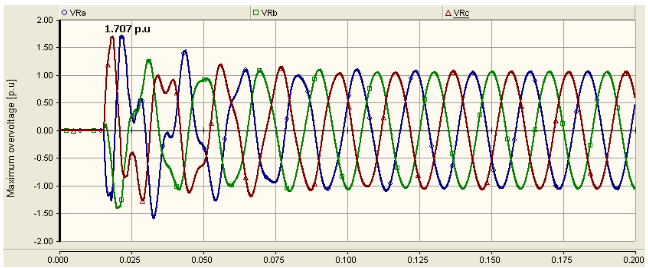

Fig. 3 SOV NTN 2- RE 2 during line energizing with protective devices.

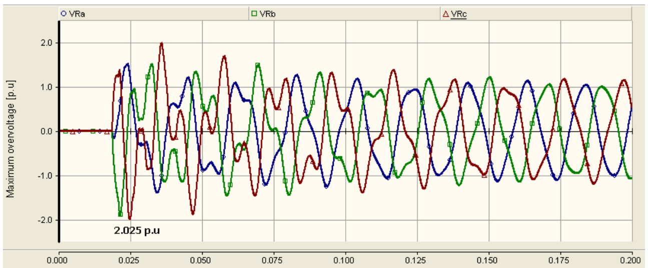

Fig. 4 SOV NTN 2- RE 2 due to line energizing without arrester at receiving end (RE 2) sides.

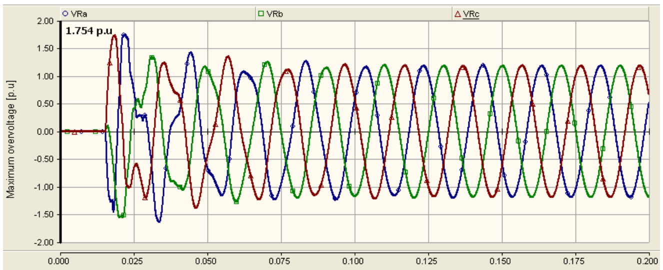

Fig. 5 SOV NTN 2- RE 2 due to line energizing without shunt reactor at both sides.

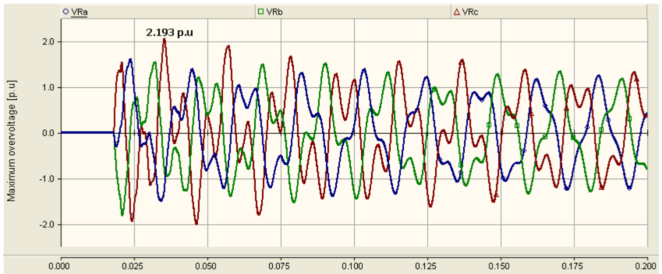

Fig. 6 SOV NTN 2- RE 2 due to line energizing without arrester at both sides.

B. *Line re-energization overvoltage*

Line fault initiation and clearing could also produce high switching overvoltages occurred in the transmission lines [5]. For the 500 kV transmission lines between NTN 2 and RE 2 substation, the configurations of the lines are also used to analyze switching overvoltage during a line fault. Two types of faults, single phase to ground which is most frequently occurred to the system and three phases to ground which causes more severe damage are considered for the study.

♦ *Line fault location*

The line fault is short circuit that occurs at transmission line in the immediate vicinity of the circuit breakers as illustrated in Fig.7. The fault will be applied at different location along the series compensated transmission lines between NTN 2 and RE 2 substation. The distance of the variation of fault position from sending end to receiving end is in the step of approximately 50 km.

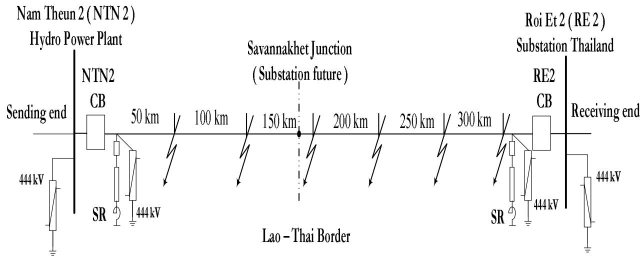

Fig. 7 Fault at different location from sending end

♦ *S0V Re-energization due to single phase to ground fault*

The case of single phase to ground fault with re-energization, faults are applied at different location on the studied line and transient overvoltages are record in the system. The single line to ground fault at each circuit and changing phase fault from A, B and C is selected in determining the maximum overvoltage. The single phase to ground fault is applied at time t=0.02s. While the fault clearing is made at t=0.05s and re-energized at t= 0.1 s at different load condition. The result is illustrated in Fig.8 - Fig.10 as illustrates the maximum reclosing overvoltages obtained in the system at the different fault location for single line to ground fault at the full load, half load and no load respectively. The maximum overvoltage phase A is 1.750 p.u, phase B is 1.752 p.u and phase C is 1.730 p.u at no load condition. In case of protective device, the waveform of the maximum re-energizing overvoltage due to single line to ground fault without shunt reactor at both sides is shown in Fig.11 and without arresters is shown in Fig.12. The reclosing overvoltage at no load condition or slight load will cause highest value compare with other load conditions.

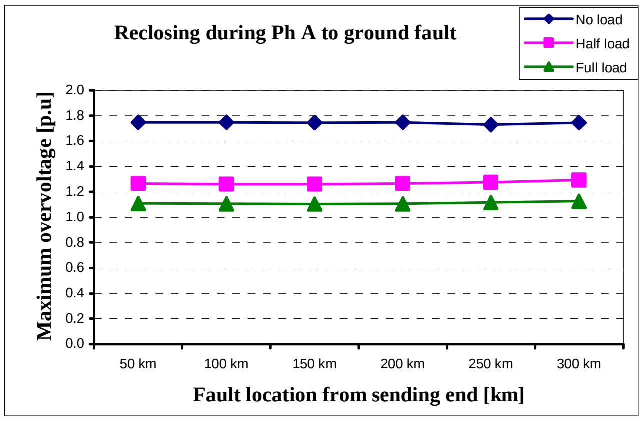

Fig.8 Re-energizing overvoltage due to phase A to ground fault.

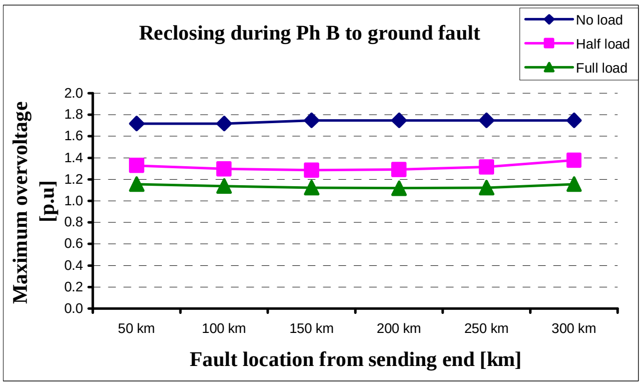

Fig.9 Re-energizing overvoltage due to phase B to ground fault.

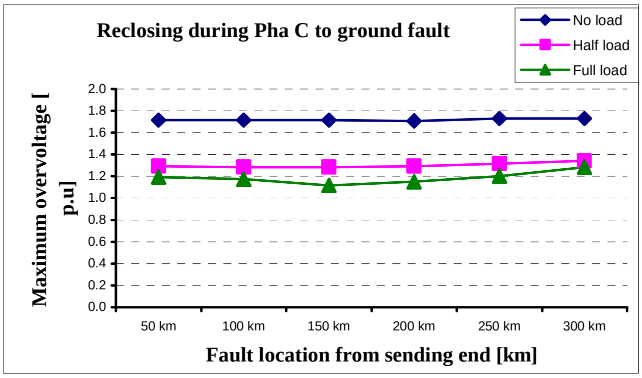

Fig. 10 Re-energizing overvoltage due to phase C to ground fault

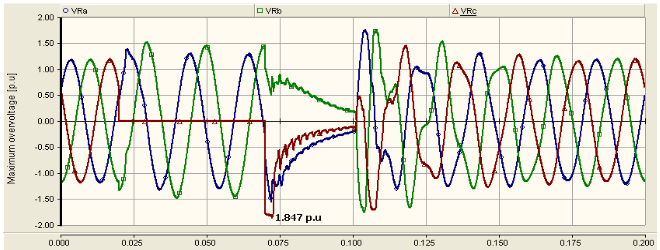

Fig.11 Re-energizing overvoltage during phase C to ground fault without shunt reactor at both sides.

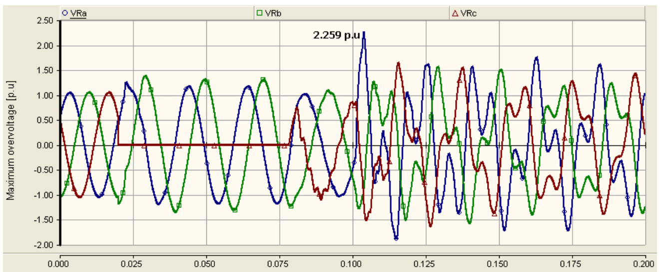

Fig.12 Re-energizing overvoltage due to phase C to ground fault without arrester at both sides.

♦ *SOV re-energization due to three phases to ground*

The three phases to ground fault clearing with line re-energization are also applied at different load condition. It is found that the highest maximum overvoltage when energized NTN 2 – RE 2 line, the time during fault is applied at time t = 0.02 s with clearing time at t = 0.05 s and re-energized at t = 0.1 s at different load condition. Maximum overvoltage during three phases to ground fault reclosing is 1.771 p.u. with all protection devices in services, at no load condition as illustrated in Fig.13. Maximum overvoltage during three phases to ground fault is 2.561 p.u. and quite high without arrester at both sides as illustrated in Fig.14 and Fig.15. For three phases to ground fault, reclosing overvoltage is very severe especially at no load condition. In case of no protection devices in services, maximum overvoltage obtained from re-energization due to three phases to ground fault is 4.073 p.u as shown in Fig.16.

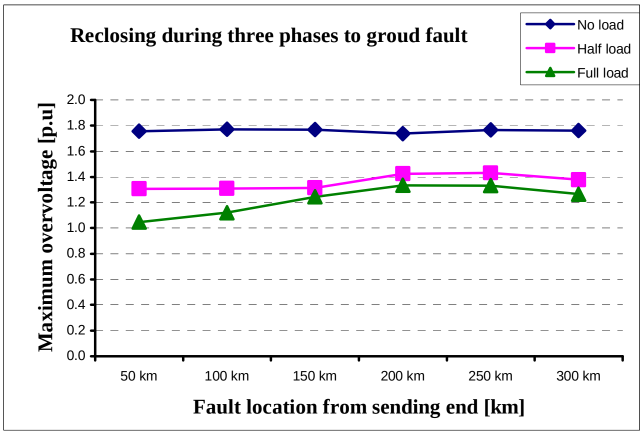

Fig. 13 Re-energizing overvoltage due to three phases to ground fault.

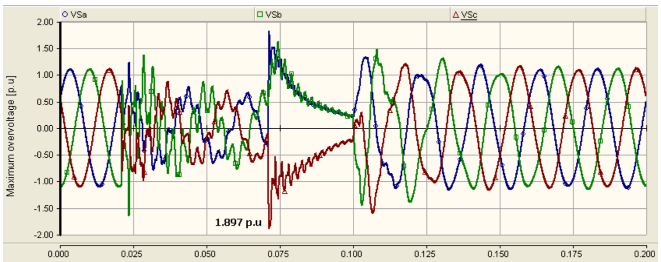

Fig. 14 Re-energizing overvoltage due to three phases to ground fault without shunt reactor at both sides.

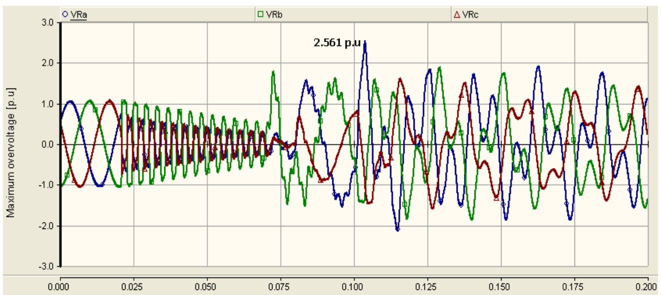

Fig. 15 Re-energizing overvoltage due to three phases to ground fault without arrester at both sides.

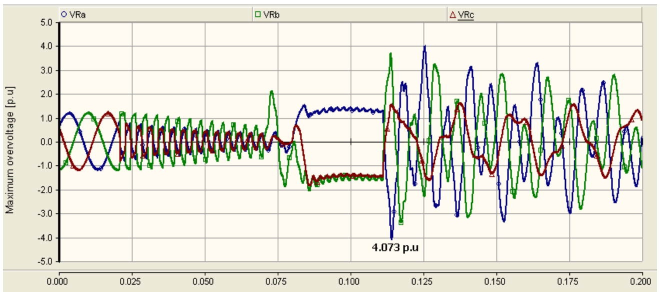

Fig. 16 Re-energizing overvoltage due to three phases to ground fault without protection devices (surge arrester and shunt reactor) at both sides.

V. CONCLUSIONS

Switching overvoltages obtained from different switching condition are investigating in the 500 kV interconnection transmission line between NTN 2- RE 2. The study is based on computer simulation using PSCAD/EMTDC. Three conditions of loading are studied; full load, half load and no load. Switching operations during a period of very light load or unloaded system will produce the most severe transient overvoltage.

Energizing is investigated statistically, that is, for system condition investigated, 200 switching operations are made. Each statistically controlled with respect to the source bus driving voltage and with three breaker poles closing randomly with respect to each other and re-energizing during to three phase to ground fault are too high. Without arresters switching overvoltage are too high for the actual design of the 500 kV transmission lines at no load condition.

The presence of the line terminal 444 kV surge arresters allows reducing transient overvoltage stresses to acceptable levels for the actual design of the 500 kV transmission line. The most effective device to control the overvoltage for the studied system is surge arrester. The study results are assessed, analyzed and considered as a guide line for 500 kV operations in Lao PDR.

VI. ACKNOWLEDGMENT

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VIII. BIOGRAPHIES

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