

Capacitor Bank Switching Recovery Voltages in an Electrical Power System Using Different Line Models

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Abstract -- Capacitor banks are used to compensate the reactive power demand of large commercial and industrial loads in order to withstand busbar voltages within specified limits and to minimise electric power system line losses. This requires switching operations of the circuit breakers that produce transients, which may cause system disturbances and a shortage of the capacitors life. In this paper the transient recovery voltages are studied and analysed in an electrical power system using the commercial software package EMTDC/PSCAD. In the simulation it were considered the Pi and the Frequency Dependent models for the transmission lines. It was also analysed the influence of the transmission lines length. The capacitor bank was connected in star with the neutral solidly grounded and assuming a small capacitance value. Finally, some conclusions were extracted from the obtained results, as well as from previous published papers by the authors that can be used by the circuit breakers designer in order to ensure a reliable operation and an electromagnetic compatibility.

Index Terms—capacitor switching, circuit breakers, switching transients, transient analysis.

I. INTRODUCTION

The voltage stress in the switching devices depends on the network configuration [1,2]. Usually, the electromagnetic transient simulations are performed considering two different transmission line models [2,3]. The most common approach is to use the Pi-model, although the Frequency-Dependent model should be considered in transient studies in order to obtain accurate results. This second model is based on the travelling waves formulation, with the voltage disturbances reflecting the delay function and the wave-shape attenuation.

This paper is devoted to the evaluation of the transient recovery voltages in a test power network using the commercial software package EMTDC/PSCAD. The simulation was performed considering two different

transmission lines models (Pi-model and Frequency-Dependent model). It was also analysed the effect of the transmission lines length. Five different capacitance values were assumed for the capacitor bank that was connected in star, with the neutral solidly grounded as well as with a small capacitance.

II. ANALYTICAL APPROACH

The analysis of transient phenomena at the disconnection of three-phase capacitor banks can be made analytically by using the following mono-phase schematic circuit proposed by CIGRE (fig. 1).

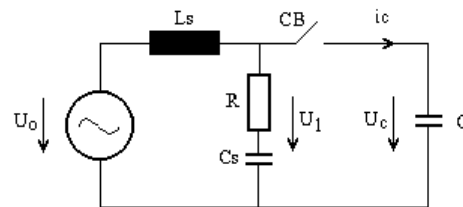


Fig.1. Schematic circuit of capacitor bank switching

In this figure L_s is the source equivalent inductance, R and C_s represent source side capacitance and dumping, U_0 is the voltage (peak value), CB represent the circuit breaker and C represents the capacitor bank.

Writing the transitory regime equations [4-6], the transient recovery voltage at the circuit breaker terminals may be expressed [1,4-6] by the following equation, considering $\delta = R/(2L_s)$ and $\omega_e = (\sqrt{L_s C})^{-1}$.

$$u(t) = U_0 \left[1 - e^{-\delta t} \left(\cos \omega_e t + \frac{\delta}{\omega_e} \sin \omega_e t \right) \right] \quad (1)$$

This transient phenomenon is particularly influenced by the circuit breakers characteristics, as well as by the capacitance to be disconnected and by the feeding network parameters.

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The growing speed of dielectric rigidity ($U_d = f(t)$) and the raise of the transient recovery voltage ($U_r = f(t)$), play also a very important role in this process [6-9].

III. APPLICATION EXAMPLE

In order to analyse the transient overvoltages at disconnecting of capacitor banks in a 220 kV Electric Power System, it was studied by model from figure 2. This model was evaluated using the EMTDC/PSCAD software package. The tables 1, 2, 3 and 4 present the network data. The 220 kV High Voltage Power System (fig.2) presents for analysis: 4 voltage generators; 4 transformers; 6 transmission lines modelling by the PSCAD, T-Line Model (Frequency-Dependent Model) and Pi-section line; 5 busbars and 3 branches of capacitor banks, connected on busbars 1, 3 and 5, each with the circuit breaker for the switching modelling. That was used: 103 components; 50 signals; 30 nodes; 18 branches and 27 meter points. The transient phenomena were simulated with the circuit breaker on first position it was closed, following disconnecting operation. The 1st time was 0.205 [sec] and the 2nd time was 3 [sec]. For capacitor bank it were assumed discrete capacitance values from 3.3 μF until 16.5 μF with a step of 3.3 μF , considering a star connection.

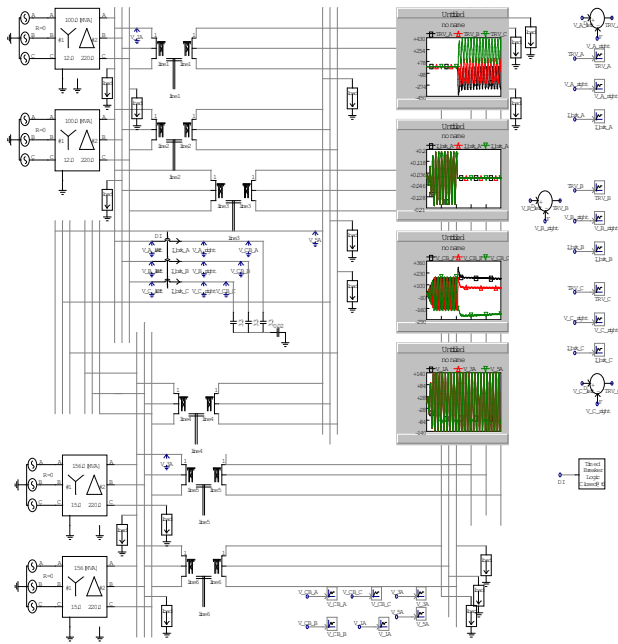


Figure 2. 220 kV Electric Power System with a capacitor bank located at busbar 1.

TABLE 1
GENERATOR DATA

Voltage Generator	S_n (MVA)	U_n (kV)	P_G^{\max} (MW)	Q_G^{\max} (MVar)
G_1, G_2	100	12	90	80
G_3, G_4	156	15	125	100

TABLE 2
TRANSFORMER DATA

Transformers	S_n (MVA)	U_{1n}/U_{2n} (kV/kV)	X_f (%)
T_1, T_2	100	12/220	10
T_3, T_4	156	15/220	12

TABLE 3
GENERATOR DATA

Busbars	R (Ω)	X_L (Ω)	Y_{sh} (mS)
1 - 2	10	40	0,04
1 - 4	8	30	0,03
1 - 5	5	20	0,02
2 - 3	7	28	0,02
3 - 4	8	30	0,03
3 - 5	6	20	0,02

TABLE 4
ACTIVE AND REACTIVE POWER LOAD DEMAND

Busbar	P (MW)	Q (MVar)
1	40	25
2	60	40
3	100	60
4	110	80
5	80	50

IV. RESULTS

The results are presented in the following tables and figures:

TABLE 5
INFLUENCE OF CAPACITOR BANK NEUTRAL CONNECTION ABOUT THE TRANSIENT RECOVERY VOLTAGES [p.u.]

Neutral Position	Capacitor Bank Placement	Capacitor bank (μF)				
		3,3	6,6	9,9	13,2	16,5
Solidly Grounded	Busbar 1	2,14	2,22	2,29	2,34	2,38
	Busbar 3	2,11	2,17	2,23	2,27	2,32
	Busbar 5	2,09	2,19	2,27	2,35	2,43
Capacity Grounded	Busbar 1	2,37	2,40	2,43	2,46	2,65
	Busbar 3	2,36	2,37	2,40	2,42	2,44
	Busbar 5	2,33	2,40	2,47	2,55	2,63

In table 5 is presented the influence of the capacitor bank neutral connection in the transient recovery voltages, for different capacitances and different locations of the capacitor bank. It observes that the transient recovery voltage increase with the capacitor banks capacitance. The maximum transient recovery voltages were obtained on busbar 5. When the neutral point is capacity grounded the transient recovery voltages increase with 20 %.

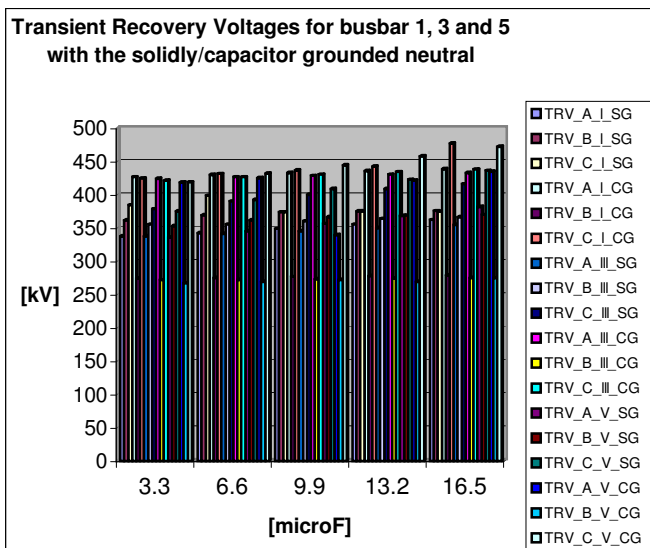


Figure 3. Transient Recovery Voltages on busbars 1, 3 and 5, for different neutral connections

In figure 3, were presented comparatively the maximum transient recovery voltages (TRV) on busbars 1, 3 and 5, when the neutral point is solidly grounded or connected through small capacitor (20 nF). It is shown that maximum TRV appear on the 5 busbar, C phase, this being 436.21 kV, 2.43 [p.u.], when the neutral point is solidly grounded (SG) and on 1 busbar, A phase, the value being 476.66 kV, 2.63 [p.u.], when the neutral point is grounded through capacitor (CG).

TABLE 6
INFLUENCE OF THE LINE LENGTH ABOUT THE TRANSIENT RECOVERY VOLTAGES [p.u.]

Capacitor bank placement	Line modified	Capacitor bank (μF)				
		3,3	6,6	9,9	13,2	16,5
Busbar 5 (Solidly grounded)	Line 1	2,11	2,21	2,31	2,39	2,47
	Line 2	2,10	2,00	2,30	2,40	2,50
	Line 3	2,11	2,20	2,29	2,37	2,45
	Line 4	2,11	2,22	2,32	2,42	2,52
	Line 5	2,10	2,20	2,29	2,37	2,45
	Line 6	2,10	2,20	2,29	2,37	2,45
	all	2,20	2,35	2,49	2,65	2,84

Considering the neutral solidly grounded, and assuming twice the length of one line at each time and of all lines at the same time, the influence of the length was studied. The results are presented in table 6, considering the capacitor bank connected at busbar 5. In this way, when only one line was doubled, the maximum transient recovery voltages were obtained for line 4 2.52 [p.u.]. When all lines were doubled the transient recovery voltages were increasing to 2.84 [p.u.].

In figure 5 are showed the maximum transient recovery voltages on busbars 1, 3 and 5 for T-line model (Frequency dependent) and Pi-line model (PI equivalent), when the capacitor bank neutral is solidly grounded.

It observes that the maximum transient recovery voltage was obtained for the PI equivalent line model, the busbar 5, the phase C (476.66 kV).

TABLE 7
INFLUENCE OF THE LINE MODEL ABOUT THE TRANSIENT RECOVERY VOLTAGES [p.u.]

Line Model	Capacitor bank placement	Capacitor bank (μF)				
		3,3	6,6	9,9	13,2	16,5
Frequency dependent	Busbar 1	2,14	2,22	2,29	2,34	2,38
	Busbar 3	2,11	2,17	2,23	2,27	2,32
	Busbar 5	2,09	2,19	2,27	2,35	2,43
PI equivalent	Busbar 1	2,18	2,25	2,32	2,37	2,42
	Busbar 3	2,15	2,21	2,26	2,31	2,35
	Busbar 5	2,15	2,23	2,31	2,39	2,46

The table 7 presents comparatively, on busbars 1, 3 and 5, the maximum transient recovery voltages for T-line model (Frequency dependent) and Pi-line model (PI equivalent). The capacitor bank neutral was solidly grounded.

It was observed that the maximum transient recovery voltages were on busbar 5, the phase C, when it was used the Pi-line model, 2.46 [p.u.]. The difference between the two models was of 3-4 %.

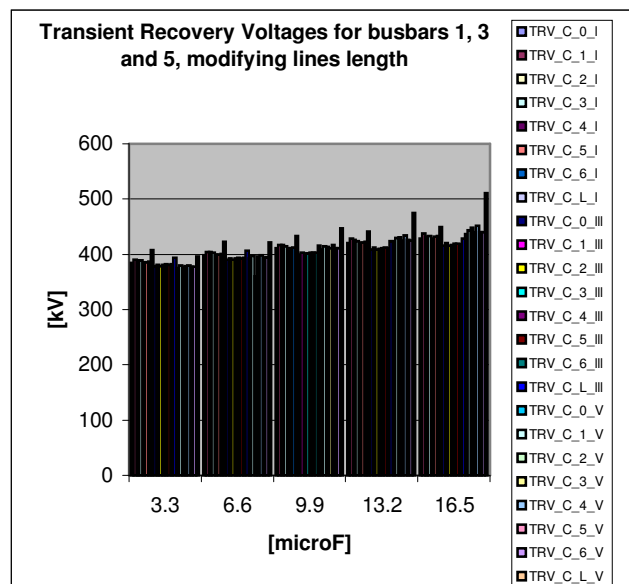


Figure 4. Transient Recovery Voltages on busbar 1, 3 and 5, modifying the lines length

In the figure 4 are presented, comparatively, the maximum transient recovery voltages (TRV) when it modify the lines length (0 is for normal lines length; 1-for double length of line 1; 2-for double length of line 2;o.s.o.; 6-for double length of line 6 and L-for double length of all lines).

The maximum transient recovery voltages for busbars 1, 3 and 5 appear on the phase C. The all Transient Recovery Voltages raise with increases the capacitance of capacitor bank. The maximum transient recovery voltages appear on the busbar 5. They present a variation between 436.21 kV; 2.43 [p.u.] (TRV_C_0, which is for the normal line lengths) by 510.5 kV;

2.84 [p.u.] (TRV_C_L, which is for the double lengths of the all lines).

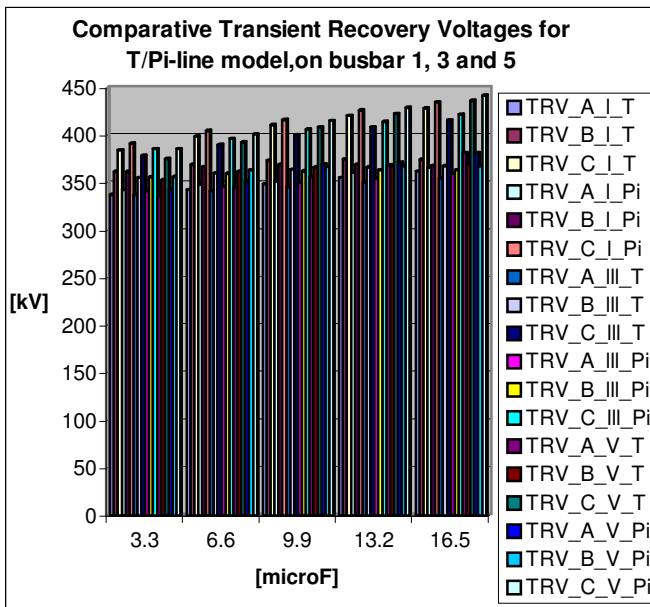


Figure 5. Transient Recovery Voltages for T/Pi-line model, on busbar 1, 3 and 5

IV. CONCLUSIONS

From the results some important conclusions can be extracted: Transient recovery voltages are affected by the Power System equivalent parameters;

- The connection of neutral to the earth has great influence in the maximum transient recovery voltages (2.43 [p.u.], when the neutral point is solidly grounded and 2.65 [p.u.], when the neutral point is grounded through capacitor; therefore, a difference of 22 %).
- The modification of line length results in an increase of the recovery voltages of near 40% when the length of all lines is doubled;
- The using of the two line models: the T-line model (Frequency dependent) and the Pi-line model (PI equivalent) emphasise the different result of 3-4 %.
- Due to the obtained transient recovery voltages results, it is necessary to use some techniques methods to limit its effects.

V. ACKNOWLEDGEMENTS

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VII. BIOGRAPHIES



1)

Petre Tusaliu was born in Melinesti, Romania, at the 25th April 1949. He is full professor at University of Craiova, doctor in "switching transient phenomena". Is author and joint author of over 150 works of their area, has seven invention and innovation patents, four works for Education and two books published: "Electric Equipment - Design and Engineering" and "Genie des Hautes Tensions". He was CIGRE member (5 years) and their Curriculum vitae and activity have been included in "The International Directory of Distinguished Leadership, 1997", edited by "American Biographical Institute". Also, he have received the title "Man of the Year-1997", awarded by "American Biographical Institute-North Carolina-USA". He was specialising in Germany and in last years worked two stages, in co-operation at the Polytechnic Institute of Coimbra, Instituto Superior de Engenharia de Coimbra (ISEC), Portugal, for an important scientific co-operation was made possible due to the NATO Fellowship Research Program. He has participated as member of many "Steering Committee" and "Editorial Board" of numerous International Conferences.