ABOUT MODELLING OF DISTURBANCES IN POWER SYSTEMS AT THE TRANSIENTS DUE TO SWITCHING OPERATIONS OF MULTIPLE CAPACITOR BANKS

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Abstract

The study presents the main disturbances, generated by the transitory phenomena at the commutation of simple and multiple capacitor banks. The same are presented **electromagnetic stresses modelling features** at the commutation of capacitor banks as part of the National Electrical Energetic System. Successfully used for the compensation of wattles-inductive energy, capacitor banks are characterised during connecting and re-energise of electric arc by the powerful current shocks, which produces dynamic, thermal stresses and electrical wear extremely pernicious for the commutation equipment for the banks themselves and for electrical network, thus possible serious disturbances in the Power Systems may occur.

At the disconnection of simple capacitor banks but more especially at the disconnection of multiple capacitor banks may appear an important commutation over voltage, which in certain occasions may become very dangerous for the apparatus-network assembly and sometimes even for the environment.

This stress evaluation is based on adequate **numerical programs** concerning certain equipment and capacitor banks as part of the Power Systems.

The final part of this study contains proposals and recommendations for construction, function, operation of the assembly capacitor banks-circuit breaker-network, to limit the level of stress and to rise the security in function.

1. INTRODUCTION

During the recent years there have been intensive discussion concerning the capacitance switching, particularly line - charging current switching [1-3]. These works will provide general information on the physical phenomena and stresses as well as to make recommendations whether and how the standards for circuit - breakers should be revised [2,3].

A large majority of the users wants circuit - breakers which will not restrict in their networks. Exceptions are limited the bellow 245 kV for which the consequences of a restrict are less dangerous because the ratio of the permissible over voltage to the rated voltage is greater than for higher rated voltage levels. However, it remains how a circuit - breaker shall be defined as restrict - free [1-3].

The increasing use of electronic and digital technologies in power systems and the wider diffusion of sensitive utilisation connected to them make the problem of Power System Electromagnetic Compatibility (PS-EMC) of great interest. There is potentially a great number of possible sources of disturbance in power systems. The paper presented refer to transients due to switching operations and faults.

Recent researches [1-3] underline as main electromagnetic stress source, in the power systems framework the breakers commutation so much in the normal working condition so in the damage condition. From these, the conditions of capacitance commutation occupies an central place, having a view to the advantages of the using of capacitor banks at the reactive-inductive energy compensation and the commutation process from the idly electric aerial cables or of the cables used in the electric energy transportation. So, in this working conditions, could be resulted at the connecting current shocks which values of (10-100)In are producing electric-dynamic and thermoelectric stresses on the ensemble breaker-network element, and at the disconnection could be resulted important overvoltages (amplified by the each electric arc relegating and by each pull out of current, soliciting extremely hard as much the breaker's chamber as the other equipment's from the system [2,3]. So, this regime is able to produce strong stresses and functional perturbations in the power systems.

Further on, are presented theoretical aspects and experimental data concerning the main stresses and perturbations resulted from the multiple capacitor banks disconnection process. It is presented on computer programs concerning the stresses level and the comparison of these given the admitted stresses. Also, here are presented recommendations and proposals concerning the limitation of the stresses levels and the correct exploitation of the ensemble breaker-network-capacitor bank.

2. DISCONNECTION OF THE CAPACITOR BANKS

The phenomena which appear at the capacitor banks disconnection are dependent of the breaker's specific features, the disconnected bank size and of the feeding network parameters. So, in this process, two elements are very important and these are: the growing speed of the dielectric rigidity of the space between the breaker's contacts (Ud = f(t)) and the growing speed respectively the oscillate recovering voltage amplitude (Ur = f(t)) [2,3]. The growing speed of the dielectric rigidity dependent from others as: the breaker's contact specific features; the contacts moving speed; environment and possibilities of breaking used; the disconnected bank size, presents generally dependencies of breaker's parameters. The oscillate recovering voltage presents dependencies of the feeding voltage value, induction and feeding network capacity. For the three phase circuits can be thought that the four possible cases of ties on the earth of the neutral points of these two circuits: the source and the neutral point of the feeding network and of the capacitor bank are tied on the earth, each phase can be considered in single phase circuit separate, which is not influenced by the other phases. If the neutral point of the feeding network is tied on the earth on the neutral point of the capacitor bank is isolated, which cannot be influenced by the other phases. If the neutral point of the feeding network is tied on the earth on the neutral point of the capacitor bank is isolated, the oscillate recovery voltage between the poles of the some phase of the breaker depends as much of the neighbour phases as of the bank neutral point potential.

This situation makes that the overvoltage appears only because of the capacitor bank [2,3]. Also, knowing that the network inductance is in conversely proportion with the short circuit power, it can be said that so much that the short circuit current at the bank place is smaller, as big is the initial voltage falling produced by the bank current on the inductance and a longer average time to break the electric arc. It results that, for one short circuit current, moment critical value of the short circuit current, the average breaking electric arc time-out runs the maximum time which ensures the capacitor bank disconnection without electric re-lighting [2,3].

With reference to fig. 2.1. the following values for voltage and current at the switching device (CB), apply [1-3]: The voltages U, Uc to ground at the closed breaker is higher than the source voltage Uc due to resonance effects and is given by equation (1):

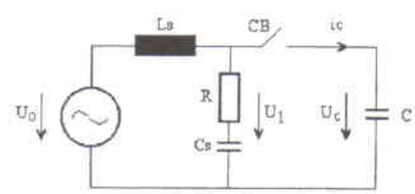


Fig. 2.1. Schematic circuit of capacitor bank switching: Ls - source inductance; R, Cs - representation of source side capacitance and dumping; Uo - peak value of source.

$$U_1 = U_c = U_0/\left(1 - \left|\omega^2/v^2\right|\right) \qquad (1)$$

$\omega = 2\pi f_p$ (f_p - power frequency)

$\left|v^2\right| = 1/(L_s C)$.

The capacitive current i_0 flowing through the breaker is calculated by equation (2):

$$i_0 = U_c \omega C \qquad (2)$$

The frequency fj, the rate of rise duj/dt and the amplitude Uj of this transient are given by the inherent features of the source network:

$$f_j = \frac{1}{2\pi\sqrt{L_s C_s}}; \quad \frac{du_j}{dt} = Z_s \frac{di_c}{dt}; \quad Z_s = \sqrt{L_s / C_s}$$

3. THE MULTIPLE CAPACITOR BANKS COMMUTATION

The phenomena with appear at the disconnection of the multiple capacitor bank from the network are same with the others from the simple bank disconnection if the breaker does not appear re-lighting of the electric arc [2,3]. In the case of the electric arc re-lighting, the physical process to another already working connection, and between these it is produced on discharge with a frequency dependent of the inductivity and capacity of the discharge current. The discharge current can have very high values, being dependent of the voltage difference from the step working and the step disconnected . The discharge is produced without break till the voltage difference from the two bank sizes diminishes to zero.

At the disconnection of simple capacitor banks but more especially at the disconnection of multiple capacitor banks may appear an important commutation overvoltage, which in certain occasions may become very dangerous for the apparatus-network assembly and sometime even for the environment.

Especially at multiple capacitor banks, besides the transition current shock, the switching overvoltages at disconnecting are creating important values (not to be neglected) of magnetic and electric fields, which through their amplitudes, but especially the rapid variation in time are leading directly to important stress, some-time with destructive effects with unfavourable and undesirable effects for the Power

On the main equivalent draft base from fig. 3.1. a), of the electric equivalent parameters determined (R_ech=0,013Ω; X_ech=3,105Ω; Z_ech=3,105Ω), suitable to the real elements from the circuit on base of analytic calculation [2], there made and executed on the computer many programmes, where from we select "The disconnecting voltage" which having at base the programming method it follows the electric stresses determination in transitory regime at disconnection, using the Runge - Kutta method, the results being synthetically presented in the table 1.

Table 1

U [kV]	Phase difference current-voltage [degrees]	Umax [kVmax]	Ku [overvoltage factor]
12	0	25.013	2.08
	15	31.993	2.66
	30	35.559	3.29
	45	44.824	3.93
	60	-50.628	4.28
	75	-56.58	4.71
	90	90	4.95

The results at the disconnection, having in account the non-linearity of the electric arc through the Runge-Kutta method, are presented in the table 2.

In the programme's frame with the computer's aid, too, there were drawn the overvoltages graphics at disconnection for some phase difference, obtaining maximum overvoltages (so, maximum electric stresses): U_max=47,265 kV_max (ku=3,93) for positive alternation and U_max=-59,407 kV_max (ku=4,95) for negative alternation .

Table 2

U [kV]	I [A]	Phase difference current-voltage [degrees]	I [overcrrent]	Ku [overvoltage factor]
12	251.7	0	-2100.3	8.34
		15	-2213.8	8.79
		30	-2482.5	9.86
		45	-2774.8	11.02
		60	-2996.2	11.90
		75	-3095.8	12.29
		90	-5048.5	12.11

Were drawn, too, in the frame of this programme, the disconnecting overvoltages graphics for different phase difference obtaining maximum overvoltages (maximum dielectric stresses): U_max=47.566 kV_max (ku=3.96) for the positive alternation and U_max=-60,916 kV_max (ku=5,67) for the negative alternation (table 3).

Table 3

U [kV]	Phase difference current-voltage [degrees]	Umax [kVmax]	Ku (overvoltage factor)
12	0	24.006	2.003
	15	31.995	2.66
	30	39.693	3.3
	45	45.084	3.75
	60	-52.035	4.33
	75	-58.26	4.85
	90	-60.916	5.67

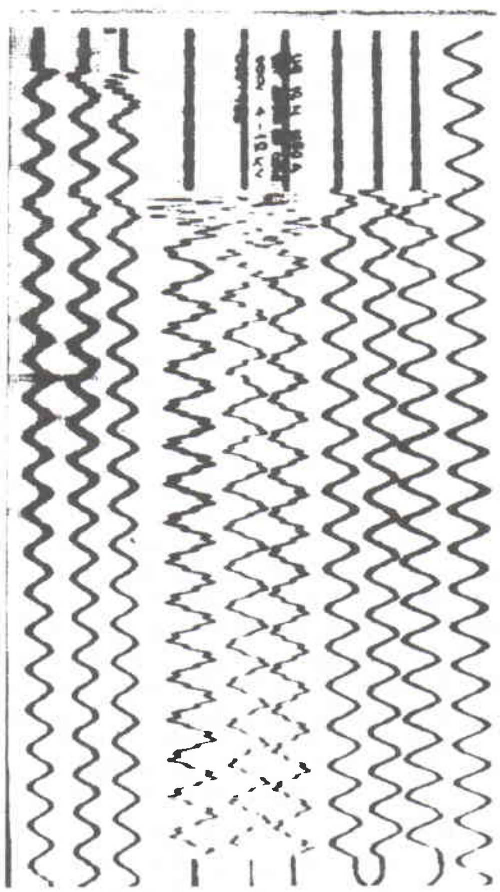
4. STRESSES AT THE MULTIPLE CAPACITOR BANKS DISCONNECTION

In the multiple capacitor banks disconnecting process results overvoltages and overcurrents which can take very big values, very often bigger then the others obtained at the capacitor banks connection, producing in this way serious stresses in the power systems. So, in the single-phase circuits at the capacitor banks disconnection without electric arc re-lighting, the oscillate recovering voltage which appears at the breaker's contacts doesn't exceed the double value of the feeding network voltage; the appearance of the overcurrents is not possible. If it appears electric arc re-lighting, the overvoltages can reach important values which can be transmitted in the feeding network under the form of some impulse waves, which amplitude is dependent by the number of re-lighting. The trickling to ground resistance and the neutral point capacity of the equivalent network transformer have a considerable influence on the capacitor banks disconnecting process. So, at small capacities and big resistance the two impedance in parallel can be comparable and the voltage stress of the trickling resistance is diminishing, the breaking of the capacitive current could be diminished a lot. At the growing of the capacity because the hard process of trickling of the charge through the big value resistance, the breaking process of the capacitive current is more complicated, on the breaking interval are adding on the initial voltage salt from the disconnected part and the industrial frequency voltage from the feeding network part. When the tie at the ground, considered on the third phase is situated down the breaker, the third pole is no more stressed and the connection which can be effectuated in the 1 - 2,3 or 2 - 1,3 succession can generate an oscillate recovering voltage of 3,46 U_{phase}, or 3 U_{phase} (when in the second stage is disconnecting pole 2). In the case of tying at the ground, on the third phase, down the breaker, the disconnection is maiden in two stages, being stressed all the poles in this way: for the 3 - 1,2 succession the maximum voltage stress of the third pole is 2,5 * U_{phase}, and for the others two, only 1,5 * U_{phase}; in the case of 1 - 2,3 succession the voltage stress at the first pole, at 90 degrees after the breaking of the current is equal with 1,73 * U_{phase}, and the maximum stress, obtained at 150 degrees after the breaking of the same current, is equal with 1,7 * U_{phase}, the other two poles being stressed with 0,37 * U_{phase} and 1,37 * U_{phase}; for the 2 - 1,3 succession the stresses are bigger at the pole which disconnects the first, so that after 90 degrees from the breaking of the current from the second phase the voltage stress of the pole is 1,73 * U_{phase} and the other two poles can reach at the value of 3,6 * U_{phase}.

There are cases where the maximum stresses of the breakers can be bigger but being given the fact that the probability of opposition of these very low, these were not mentioned.

The scope of the researches is to keep abreast of relevant developments concerning electric and magnetic fields and health, to prepare state-of-art , to produce information documents and to organise panel sessions, workshops , etc.

As a future activity is the implementation of models for the calculation of induced voltages and currents on cables and equipment.



5. CONCLUSIONS

The spectrum of switching arc modelling features is vast. Of course that it presents a real interest the elucidation of some aspects with general character but of details, too. So, it will be wished to know:

- what parameters of the phenomena are the most relevant for switching arc modelling.;

- how, further, should the investigation go on, on traditional or new item of interest, to identify adequately the sources of disturbance;

- which are, if any, the methods for reducing the various disturbances at the sources and where these methods are technically and economically convenient when compared to alternative measures to improve the immunity of the apparatus.

The work gives a inscription of the basic phenomena to be considered for line charging current switching when the circuit-breaker is still closed, when it opens and if it re-ignites. For closing the effects of the pre-ignition are considered as well as the working principle of closing resistors and controlled switching. After the opening operation the d.c. line voltage (trooped charge) of the first cleared phase is increased by the coupling with the not yet switched phases and by the Ferranty effect. The amount of voltage elevation depends on he line length. Line configuration and the source impedance [1-3]. For single-circuit lines the maximum voltage stress after half a period across an opening circuit-breaker usually reaches 2.2 -2.3. p.u. This is covered by IEC 56 which indirectly asks for 2.3-2.4 p.u. In case of a grounded neutral source. However, this voltage is 2.4-2.5 p.u. when the line has several circuits and it increases with line length in case of uncompensated lines. Compensation by shunt reactors is effective in limiting switching sources to such a degree that switching does not present difficulties for the circuit-breaker [2-6].

From the numerous possible sources of perturbations and stresses, "transients due to switching operations and faults" have a special place.

Switching of capacitor banks is specially in case of re-strike and switching of multiple banks (the so called "back - to - back" oscillations between adjacent banks), may be source of severe disturbances. Paper examines the phenomenon for different network conditions and also the possibility to reduce the disturbance using insertion of resistors. It is tried to show, at which part of the transient is more relevant to switching arc modelling: the high frequency emissions, dumping very quickly, due to the voltage collapse across the circuit breaker contacts, or the subsequent oscillations dominated by the circuit parameters.

The disconnection of the capacitor banks imposes, from the point of view of dielectric stresses (so of the perturbations introduced in the power systems) conditions very hardly at the breaker's contacts, capacitor banks and feeding network. So, the electric arc re-lighting can conduct at inadmissible stresses of isolation, which can product as much the capacitor destroy as the breakers.

It is imposed; so, that the breakers in use to function very strictly without electric arc re-lighting and without current snatches. If at the disconnection of the multiple capacitor banks appears electric arc re-lighting, the transitory phenomena are the same like with the others from the connection of bank's stage to another stage, already being in function, resulting big shocks of current and so, stresses produced by these effects.

With results that at the capacitor banks disconnection, generally, it would not produce very big stresses in the power systems if it would not appear electric arc re-lighting between the breaker's contacts and current snatches. Sometimes these desiderata are not fulfilled in the construction and function of the breakers because of generalising of the economic part of the breaker's construction, or because of realisation of non-performance breakers [1-4].

It results that the number of re-lighting and the overvoltage's and overcurrent's measure it alter in report with the disconnected bank power, in the idea the feeding circuit remains unchanged.

It can be realised disconnection without electric arc re-lighting, with the conditions to use breakers with dielectric rigidity (holding voltage) to grow more quickly then the growing speed of the oscillate recovering voltage. It answers very well at this request the breakers with SF6 and with vacuum. Also, the pneumatic breakers or with oil if are equipped with driving mechanisms which can assure high speed for opening the contacts [5-8].

How the breakers are subdued in exploitation to divers normal states of function and of damage and how very often this requests technical and functional from one state are opposites to another state of function it is imposed in the next preoccupation in the view to perfect the construction and the function of these and in the same time the limitation at maximum of the electromagnetic stresses introduced in the power systems.

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