EVALUATION OF SWITCHING CONCERNS RELATED TO SHUNT CAPACITOR BANK INSTALLATIONS

by

Dr.R.Shivakumar Aradhya, Smt. Sujatha Subash
Smt. Meera K.S

CENTRAL POWER RESEARCH INSTITUTE, BANGALORE (INDIA)

ABSTRACT

Energisation of shunt capacitor banks normally result in high frequency inrush currents , especially while switching in parallel capacitor banks. Recent site measurements by CPRI showed a recording of abnormal maximum inrush current, which defies the conditions normally depicted in the literature. This prompted studies on EMTP to investigate the probable causes for the high inrush currents. Few of the maximised cases have also been compared on TNA. The results of the parametric study carried out to study the influence of various system parameters are discussed in this paper.

INTRODUCTION :

Shunt capacitor banks are increasingly used in Power systems, virtually at all voltage levels, to increase power transfer capability, reduce equipment loading, improve power factor and control system voltage. One of the significant characteristics of shunt capacitor banks is that they are switched quite often on daily basis, to react to changing system conditions. Thus the transients generated occur frequently. These transients include,

1. High frequency inrush currents while switching in.
2. Transient and sustained overvoltages due to prestrike in circuit breakers while energising capacitors.
3. Transient currents while switching out due to circuit breaker restrike or reignition.
4. System overvoltages caused by local resonances and excited by capacitor switching.
5. Transient recovery voltages across the breaker poles.

The circuit breakers performing the switching operation of capacitors require special attention due to the severe switching duties imposed on them, particularly in bank-to-bank capacitor switching. Attention must be paid not only to the peak value of the inrush currents, but also to its associated frequency and the damping characteristic of the circuit.

Specific inrush current magnitude and frequency limits are included in the ANSI breaker standards [1] for definite purpose breakers upto 362kV. If the inrush currents are excessive , they can be controlled by adding current limiting reactors or by incorporating closing resistors/controlled closing features in the breaker. The size of the reactor could also provide overvoltage control for accidental and unexpected out of synchronised operation of the switching device and mitigate the odd number of harmonics like 3rd,5th etc in the system.

Recently field measurements carried out by CPRI [2] on energisation of capacitor banks installed on an 11kV system, measured an abnormal rise in the inrush current about 500amps, which is almost 1.3 times the maximum value predicted in the literature [3] and is given by

$$Ie=Ic*fe/f \qquad (1)$$

$$fe= 1/(2*pi*sqrt(LC)) \qquad (2)$$

where,
Ie - estimated maximum inrush current
Ic - rated current of the capacitor bank
fe - natural frequency in Hz
f - system frequency in Hz
L - power system inductance
C - capacitance of the capacitor bank.

This led to a detailed investigation comprising of studies using tools like the Electro-magnetic Transients program EMTP and the Transient Network Analyser TNA, to know the probable causes for this discrepancy, which could have arisen due to the network conditions or due to other switching sequences.

Parametric study was performed using the BPA's EMTP to find the effect of various system parameters, like pole spread, damping resistor etc on capacitor energisation. This paper presents the results of both EMTP and TNA simulations and illustrates the effects of the parameters.

SYSTEM REPRESENTATION AND DATA

All calculations were performed using the BPA 's EMTP. This program makes provisions for the connection of any combination of network elements, including switches, non-linear devices, transmission lines, transformers and generators, thus allowing a three-phase network of the type required here to be readily set up and the appropriate switching operations initiated. A single line diagram illustrating the complete model used in EMTP is given in Fig 1. The values used in the model are as follows:

- voltage source : 11kV rms L-L 50Hz
- source impedance : single phase fault level of 70MVA x/r =10
- current limiting reactor : 23.1mH
- capacitor bank rating : 1Mvar

The maximised cases alone were simulated on the TNA for further confirmation.

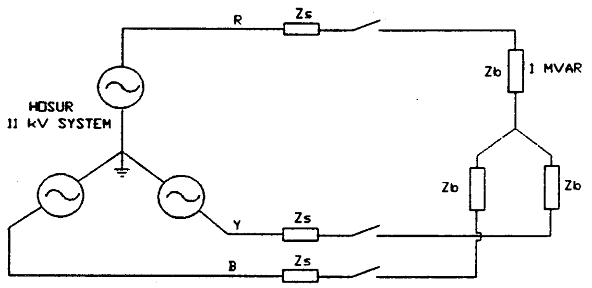

Fig. 1 SWITCHING IN CAPACITOR BANKS

Zs = 0.05 + j1.59 mH
Zb = Rd + j(wL -1/wC)
C = 26.3 uF L = 23.1 mH Rd = 0

Comparison with Field test recording

Though field recordings indicated a maximum of 555amps, a specific case of switching sequence which showed a maximum of 472.4amps is reproduced on the EMTP to analyse the inrush current phenomena. Here the phases R & B closed simultaneously with the Y-phase closing 0.11ms later. The R-phase closes at its voltage maximum. The computed peak value of the current (see Fig2) was much lower than the measured value of 472.amps.

Further studies showed that the condition of the capacitor neutral whether it is isolated or solidly grounded or earthed through a capacitor, has no significant influence on the peak value. This is also confirmed in published articles that the capacitor neutral has more influence on transient overvoltages compared to transient currents.

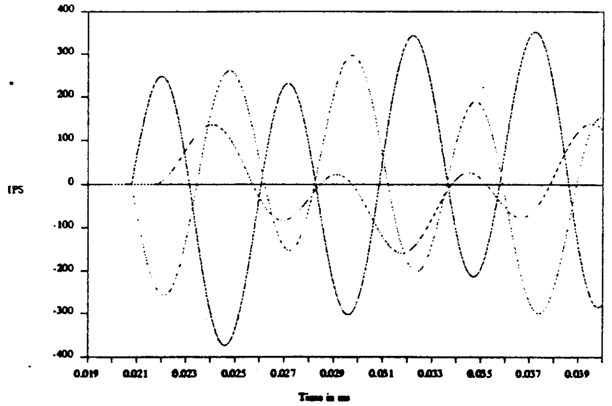

Fig 2. Capacitor bank currents comparison with field test

The discrepancy found between the value recorded at site and the estimated value only implies that either there could be other switching possibilities or system conditions which could give rise to higher currents. These conflicting observations prompted a parametric study to better illustrate the influence of various system parameters.

PARAMETRIC ANALYSIS

The following system parameters are considered in the analysis

- pole spread
- natural frequency of oscillation fe
- damping resistance in the reactor Rd
- saturation in current limiting reactor

In order to evaluate the performance of capacitor bank energisation under the influence of various system parameters, an index given by,

$$\alpha = I_{max}/I_e$$

is chosen. The factor α estimates the deviation of the maximum inrush current Imax computed statistically using EMTP, from the conventional practice of computing Ie using eqn 1.

Pole spread : The maximum inrush current is determined by the statistical analysis on EMTP wherein the random point-on-wave closing is taken into account. In this analysis the energisation operation is performed randomly varying the breaker pole closings over the closing span with normal probability distribution. A 120deg closing span between phases and 100 operations are considered in the study.

The maximum value is found to be 419amps for a switching sequence of 1.61,3.5,5.11ms. Similar result was found in the TNA study too. This value though greater than the estimated value, is still less than the field recorded value. This necessitated to extend the study further to other possible, but less probable switching conditions.

Manufacturers generally specify a pole spread of 5ms, but there is a posibility of a larger pole spread which may be due to ageing and/or improper maintenance. So Systematic switching approach is utilised in the EMTP study. Here the phases R&B are closed simultaneously and the Yphase is closed after a delay, the delay is varied over a period of 5ms at discrete steps. A maximum of 488am is found for the sequence of 5.56,11.0,5.78 ms. Figures 3a and 3b show the corresponding oscillograms obtained on EMTP and TNA resp. Since this approach gave maximum value closer to the recorded value, it is used further for studying the influence of other parameters on the inrush current.

Effect of system damping Rd

The results of the parametric study for system damping resistor Rd variations are provided in Fig 4. The inrush current is more damped for higher values of Rd, which matched closely to the field recording.

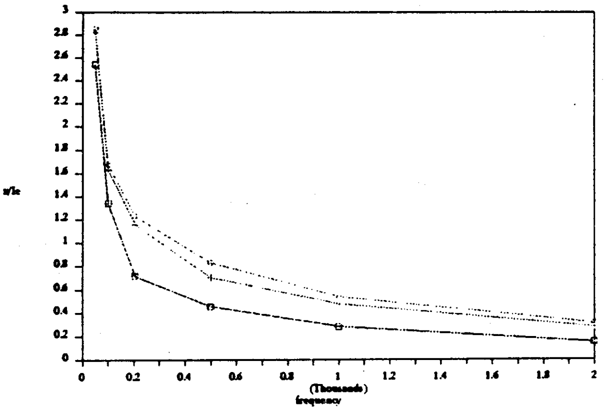

Fig 4. Variation of α versus frequency
□ Rd=10Ω, + Rd=1Ω, * Rd=0Ω

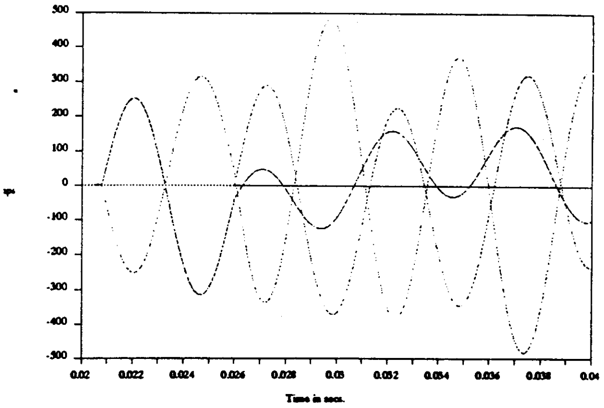

Fig 3a. Capacitor bank currents maximised case on EMTP

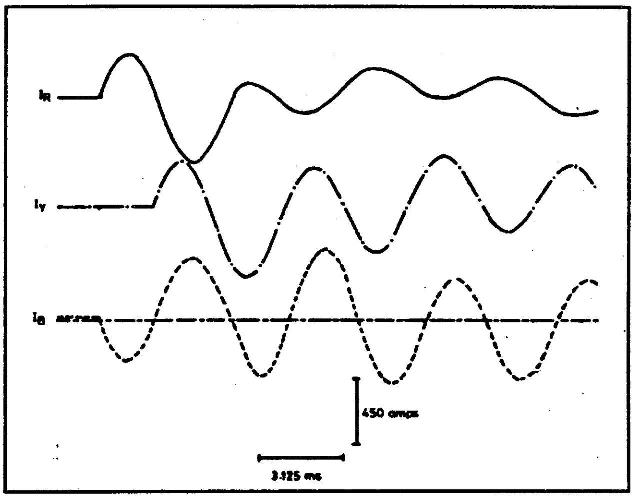

Fig 3b. Capacitor bank currents maximised case on TNA

Effect of natural frequency fe

As shown in Equation 2, fe depends on the value of L for a given capacitor bank value. For the system considered in Fig 1 the natural frequency is 204Hz. The value of fe is varied by varying the value of inductance L of the current limiting reactor. The results are shown in figs. 5 & 6. As frequency fe is increased the index factor decreases, showing that the estimated value Ie holds good for high natural frequencies. Increasing damping resistor Rd also show the same trend.

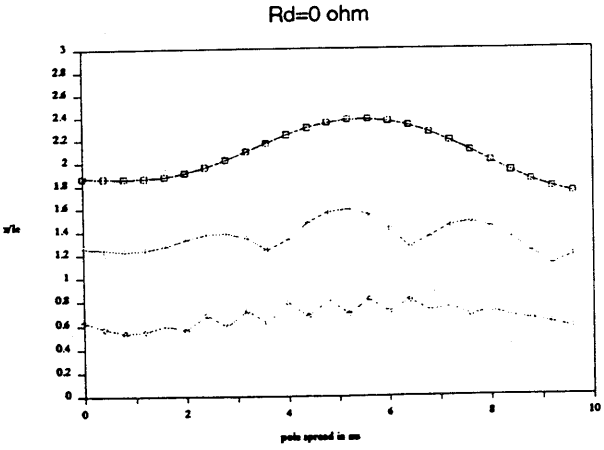

Fig. 5. Effect of Pole Spread on α at different frequencies □ fe/f=2, + fe/f=4, * fe/f=20

Fig. 5 shows the effect of last pole closing instant on α for different frequencies fe. It is clearly observed that at lower values of fe say 100Hz, 200Hz the factor α can go as high as 2.5. But at frequencies in the kHz range the factor α is always less, concluding that the estimated Ie value is the maximum inrush current.

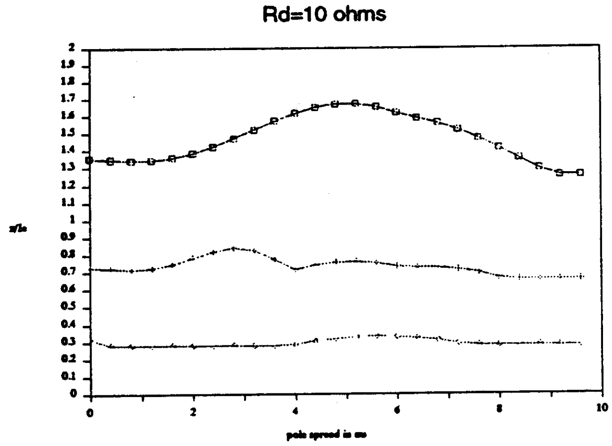

Fig 6. Effect of pole spread on α at different frequencies. □ fe/f=2, + fe/f=4, * fe/f=20

Effect of saturation in current limiting reactor

Increasing the value of damping resistance in the reactor reduces the value of the peak current. Since the field measurements recorded a value of 555amps, possibility of reactor going into saturation at a low voltage level exists. Reactor saturation simulation is done for, two values of Rd- 5and 10ohms, and two values of kneepoint 150amps and 250amps.In all these cases the inductance value drops down to 10% of its original value. The results shown in Table 1 indicate higher peak for inrush currents if saturation is included in the simulation.

TABLE 1 : Effect of saturation in reactor on Imax

Saturation level (amps)	Rd (ohms)	Imax (amps)
no	5	280.6
no	10	230.8
150	5	402.0
150	10	260.0
250	5	295.0
250	10	180.0

CONCLUSION

Inrush currents need to be carefully evaluated while energising capacitor banks.

1. Simulating a specific test case with EMTP results in peak inrush current value much lower than the recorded value at site.

2. Statistical analysis based on Gaussian normal distribution need not necessarily give the maximum value. If the breakers are aged or of older design and/or not properly maintained then random closing of the last pole need to be considered to determine the maximum value.

3. Parametric analysis show that the instant of last pole closing has significant effect on the value of a. At lower frequencies say 100-200Hz the factor can go as high as 2.5. But at higher frequencies this factor is always less than 1.0.

4. Saturation in reactors at lower levels could give higher magnitudes of current maximum.

ACKNOWLEDGEMENT

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REFERENCE

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ilities for ac High Voltage Circuit Breakers rated on a symmetrical current basis, ANSI C37,06-1979.

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