IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007), Dr. M.G.R. University, Chennai, Tamil Nadu, India. Dec. 20-22, 2007. pp.464-468.

DESIGN, SIMULATION AND COMPARISON OF SYNTHETIC TEST CIRCUITS FOR EXTRA HIGH VOLTAGE CIRCUIT BREAKERS

J.G. Jamnani*, S.A. Kanitkar†

* Electrical Engg. Dept., Institute of Technology, Nirma University,
Ahmedabad, India.
† Elect. Engg., Faculty of Technology & Engg., MSU, Baroda,India.

Keywords: TRV circuits, a.c. high voltage CBs, Synthetic tests.

Abstract

Development in electrical power transmission system requires the use of circuit breakers with increasing breaking capacity. At present circuit breakers are to be installed on 245 kV to 760 kV power system with short circuit ratings upto 63kA. To test high voltage CBs, direct testing using the power system or short circuit alternators are not feasible. The testing of high voltage CBs of larger capacity requires very large capacity of testing station. To increase testing plant power is neither an economical nor a very practical solution. Therefore indirect methods of testing are used for testing of large CBs. Synthetic testing is an alternative equivalent method for testing of high voltage circuit breakers and is accepted by the standards. Parallel current injection synthetic testing is the most widely used method for testing of CBs.

This paper presents a comprehensive review of TRV rating concepts, standard TRV envelopes, types of synthetic test circuits used for high voltage circuit breakers. Design and simulation of 4-parameters TRV synthetic testing circuits is done by using PSIM simulator. Three different 4-Parameters TRV circuits are simulated for a 420 kV rating circuit breaker for comparison purpose. Design optimization is also done to reduce the energy required by the capacitor banks. The results obtained by using different circuits have been discussed in the paper. The comparison is made on aspects of equivalence, operation, required capacitive energy and applicability. The comparison shows that although each circuit has its own merits, the Weil Dobke circuit appears to be very effective and is better than other circuits.

1 Introduction

In Synthetic testing, there are two sources of power supply for the testing.

(i) Current source (ii) Voltage source

The current source is a high current, low voltage source. It supplies short circuit current during the test. The voltage source is a high voltage low current source. It provides restriking and recovery voltage.

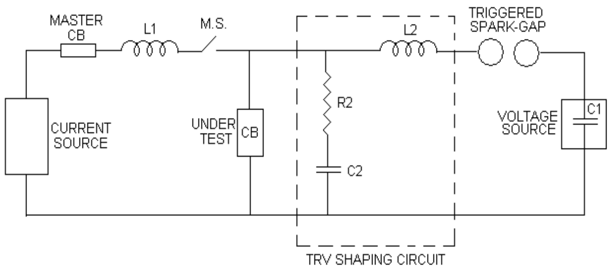

Figure 1: Synthetic testing circuit

The synthetic testing circuit is shown in Fig.1, where inductance L1 is to control the short circuit current. The master CB is used as backup circuit breaker. Make switch is used to apply short circuit current at the desired moment during the test.

The capacitor C1 is a high voltage source. L2, R2 and C2 are to control transient recovery voltage and RRRV. The triggered spark gap is fired slightly before the short circuit current reaches its natural zero. There is a control circuit to fire the triggered spark gap at the desired moment.

Advantages

- The breaker can be tested for desired TRV and R.R.R.V.
- The short-circuit generator has to supply current at a relatively less voltage (as compared to direct testing).
- Both test current and test voltage can be independently varied. This gives flexibility to test. The method is simple.

2 Types of Synthetic Test Circuits and Comparison

The synthetic testing circuits for CBs can be of two types:

1. Current Injection
    - Parallel Current Injection
    - Series Current Injection
2. Voltage injection

Depending on whether Voltage circuit is switched on before or after current zero, the type of synthetic testing is known as current injection or voltage injection respectively.

More than forty years of synthetic testing experience shows that the current injection method has better equivalence than the voltage injection method. To produce four-parameter TRV, several TRV circuits have been developed but parallel current injection method with a Weil-Dobke TRV control circuit is the most popular used synthetic testing circuit in the high power laboratories as it is capable of providing RRRV and recovery voltage as required by various standards. Weil-Dobke circuit has a low capacity requirement on the main capacitor bank as compared to other TRV control circuits and is easy to design the various component. However, special attention should be paid on the insulation coordination of TRV branches.

3 TRV Rating Concepts and IEC Standards TRV Envelopes

Short circuit tests require circuit with response specified by IEC standards shown in Fig. 2 and Fig.3.

IEC standards define two TRV envelopes.

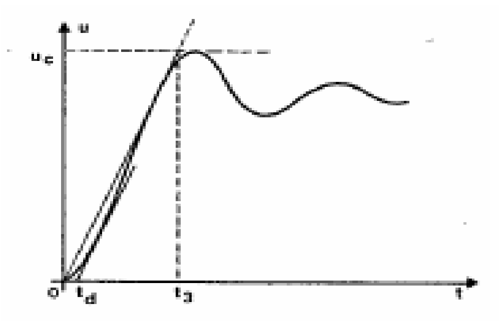

Figure 2: IEC envelope defined by 2 parameters: u_c and t_3

3.1 Case of two parameters

For circuit breakers rated 72.5 kV and below, the envelope is defined by the two parameter method shown in Fig. 2.

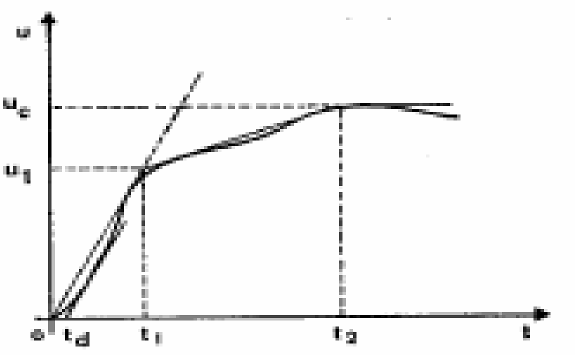

Figure 3: IEC envelope defined by 4 parameters: u_1 and t_1 u_c and t_2

u_c = reference voltage (TRV peak value) in kV.

t_3 = time to reach u_c in microseconds.

$u_c = 1.4 \times 1.5 \sqrt{\frac{2}{3}} = 1.715\ E_{rated}$

$u' = 1/3\ u_c$

t_3 = variable

$t_d = 0.15\ t_3$ for $E_{rated} < 72.5$ kV

$= 0.05\ t_3$ for $E_{rated} = 72.5$ kV

$t' = t_d + ½\ t_3$

3.2 Case of four parameters

For circuit breakers rated above 72.5 kV, the TRV envelope is defined by the four-parameter method shown in Fig. 3.

u_1 = first reference voltage, in kilovolts,

t_1 = time to reach u_1, in microseconds

u' = ½ u_1

u_c = second reference voltage (TRV peak value) in kilovolts

t_2 = time to reach u_c in microseconds.

$u_1 = 1.3 \sqrt{\frac{2}{3}}$ times rated voltage

$= 1.061\ E_{rated}$

or

$u_1 = 1.5 \sqrt{\frac{2}{3}}$ times rated voltage $= 1.225\ E_{rated}$

$t_2 = 3t_1$

$td = 0.02\ t_1$

$u_c = 1.4\ u_1 = 1.485\ E_{rated}$ for grounded systems

$= 1.715\ E_{rated}$ for ungrounded system

Two ratings are available at voltage of 100 to 170 kV.The first, for grounded systems, uses a first pole to clear factor of 1.3.The second, for ungrounded systems, uses a first pole to clear factor of 1.5. For 245 kV and above only the 1.3 factor is used.

4 Design and Simulation of 4-Parameters TRV Synthetic Test Circuits

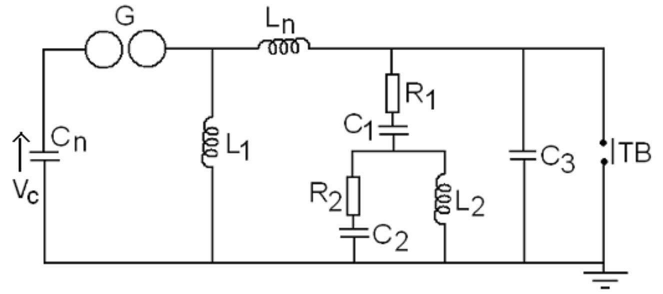

Figure 4: 4 parameters TRV synthetic testing control circuit I

To produce 4 – Parameters TRV, several TRV control circuits have been developed. These circuits are given in Figs. 4 to 6 and permits to produce 4 – parameters transient recovery voltages (TRV) according to IEC standards.

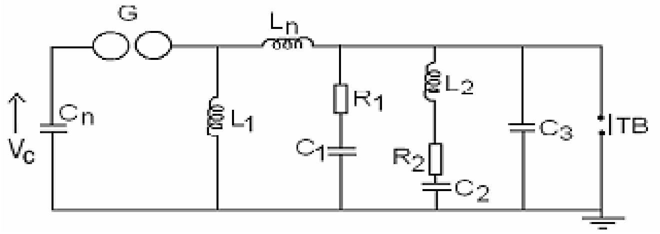

Figure 5: 4 parameters TRV synthetic testing control circuit II

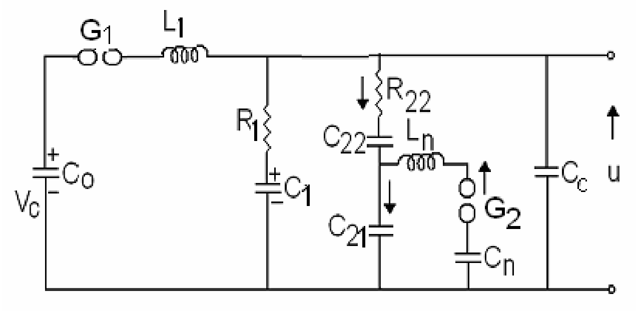

Figure 6: 4 parameters TRV synthetic testing control circuit III

The general flowchart to design 4-parameters TRV synthetic testing circuits is shown in Fig.7. The design and simulation of these circuits were carried out by using PSIM Simulator and simulated for 420kV rating circuit breakers for comparison purpose. The TRV curves obtained are shown in Fig. 8, 9 and 10.

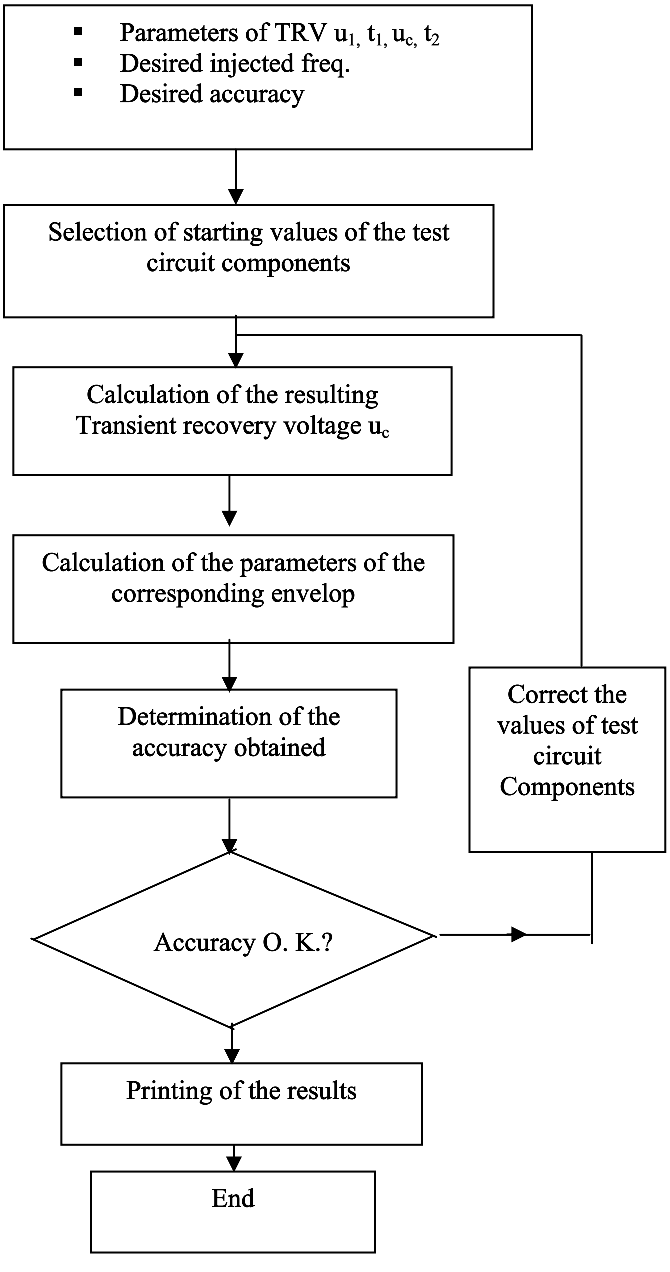

Figure 7: Flow Chart for design of synthetic testing circuit

TRV parameters from this waveforms are shown in table below:

TRV Control Circuit I II III

First reference voltage u_1,kV 445.8 444 444.8

Time to reach u_1, t_1 μs 445 445 445

Second reference voltage u_c, kV 620.1 620.3 620.1
(TRV peak value)
Time to reach u_c, t_2 ,μs 1340 1340 1340

The results shown are almost the same according to standards.

5 Comparison of 4-Parameters TRV Synthetic Test Circuits

The comparison of TRV control circuits shown in Figs. 4,5 and 6 is made on aspects of equivalence, operation, required capacitive energy and applicability.The energy requirement for each capacitor bank used in different control circuits is given in the Table- I for comparison purpose.

In control circuit–I, the transformation from a 2-Parameters to 4-Parameters TRV circuit is simpler. But this circuit needs the highest capacitive energy and allows the lowest voltage rating of circuit breaker which can be tested compared with other two circuits.

TRV waveform of control circuit – II is good and needs only 58 % capacitive energy of circuit – I for the same test conditions. The voltage rating of circuit breaker which can be tested is higher than with circuit – I. The voltage on C_2 , however is higher and special attention should be paid to the insulating level of this bank.

Circuit – III is the most economical test circuit in terms of capacitive energy necessary and needs only 35% capacitive energy of circuit – I for the same test conditions. Voltage rating which can be tested is highest with circuit – III. But circuit – III is the most complex to operate due the use of two spark gaps and more number of circuit components.

Table 1: Calculated minimum energy requirement for each capacitor bank

Control circuit	Capacitive Parameters μF	Total energy required
I	C_n C_1 C_2 C_3 206 3. 3 2. 2 21nF	21427 kJ
II	C_n C_1 C_2 C_3 94 2. 8 3. 6 21nF	12326 kJ
III	C_o C_1 C_{21} C_n C_{22} C_c 62 1. 6 3. 6 1. 6 3. 0 21nF	7360 kJ

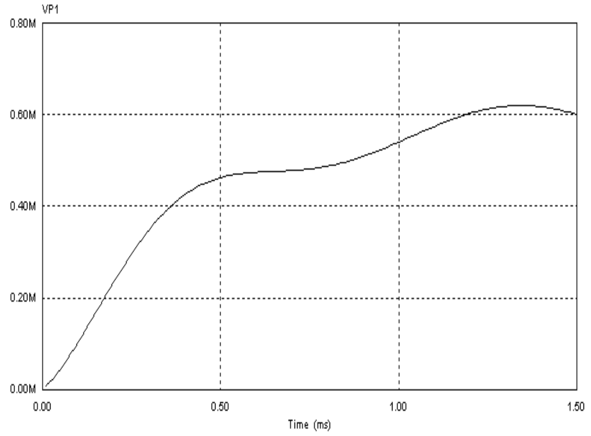

Figure 8: TRV curve for 420 kV circuit breaker (for the simulated control circuit- I shown in fig. 4)

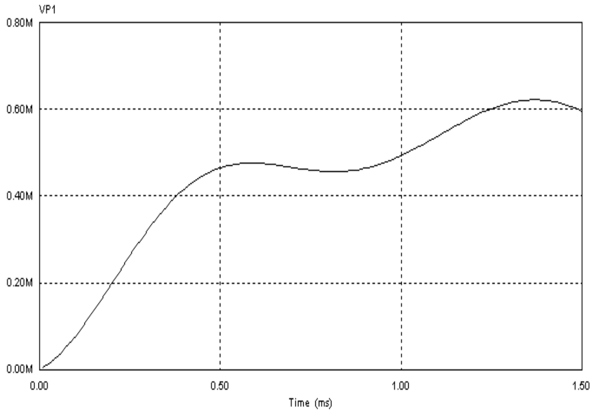

Figure 9: TRV curve for 420 kV circuit breaker (for the simulated control circuit- II shown in fig. 5)

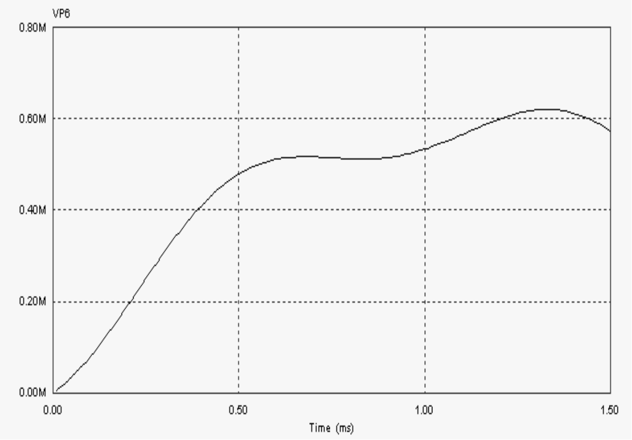

Figure 10: TRV curve for 420 kV circuit breaker (for the simulated control circuit- III shown in fig. 6)

6 Results and Conclusion

IEC standards define the parameters of TRV, it is quite impossible to analytically link these parameters with the values of the components of the test circuit. So computer aided design and simulation of synthetic testing circuits is first necessary in order to determine the parameters of the TRV corresponding to a given test circuit.

The objective was to design and simulate 4-Parameters TRV synthetic testing circuits used for testing high voltage circuit breakers. Three different 4-parameters TRV circuits, are simulated for a 420kV rating circuit breaker for comparison purpose. The results shown are almost the same according to IEC standards. The results shows that although each circuit has its own merits, the Weil Dobke circuit appears to be very effective and is better than other circuits.

References

[1] Ruben D. Garzon, High Voltage CBs – Design, Testing and applications, Marcel Dekker Inc, New york.

[2] C.L.Wagner, H.M.Smith, “Analysis of transient recovery voltage (TRV) rating concepts”, IEEE transactions on Power Apparatus and Systems Vol. PAS – 103, 1984, P. 3354.

[3] W.P. Legros, A.M.Genon , “Computer aided design of synthetic test circuit for high voltage circuit breakers “, IEEE transactions on power delivery, Vol. 4, No. 2, April 1989.

[4] Dufournet D. , Montillet G. “Three-phase short circuit testing of high voltage circuit breakers using synthetic circuits”, IEEE transactions on power delivery, Vol. 15, No. 1, Jan. 2000.

[5] B.L. Sheng, “ Design consideration of Weil – Dobke synthetic testing circuit for the interrupting testing of HV AC circuit breakers” IEEE conference ,2001.

[6] B.L. Sheng and L. Van der sluis , “The influence of the arc voltage in synthetic test circuits” IEEE Trans. on power delivery, Vol. 10, No. 1, January 1995.

[7] B.L. Sheng and L. Van der , “ Comparison of synthetic test circuits for ultra high voltage circuit breakers”, IEEE Trans. on power delivery, Vol. 11, No. 4, October 1996.

[8] B.L. Sheng and L. Van der , “ A new synthetic test circuit for Ultra-high voltage circuit breakers” IEEE Trans. on power delivery, Vol. 12, No. 4, October 1997.

[9] L. Van der and W.R.Rutgers, “comparison of test circuits for high voltage circuit breakers by numerical calculations with arc models” IEEE Trans. on power delivery, Vol.7,No.4, oct.1992.

[10] IEC 60427 : Synthetic testing of high voltage alternating current circuit breakers.

[11] IS: 2516, Specifications for A.C. circuit breakers.

[12] M.Smith, IEEE Standard No.C37. 081 “Guide to synthetic testing of A.C. high voltage circuit breakers rated on a symmetrical current basis”.