Analysis and Computer Aided Design of Synthetic Testing Circuits for High Voltage Circuit Breakers

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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 245kV 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 discusses transient recovery voltage(TRV) rating concepts and analysis of synthetic testing circuits according to IEC. Design and simulation of 4-parameters TRV synthetic testing circuits is done by using PSIM simulator. Design considerations of the parallel current injection synthetic testing circuit (Weil – Dobke) circuit is focussed and two 4-parameters TRV circuits are simulated. Simulation results are shown for a 245kV and 420 kV circuit breaker.

Index Terms- TRV circuits, a.c. high voltage CBs, Synthetic tests.

I. SYNTHETIC TESTING OF CBS

In this method of 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.

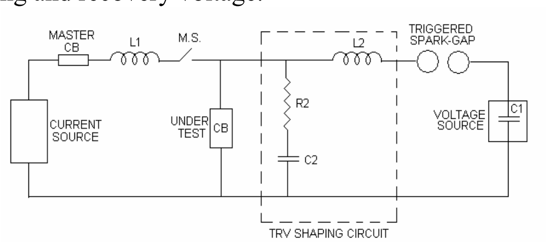

Fig.1. Synthetic testing circuit

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.

II. TYPES OF SYNTHETIC 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.

III. IEC Standards TRV Envelopes

Short circuit tests require circuit with response specified by IEC standards shown in Fig. 2 and Fig.4.

- IEC standards define two TRV envelopes.

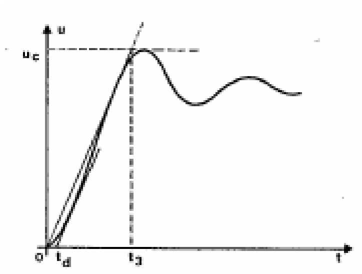

Fig.2. IEC envelope defined by 2 parameters:u_c and t_3

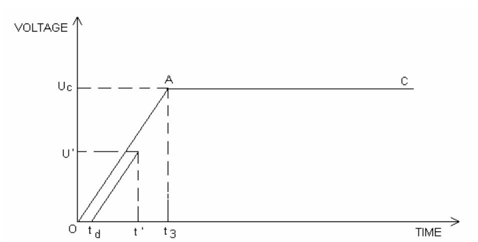

Fig. 3. 2 parameters TRV envelope

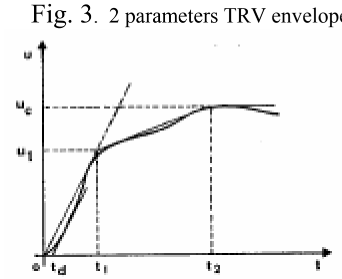

Fig.4. IEC envelope defined by 4 parameters: u_1 and t_1 u_c and t_2

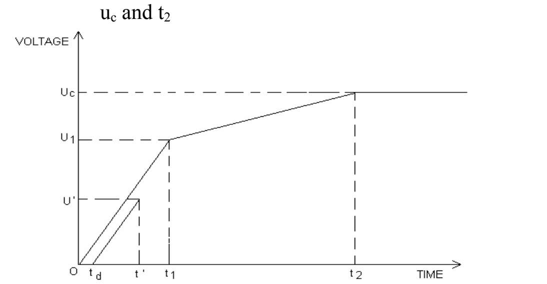

Fig. 5. 4 parameters TRV envelope

A. 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.

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

$t' = t_d + ½\ t_3$

B. 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. 4.

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.

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

$= 1.061\ E_{rated}$

or

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

$= 1.225\ E_{rated}$

$t_2 = 3t_1$

$td = 0.02\ t_1$

$u_c = 1.4\ u_1 = 1.485\ E_{rated}$ 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.

IV. Design and Simulation of 4 – Parameters TRV Circuit

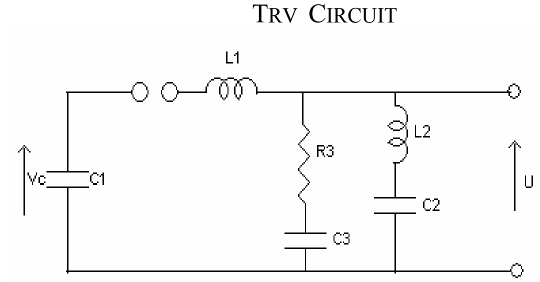

Fig. 6. 4 parameters TRV synthetic testing circuit

The circuit shown in Fig.6 permits to produce 4 – parameters transient recovery voltages (TRV) according to IEC standards. Vc is the charging voltage . C_1 is the main capacitor bank. C_2 , C_3 ,L_1 ,L_2 and R_3 are the circuit components and to control TRV and RRRV. The magnitude and the frequency of the transient restriking voltage depend on the voltage to which the main capacitor C1 is charged and the values of circuit components. The flowchart to design 4-parameters TRV synthetic testing circuit is shown in Fig.7.The simulations were carried out with the PSIM software. The circuit shown in Fig.6 were simulated for 245kV and 420kV circuit breakers. The TRV curves obtained are shown in Fig.8 and Fig.9. TRV parameters from this waveforms are shown in table below:

Rated voltage, kV	245	420
First reference voltage u_1,kV	268	442
Time to reach u_1, t_1 µs	260	445
Second reference voltage u_c, kV (TRV peak value)	365	621.5
Time to reach u_c, t_2 ,µs	779	1340

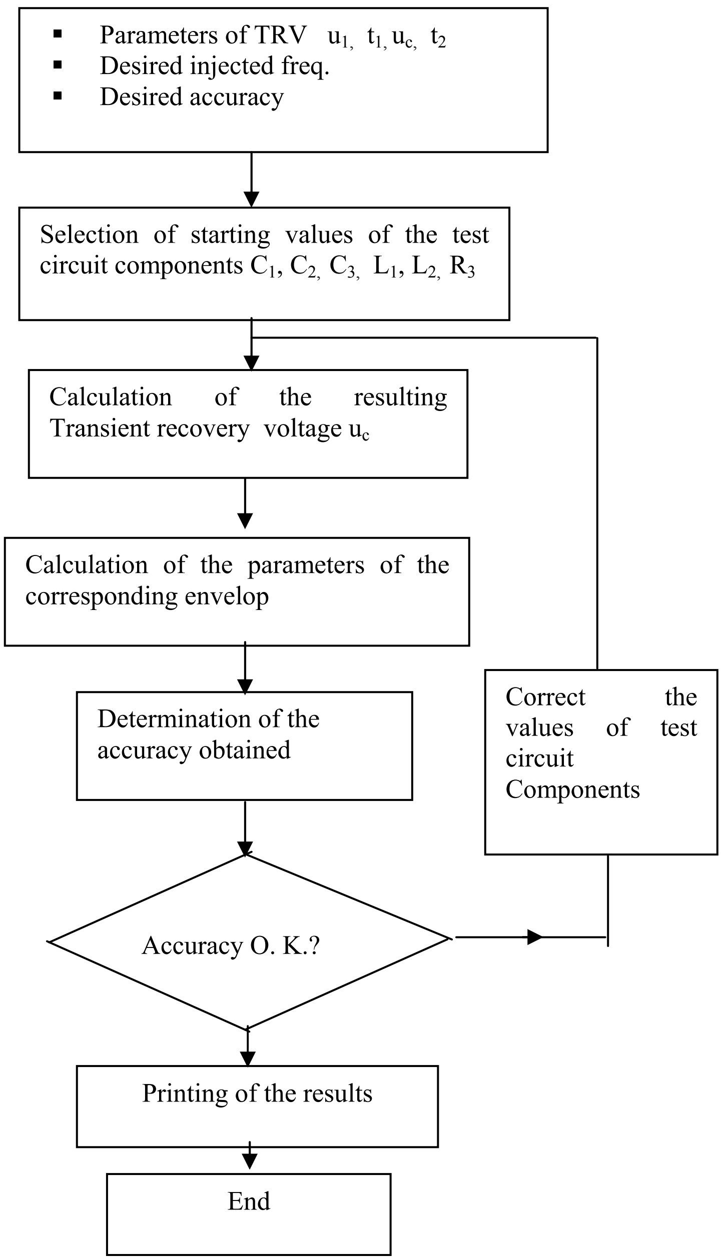

Fig.7. Flow Chart for design of synthetic testing circuit

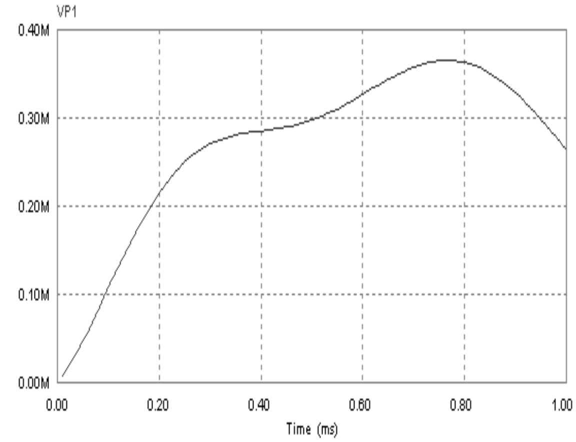

Fig.8. TRV curve for 245 kV circuit breaker (for the simulated circuit shown in fig. 6)

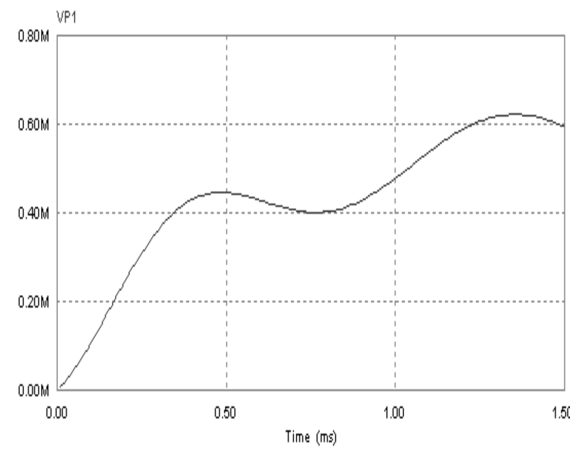

Fig.9. TRV curve for 420 kV circuit breaker (for the simulated circuit shown in fig. 6)

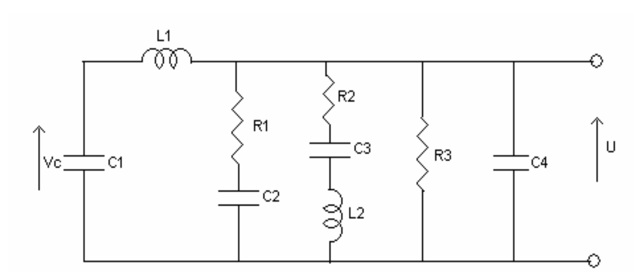

Fig.10. Four – parameters TRV synthetic testing circuit (used in ABB,Ludvika)

The circuit shown in Fig.10 is used in new synthetic test plant in ABB, Ludvika which is also based on Weil-Dobke parallel current injection synthetic test circuit. This circuit is simulated for 245kV circuit breakers and the TRV curve obtained is shown in Fig.11.

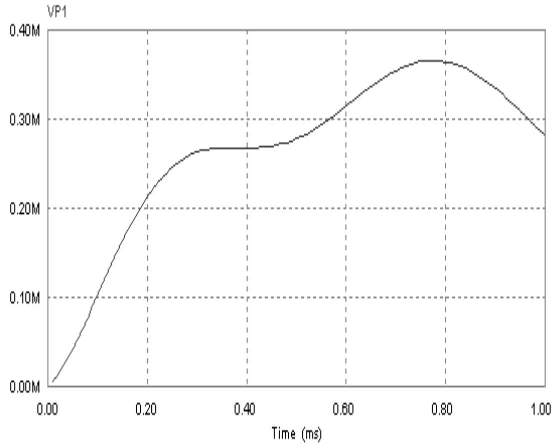

Fig.11. TRV curve for 245 kV circuit breaker (for the simulated circuit shown in fig. 10)

TRV parameters from this waveform are shown in table below:

Rated voltage, kV	245
First reference voltage u_1,kV	260
Time to reach u_1, t_1 µs	260
Second reference voltage u_c, kV (TRV peak value)	365.6
Time to reach u_c, t_2 ,µs	780

V. 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 circuit for testing high voltage circuit breakers. Two 4-parameters TRV circuits were simulated.The simulation of the synthetic circuit which is currently used in ABB,Ludvika is also done . Simulations were carried out by PSIM software. The results shown are almost the same according to IEC standards.

VI. References

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