Development and Fabrication of Automatic Controller and Triggering Circuit for Circuit Breakers Synthetic Test Circuit

J. G. Jamnani , Mrs. S.A. Kanitkar

Abstract—**Short circuit tests on circuit breakers are performed to prove the ratings of the circuit breakers. 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.**

In order to test circuit breakers by synthetic testing, it is needed to accurately control the synthetic test circuit so as to satisfy the test criterion. In this paper the synthetic test circuit with automatic controller to interrupt short circuit current and to fire the triggered spark gap at the desired moment is presented. The control circuit has been setup and the experiment shows a good agreement with the predictions.

Index Terms—A.C high voltage circuit breakers, Micro-controller, Synthetic tests, TRV circuits.

I. 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.

The synthetic testing circuit is shown in Fig.1, where inductance L1 is to control the short circuit current. The master CB (MB) is used as backup circuit breaker. If the CB under test (TB) fails to operate, the master CB opens. Also after every test, it isolates the CB under test from the supply source. Current sensor is used to give signal to the automatic controller and also for measurement purpose. Make switch (MS) is used to apply short circuit current at the desired moment during the test. For the operation of the circuit, First of all the MB and TB are closed. Then the short circuit current is passed by closing Make switch (MS). The short circuit current is interrupted by opening the circuit breaker under test at desired moment. The closing and opening of the circuit breakers at the desired moment is done by the Automatic controller.

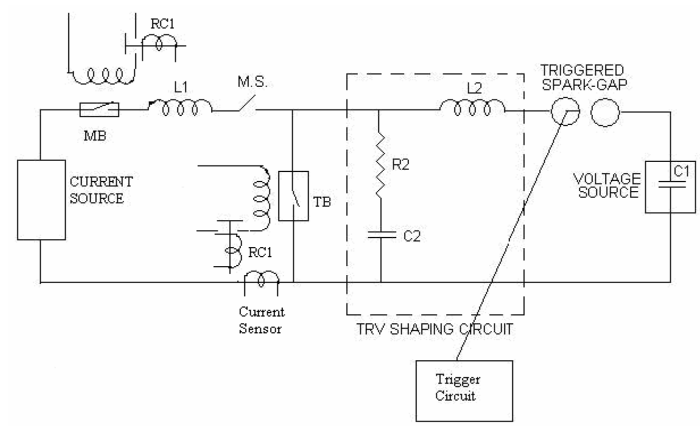

Fig.1. Synthetic Testing Circuit

The capacitor bank C1 is a high voltage source. It is charged to give the required recovery voltage. L2, R2 and C2 are to control transient recovery voltage and RRRV. The magnitude and frequency of transient recovery voltage (TRV) depend on the voltage to which the capacitor bank C1 is charged and the circuit parameters. The triggered spark gap is fired slightly before the short circuit current reaches its natural zero. Trigger circuit with controller is used to fire the triggered spark gap at the desired moment.

Advantages

- The breaker can be tested for desired TRV and R.R.R.V.

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- 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 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.

III. Automatic Control Circuit

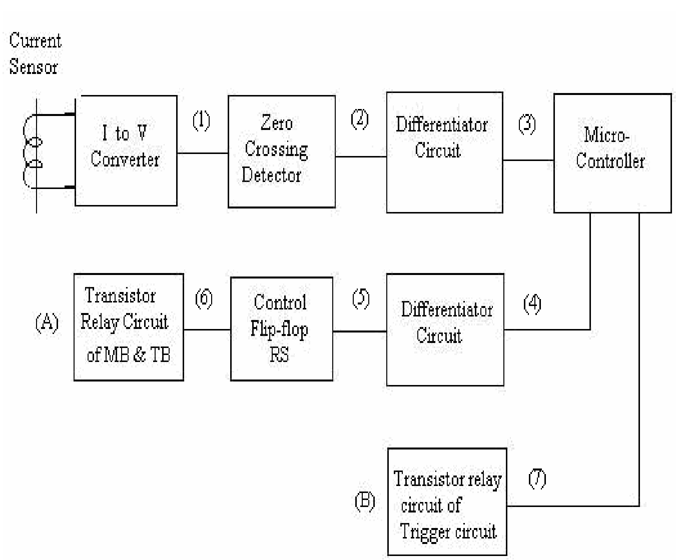

Fig.2. Functional block diagram of automatic controller

This circuit is used for the automatic closing and opening operation of circuit breakers and to fire triggered spark gap at the desired moment. Fig.2 shows the functional block diagram of automatic controller and Fig.3 shows the corresponding waveforms of each block. Fig.4 shows the detailed circuit diagram of Automatic Controller. The automatic control circuit employs the following:

1. Current sensor (ratio 1:1000)
2. I to V Converter
3. Zero crossing detector
4. Differentiator circuit
5. Micro-controller (ATmega8)
6. Control Flip-flop (RS)
7. Transistor relay circuit

The functional block diagram shown in Fig.2 consists of two circuit paths (A) and (B). Path (A) is for the operation of Master circuit breaker (MB) and Test breaker (TB), and path (B) is for firing triggered spark gap at the desired moment.

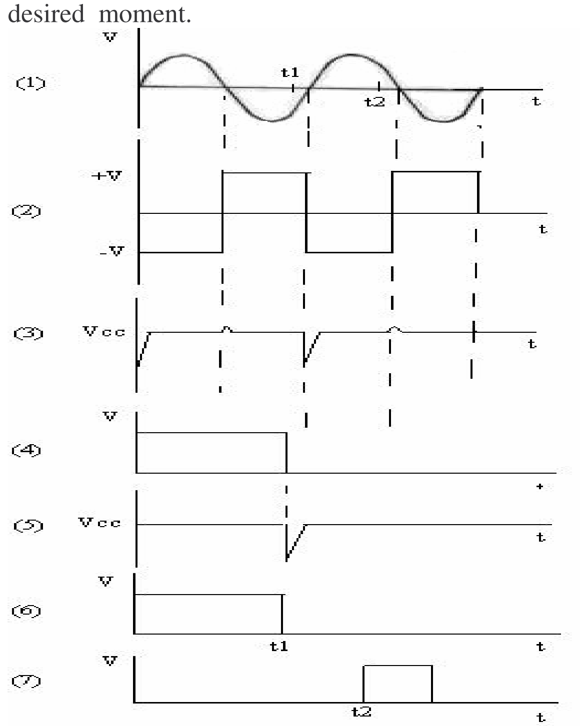

Fig. 3. Waveforms of each block of automatic control circuit

The current sensor reduces the primary high short circuit current to the suitable low value. Since the turns ratio of current transducer is 1000, it divides the primary current by 1000. For testing purpose the primary current were set at 30A. The secondary current will be 30mA. The current signal is then converted into proportional voltage signal using I to V converter. The voltage signal is fed to Zero crossing detector circuit. The output state of this circuit changes whenever the input crosses zero. The magnitude of the output voltage becomes equal to the supply voltage. In order to obtain a negative spike output for interrupting the micro- controller, the output of zero crossing detector is differentiated by using an R-C circuit.

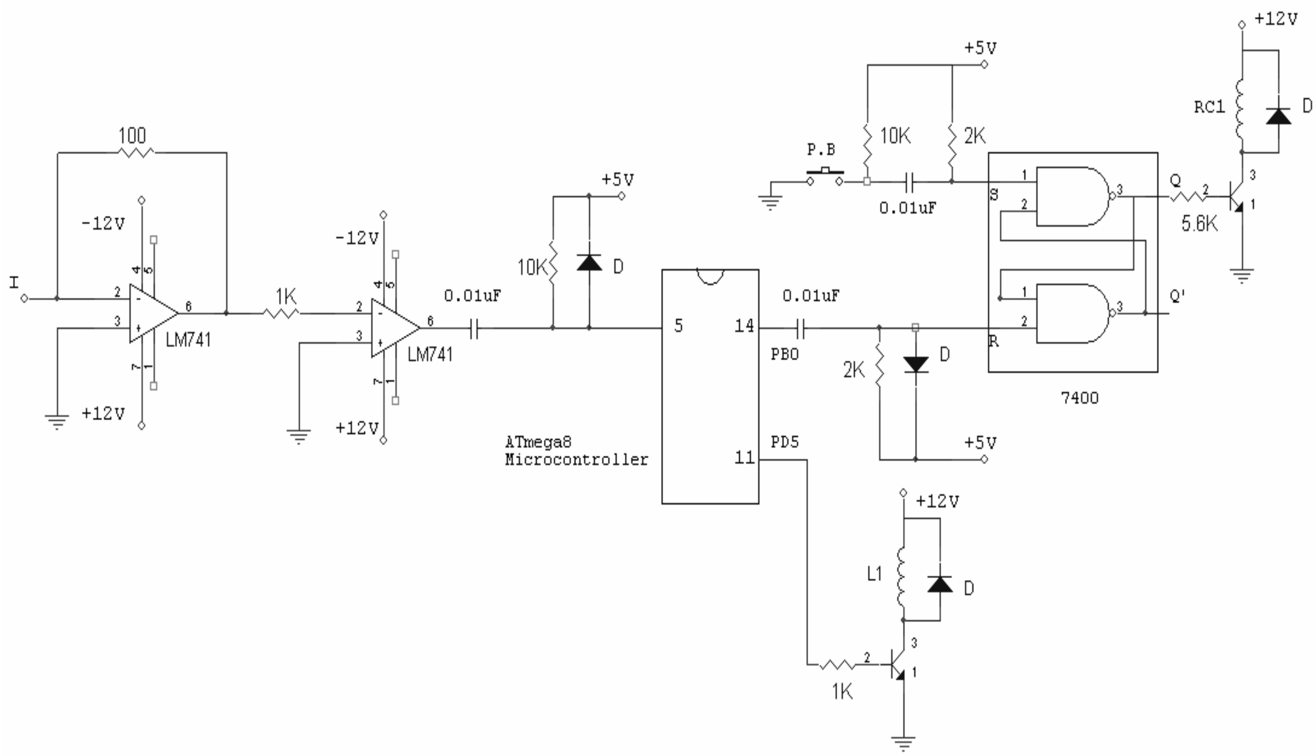

Fig.4. Detail Circuit diagram of Automatic Controller for the automatic closing and opening operation of circuit breakers and to fire triggered spark gap at the desired moment

Program has been developed by using BASCOM-AVR software version 1.11.8.3 from MCS Electronics to generate the pulses at the desired moment by using timers, one for denergization of MB and TB, and the second for firing triggered spark gap at the desired moment. The program is down loaded and tested on ATmega8 Micro-controller.

IV. Operation Of Automatic Control Circuit

- The high current source injects a high short circuit current i_1 into the CB under test at relatively reduced voltage.
- The test is initiated by closing the making switch (MS) which initiates the flow of the short circuit current i_1 from the high current source through the Master CB.
- According to the test criterion, it is needed to denergize the MB and TB at time t_1 i.e before the current zero (delay after first positive zero). The MB and circuit breaker under test (TB) are tripped. These CBs are fully opened by the time t_3.
- The triggered spark gap is fired at time t_2 (greater delay after first positive zero) slightly before the short circuit current reaches its natural zero.

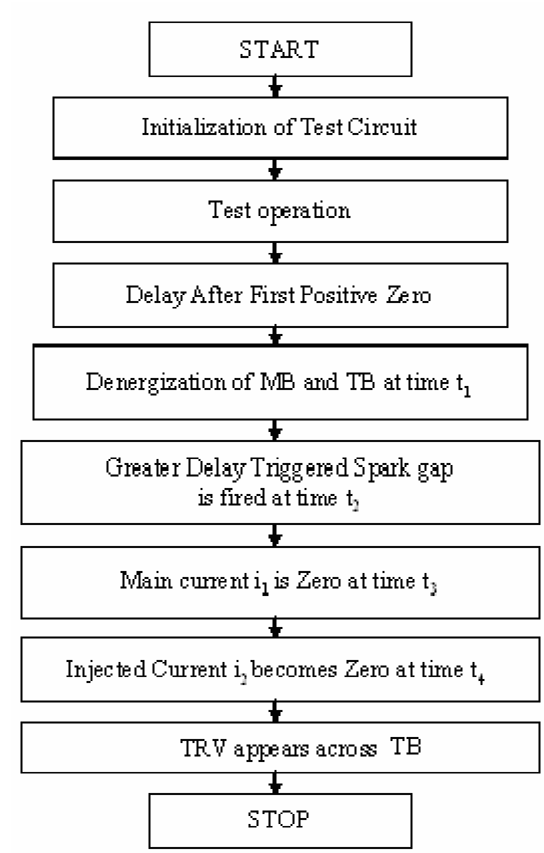

Fig. 5. Flowchart for the automatic sequence of operation of developed CB synthetic test circuit

The current sensor is used in the circuit to give the signal to automatic control circuit and for measurement purpose.
For the operation of the circuit, First of all, the MB and the breaker under test (TB) are closed by applying momentary zero to the SET input of control RS Flip flop, then the short circuit current is passed by closing the make switch (MS). The short circuit current is interrupted by opening the breaker under test (TB) at the desired moment. The closing and opening of CBs at the desired instant is done by Automatic control circuit.

The main capacitor bank C_1 is charged to give the required recovery voltage. The triggered spark gap S is fired at the desired moment. The triggered spark gap is set ready to be fired. The flowchart and time scale for the automatic sequence of operation of developed CB synthetic test circuit are shown in Fig. 5 and 6 respectively.

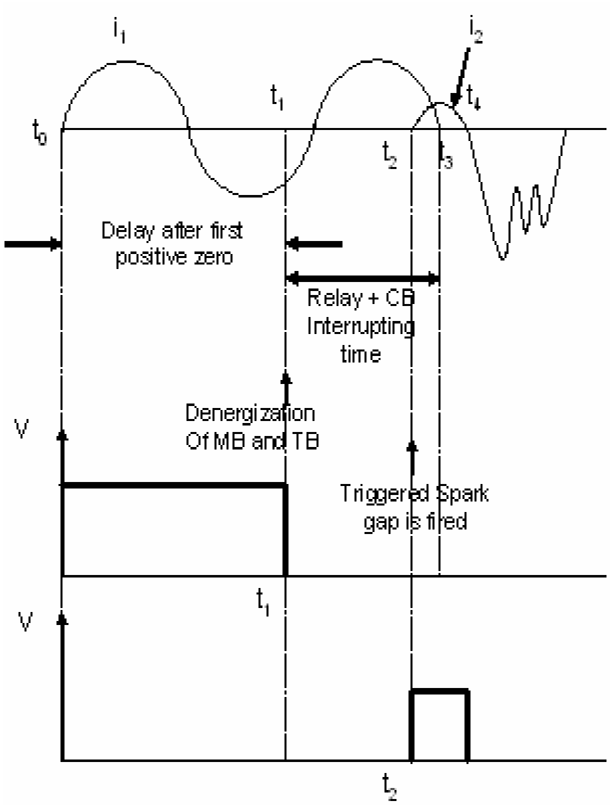

Fig. 6. The time scale for the automatic sequence of operation of developed CB synthetic test circuit.

V. TRIGGERING CIRCUIT

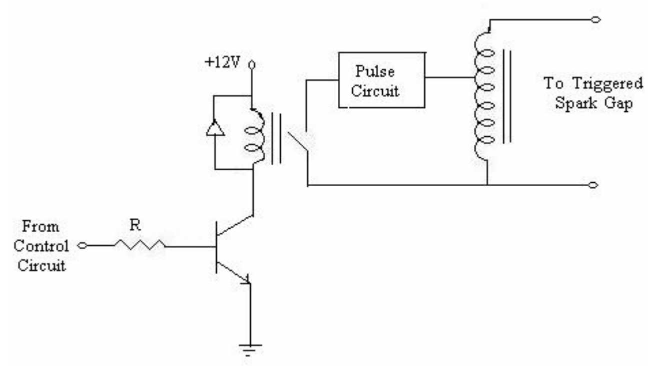

Fig.7. Schematic diagram of trigger circuit

Trigger circuit consists of automatic control circuit and triggered spark gap. This circuit is used to fire the triggered spark gap at the desired moment. Fig.7 shows the schematic diagram of trigger circuit. The triggered spark gap is set ready to be fired. The main capacitor bank C_1 is charged to give the required recovery voltage. In Fig. 2., the path (B) is to generate the pulse for firing triggered spark gap.

The task of spark gap is to withstand the voltage on the pre charged main capacitor bank and to trigger at the right instant with least time delay. Now a days, two types of spark gap are used by high power laboratories. They are plasma injection spark gap and voltage triggered spark gap. For plasma injection type spark gap, certain time is necessary to build up and inject the plasma between two electrodes. This delay time can vary from 50 µs to 250µs depending on the design of gaps and the test voltages. Gaps fired by means of third electrode in voltage triggered spark gaps significantly minimize the variation in the delay times of the gap. The variation is in the range of a few micro seconds.

The spark gaps are generally sphere gaps. Gaps with three electrodes (by introducing auxiliary electrode) function as time dependent switching devices and are called trigatron. A trigatron gap consist of two main electrodes and trigger electrode. The trigger electrode is a metal rod with an annular clearance of about 1 mm fitted into the main electrode through bushing. The trigatron is connected to a pulse circuit. A high voltage pulse from this circuit is applied between the trigger electrode and one of the main electrodes at the desired instant. Due to space charge effects and distortion of the field in the main gap, spark over of the main gap occurs. Trigatron gaps require a tripping voltage of about 5 kV of either polarity. The dc pulse from the pulse circuit is given to high voltage ignition coil to steps up the voltage to a peak pulse of 5kV. This tripping voltage is sufficient to cause the triggering of the third electrode i.e. trigger electrode of trigatron gap.

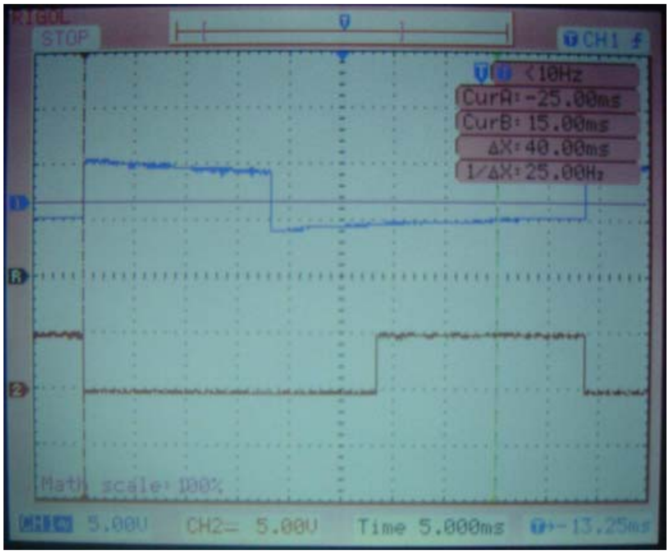

Fig.8. Oscillographs recorded for two generated pulses by Microcontroller
(Scale: X-axis 1 div. = 5 ms, Y-axis 1 div. = 5V)

VI. Results And Conclusion

According to the test criterion, it is needed to interrupt the MB and TB at time t_1 i.e. before the current zero (delay after first positive zero). The MB and circuit breaker under test (TB) are tripped. These CBs are fully opened by the time t_3. Also it is needed to ignite the sphere gap of high voltage circuit at time t_2, (greater delay after first positive zero) slightly before the short circuit current reaches its natural zero.
Programs has been developed by using BASCOM-AVR Compiler from MCS Electronics to generate the pulses at the desired moment by using timers, one for denergization of MB and TB (i.e. at time t_1) and the second for firing triggered spark gap at the desired moment (i.e. at time t_2). The objective was to develop and fabricate the Automatic controller and triggering circuit for CB synthetic test circuit. The developed automatic controller was tested and Oscillographs were recorded for pulses, one for interruption of MB and TB, and the second high pulse generated for firing triggered spark gap. These oscillographs are shown in Fig.8. The experiment results shows a good agreement with the predictions and according to the desired test criterion.

VII. Appendix

TRV RATING CONCEPTS AND IEC STANDARDS TRV ENVELOPES

Short circuit tests require circuit with response specified by IEC standards shown in Fig. 9 and Fig.10.

IEC standards define two TRV envelopes.

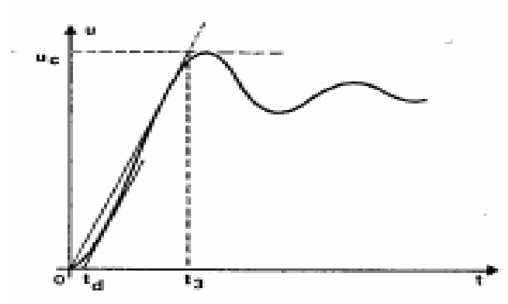

Fig.9. IEC Envelope defined by 2 parameters: u_c and t_3

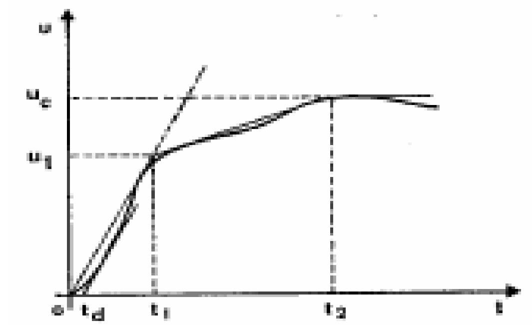

Fig.10. IEC Envelope defined by 4 parameters: u_1 and t_1 u_c and t_2

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. 9.

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

$t' = t_d + \frac{1}{2} t_3$

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.10.

u_1 =first reference voltage, in kilovolts,

t_1 =time to reach u_1, in microseconds

$u' = \frac{1}{2} u_1$

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.

VIII. References

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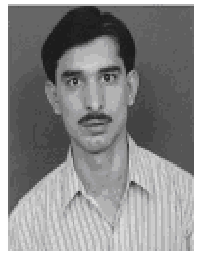
IX. Biographies



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