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## Development of Passive Fault Current Limiter in Parallel Biasing Mode

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**Abstract-** So far the reported literature on the magnetic fault current limiter (FCL) are based on series biasing mode in which the flux due to line current flows through the permanent magnet. As a result there is a high possibility of demagnetization of the permanent magnet. A passive fault current limiter is a combination of passive elements such as permanent magnet and saturable core. Permanent magnet is used to bias the core. In order to avoid severe demagnetization of permanent magnet, in this paper we have investigated the performances of passive fault current limiter based on permanent magnet and saturable core in parallel biasing mode. The functional characteristics have been analyzed by Tableau approach and the simulation results are presented. The experimental results for a small scale prototype model are also presented for verification.

**Index terms -** Magnetic current limiter, permanent magnet, saturable core, parallel biasing.

### I. INTRODUCTION

In order to restrict the flow of the excessively large value of current in power system during sudden load switching, overload, fault and any other abnormal operating conditions, use of some kind of current limiting equipments are gaining momentum. Magnetic current limiters, combination of permanent magnet (PM) and saturable core is very important in this respect as it is easy to manufacture and simple in installation.

The permanent magnet is used for the biasing of the core and forced the core into saturation under normal operating condition. The PM-core assembly behaves like an inductor and during low value of operating current, it offers saturated inductance to the circuit which is normally low. During large value of current each core comes out of saturation alternately, and goes to the unsaturated state in alternate half cycle, thereby,

offers large value of unsaturated inductance in combination with the saturated inductance of the other half to the circuit, and consequently the fault current is restricted.

### II. CONFIGURATION OF FCL

The earlier developed model based on series biasing is shown in Fig.1[1]. In series biasing mode the magnetomotive force (mmf) of the winding and the mmf of the permanent magnet are acting in series with respect to each other. During the negative half cycle the negative mmf due to line current oppose the permanent magnet mmf and consequently there is a reduction of resultant flux. The resultant flux always passes through the permanent magnet and as a result there is a high possibility of complete demagnetization of the permanent magnet, especially during fault condition associated with large value of current. In order to reduce the effect of demagnetization and to augment the performances of FCL, some other forms of structures and biasing mode are explored and the optimum structure in parallel biasing mode has been achieved. Fig.2 shows the structure of FCL in parallel biasing mode. The magnet in the middle biases the core of both the limbs. Each limb is used for each half cycle. The use of two coils in two limbs in magnetically counter direction makes it to function as a bipolar current limiter and to be used to limit the flow of large current in a.c. circuit.

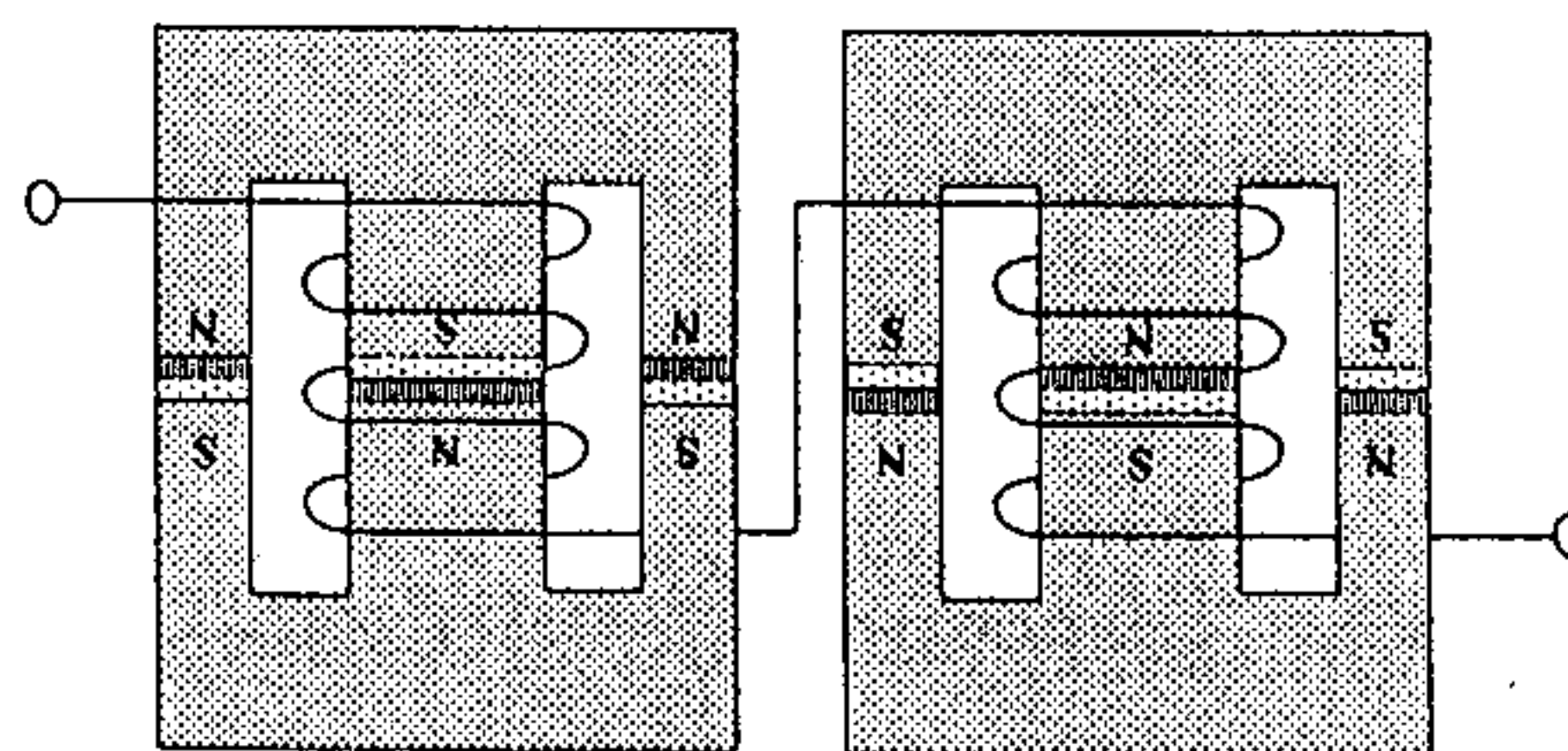


Fig.1. FCL configuration in series biasing mode

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### III. FUNCTIONAL $\phi$ - $i$ CHARACTERISTICS

Due to the biasing of the core by the permanent magnet, the B-H characteristics of the core is modified. Since the device behaves as a fault current limiter the voltage-current or  $\phi$ - $i$  characteristics are more important. Fig.3 shows the combined

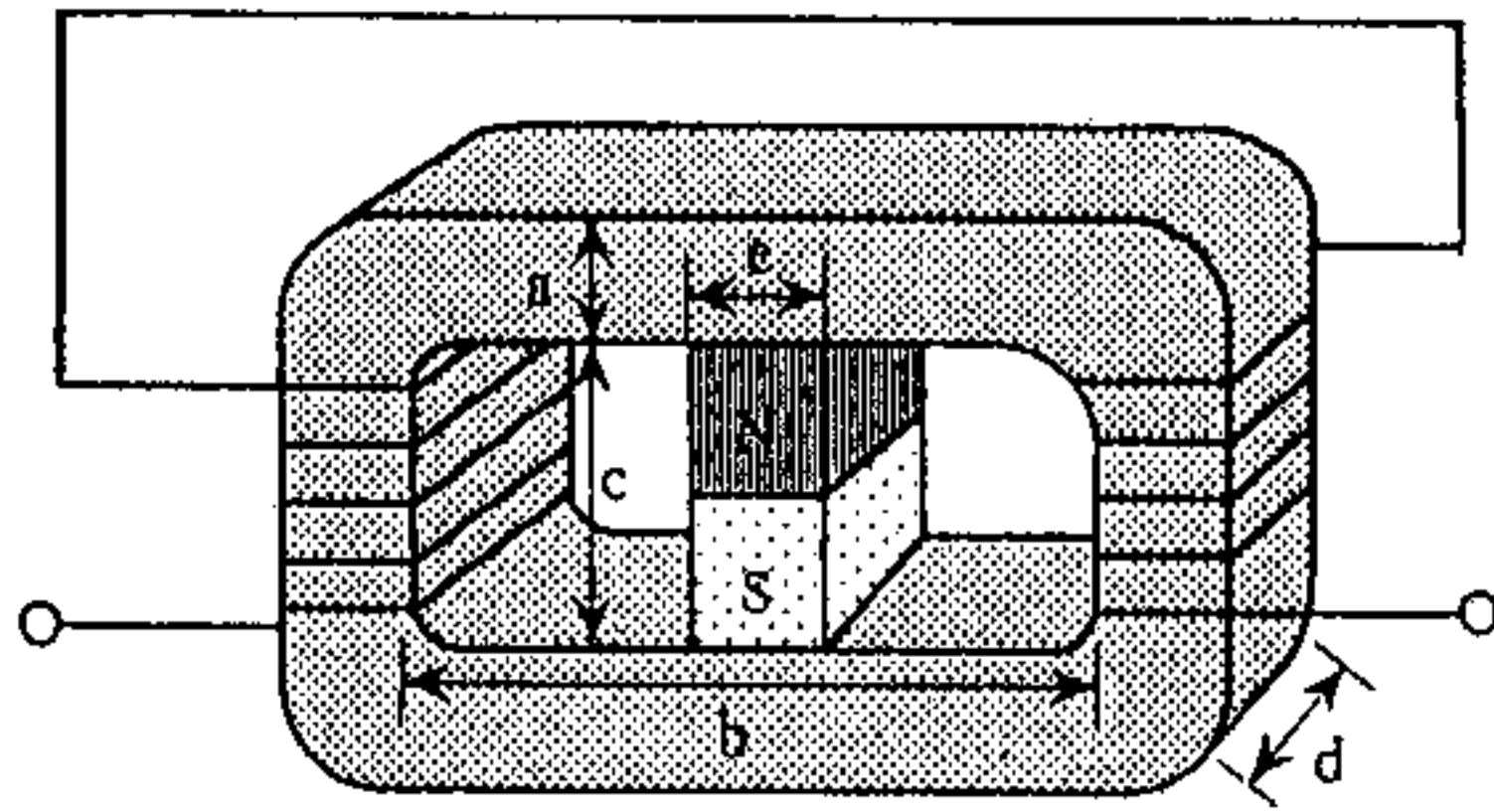


Fig. 2. FCL configuration in parallel biasing mode

$\phi$ - $i$  characteristics of the FCL for both desired and observed condition. The slopes are designated by S1 and S2. A very low value of S1 and large value of S2 is desirable. It is seen that because of the imperfection of the material characteristics and manufacturing, the transition for the observed characteristics is not sharp compared with the desired one. For low value of current, change of  $\phi$  is small but the change of  $\phi$  is very large when the current exceed  $I_{knee}$ . The operating areas of normal operation, fault operation and loss of fault limiting are also marked in Fig.3.

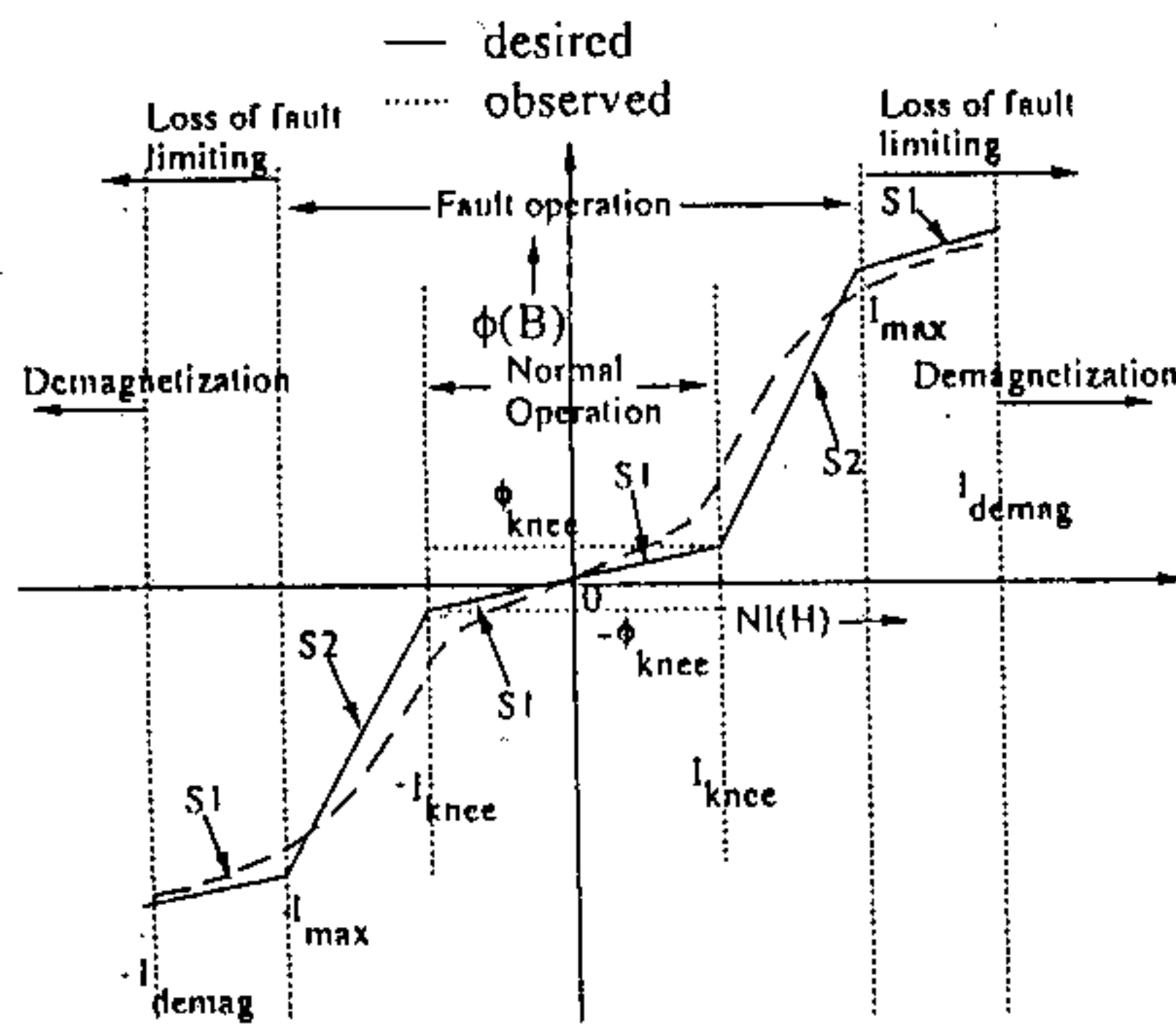


Fig. 3.  $\phi$ - $i$  characteristics of FCL.

### IV. ANALYSIS AND SIMULATION

The experimental circuit for the simulation as well as for the experimentation is shown in Fig.4 and the corresponding

electromagnetic equivalent circuit is shown in Fig.5. With the help of Tableau method the operation of the circuit is analyzed[2]. By changing the load resistance from a large value to a small value the fault is simulated. The parameters used in the simulation are listed in Table1. Fig.6 shows the simulated waveforms of the FCL current, voltage across FCL ( $V_{fcl} = V_{fcl1} + V_{fcl2}$ ) and the load voltage at a typical fault condition. It is seen that the voltage across FCL is low before the fault takes place but it increases to a large value at and after the fault. Fig.7 shows the variations of the fluxes in two limbs and through the permanent magnet. It is seen that the fluctuation of the flux in the magnet is not so large which confirms the demagnetization of the permanent magnet is not so severe. Fig.8 shows the variation of voltage across FCL as a function of the current. This curve is important for the selection of FCL for any specific application.

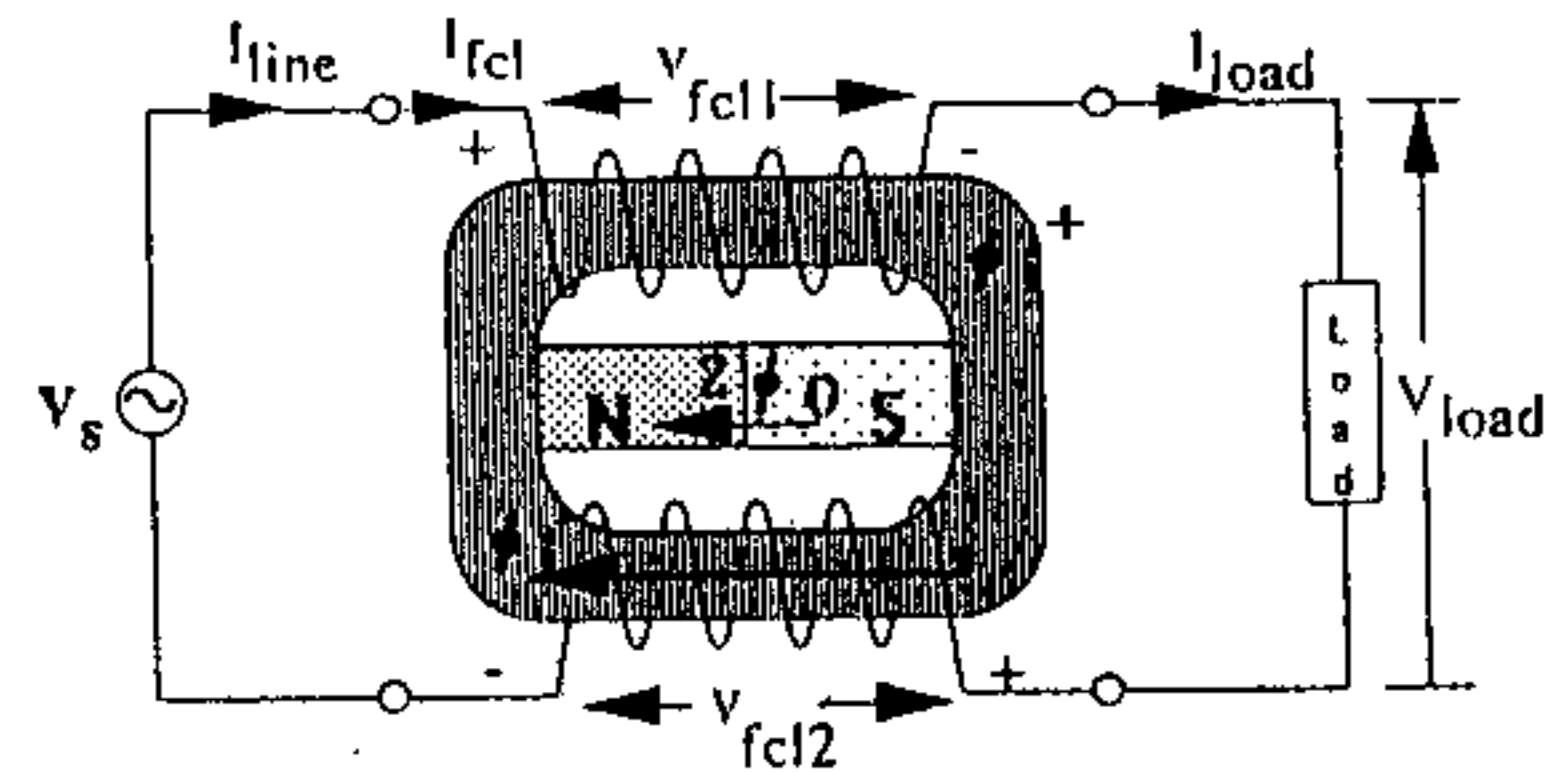


Fig. 4. Circuit for analysis

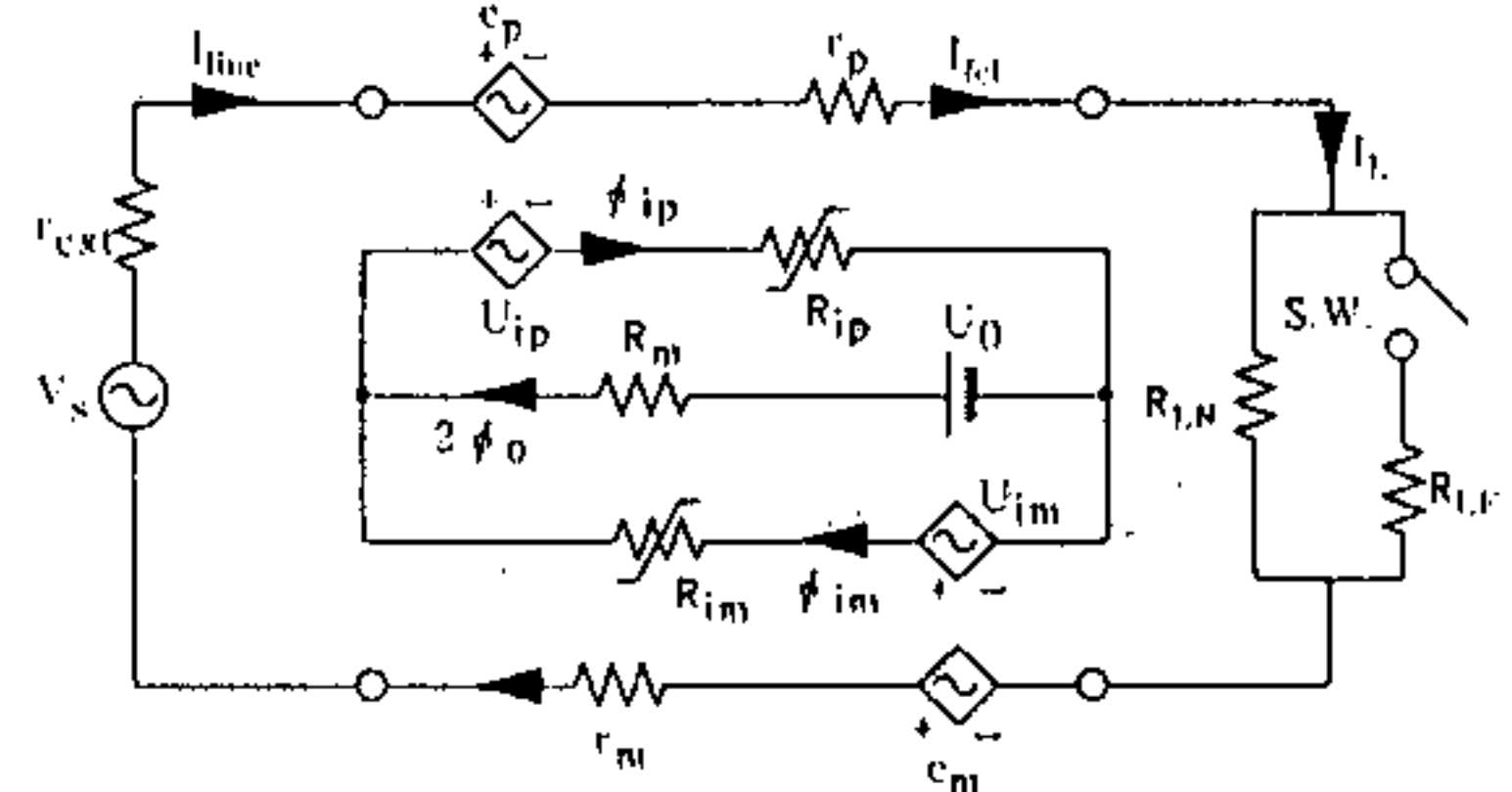


Fig. 5. Electromagnetic equivalent circuit

TABLE I  
PARAMETERS USED IN THE SIMULATION

Dimension of FCL [mm]	a=6.0, b=39.7, c=19.7, d=20.0, e=24.0
Core	$\mu_{ru}=1000, \mu_{rs}=5, B_k=1.8T$
Permanent magnet	$H_c=0.20MA/m, \mu_{ru}=2.3 \times 10^{-6}H/m$
Others	$V_s=20V, 60Hz$ Coil turns $N=100turn$ $R_{LN}=11.0\Omega, R_{LF}=1.7\Omega$

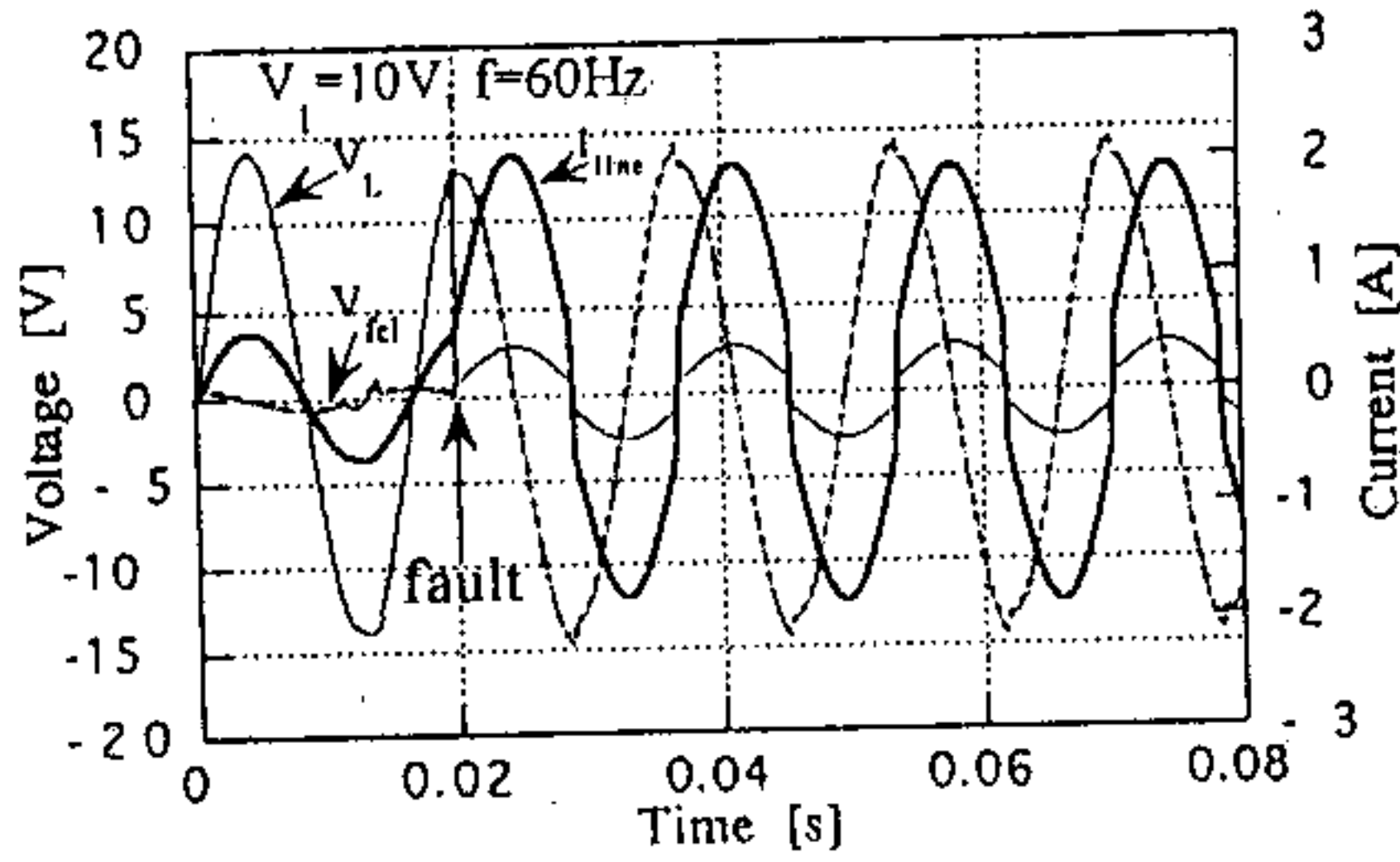


Fig. 6. Simulated waveforms of voltage and current

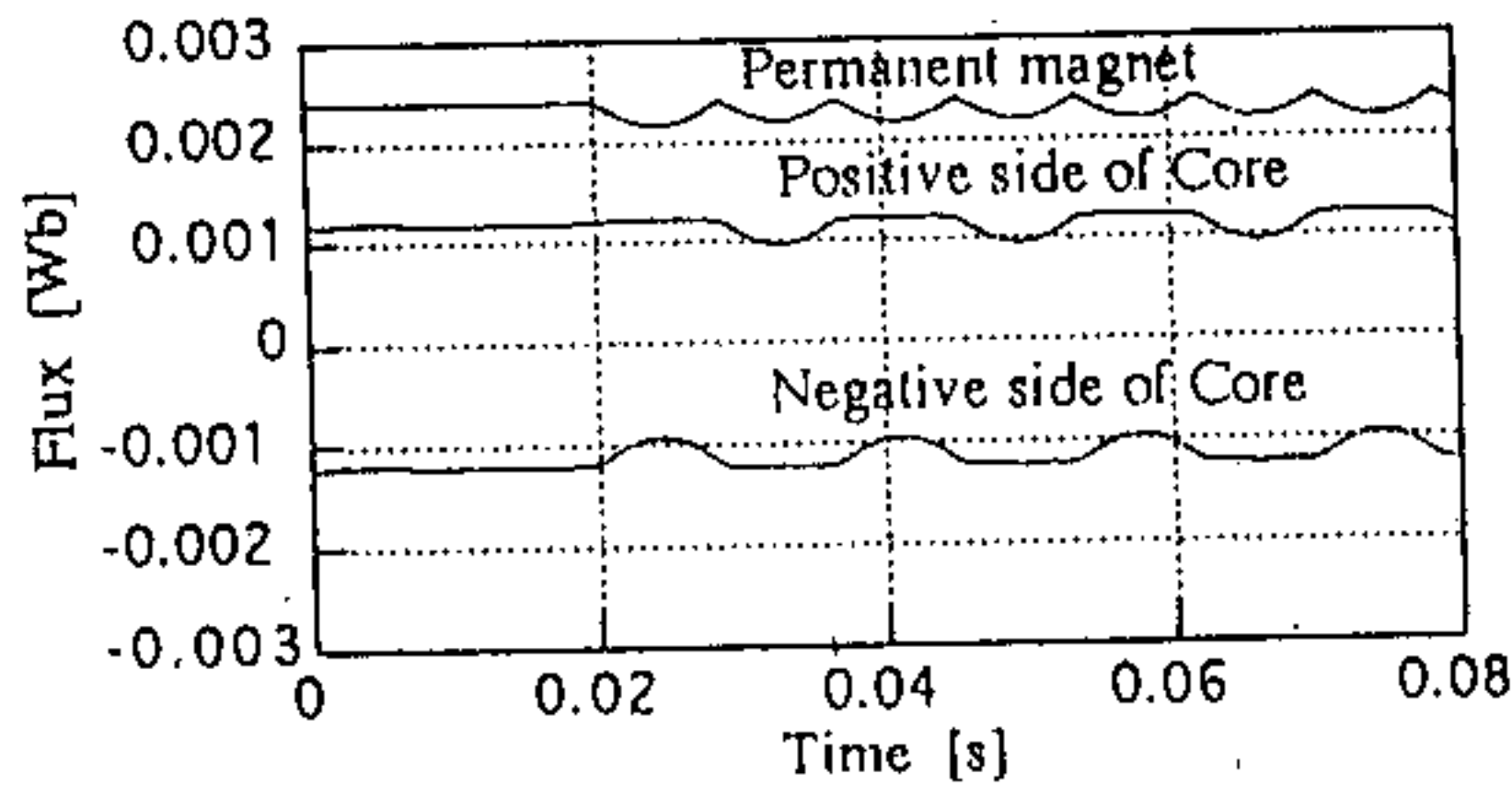


Fig. 7. Variation of fluxes in the core

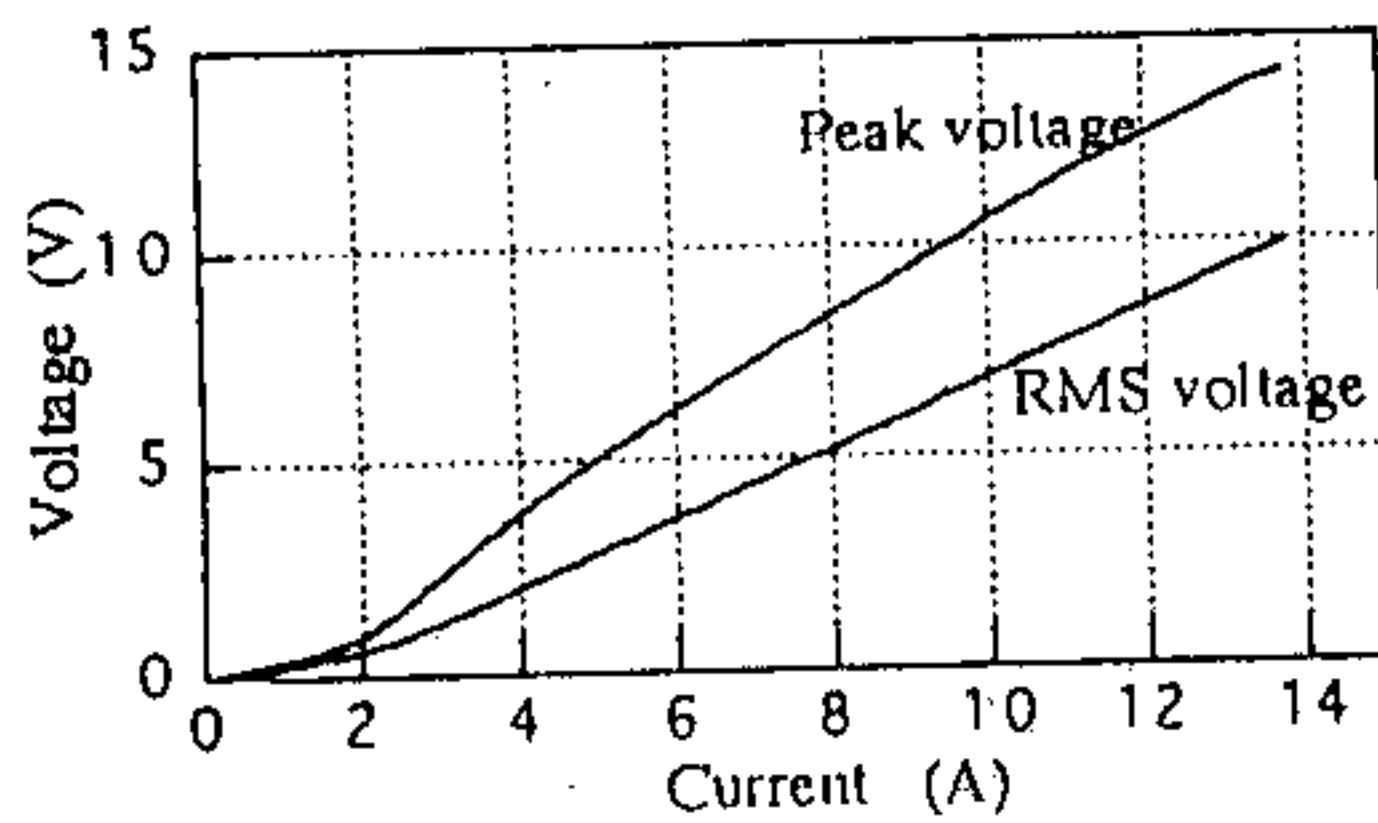


Fig. 8. Voltage-current characteristics

V. EXPERIMENTAL RESULTS

A small scale prototype model has been fabricated in our laboratory and experiments are carried out. The operating conditions are kept same to that of the simulated one. Fig.9 shows the experimental waveforms of the FCL current, voltage across FCL and load voltage. It is seen that the both the simulated and experimental waveforms are in close agreement to each other. Fig. 10 shows the variation of the voltage across FCL, current with and without FCL as a function of load resistance. It is seen that the presence of FCL in the circuit limited the current to a appreciably low value. Fig.11 shows the picture of a small scale fabricated laboratory model.

VI. CONCLUSIONS

In this paper we have investigated the development of magnetic current limiter in parallel biasing mode. It has been shown with the help of simulation and experimental results that this

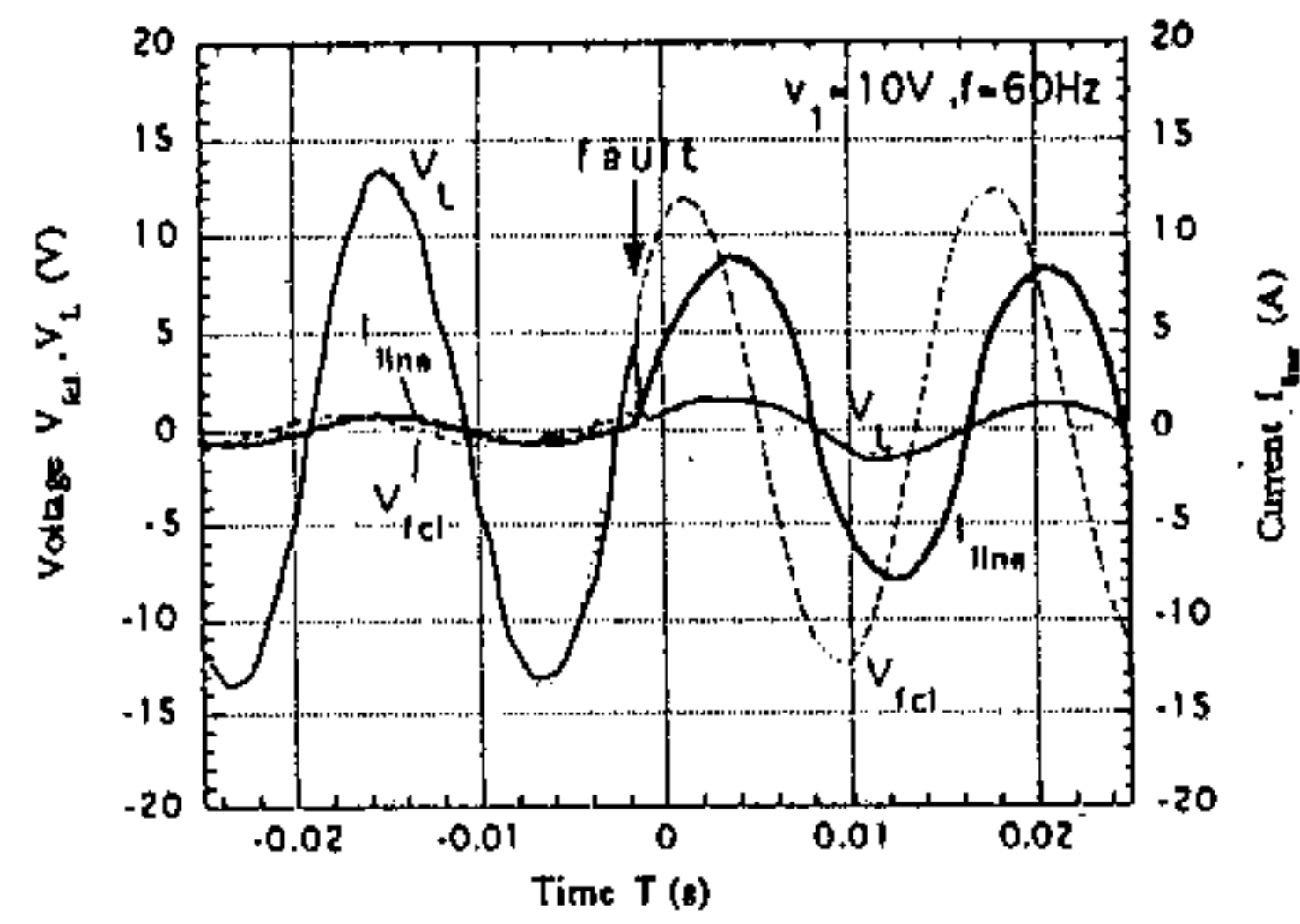


Fig. 9. Typical experimental waveforms of voltage and current

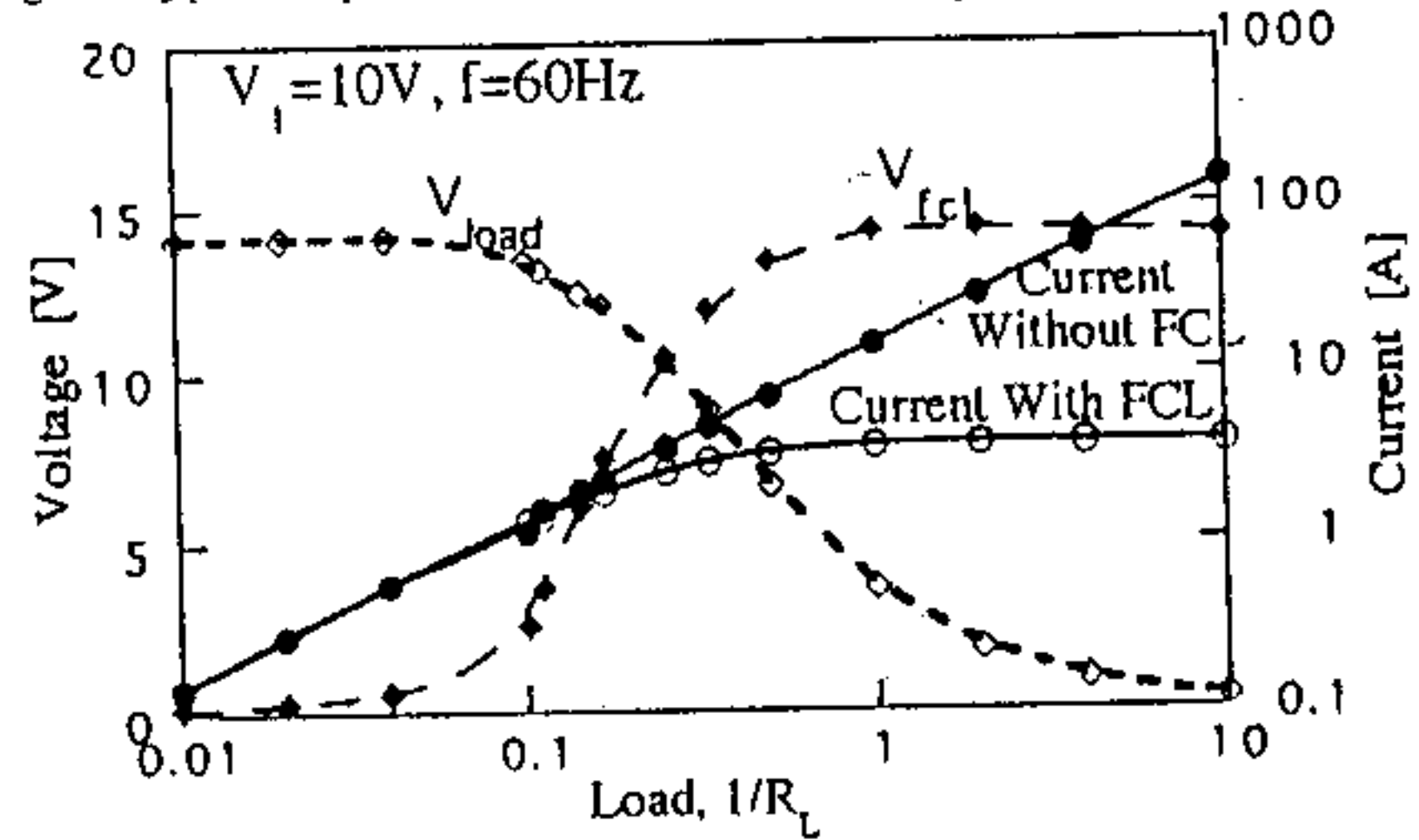


Fig. 10. FCL characteristics

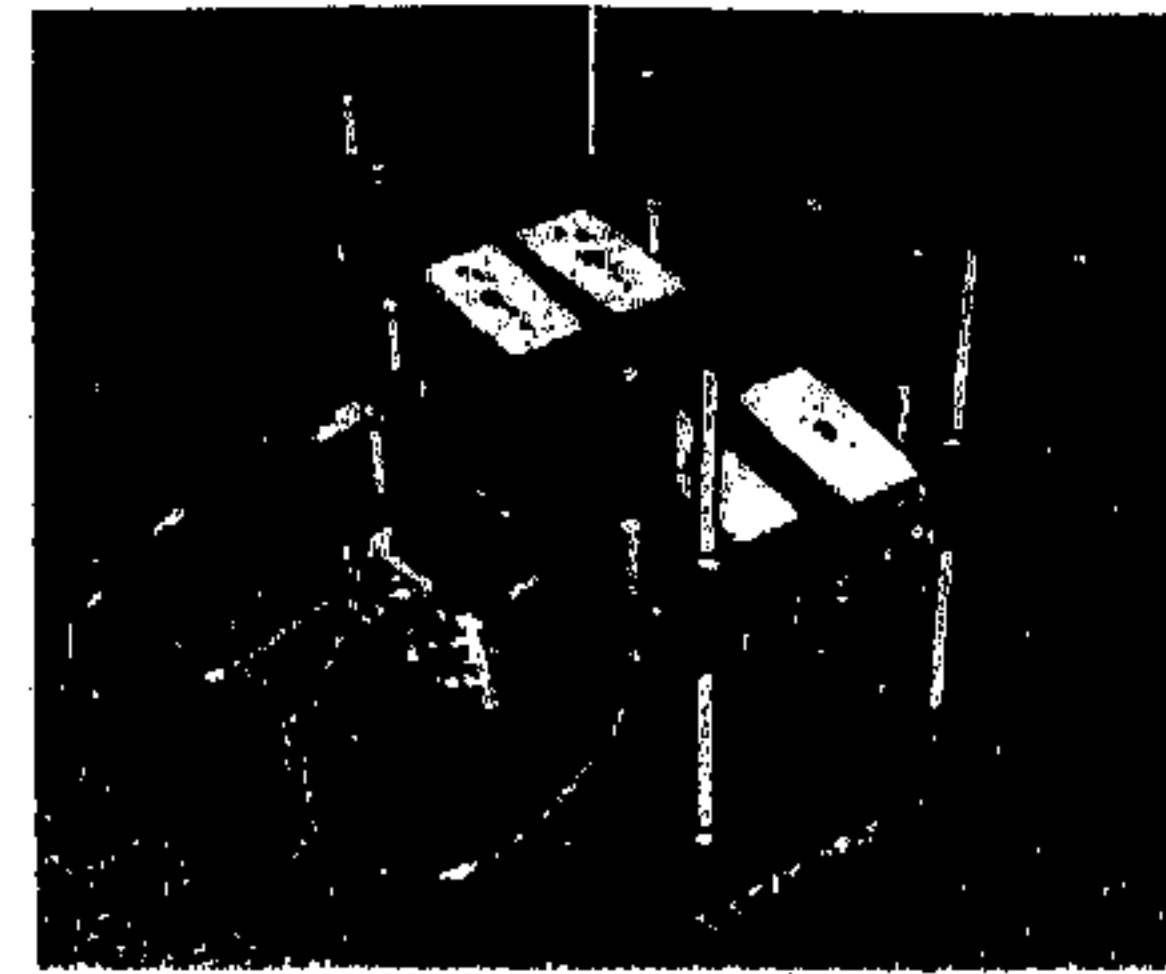


Fig. 11. Picture of the fabricated laboratory model.

device has the potential to be used as a fault current limiter in practical application. The advantage of this type of structure over series biasing mode is that the demagnetization of the permanent magnet is not so severe, consequently the performances in successive operation will be better and the longevity will be more compared to that of earlier model.

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