

### 1.1. A GENERAL DISCUSSION OF SHORT-CIRCUIT CURRENTS IN SYNCHRONOUS GENERATORS

When a synchronous generator, fully excited and running at synchronous speed, is suddenly short-circuited at the armature terminals, it undergoes a period of disturbance during which the armature currents attain high values. The peak currents that occur immediately after short-circuit have values - dependent on the machine design - between 2 to 20 times rated current. It is necessary to predetermine accurately these peak currents, since they give rise to mechanical stresses - in the machine windings - that are proportional to the square of the current. A method of analysis, which permits a designer to vary the machine proportions with facility, to achieve an acceptable peak current, is therefore desirable.

Subsequent to the instant of short-circuit, there is a period during which the peak currents decay to their steady-state a.c. short-circuit values. This period contains two distinct intervals, the first of which is characterised by a relatively sharp decay in the currents, and this is called the sub-transient period. The second interval is associated with a relatively slow exponential decay of the currents, and this is referred to as the transient period. Accurate knowledge of the current values during the sub-transient and transient periods, is required by the designer of protective equipment, who has to ensure that a given load-fault current can be cleared, while maintaining the supply as long as possible.

The short-circuit analysis given in the present work is concerned

with a single-phase alternator, since this is the most general case and is easily adapted to give the performance of a polyphase machine. Previous analytical methods of treating the single-phase alternator, Ref. 1, 2 and 3, have also indicated that this is the most difficult case to solve.

The method presented in the present analysis involves a step-by-step analysis of the short-circuit period, and therefore is based on a computational analysis using a digital computer. The theory involved is relatively straightforward requiring only a knowledge of the calculation of self and mutual inductances for the coils in the machine. Linear conditions for the magnetic circuit are assumed, in order that superposition theorem for the separate fluxes of each coil, may be employed.

The analysis, however, leads to a large set of simultaneous differential equations to be solved, and with the limited capacity of the available computer (an IBM 1620), special methods had to be devised for processing the calculations. A particular feature of this work has been the adoption of a "shifting" technique for the elements in the matrix equations. This was made possible by using an incremental time  $\Delta t$ , (for the step-by-step method), corresponding to the rotation of the rotor through one slot-pitch of the a.c. winding. In addition it has been shown that, because coils in a machine are connected in a specific way, the large set of simultaneous equations can be reduced to  $n$  simultaneous equations, where  $n$  is the number of separate windings in the machine.

Owing to shortage of time the damper windings of the experimental machine were not included in the present analysis, and some discrepancy between analytical and test results are therefore expected and remarked upon. However, the method developed here can be simply carried over to any number of separate windings in the machine. The purpose here has been to develop the necessary technique, while maintaining clarity of description.

The object, therefore, has been to show that a programme can be produced which requires only design data, e.g. machine dimensions, number of winding turns, etc., in order to obtain a complete short-circuit performance of a synchronous generator.

## 1.2 A SIMPLIFIED TREATMENT OF SHORT-CIRCUIT CURRENTS IN SYNCHRONOUS GENERATORS

The behaviour of the short-circuit currents can be explained with the aid of the theorem of constant flux linkages. This theorem states that the flux linking a circuit will remain constant during a disturbance (e.g. a short-circuit), if the circuit resistance is negligible.

When the armature terminals of an alternator are short-circuited, the armature induced voltage will begin to collapse as the mutual flux is forced into the leakage paths under the demagnetising action of the rising armature m.m.f. The decaying mutual flux linking the field and damper windings will cause induced currents to flow in these windings in such a direction that the resulting m.m.f.'s will tend to maintain the