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(54) DYNAMOELECTRIC MACHINES

(71) We, SUNDSTRAND CORPORATION, a corporation organised and existing under the laws of Delaware, United States of America, of 4751 Harrison Avenue, Rockford, Illinois 61101, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement.—

The invention relates to synchronous generators, and provides in such machines circuitry for reducing the effect of transient voltages and currents in the main field windings and rectifiers thereof.

In a synchronous generator having a main field winding, an exciter armature winding and a rectifier for supplying the main field winding with a DC current all located on the rotor, the relatively long transient recovery time for the field current when the load is removed from the main armature has posed a very significant problem. In addition, the necessity for protecting the rectifier and associated motor components from the relatively high voltages generated in the main field winding during inductive start-up has similarly posed a very significant problem. Normally, when the machine is running a voltage regulator adjusts the current through the exciter field winding so as to provide the desired output voltages. Specifically, the exciter field current results in the generation in the exciter armature windings of a current which is rectified by the rectifier and applied to the main field winding to generate the desired generator output voltage. However, when the generator load is removed from the main armature, a portion of the main field current continues to flow for an appreciable amount of time due to the high inductance of the main field winding and the low resistance of the rectifier diodes. Thus, the generator output voltage transient on load removal tends to be relatively high in amplitude and long in duration.

The invention provides a synchronous generator having one or more main armature

windings, a main field winding, one or more exciter armature windings, a rectifier for providing a rectified DC main field current through the main field winding from the one or more exciter armature windings, a resistive circuit including a load resistor operatively connected between the main field winding and the rectifier in series or in parallel with the main field winding, and switch means comprising a transistor which is connected to carry the main field current during normal generator operation and is responsive to the excitation voltage for directing or diverting current flowing in the forward direction through the main field winding through the resistive circuit when the excitation voltage generated in the exciter armature is below a predetermined value. In a generator according to the invention the exciter armature winding or windings, the rectifier and the main field winding are advantageously all located on the rotor, with the load resistor connected across the main field winding and the transistor of the switch means responsive to the excitation voltage for effectively disconnecting the main field winding from the rectifier, thereby causing the main field current to flow through the load resistor during generator load removal and induction motor start-up.

A synchronous generator according to the invention alternatively may have its exciter armature winding or windings, rectifier and main field winding located on the rotor, with the load resistor connected in series between the main field winding and the rectifier, and the transistor of the switch means effective to permit the main field current to flow around the load resistor at or above the predetermined excitation voltage. Such a generator advantageously also has a transistor controlled by-pass circuit around the rectifier, responsive to an induced alternating voltage in the main field coil, for permitting an induced main field current, flowing in a direction opposite to the direction of rectifier conduction, to by-pass the rectifier.

Because it eliminates the need for brushes and sliprings the synchronous generator,

having the main armature windings located on the stator with the main field winding located on the rotor along with the exciter armature windings and a rectifier to provide the main field DC current, has found a wide variety of applications such as generators for aircraft. Typically, the output voltage of such a synchronous generator is controlled or governed by the application of a current through the exciter field winding. The exciter field winding, normally located on the stator, induces an alternating voltage and current in the exciter armature windings rotating on the rotor. The alternating current is rectified usually by a bridge rectifier composed of semi-conductor diodes, into a direct current for use in the main field winding. The rotating magnetic field, produced by the direct current flowing through the rotating main field winding, generates the voltage output in the main armature windings and hence the power output of the generator. Usually, the voltage output of the synchronous generator is controlled by a voltage regulator which monitors the voltage output of the main armature winding and adjusts the exciter field current accordingly.

Normally, as the load is removed from a synchronous generator, the output voltage of the generator increases and the voltage regulator reduces exciter field current to zero or a very low level. Even with the complete termination of current in the exciter field winding, a certain proportion of the main field current will continue to flow due to the high inductance of the main field winding. The continuation of this transient field current results in significant difficulties in maintaining the voltage and power output of the synchronous generator within desired limits.

The first approach to solving the problem of transient currents in the main field winding and rectifier includes the insertion of a load resistor in parallel with the main field winding. A transistor is connected between the main field winding and the rectifier and is responsive to voltage generated in the exciter armature winding. When the exciter field current is shut off, for example, when the load has been removed from the generator the transistor acts to direct the main field current through the load resistance. The value of the resistance is selected so as quickly to attenuate the field current when the load has been removed from the generator and to provide a load for the main field winding.

A second approach involves inserting a load resistor between the main field winding and the rectifier along with a by-pass circuit controlled by a transistor. The load transistor is also responsive to the exciter voltage so as to provide a relatively low resistance current path during normal generator or motor operation. When the load is removed from

the generator, the exciter voltage causes the by-pass transistor circuit to be disconnected, which in turn causes the field current to flow through both the load resistor and the rectifier. In addition, circuitry is provided to cause any current induced in the main field winding to flow through the load resistor and the rectifier when the induced current is compatible in direction with the rectifier and to by-pass the rectifier when the induced current is not compatible with the direction of the rectifier. In this manner, a load is provided for the main field current and there is eliminated the destabilizing effects of the rectifier on the alternating current induced in the main field winding. (i.e. the large voltages and currents that may be generated in the exciter circuit of a synchronous generator when it is being driven as a motor).

The invention is hereinafter particularly described, by way of example only, with reference to the drawings of which:

Figure 1 is a schematic diagram of a synchronous generator having its exciter armature, rectifier and main field mounted on the rotor but not showing the main field current control circuit;

Figure 2 is a schematic diagram of the main field winding and rectifier circuit of Figure 1 including a first main field current control circuit; and

Figure 3 is a schematic diagram of the main field and rectifier circuit of Figure 1 including a second main field current control circuit.

A typical synchronous dynamoelectric generator is illustrated in the schematic diagram of Figure 1. In this particular type of brushless, synchronous generator the exciter field winding 10 is located on the generator's stator. The exciter armature windings 12 are located on the rotor and as such, rotate through the flux field generated by the exciter field winding 10. Alternating current, generated in the exciter armature windings 12, is rectified by the bridge rectifier composed of the semi-conductor diodes 14. The rectified DC current, represented by I_f , flows through the field winding 16 and is referred to as the main field current. The rotating flux produced by the main field winding 16 induces alternating voltages in the main armature windings 18, which are located on the stator. Normally, the output of the main armature will be a three-phase voltage. As is well-known in the art, the voltage output of the synchronous generator is controlled by a voltage regulator 20 which measures the voltage output of each phase of the main armature 18 and adjusts the current applied to the exciter field winding 10 in order to maintain the desired voltage output of the generator.

A circuit illustrating a first main field current control circuit is presented in Figure 130

2. Added to the rectifier semi-conductor diodes 14 and the main field winding 16 of the circuit of Figure 1 are resistors 22 and 24 and an NPN transistor 26. During normal generator operation, when an excitation current is being applied to the exciter field, the rectifiers will apply a positive voltage V_1 across lines 28 and 30. In addition to causing the field current I_f to flow through the main field winding 16 and the diode 32, the positive voltage V_1 will apply a positive voltage across the base and emitter terminals of transistor 26, thereby placing transistor 26 in a conducting state. Since, at this point, the transistor 26 is in a conducting state with relatively little internal resistance, the majority of the field current I_f will flow through the main field winding 16 with very little flowing through the load resistor 24. However, when the load is removed from the main armature windings 18 of Figure 1, the increased voltage output of the main armature windings 18 will cause the voltage regulator to decrease or completely stop the current flow through the exciter field 10. This will result in the elimination of the positive voltage V_1 and the reversal of voltage V_2 , due to discharge of the main-field, thereby having the effect of shutting off the transistor 26. The resultant main field current I_f which continues to flow through the main field winding 16 due to its inductance will, of necessity, flow through the load resistor 24 where it is rapidly attenuated. Therefore, by selecting an appropriate value of the load resistor 24, the duration of the transient current and voltage produced by the inductive nature of the main field winding 16 can be greatly reduced. It should be noted that the resistor 24 can be replaced with other types of voltage producing or current attenuating devices such as gas discharge tubes or zener diodes.

In the case where the machine represented in Figure 2 is being operated as a motor, the resistor 24 will provide a load resistance for the current induced in the main field windings 16 by the polyphase AC current applied to the main armature winding 18. When the motor is in the start-up phase of operation, current is not normally applied to the exciter field winding 10 and as a result, there is no positive voltage V_1 so that the transistor 26 is off, thereby forcing all of the induced current through the resistor 24. In addition, a diode 32, inserted between the main field winding 16 and the base of the transistor 26, prevents the positive voltage induced in the main field winding 16 from switching the transistor 26 into a conducting state.

A second main field control circuit is illustrated in Figure 3, in which a resistor 34 is connected to the base of an NPN transistor 36 acting as a first transistor circuit, and serves to switch the transistor 36 into a conducting state when the excitation voltage V_1 is positive.

The transistor 36 is operatively connected in parallel with a load resistor 40. During normal generator operation the positive voltage V_1 results in the transistor 36 being in a conducting state, thus permitting the main field current I_f to flow through a diode 38 and bypassing the load resistor 40. As in the previous case when the load is removed from the main armature windings 18, the positive voltage V_1 will be removed and V_2 will reverse, thus shutting off the transistor 36, resulting in the flow of the induced field current I_f through the load resistor 40 and the rectifier diodes 14. Since the induced main field current I_f is forced to flow through the load resistor 40, it will be rapidly attenuated, depending upon value of the resistor.

During start-up in the motor phase of operation, the application of a polyphase AC voltage to the main armature windings 18 induces alternating voltages in the main field winding 16. Again, the positive voltage V_1 produced by the rectifier diodes 14 will not be present during the start-up phase of operation. When a positive voltage V_2 is induced at the main field winding 16, current will flow through the resistor 34 and through the base-emitter junction of the transistor 36. A portion of the current will also flow through a resistor 46 to the base of an NPN transistor 48, acting as a second transistor circuit. This has the effect of switching the transistor 48 from a first, non-conducting state to a second, conducting, state. A diode 49 serves to protect the emitter-base junction of the transistor 48 during generator load removal. Since at this point the transistor 48 is in its second conducting, state, the combination of the positive voltage on terminal 42 with the conducting state of transistor 48 will cause a PNP transistor 50, responding to a current through a resistor 52, to be switched on. The resultant current through the emitter-collector junction of the transistor 50 and resistor 54 will serve to switch on the NPN transistor 56. The transistors 50 and 56 form a transistor network in parallel with the rectifier circuit and responsive to the second state of the transistor 48. The net result of an induced positive voltage on terminal 42 of the main field winding 16 and the second, conductive, state of the transistor 48 will be to cause the induced main field current I_f to flow through the transistor 56 and the load resistor 40, thereby having the dual effect of providing the main field with a load resistance and bypassing the rectifier circuit represented by the diodes 14. When the machine is operating as a motor, the main field winding 16 becomes a voltage source and a positive induced voltage on the terminal 42 induces the main field current I_f to flow in a direction opposite to the normal direction of flow and opposite to the direction of rectifier 14 conduction, and the activation of the by-pass circuit including

the transistor 56 eliminates the half-wave rectification effect on the alternating current I_f induced during motor start-up. When the induced voltages on the main field winding 16 reverses to provide a positive voltage on terminal 44, the induced field current will flow through the load resistor 40 and the rectifier diodes 14. This is due to the fact that the negative voltage on terminal 42 will serve to keep transistor 36 off, or in a non-conducting state, thereby resulting in a single current path through resistor 40 and the rectifier diodes 14.

To summarize the operation in the motor-ing mode of the circuit illustrated in Figure 3: when a positive voltage is induced on terminal 42 of the main field winding 16 the induced main field current I_f by-passes the rectifier diodes 14 by flowing through transistor 56 and through the load resistor 40. By the same token, when a positive voltage is induced on terminal 44, the current I_f will flow through the load resistor 40 and through the rectifier diodes 14. Thus, a load resistance is provided to the main field winding during motor start-up and the deleterious effects of half-wave rectification of the main field current are also avoided.

WHAT WE CLAIM IS:—

1. A synchronous generator having one or more main armature windings, a main field winding, one or more exciter armature windings, a rectifier for providing a rectified DC main field current through the main field winding from the one or more exciter armature windings, a resistive circuit including a load resistor operatively connected between the main field winding and the rectifier in series or in parallel with the main field winding, and switch means comprising a transistor which is connected to carry the main field current during normal generator operation and is responsive to the excitation voltage for directing or diverting current flowing in the forward direction through the main field winding through the resistive circuit when the excitation voltage generated in the exciter armature is below a predetermined value.

2. A generator according to claim 1, wherein the load resistor of the resistive circuit is connected in parallel with the main field winding, and the transistor of the switch means is in series between the main field winding and the rectifier.

3. A generator according to claim 2, further comprising one or more diodes operatively connected between the main field winding and a base of the transistor for preventing an induced voltage in the main field winding from placing the transistor in a conductive state.

4. A generator according to claim 1, wherein the load resistor of the resistive circuit is connected in series between the main field winding and the rectifier, and the transistor of the switch means is connected in parallel with the load resistor for by-passing the load resistor during normal generator operation.

5. A generator according to claim 4, further comprising a by-pass transistor circuit, responsive to an induced voltage in the main field winding, for permitting an induced main field current, flowing in a direction opposite to the direction of rectifier conduction, to by-pass the rectifier.

6. A generator according to claim 5, further comprising a second transistor circuit for triggering the by-pass transistor circuit, the second transistor circuit being operatively connected to the load resistor and being effective to switch from a first state to a second state when an induced voltage in the main field winding tends to cause the main field current to flow in a direction opposite to the direction of rectifier conduction, and the by-pass transistor circuit is a transistor network operatively connected in parallel with the rectifier and responsive to the second state of the second transistor circuit to provide a current by-pass path around the rectifier.

7. A generator according to any preceding claim, having the one or more main armature windings and the exciter field winding secured to a stator, and the main field winding and the one or more exciter armature windings secured to a rotor.

8. A synchronous electrical generator substantially as particularly described herein with reference to Figures 1 and 2 of the drawings.

9. A synchronous electrical generator substantially as particularly described herein with reference to Figures 1 and 3 of the drawings.

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2. A generator according to claim 1, wherein the load resistor of the resistive circuit is connected in parallel with the main field winding, and the transistor of the switch means is in series between the main field winding and the rectifier.

3. A generator according to claim 2 further comprising one or more diodes operatively connected between the main field winding and a base of the transistor for preventing an induced voltage in the main field winding from placing the transistor in a conductive state.

4. A generator according to claim 1, wherein the load resistor of the resistive circuit is connected in series between the main field winding and the rectifier, and the transistor of the switch means is connected in parallel with the load resistor for by-passing the load resistor during normal generator operation.

5. A generator according to claim 4, further comprising a by-pass transistor circuit, responsive to an induced voltage in the main field winding, for permitting an induced main field current, flowing in a direction opposite to the direction of rectifier conduction, to by-pass the rectifier.

6. A generator according to claim 5, further comprising a second transistor circuit for triggering the by-pass transistor circuit, the second transistor circuit being operatively connected to the load resistor and being effective to switch from a first state to a second state when an induced voltage in the main field winding tends to cause the main field current to flow in a direction opposite to the direction of rectifier conduction, and the by-pass transistor circuit is a transistor network operatively connected in parallel with the rectifier and responsive to the second state of the second transistor circuit to provide a current by-pass path around the rectifier.

7. A generator according to any preceding claim, having the one or more main armature windings and the exciter field winding secured to a stator, and the main field winding and the one or more exciter armature windings secured to a rotor.

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