

PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO A METHOD OF STARTING GENERATOR SYSTEMS

(71) We, TAKAO KAWABE and KAZUO KAWABE, both of Japanese nationality, and both of 41-5, Higashiogu 2 chome, Arakawa-ku, Tokyo, Japan, 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:-

This invention relates to improvements in or relating to a method of starting engine or motor generator systems, more particularly systems including an alternating current generator (AC generator) as a power supply and an AC load having lagging power factor, i.e. a power factor which produces a lag in the phase of the power consumed by the load.

It is well known that in an engine or motor generator system using a synchronous generator, the voltage drop at the generator's terminals is small when the load is resistive such as a lamp or a heater, or one with a power factor of 1, whereas when load is, for example an induction motor or an AC arc welder, or other load which has a lagging power factor, the voltage drop is significant, and a particularly abrupt voltage drop occurs when the load is connected to the generator.

It is customary to use an automatic voltage regulator to control the voltage drop due to load fluctuation, but such a regulator cannot counteract fully the abrupt, initial voltage drop.

In general, a sole countermeasure to this problem is the use of a generator with a capacity corresponding to the voltage drop at the start, which leads to expansion in the size of the system and increased cost.

For instance, in a system in which the load is a three-phase induction motor, when the motor starts at full voltage, a current of not less than six times the rated motor capacity flows, so that the generator needs a rated capacity of not less than six times the rated motor capacity. Otherwise, the terminal voltage falls to not more than 70% of the rated value, resulting in extremely difficult

control of other units in the system, for example, electromagnetic switches.

If a starting compensator, or the like is used the terminal voltage drops increasingly. For example, when the starting compensator is used at 65% tap, the terminal voltage "Et" drops down to 0.455 Et (= Et x P.7 x 0.65). As a result, the starting torque is much reduced since induction motor torque is proportional to the square of the applied voltage, so that the application of the motor is strictly limited.

According to the present invention there is provided a method of starting a generator system comprising an engine or motor, an AC generator coupled to be driven by said engine or motor, a voltage regulator for said generator and a primary load connected to be energised by said generator which method comprises saturating the magnetic circuit of said generator prior to energisation of said primary load so as to reduce the terminal voltage drop at the output of said AC generator at the moment that said primary load is energised by said generator and accordingly also to reduce drop of the voltage supplied initially to the primary load.

The AC generator may be a synchronous generator, and the voltage regulator may be manual or automatic. Any type of voltage regulator that delivers field current to the generator to increase the electromotive force when the terminal voltage drops owing to a load is applicable. For this purpose, voltage regulators employing in an amplifying generator, magnetic amplifier or thyristor are well known among engineers in the concerned field.

To saturate the magnetic circuit of the generator a temporary load, may be initially connected to the generator, to cause a drop of terminal voltage in a manner similar to the primary load, and may be, for example a reactor, resistance or semi-conductor. In the engine or motor generator system, the

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load is in general an induction motor, so that the temporary load will have a lagging power factor related to that of the motor.

More specifically, the temporary load will have a lagging power factor under 100% or under reduced load, and such factor is determined according to an intended application and required characteristics. In addition, the temporary load may be separated into several parts that are connected in sequence to obtain the required value.

Switching may be made by various switches of the prior art, but there should be slight overlap between the energisation of the primary load and of temporary load, that is, the primary load and temporary load are switched in such a manner that both are connected to the generator during an overlap period lasting from one-half to a few cycles of the AC frequency or from 0.01 to 0.06 second at general commercial frequency.

By using the above method, terminal voltage drop at the start of load energisation can be reduced to a minimum without increasing the output capacity of the generator, as will be described with reference to Figures 1 and 2 of the accompanying drawings, wherein:—

Figure 1 is a graph showing the general characteristics of a generator when it directly starts a load, and

Figure 2 is a graph showing the general characteristics of a generator when it starts a load in accordance with a starting method of the present invention.

If the surge current is six times the rated current on starting the induction motor, the starting capacity of an AC generator at the same time is:

at full voltage starting of the induction motor; $6M_p$, and at reduced voltage starting of the induction motor using a starting compensator with 65% tap setting;

$$6M_p \times 0.65^2 = 2.54 M_p$$

where, M_p = Induction motor output

G_p = AC generator capacity

Therefore, when the AC generator capacity is 2.5 times Induction motor capacity using the starting compensator with 65% setting, the starting capacity ratio is:

$$\text{Starting capacity ratio} = \frac{2.54M_p}{G_p} = \frac{2.54M_p}{2.5M_p} \div 1 (= 100\%)$$

When the AC generator capacitor is 2.0 times induction motor capacity,

Starting capacity ratio =

$$\frac{2.54M_p}{2M_p} \div 1.3 (130\%)$$

And, when the AC generator capacity is 1.5 times induction motor capacity,

$$\text{Starting capacity ratio} = \frac{2.54M_p}{1.5M_p} \div 1.7 (= 170\%)$$

Figure 1 shows the general characteristic of terminal voltage drop due to surge current to the generator at the start when the load is directly connected to the generator. Figure 1 shows that the terminal voltage drop to approximately 77% in case of surge current corresponding to 50% load of the generator capacity and synchronous reactance drop corresponding to curve "O-A"; and drops down to approximately 65% in case of surge current corresponding to 100% load and starting capacity ratio of 100%.

On the contrary, according to the present invention, when the magnetic circuit of the AC generator is saturated immediately before energisation of the load by the AC generator, the characteristics of terminal voltage and surge current load are illustrated as Figure 2. More specifically, when the temporary load is previously connected to the AC generator via any of reactor, resistance, semi-conductor, etc., curves shown in Figure 2 can be obtained. For instance, under 50% load of the AC generator capacity operation is made at the rated voltage point "O" on 50% load curve as shown in Figure 2. Under this condition, if the 50% load is released, voltage instantly rises up to a point "A", thus arriving at no-load curve.

In other words, at the same rated voltage, magnetic saturation degree under the 50% load is higher than that on no-load curve. Furthermore, when loaded with 100% load (starting capacity ratio of 100%) under the same condition, synchronous reactance corresponding to a line "B-C" rises from a point "A" on the 50% load curve as shown in Figure 2, while the terminal voltage drops along a line "O'-" corresponding to a line "B-C", stopping the drop at 86%.

Similarly, at 130% load start, the terminal voltage is reduced to approximately 80% of it, and at 170% load start, the terminal voltage to approximately 78% of it. When compared with Figure 1, it will be clearly understood that the drop in terminal voltage is remarkably reduced.

The following is a comparison table between Figure 1 and Figure 2.

	AC Generator Capacity	Starting Capacity Ratio	Terminal Voltage
Figure 1	$G_p = 2.5 M_p$	100%	65%
Figure 2 (Present Invention)	$G_p = 2.5 M_p$	100%	86%
	$G_p = 2 M_p$	130%	80%
	$G_p = 1.5 M_p$	170%	78%
where, G_p = AC generator output (KVA)		M_p = Induction motor output (KW)	

$$\text{Starting capacity ratio} = \frac{\text{Induction motor starting capacity}}{\text{AC generator capacity}} \times 100$$

The above comparison is made when the starting compensator with 65% tap setting is in use. In the above description, only the application of the temporary load of 50% is explained with reference to Figure 2, but the temporary load of 75% or 100% may be applied: in this case, drop of the synchronous reactance of the AC generator can be further reduced when starting the induction motor, thus raising the terminal voltage of the AC generator. Moreover, in case of the temporary load such as 100%, it can be stepwise increased, for example 30% and 70%, to reduce the fluctuation of the terminal voltage under load.

As described earlier, using a method according to the present invention, the terminal voltage of the AC generator can become approximately 80% when the induction motor is started using the starting compensator at the generator capacity (Gp) of approximately 2 Mp, while according to the starting method of the prior art, the terminal voltage becomes 65% at even Gp of 2.5Mp. As a result, the terminal voltage ratio becomes $80\%/65\% = 123\%$, and the capacity ratio becomes $2\text{Mp}/2.5\text{Mp} = 80\%$, which make it possible to reduce the AC generator size by 20%, retaining the above-mentioned outstanding characteristics.

Less drop in the terminal voltage mentioned above means less influence to lamp and other electrical units which are power-supplied by the same AC generator, ensuring stability of the AC generator power supply.

The starting method of the prior art induces not only the synchronous reactance drop due to starting surge current at the AC generator but reduction in engine speed due to an abrupt braking effect caused by the surge current, which further promotes terminal voltage drop at the AC generator.

On the other hand, the starting method of the present invention may provide magnetic saturation of the AC generator, increase engine output and reduce speed-down of the engine at the start of the induction motor.

Some embodiments of the invention will now be described by way of example with reference to Figures 3 to 6 of the accompanying drawings in which:

Figure 3 is a wiring diagram illustrating an AC generator system wherein an induction motor is arranged for full voltage starting;

Figure 4 is a wiring diagram illustrating how an induction motor is arranged for reactor starting;

Figure 5 is a wiring diagram illustrating how an induction motor is arranged for compensator starting, and

Figure 6 is a wiring diagram illustrating how an induction motor is arranged for star-delta connection starting.

Figure 3 illustrates an engine generator

system wherein an induction motor is arranged for full-voltage starting. A synchronous generator 11 is of a well known type in the prior art. A shaft of an engine 12 is appropriately connected to a field pole of the generator in such a manner that the field pole rotates with the turning of the engine 12 in order to produce an electro-motive force. Output terminals of the synchronous generator are connected to a breaker 15 through lines 14, and the breaker 15 is further connected to a three-phase induction motor 17 through lines 16.

The breaker 15, consisting mainly of a well known molded case circuit breaker, protects the motor from short-circuit current and overload current.

An automatic voltage regulator 18 is of a well known type in the prior art, and corrects starting force by regulating exciting current at a field winding 13 of the generator in response to the variation of terminal voltage in lines 14.

In this system, batteries 19 are provided in parallel connection with the field winding 13 with a push-button switch 20 in between, and constitute an emergency power supply for use when there is not residual magnetism at the field winding at the start of the generator.

Lines 16 are in parallel connection with lines 21 which are wired to a temporary load 22. Moreover, lines 16 are connected to a switch 23, and lines 21 to a switch 24. Both switches remain open at normal condition. When a contact of the switch 23 closes, the motor is connected to the generator, and when a contact of the switch 24 closes, the temporary load is connected to the generator.

The temporary load comprises a reactor having lagging power related to the power factor at the start of the motor.

In this system, an ammeter 25 and a voltmeter 26 are provided in the lines 14 to monitor the terminal voltage.

In the above arrangement, the armature of the generator 11 starts to rotate at the start of the engine 12.

At this time, if residual magnetism is present in the field winding, the voltage in lines 14 increases. When the voltmeter 26 indicates the rated voltage, the switch 24 is closed, and the temporary load 22 is connected to the generator. The subsequent voltage drop in lines 14 is sensed by the voltage regulator which adjusts the current supplied to the field winding 13 thereby to increase the electro-motive force at the generator.

When the voltage on lines 14 reaches the rated value, the contact of the switch 24 opens and that of the switch 23 closes so that the motor is connected to the generator. At this connection, the temporary load and the motor are switched in such a manner that both are connected simultaneously to

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the generator for an overlap period lasting at least 0.01 to 0.06 seconds or one-half to a few cycles at the AC frequency of the generator. Therefore, start of the motor may be performed with high voltage, and thereafter the load fluctuation is corrected with the automatic voltage regulator similar to the system of the prior art.

Figure 4 to Figure 6 are wiring diagrams which show starting methods of an induction motor using a reactor, a starting compensator and a star-delta connection, respectively, and those parts that are the same as shown in Figure 3 are shown in these figures by like reference numerals.

Figure 4 is a wiring diagram showing the reactor-starting method.

A starter 28 has two reactors 28A and 28B in each line 16, these reactors being in parallel connection in the respective lines 16. A switch 28C, connected in series with the reactor 28B in the branch line, is operated so that only the reactor 28A, or both the reactors 28A and 28B are connected to the lines 16.

The temporary load 22 is a reactor which has power factor corresponding to that of the induction motor at the start. As explained earlier, when the rated voltage is obtained in the generator by means of engine operation, the switch 24 closes to connect the temporary load 22 to the generator. When the rated voltage is obtained again in the lines 16, switches 24 and 23 are switched with the above-mentioned overlap time so that the reactor is connected to the lines 16 in order to start the motor 17. The motor 17, after the required speed being obtained, is fully energised by closing the switch 28C.

Figure 5 is a wiring diagram of an arrangement to be used when the induction motor is to be started using a starting compensator. An autotransformer 29A of the starting compensator 29 is star connected, and has a 65% tap and an 80% tap, the former being connected to the motor. A switch 29B is connected in series with, and a switch 29C in parallel with the autotransformer 29A, respectively. When the switch 29B closes, voltage already reduced by the autotransformer and its relating starting current are delivered to the motor 17. When the switch 29B opens and the switch 29C closes, higher voltage and current are supplied to the motor 17.

In this system, when voltage on the lines 16 reaches the required value after operation of the generator, the switch 24 closes and the temporary load 22 having a lagging power factor corresponding to the power factor at the start of the motor is connected to the generator.

The subsequent voltage drop is corrected by the automatic voltage regulator, and then switch 23 closes and the switch 24 opens with the overlap time mentioned above. At the same time, the switch 29B closes and accordingly the

motor starts. After rotational speed of the motor increases, the switch 29B opens and the switch 29C closes, which puts the motor into its normal running condition.

Figure 6 is a wiring diagram of an arrangement to be used when the induction motor is to be started using the star-delta connection.

In this system, the star-delta switch 31 is provided so that a switch 31B is star-connected to the coil of the induction motor 17 and a switch 31A is delta-connected to the coil.

As mentioned above, after operation of the generator, the switch 24 closes and a temporary load 22, which has a lagging power factor corresponding to the power factor at the start of the motor, is connected to the generator. When the generator voltage is raised again by the operation of the automatic voltage regulator, the switch 24 opens and the contact 31B of the switch 31 closes with the above-mentioned overlap time, thereby to effect reduced voltage start of the motor.

After rotational speed of the motor is increased, the contact 31B opens and the contact 31A closes, which puts the motor into its full voltage operation.

It will be seen that in each of the above-described methods of starting the respective AC generator-motor system, the magnetic circuit of the generator is first saturated by connecting the temporary load to the generator so as to reduce the terminal voltage drop at the moment that the induction motor, or the starter therefor, is thereafter energised.

WHAT WE CLAIM IS:—

1. A method of starting a generator system comprising an engine or motor, an AC generator coupled to be driven by said engine or motor, a voltage regulator for said generator and a primary load connected to be energised by said generator which method comprises saturating the magnetic circuit of said generator prior to energisation of said primary load, so as to reduce the terminal voltage drop at the output of said AC generator at the moment that said primary load is energised by said generator and accordingly also to reduce drop of the voltage supplied initially to the primary load.

2. A method of starting a generator system according to claim 1 wherein to saturate the magnetic circuit of said generator as aforesaid, a temporary load such as a reactor, resistor or semi-conductor is connected to the generator, and thereafter said temporary load is disconnected and replaced by the primary load, such as a motor, when the terminal voltage of said generator is regulated to a predetermined rated voltage.

3. A method of starting a generator system according to claim 1 or claim 2 wherein the primary load to be energised after saturation of said magnetic circuit comprises an induction motor and a starter for said induction motor.

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the generator for an overlap period lasting at least 0.01 to 0.06 seconds or one-half to a few cycles at the AC frequency of the generator. Therefore, start of the motor may be performed with high voltage, and thereafter the load fluctuation is corrected with the automatic voltage regulator similar to the system of the prior art.

Figure 4 to Figure 6 are wiring diagrams which show starting methods of an induction motor using a reactor, a starting compensator and a star-delta connection, respectively, and those parts that are the same as shown in Figure 3 are shown in these figures by like reference numerals.

Figure 4 is a wiring diagram showing the reactor-starting method.

A starter 28 has two reactors 28A and 28B in each line 16, these reactors being in parallel connection in the respective lines 16. A switch 28C, connected in series with the reactor 28B in the branch line, is operated so that only the reactor 28A, or both the reactors 28A and 28B are connected to the lines 16.

The temporary load 22 is a reactor which has power factor corresponding to that of the induction motor at the start. As explained earlier, when the rated voltage is obtained in the generator by means of engine operation, the switch 24 closes to connect the temporary load 22 to the generator. When the rated voltage is obtained again in the lines 16, switches 24 and 23 are switched with the above-mentioned overlap time so that the reactor is connected to the lines 16 in order to start the motor 17. The motor 17, after the required speed being obtained, is fully energised by closing the switch 28C.

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In this system, when voltage on the lines 16 reaches the required value after operation of the generator, the switch 24 closes and the temporary load 22 having a lagging power factor corresponding to the power factor at the start of the motor is connected to the generator.

The subsequent voltage drop is corrected by the automatic voltage regulator, and then switch 23 closes and the switch 24 opens with the overlap time mentioned above. At the same time, the switch 29B closes and accordingly the

motor starts. After rotational speed of the motor increases, the switch 29B opens and the switch 29C closes, which puts the motor into its normal running condition.

Figure 6 is a wiring diagram of an arrangement to be used when the induction motor is to be started using the star-delta connection.

In this system, the star-delta switch 31 is provided so that a switch 31B is star-connected to the coil of the induction motor 17 and a switch 31A is delta-connected to the coil.

As mentioned above, after operation of the generator, the switch 24 closes and a temporary load 22, which has a lagging power factor corresponding to the power factor at the start of the motor, is connected to the generator. When the generator voltage is raised again by the operation of the automatic voltage regulator, the switch 24 opens and the contact 31B of the switch 31 closes with the above-mentioned overlap time, thereby to effect reduced voltage start of the motor.

After rotational speed of the motor is increased, the contact 31B opens and the contact 31A closes, which puts the motor into its full voltage operation.

It will be seen that in each of the above-described methods of starting the respective AC generator-motor system, the magnetic circuit of the generator is first saturated by connecting the temporary load to the generator so as to reduce the terminal voltage drop at the moment that the induction motor, or the starter therefor, is thereafter energised.

WHAT WE CLAIM IS:—

1. A method of starting a generator system comprising an engine or motor, an AC generator coupled to be driven by said engine or motor, a voltage regulator for said generator and a primary load connected to be energised by said generator which method comprises saturating the magnetic circuit of said generator prior to energisation of said primary load, so as to reduce the terminal voltage drop at the output of said AC generator at the moment that said primary load is energised by said generator and accordingly also to reduce drop of the voltage supplied initially to the primary load.

2. A method of starting a generator system according to claim 1 wherein to saturate the magnetic circuit of said generator as aforesaid, a temporary load such as a reactor, resistor or semi-conductor is connected to the generator, and thereafter said temporary load is disconnected and replaced by the primary load, such as a motor, when the terminal voltage of said generator is regulated to a predetermined rated voltage.

3. A method of starting a generator system according to claim 1 or claim 2 wherein the primary load to be energised after saturation of said magnetic circuit comprises an induction motor and a starter for said induction motor.



4. A method of starting a generator system comprising an engine or motor, a synchronous generator coupled to be driven by said engine or motor, a voltage regulator for said synchronous generator coupled to be driven by said engine or motor, a voltage regulator for said synchronous generator, and a primary load which has a delayed phase power factor i.e. which has a power factor such that when initially energised by the generator the phase of the power consumed thereby lags behind that of the generator output which method comprises, prior to the energisation of said primary load, saturating the magnetic circuit of said generator by connecting a temporary load also having a delayed phase power factor and thereafter disconnecting the temporary load and replacing it by the primary load when terminal voltage of said generator is regulated to a predetermined rated voltage in a such a

way that for a limited overlap period both the temporary load and the primary load are connected to the generator.

5. A method of starting a generator system according to Claim 4, wherein the length of the overlap period corresponds to at least one-half cycle at the AC frequency of the generator.

6. A method of starting a generator system according to Claim 5, wherein the temporary load is a reactor.

7. A method of starting a generator substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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