OPERATION OF A SWITCHED RELUCTANCE MOTOR FROM A SINGLE-PHASE AC SUPPLY

BACKGROUND OF THE INVENTION

A conventional switched reluctance motor is disclosed in, for example, GB 2231214A. This switched reluctance motor includes a housing; a stator fixed in an inner bore of the housing and formed by laminating of electromagnetic steel plates and a rotor disposed in the stator and formed by laminating of electromagnetic steel plates. The stator has a plurality of pairs of opposing stator pole portions which project inwardly in the radial direction and which extend in the axial direction and the rotor has a plurality of pairs of rotor pole portions which project outwardly in the radial direction and which extend in the axial direction. The rotor is fixed to an output shaft, which is rotatably supported on side portions of the housing through bearings and thereby is rotatably disposed in the stator. As the rotor rotates, each of the rotor pole portions moves in and out of the alignment with each of the stator pole portions but a certain clearance is always maintained between the stator pole portions and the rotor pole portions. On each of the stator pole portions, a coil is wound such that the coils which are wound on each of the pairs of opposing stator pole portions are connected in series with each other and thereby a magnetic flux is generated between each pair of stator pole portions when a current is supplied to the coils and as a result a magnetic attractive force occurs between the rotor pole portions and stator pole portions as they approach one another. This magnetic attractive force is controlled by controlling the switching of a current on and off supplied from a DC battery as a pulse through switching elements such as transistors or forced commutated thyristors in response to the rotational position of the rotor. In general, when a pair of rotor pole portions approaches alignment with a pair of stator pole portions, the current in the coil wound on this pair of stator pole portions is switched on and chopped on and off through the DC supply and the switching elements to keep the current at a certain maximum level as long as the rate of change of inductance of this stator coil is positive then and the current is switched off just before the pair of rotor pole portions is aligned with the pair of stator pole portions. Thereby, the magnetic attractive force increases while the current is supplied from the DC supply, and disappears in a moment when the current is switched off when the rate of change of inductance of this stator coil is negative. Therefore a motoring torque is obtained by this magnetic attractive force.

It is, therefore an object of the present invention to operate switched reluctance motor from a single-phase AC supply.

THE INVENTION

The invention provides a switched reluctance motor comprising: a stator, having a plurality of pairs of opposing stator pole portions projecting inwardly in a radial direction and extending in an axial direction, each stator pole portion having a coil wound thereon; a rotor disposed in the stator and rotatably supported on end brackets and having plurality of rotor pole portions projecting outwardly in a radial direction and extending in the axial direction.

On each pair of opposing stator pole portions coils are wound, and connected in series with each other to form a winding coil of stator phases; each winding coil of a phase is connected in series with a switching element to form one branch; all braches are connected in parallel to a single-phase AC supply.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of an embodiment of a switched reluctance motor in accordance with the present invention; and

Fig. 2 is a longitudinal sectional view of an embodiment of a switched reluctance motor in accordance with the present invention; and

Fig. 3 is a schematic diagram of the connection circuit comprising the phase coil of the switched reluctance motor, thyristor, ac voltage supply, controller circuit, voltage sensor and gate drive circuit; and

Fig. 4 is a connection diagram of the single phase fully controlled bridge rectifier; and

Fig. 5 is a connection diagram of the single phase semi-controlled bridge rectifier; and

Fig. 6 is the instantaneous relationship between phase inductance and time; and

Fig. 7 is the instantaneous relationship between position signal and time; and

Fig. 8 is the instantaneous voltage signal waveform transmitted from voltage sensor to the controller circuit; and

Fig. 9 is the gate pulses waveform generated in response to voltage signal of the voltage sensor; and

Fig. 10 is the control signal waveform transmitted from the controller circuit to the gate drive circuit; and

Fig. 11 is the periodical waveform of the phase current and the supply voltage; and

Fig. 12 is the periodical waveform of electromechanical torque per phase and the supply voltage; and

Fig. 13 is the torque-speed characteristics of the switched reluctance motor in accordance with the present invention.

DESCIPRION WITH REFERENCE TO THE DRAWINGS

Referring to Fig. 1 and 2, a switched reluctance motor 1 is provided with a stator S comprising a plurality of pairs of opposing poles, shown here as two poles S1 S2, which are located at regular circumferential intervals which project inwardly in the radial direction and extend in the axial direction. A rotor R which is formed by laminating of electromagnetic steel plates is fixed on an output shaft SH which is rotatably supported on end brackets EB at both ends through bearings BR fixed in inner bores of the end brackets. Thereby, the rotor R is able to rotate with the output shaft SH in a body in the stator S. Furthermore, the rotor R is comprising a plurality of pairs of opposing poles, shown here as two pole R1 R2, which project outwards in the radial direction at regular intervals and which extend in the axial direction. As shown in Fig. 1, each of these rotor pole portions R1 R2 is able to be aligned with each of the stator pole portions S1 S2 as the rotor rotates, while maintaining a certain clearance there between. On each pair of stator pole portions, coils are wound (not shown in Fig. 2) and connected in series with each other to form the phase winding coil, for example, on the pair of stator pole portions S1 S2, coils A1 A2 are wound, and connected in series with each other to form the winding coil of phase A, shown in Fig. 3.

Each phase is connected in series with a switching element, such as a thyristor, a traic, a single phase fully controlled bridge rectifier, shown in Fig. 4, or a semi-controlled bridge rectifier, shown in Fig. 5, to form one branch. All braches are connected in parallel to a single phase AC supply, for example, the branch Br_a shown in Fig. 3, which consists of phase A in series with a thyristor T_a, is connected to single phase AC supply 2 whose maximum voltage and frequency are v_s in volt and ω_s in rad/sec respectively.

A well-known rotation sensor RS, shown in Fig. 2, such as an encoder or a resolver is disposed on the end of the output shaft SH in order to detect the rotational position of the rotor R. The rotational sensor is electrically connected to a controller circuit CON shown in Fig. 3 and therefore a position signal v_p, shown in Fig. 7 detected by the rotation sensor RS, is transmitted to the controller circuit CON. Also, a well-known voltage sensor SEN shown in Fig. 3, such as a step down voltage transformer or a voltage transducer module, is used in order to sense the AC supply voltage 2. The voltage sensor SEN is electrically connected to the controller circuit CON and therefore a voltage signal v_v, shown in Fig. 8, detected by the voltage sensor SEN, is transmitted to the controller circuit CON which is electrically connected to the drive circuit D. The controller circuit CON transmits an output control signal v_c shown in Fig. 10 to the drive circuit D to which the phase coils wound on each of the stator pole portions are connected in response to a position signal v_p and a voltage signal v_v. The drive circuit D, supplies pulses of gating current signal i_g, shown in Fig. 3, to a switching element such as a thyristor, a traic, a single phase fully controlled bridge rectifier, shown in Fig. 4, or a semi-controlled bridge rectifier, shown in Fig. 5, in response to the output control signal v_c of the controller circuit CON.

The above-described embodiment of the switched reluctance motor operates as follows:

When the rotor R is in a predetermined position in which the two rotor pole portions R1 R2 begin to approach alignment with the two-stator pole portions S1 S2, the rotation sensor RS transmits a position signal v_p to the controller circuit CON and continues until the rotor pole portions R1 R2 reach alignment with the two-stator pole portions S1 S2, during which the rate of change of inductance, L_a of phase A is positive, this period is shown in Fig. 6 between time zero to $0.25t_r$ and between time $0.5t_r$ to $0.75t_r$. Also, the voltage signal v_v applied to the controller circuit CON from the voltage sensor SEN is used to generate a train of pulses G, shown in Fig. 9 synchronized with the supply voltage and delayed by a delay angle α which can be controlled from zero to π in radian with reference to the zero crossing instants of the supply voltage 2. The gating pulses G and the position signal v_p from the rotational sensor RS, which are not necessarily to be synchronous, are logically ANDed to produce the control signal v_c, shown in Fig. 10, which is transmitted from the controller circuit CON to the drive circuit D. In response to this output control signal, v_c, the drive circuit supplies a gating current signal i_g to the thyristor connected to the coils wound on the stator pole portions, which the two pairs of the rotor pole portions are approaching. With reference to Fig. 11, when a gate pulse is applied to the thyristor, T_a, at a delay angle, α, with reference to zero crossing instants of the supply voltage, the current i_A rises in the coils of phase A and continues up to π and due to inductive nature of the motor, the thyristor continues to conduct where the power stored in the phase is recovered from the motor winding to the AC supply 2 until the current i_A falls to zero at an extinction angle, γ, after which the current i_A remains zero up to instant $\alpha+2\pi$ when the next gate pulse is applied to the thyristor. Therefore, for each cycle of supply voltage, the current i_A of phase A shown in Fig. 11 is periodical. As long as the rate of change of inductance, L_a of phase A is positive, the position signal v_p is high and the current i_A repeats number of cycles depending on the ratio between the rotor speed ω_r in rad/sec to frequency of the AC voltage supply ω_s in rad/sec. It should be noted that the extinction angle, γ in radian ranges from π to 2π depending on rotor speed ω_r, supply maximum voltage v_s, supply frequency ω_s, phase resistance $R_{a,}$ phase inductance L_a which is rotor position dependent and the delay angle α which can be controlled from zero up to π. Thereby, The stator pole portions on which these coils are wound are magnetized and a magnetic flux is generated between the magnetized stator pole portions. A magnetic attractive force occurs between the stator pole portions and the rotor pole portions, which are approaching them. A component of the magnetic attractive force produces a torque on the rotor shown in Fig. 12, which draws the rotor portions towards alignment with the stator pole portions.

Once the rotor R has been rotated by the torque to a predetermined position in which the rotor pole portions are almost nearly unaligned with regard to the magnetized stator pole portions where the rotor R is in the final effective position in which the above torque acts on the rotor R, the rotational sensor transmits zero position signal v_p to the controller at this instant and continues until the rotor pole portions reach alignment with the stator pole portions, shown in Fig. 6 between period from $0.25t_r$ to $0.5t_r$ and between period from $0.75t_r$ to t_r during which the rate of change of inductance L_a is negative. When the position signal v_p is logically ANDed to the gating pulses G, the output control signal v_c is zero as shown in Fig. 10 and then the drive circuit stops supplying gate pulses to the thyristor that connected to the coils wound on the magnetized stator pole portions in response to an output control signal of the controller circuit and consequently the phase current i_A is zero.

Thereby, the current supplied to the coils wound on stator pole portions is switched on and off as a pulse and a motoring torque is obtained by the action of the above magnetic attractive force. Fig. 12 shows variations of torque as current is supplied to the coils wound on the pairs of stator pole portions whose average value T_L shown in Fig. 13 is able to rotate the rotor.

The torque-speed characteristics of this above-mentioned embodiments is the so-called series characteristic as shown in Fig. 13 where the higher the load torque, the lower the speed. This is because, for low speeds, the current repeats many cycles during the positive rate of change of inductance period and consequently the average torque is high while, for high speeds, the current does not repeat many cycles during the positive rate of change of inductance period and consequently the average torque is low.

The torque-speed characteristics of this motor can controlled by controlling the delay angle ranging from zero to π such that the smaller the delay angle the higher the average electrometrical torque T_L and the higher the speed. This is shown in Fig. 13.

In the above-mentioned embodiments, the present invention is applied to a switched reluctance motor, which includes a stator and rotor both having one pair of pole portions. However, it is possible to apply the present invention to other types of switched reluctance motors, for example a two phase switched reluctance motor which includes a stator having two pairs of stator pole portions and a rotor having one pair of rotor pole portions, a three phase switched reluctance motor which includes a stator having three pairs of stator pole portions and a rotor having two pairs of rotor pole portions or a four phase switched reluctance motor which includes a stator having four pairs of stator pole portions and a rotor having three pairs of rotor pole portions.

Also, in the above-mentioned embodiments, the present invention is applied to a switched reluctance motor fed from an AC supply via a thyristor. However, it is possible to apply the present invention to a switched reluctance motor fed from an AC supply via other types of switching elements, for example a single phase fully controlled bridge rectifier, a semi-controlled bridge rectifier or a traic whose circuit permits bi-directional positive and negative ac current which will produce positive torque as long as the rate of change of inductance is positive since the instantaneous electromagnetic is proportional to both rate of change of inductance and square of phase current.

CLAIMS

1. A switched reluctance motor comprising:

   a stator, having a plurality of pairs of opposing stator pole portions projecting inwardly in a radial direction and extending in an axial direction, each stator pole portion having a coil wound thereon;

   a rotor disposed in the stator and rotatably supported on end brackets, the rotor having a plurality of rotor pole portions projecting outwardly in the radial direction and extending in the axial direction.

2. A switched reluctance motor according to claim 1 wherein each pair of stator pole portions are wound, and are connected in series with each other to from the phase winding coils.

3. A switched reluctance motor according to claim 1 and 2 wherein each stator phase winding coil is connected in series with a switching element to from a branch.

4. A switched reluctance motor according to claim 3 wherein all branches are connected in parallel to a single-phase AC supply.

5. A switched reluctance motor according to claim 3 and 4 wherein each phase current is switched on many times during positive rate of change of inductance period.

6. A switched reluctance motor according to claim 5 wherein the torque-speed characteristics is the so-called series characteristic where the higher the load torque, the lower the rotor speed.

7. A switched reluctance motor according to claim 5 and 6 wherein the torque-speed characteristics can controlled by controlling the delay angle of the switching element ranging from zero to π such that the smaller the delay angle the higher the average electrometrical torque and the higher the speed.

8. A switched reluctance motor according to claim 1 wherein the present invention is possible to apply to a switched reluctance motors with any number of phases.

9. A switched reluctance motor according to claim 3 wherein the present invention is possible to apply to a switched reluctance motor fed from an AC supply via a thyristor, a traic, a single-phase fully controlled bridge rectifier, or a semi-controlled bridge rectifier.

10. A switched reluctance motor substantially as described herein with reference to the drawings.

ABSTRACT

OPERATION OF A SWITCHED RELUCTANCE MOTOR FROM A SINGLE-PHASE AC SUPPLY

A conventional switched reluctance motor (Fig. 1) includes a housing; a stator formed by laminating of electromagnetic steel plates and having a plurality of pairs of opposing stator pole portions; a rotor formed by laminations of electromagnetic steel plates and having a plurality of pairs of rotor pole portions. The rotor disposed in the stator such that when the rotor rotates, each of the rotor pole portions moves in and out of the alignment with each of the stator pole portions. On each of the stator pole portions, a coil is wound such that the coils which are wound on each of the pairs of opposing stator pole portions are connected in series with each other to form one phase winding. Each phase winding is connected in series with a switching element such as a thyristor to from one branch. All branches are connected in parallel to a single-phase AC supply (Fig. 3). Thereby a magnetic flux is generated between each pair of stator pole portions when a current is supplied from the ac supply to the stator coil (Fig. 11) and repeated many cycles as long as the rate of change of inductance of this stator phase is positive. The number of cycles of phase current depends on the ratio between the rotor speed in radian per second to the angular frequency of the supply voltage in radian per second. A magnetic attractive force occurs between the rotor pole portions and stator pole portions as they approach one another. This magnetic attractive force produces a motoring torque which can be controlled by controlling the switching delay angle of the switching element (Fig. 13) where the higher the load torque, the lower the speed. This is because, for low speeds, the current repeats many cycles during the positive rate of change of inductance period and consequently the average torque is high while, for high speeds, the current does not repeat many cycles during the positive rate of change of inductance period and consequently the average torque is low.

The present invention proposes the operation of the above-mentioned switched reluctance motor from a single-phase AC supply.

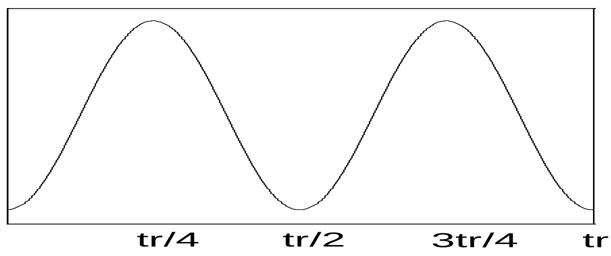

Fig. 6

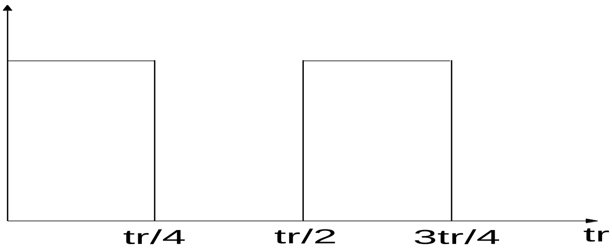

Fig 7

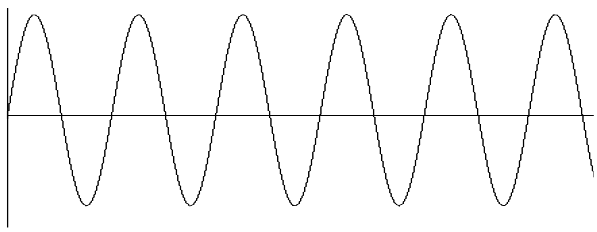

Fig. 8

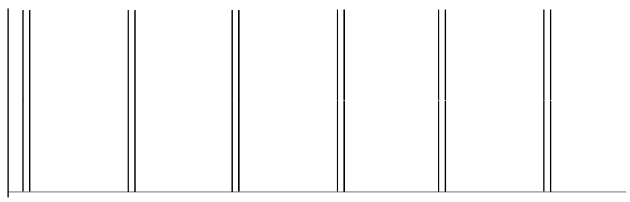

Fig. 9

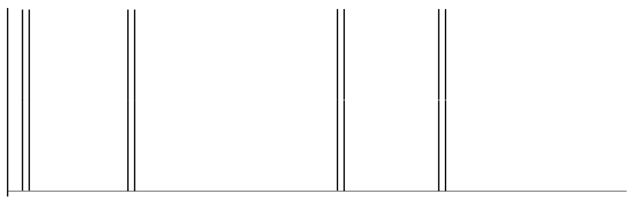

Fig. 10

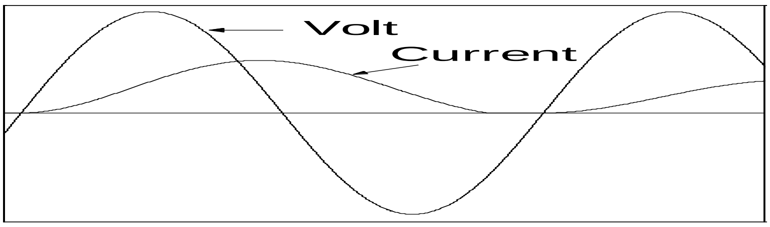

Fig. 11

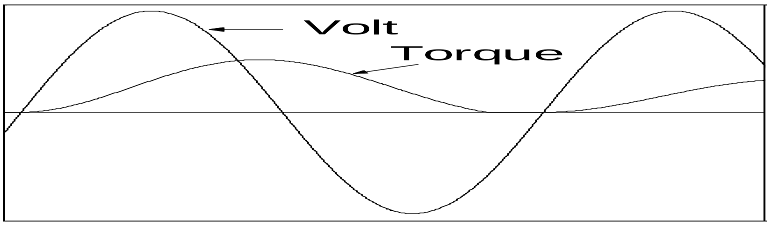

Fig. 12

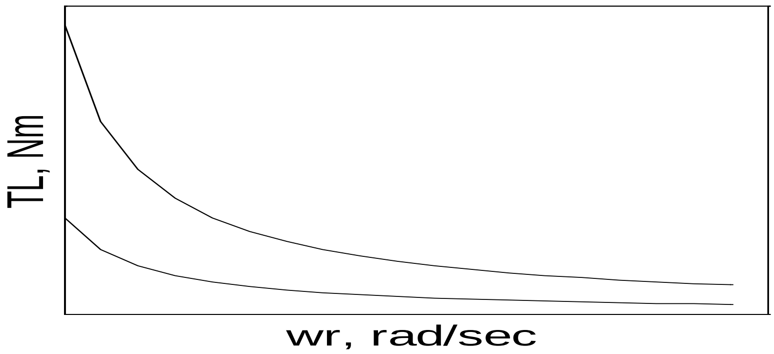

Fig. 13

Fig. 3

Fig. 4

<u>Fig. 5</u>

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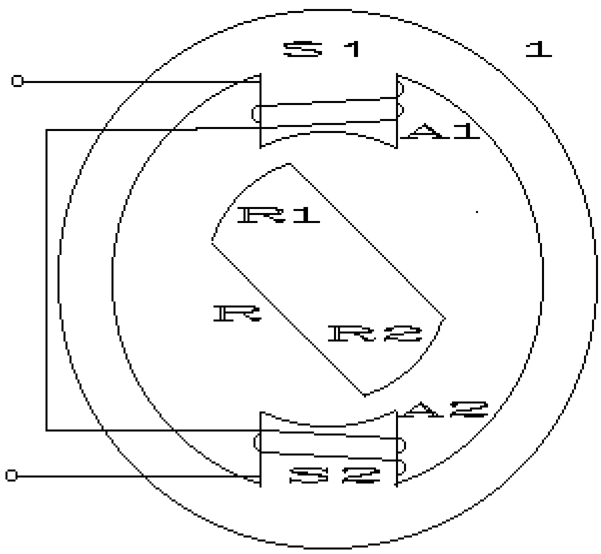

Fig. 1

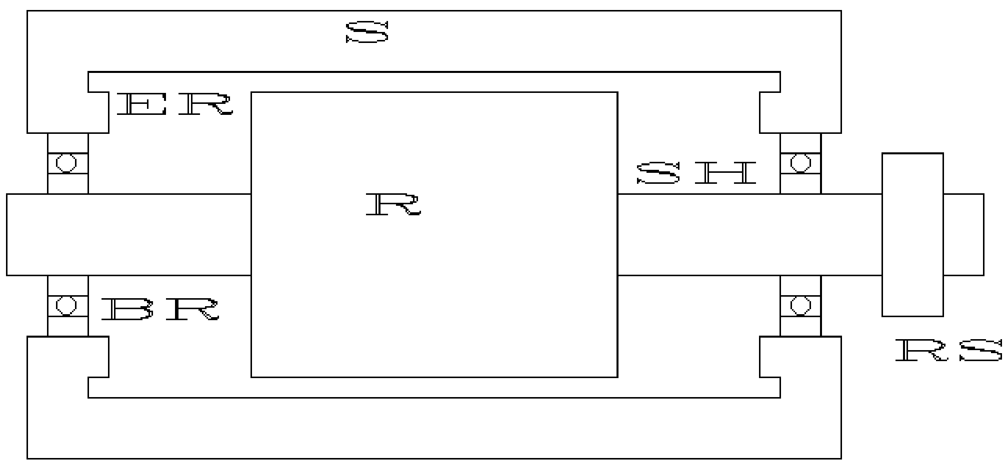

Fig. 2