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# Bridge Configured Wounded Switched Reluctance Motor

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**Abstract**

Conventional switched reluctance motors suffer from high undesired acoustic noises and vibrations caused by the production of a considerable amount of radial force due to non-uniformity in air-gap which can be controlled in order to make it more efficient. A feasible solution to pacify this problem is the introduction of a special winding scheme called bridge configured winding (BCW) in switched reluctance motor (SRM). Various winding configurations (generally dual set of windings) have been developed till date in order to produce radial force in SRM. This paper presents the incorporation of bridge configured winding capable of producing both the torque and a controllable radial force using a single set of winding, thus reducing the use of additional winding for radial force production.


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*Keywords:* Bridge configured winding; Radial forces; Switched Reluctance motor; Bearingless.

## 1. Introduction

A switched reluctance motor is a doubly salient motor where torque is produced by the tendency of the rotor pole to achieve a minimum reluctance position. In construction, the SRM is one of the simplest among all electrical machines. Only the stator has windings and the rotor contains no conductors or permanent magnets. It consists simply of steel laminations stacked onto a shaft. It is because of this simple mechanical construction that SRMs carry the promise of low cost.

For successful operation of SRM, it is required to switch the excitation according to the rotor position. The advances in the area of power electronics have made this switching operation more efficient which has motivated a large amount of research on SRM in the last decade. However due to its salient structure, high acoustic noise and

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vibration is produced. Various design methodologies of winding schemes have been introduced by researchers to produce radial force, which can be utilized for vibration suppression as well as in making the motor bearingless. Dual sets of winding was introduced by Shimada et al.[4] and Takemoto et al.[5] for bearingless switched reluctance motor where the main winding was responsible for rotation of the motor and the secondary winding for providing suspension force to the rotor. The basic concept of production of radial force using this dual winding design is that the main supply generates a 4-pole magnetic field which is responsible for the torque production and the additional winding produces a 2-pole magnetic field which is responsible for the radial force production. The flux density increases in the air gap where the direction of the 4-pole and 2-pole field is same and decreases where the pole fields are opposite. Superimposition of both of these fields produces an unbalanced flux distribution in the air-gap resulting in a net radial force in the direction of highest flux density. However, this design consumes an additional space in the stator winding which could have been otherwise used for torque production. The idea of using single winding was proposed by Higuchi and Preston and applied to a 12/8 SRM, however an account of its successful operation and control was not published [2,3]. Single layer winding for 8/6 bearingless switched reluctance motor (BSRM) was implemented by Chen and Hofmann [11] by exciting two phases together to produce both torque and suspension force. However, in 2005 a single set of winding called bridge configured winding (BCW) was introduced by Khoo [9] for polyphase self-bearing machines which could generate both torque and transverse force using the same winding. The nature of this winding was such that the currents responsible for producing torque was divided into two parallel paths and an isolated power supply called bridge currents in the midpoint of the path could produce a net lateral force. With no bridge current supply, the motor could operate as a normal torque producing machine. This design was an elegant development where no additional windings were used to produce the net lateral forces like in dual set of winding.

This present study analyzes the capability of incorporating BCW in a SRM to generate both torque and a controllable radial force, which can be utilized for vibration attenuation. Here, an analytical model incorporating the bridge configured winding in a SRM has been developed using the magnetic equivalent circuit method. Also a FE model of the SRM is designed using Maxwell 2D, which has then been used to verify the developed analytical model. The FE model is further analyzed to demonstrate the force production capability of this specialized winding scheme along with its ability to generate torque. This controllable radial force can also be utilized to convert the motor into a bearingless machine with an added benefit of requirement of low power supply for the radial force production.

## 2. Introduction of Bridge Configured Winding in Switched Reluctance Motor

Bridge configured winding (BCW) is a double layered, single set of winding consisting of two parallel paths. The principle feature of this winding is that the parallel path currents can be utilized for the production of force by using an isolated supply at the midpoint of these two paths. In the present study, this BCW has been applied on a SRM and its effect has been studied. Fig. 1(a) represents the circuit diagram of a single phase BCW scheme, where coil sets ($1_a$-$7_a'$)-($7_a$-$1_a'$) and ($10_a$-$4_a'$)-($4_a$-$10_a'$) form the two parallel paths of the winding. $1_a$ and $1_a'$ constitute a coil set with same number of turns and occupy one stator tooth while coil set 7 and $7_a'$ occupy diametrically opposite stator tooth, coil set $10_a$-$10_a'$ and $4_a$-$4_a'$ occupy stator tooth which are 90 degree apart with respect to the coil set $1_a$-$1_a'$ and $7_a$-$7_a'$ as shown in Fig. 2. When a current source is supplied across the point *p* and *s*, magnetic field of equal magnitude is produced along the teeth 1-4-7-10 as depicted in Fig. 2, which in turn produces a torque due the tendency of the rotor to attain a state of minimum reluctance. The speciality of the BCW scheme is that with an external isolated supply at the bridge points (a-b) and (c-d), the symmetry in the magnetic field distribution can be disturbed, which in turn results in the generation of the radial force along with the torque. Due to this external supply across the bridge points (a, b), current flows along the path (b-p-a and b-q-a), due to which the current density in teeth 1 and 10 increases, whereas it decreases in teeth 4 and 7. Thus the need of an additional set of winding for the force production is removed. Fig. 1(b) shows the formation of four pole field due to the main winding current and the formation of two pole field produced due to the bridge current which is used to create asymmetry in the air-gap.