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Design of Switched Reluctance Motors and also Show the Effects of Switched Reluctance Motor

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Abstract

The fundamental theory of the switched reluctance motor is presented with a number of new equations. It is used to show how the practical development of a design calculation should proceed, and this leads to a discussion of physical characteristics required to achieve satisfactory performance and to reduce acoustic noise. The paper makes a few generic observations on the characteristics of successful products that use switched reluctance motors. It is written at a basic engineering level and makes no attempt to apply sophisticated optimization theory. Passive and active filtering of current harmonics drawn from the single-phase AC supply to achieve power factor correction is reviewed for switched reluctance drives. For some power ranges, the most inexpensive solution may be to use the existing power electronic.

Index Terms— Electric motors, switched reluctance motors, inruction motors

INTRODUCTION

TO A WISE engineer, “optimal design” means a compro- mise between conflicting factors, often producing an im- perfect result from optimistic aspirations. Who would use a title such as “Compromises in the design of switched reluctance motors”? *Optimal* sounds better, particularly if used to describe the production of silk purses from sows’ ears. While the switched reluctance motor is not the silk purse of electric machines technology, it fetches more in the market than sows’ ears and, there- fore, it must be a compromise between these two extremes: in other words, an optimal result arising from less-than-perfect components.The switched reluctance motor turns many of the tenets of classical electric machines technology upside down. This possibly explains why it is popular with academics but rare in the factory. Since the emergence of serious examples of switched reluctance drives in the 1970s, only a few practitioners have made successful businesses with them, while a large number of research papers have had little effect at the factory gates and some of them make claims which are misleading or incorrect.

Definition

A *reluctance machine* is one in which torque is produced by the tendency of its moveable part to move to a position where the inductance of the excited winding is maximized.This definition covers both *switched* and *synchronous* reluctance machines. The switched reluctance motor has salient poles on both the rotor and the stator and operates like a variable-reluctance stepper motor except that the phase current is switched on and off when the rotor is at precise positions, which may vary with speed and torque. It is this switching which gives the switched reluctance motor its name. This type of motor cannot work without its electronic drive or controller. noted “2/2” because it has two stator poles and two rotorpoles.

CHARACTERISTICS OF THE SWITCHED RELUCTANCE MOTOR

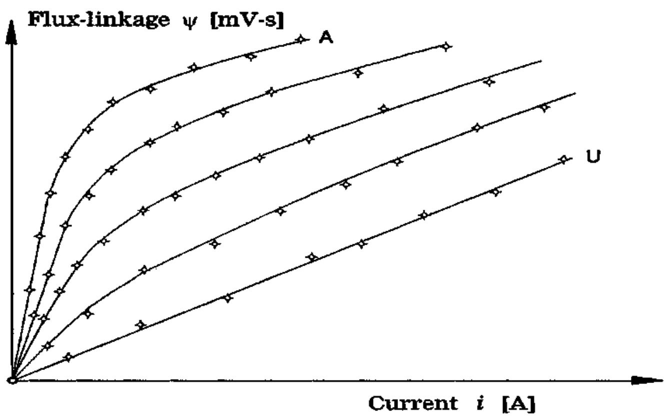
The switched reluctance motor is attractively simple in its mechanical construction and appearance, but it requires a controller that is designed and tuned for each specific application and has little in common with conventional ac drives. At first sight, it appears that the balance between the cost of the motor and the cost of the drive is shifted toward a less expensive motor and a more expensive drive, but this does not obviously produce an overall cost saving.

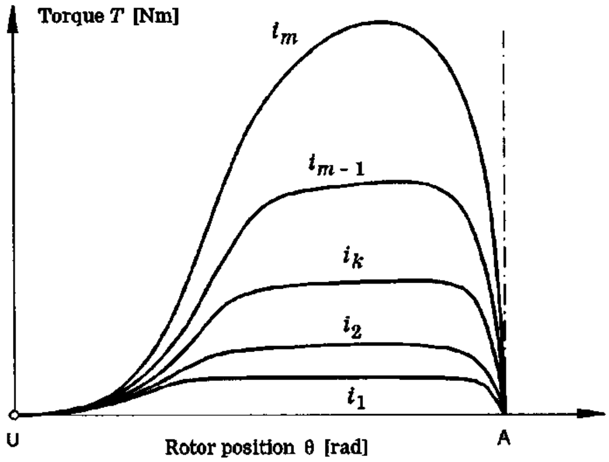
The enormous investment in tooling and infrastructure for induction motors and ac drives puts the switched reluctance motor at a disadvantage in many large sectors of the motor business. Since the vast majority of induction motors are line-start motors used without electronic drives, the switched reluctance motor has no hope of competing with the induction motor in the bulk of these applications. The infrastructure relates to the design, manufacture, sale, commissioning, maintenance, and control, and in adjustable-speed drives all these are heavily weighted in favor of induction motors. By contrast, the switched reluctance motor and its drive are specials for which very little tooling exists and almost none of the infrastructure. This will limit its role to special applications where the costs of development and support can be absorbed in a larger project—for example, the develop ment of a completely new washing machine [3]. Although the switched reluctance motor can serve important roles like this, the underlying factors will not change in the foreseeable future. Larger switched reluctance and induction motors both have high power factors and low excitation losses and, therefore, do not need magnets. In any case, a large permanent-magnet rotor.As is equally the case with field-oriented control of induction motors, much of this art is beyond the scope of a review paper such as this one, which can only set out a few basic principles. The excitation requirement becomes burdensome in small motors, not so much because of the voltampere requirement *per se*, but because the losses associated with excitation become disproportionately large as the motor size decreases. Switched reluctance and induction motors behave similarly in this regard and both are at a disadvantage compared with motors that use permanent-magnet excitation, which is essentially lossless.

Without compromising the motor design or making it more expensive, even in applications such as domestic washing machines and automo- tive electric power steering, both of which require low noise levels. out the noise to a greater or lesser degree. It has been demonstrated that acceptable results can be achieved. Torque ripple is another frequently quoted problem with the switched reluctance motor. Indeed, it can be said that it produces torque by amplifying what is known as cogging torque ture that is more susceptible to resonance than that of most “smooth-air-gap” machines. However, a sophisticated drive can alleviate some of the acoustic noise by controlling the excitation in such a way as to exploit the mechanical resonance “nuisance torque”—in other machines. At low speed it can be “controlled out” by shaping the current waveform, but at high speed the current regulator may become “saturated” and a certain amount of torquee ripple develops. which have truly independent means of excitation control are those with field windings. In high-speed machines, the fixed excitation producedby permanent magnets can produce a high no-load core loss, The current wave- shapes themselves may be more complex to determine, since they are not sinusoidal; but they are not necessarily more complex to *produce*.The drive complexity in the switched reluctance motor drive is about the same as in an induction motor drive. What is more significant than the *level* of complexity, is the fact that the theory and architecture of switched reluctance motor controllers are not widely known. Moreover, there are very few established commercial sources of drives for switched reluctance motors, or of the components that go into them. Worldwide, only a handful of engineers understand the art of designing these controllers at an adequate level to make commercially viable products.

TORQUE PRODUCTION

The theory of electromechanical energy conversion with the help of flux linkage and current is shown:-





The number of strokes per second is given by
f Hz

This frequency and all its harmonics appear in the flux wave-forms in various parts of the magnetic circuit. Equation (16) says that the fundamental magnetic frequency is twice as high as in a synchronous ac motor with the same number of rotor poles. The speed of rotation is even less simply related to the number of *stator* poles, since there are generally at least two possible choices of N_s for each value of N_r and further possibilities arise with multiple stator teeth per pole, [14]. The switched reluctance machine is usually classified as a *vernier* machine because its rotational speed is only a fraction of the fundamental electrical frequency. *lute overlap* ratio sis defined as the ratio of the absolute torque zone to the stroke angle: evidently, this is equal to/2. A value of at least 1 is necessary if the *regular* motor is to be capable of producing torque at all rotor positions. In practice a value of 1 is not sufficient, because one phase can never provide ratedtorque throughout the absolute torque zone in both directions. The *effective overlap ratio*is defined as the ratio of the ef- fective torque zone to the stroke angle,.

The flux waveforms in switched reluctance motors are not only at a higher fundamental frequency, but they carry a higher harmonic content than in ac motors and the flux waveforms may be very different in different parts of the magnetic circuit. Al- though this suggests that the core losses will be higher than in comparable ac motors, in practice, this is not the case because switched reluctance motors are usually designed with a significantly lower magnetic loading (average flux density around the air gap) and higher electric loading. Moreover, the volume of element analysis cannot help with this problem and three-dimensional finite-element calculations tend to be expensive and slow. When the rotor is at or near the aligned position, the flux is generally higher and the “bulging” of flux outside the core depends on the flux level in the laminations near the ends of the stack. At or near the aligned position at high flux levels, the stator and rotor poles can be highly saturated and the external flux paths at the ends of the machine can increase the overall flux linkage by a few percent.

Summary

In the previous three sections, we have seen that the elegance and brevity of the theoretical equations belie the practical diffi- culty of solving them in a manner which makes it easy to design and control a switched reluctance motor. For design purposes, a computer simulation is a *sine qua non* because the operation is a series of transients in a highly nonlinear magnetic system, with no discernible steady state that can be expressed by simple algebraic formulas of the type familiar with classical dc and ac machines. The main difficulties in the simulation are in interpo- lation and in th e provision of accurate magnetization curves.In relation to the control, a “series of nonlinear transients” provides no obvious architecture on which a control strategy can be based. Although the general notion of nested control loops for torque (or current) and speed still applies, the feedforward relationship between current and torque is nonlinear in both current and rotor position; and if more than one phase is simultaneously excited, additional questions of torque sharing between phases may need to be resolved. In this paper, the focus is on the solu- tion of the equations for purposes of designing the motor.

CONCLUSION

As with most engineered products, the “optimal” design of switched reluctance motors is a matter of compromise involving many parameters. The switched reluctance motor is now mature enough to have proved itself in the marketplace in a few different applications. The number and range of these applications remain small compared with those of induction motors or even brush- less permanent-magnet motors, but it can be argued that this is partly a consequence of the level of investment and tooling in these technologies, rather than a result of inherent technical defi- ciencies in the switched reluctance motor itself. Even its widely criticized “noise problem” has not prevented successful com- mercial applications.

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