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ملخص الرسالة

تقدم الرسالة برنامجاً متكاملاً SRMCAD لتصميم محرّك المعاوقة للتيّار المستمر المقطّع، مكتوب بلغة الحاسب "فورتران" ولا يتطلّب استخدامه سوى الإلمام بالحد الأدنى من المعلومات المتعلّقة بنظرية العمل وحساب الأداء، والمعلومات الأساسية الخاصة بتصميم هذا المحرّك. وقد روعي في بناء هذا البرنامج سهولة تداول البيانات سواء منها المعطيات أو المخرجات وإعداد الأخيرة للعرض بصورة رقميّة أو بيانية.

تعتمد الآلات الكهربية الدوّارة من الأنواع الأساسية في تصميمها على ما يعرف بـ "معادلة الخرج" التي تربط بين الأبعاد الأساسية للآلة ودائرتها المكافئة الخاصة بحساب الأداء المستقر. انطلاقاً من تلك المعادلة سيأتي تصميم الآلة مناسباً بدرجة كبيرة لمقنّنات الآلة وبدرجة من الجودة تقترب كثيراً من الجودة المتوقّعة.

وبالرغم من أن عدداً من الباحثين قد توصّل إلى "معادلة الخرج" الخاصة بمحرّك المعاوقة للتيّار المستمر المقطّع، فإنه من غير المؤكّد أن النموذج الأوّلي للمحرّك المراد تصميمه سيحقّق المقنّنات المطلوبة من الآلة أو الأداء المتوقّع لها. لذا فإنّه من الضروري أن يتم تصميم هذا المحرّك بطريقة تقاربية؛ لابد فيها من الاستعانة بالحاسب الآلي.

يقوم البرنامج المقترح SRMCAD على الدمج بين نوعين من الخوارزم: الخوارزم الأوّل يقترحه الباحث لحساب التصميم المبدئي لمحرّك المعاوقة للتيّار المستمر المقطّع، ويقوم الخوارزم الثاني بحساب الأداء العابر والمستقر مستعيناً بالخواص المغناطيسيّة المعدّة طبقاً للأبعاد وبيانات اللّف الخاصة بالتصميم المبدئي.

ويحكم سير العمليّات الحسابيّة وصولاً إلي "التصميم الأفضل" نظام منطقي موضّح داخل الرسالة من خلال مجموعة من خرائط الانسياب. ويعرّف "التصميم الأفضل" هنا بأنه التصميم الذي يضمن أن يعطي النموذج الأوّلي القدرة المطلوبة عند أعلى جودة ممكنة؛ عندما يعمل النموذج طبقاً للحظة التوصيل Θ_{on} وفترة التوصيل Θ_c التي يقترحها التصميم. ويقوم البرنامج بتنفيذ هذه العمليّات الحسابيّة علي مرحلتين؛ يمكن تلخيصهما كالآتي:

المرحلة الأولي:

١ – حساب التصميم المبدئي طبقا لمقننات الآلة (القدرة، الجهد، السرعة، وعدد الأوجه) وعوامل التصميم المقترحة متضمنة الجودة المتوقعة. ويشمل التصميم المبدئي الأبعاد الأساسية والتفصيلية والبيانات الخاصة بملفات الوجه.

٢ – ضبط عوامل التصميم، عدا الجودة المتوقعة، طبقا لكثافة التيار المطلوبة وبما لا يتعدى النطاق المسموح به لتلك العوامل.

٣ – الحساب التكراري للدائرة المغناطيسية في موضع التطابق والوضع البيني، وإعداد الخواص المغناطيسية الآتية في

هيئة قوائم :

أ- خواص الممانعة الحثّية؛ دالة في موضع العضو الدائر والتيّار : $L(\theta,i)$.

ب- خواص القطع المغناطيسي؛ دالة في موضع العضو الدائر والتيّار : $\psi(\theta,i)$.

ج- خواص التيّار؛ دالة في موضع العضو الدائر و القطع المغناطيسي : $i(\theta,\psi)$.

ويتم إعداد خواص التيّار تأسيساً على خواص القطع المغناطيسي، بالاستعانة بالطرق الرياضيّة المناسبة.

٤ – إعداد القائمة الخاصة بمجموعة "ظروف القطع" سواء ذاتياً بواسطة البرنامج أو بأسلوب الإدخال اليدوي. وتحوي المجموعة "لحظات التوصيل" و "فترات التوصيل" المناظرة؛ والمطلوب حساب الأداء المتوقّع لكلٍّ من ظروف القطع هذه والتي تشملها المجموعة.

المرحلة الثانية:

١ – حساب الآتي لكلٍّ من ظروف القطع المتضمّنة في القائمة الخاصة بها:

أ- حساب الأداء العابر : التيّار اللحظي، القوة الدافعة الكهربية اللحظية، العزم اللحظي، والعلاقة $(\psi\text{-}i)$ اللازمة لحساب الطاقة المحوّلة.

ب- حساب الأداء المستقر : القيمة الفعّالة للتيّار، القيمة المتوسطة للعزم، المفاقيد، القدرة الخارجة، والجودة.

٢ – مقارنة القدرة الخارجة في مجموعة الأداء المستقر والمميزة بأداء الآلة كمحرك، بالقدرة المقننة المطلوبة من المحرّك وتسجيل "مجموعة التصميم" التي تحقق القدرة المطلوبة، ويلاحظ أنه لا يفرق أيٌ من هذه التصميمات عن الآخر في تلك المجموعة سوى أنه لجودة وظروف قطع مختلفة.

٣ – البحث عن "التصميم الأفضل" في مجموعة التصميم السابقة، وهو التصميم احتواء المجموعة المذكورة والذي ينشأ عنه أعلي جودة في المجموعة.

٤ – مقارنة جودة "التصميم الأفضل" بالجودة المتوقّعة، فإذا ما كانت قيمة التفاوت كبيرة يتم تعديل عوامل التصميم المقترحة وبدء دورة تقاربية جديدة للحصول علي "تصميم أفضل" جديد بداية من المرحلة الأولي، و تعديل قيمة الجودة المتوقّعة لتكون مساوية لجودة التصميم الأفضل السابق.

وهكذا ... فإذا ما تضاءل التفاوت في قيمة الجودة إلي التفاوت المسموح به، يُنهي البرنامج العمليّات الحسابية ويُعطي كافة البيانات الخاصة بمجموعة التصميم الأفضل؛ ليتمكّن المصمّم من اختيار "التصميم المناسب". ويعرّف التصميم المناسب هنا بأنه التصميم الأفضل الذي ينشأ عنه أقل قيمة عظمى للتيّار اللحظي، وأقل عمق للنتوءات الحادثة في تغيُّر العزم اللحظي المبذول علي عمود الإدارة. وليس بشرطٍ أن يكون التصميم المناسب هو أعلاهم جودة في مجموعة التصميم الأفضل، كما يري من النتائج.

وقد تمّ تجربة البرنامج علي "مثال مرجعي للتصميم" ومراجعة صحة ودقة الحسابات، وكذلك تسلسل الأوامر المنطقية ومدى فعاليّتها. كما تمّ دراسة تأثير كلٍّ من ضغط الوجه والسرعة علي التصميم وأداء المحرّك ودراسة النتائج والتعليق عليها.

والبرنامج مناسب لتصميم المحرّك موضوع الرسالة بقدرات تبدأ بـ واحد كيلو وات أو أكبر وأية ضغوط أو سرعات. ويمكن لغير المتعمّقين في تصميم هذا المحرّك استخدام البرنامج بسهولة ويسر؛ حيث روعي الإقلال من التخاطب بين المستخدم والحاسب الآلي بشأن اتخاذ القرار المناسب مع ترك اتخاذ القرار الأخير لمستخدم البرنامج.

كما أن البرنامج لا يتيح فقط التصميم الأفضل طبقاً للبيانات المطلوبة للمحرّك، ولكنه يُعطي أيضاً "ظروف القطع" المناسبة للحصول علي القدرة المطلوبة عند أعلي جودة ممكنة يتيحها هذا التصميم. وتساعد ظروف القطع هذه، أي "لحظة التوصيل" و "فترة التوصيل"، بالإضافة إلي القيمة العظمى للتيّار اللحظي في اختيار وضبط المحكّم الخاص بالمحرّك.

وبخصوص الأعمال المستقبلية في نطاق موضوع الرسالة، يمكن اقتراح الآتي:

١ – استخدام البرنامج لاكتساب الخبرة في تصميم المحرّكات الصغيرة، أقل من واحد كيلو وات، وتطوير البرنامج ليعطي التصميم الأفضل لمثل هذه المحرّكات الصغيرة دون اللجوء إلي أسلوب التجربة والخطأ.

٢ – تحميل البرنامج بالعديد من المواد المغناطيسية ذات الصفات المختلفة، لدراسة تأثير تلك المواد علي تصميم وأداء المحرك موضوع الرسالة.

٣ – إعادة كتابة البرنامج بلغة من لغات الحاسب تتيح استخدام الشبابيك وعرض النتائج وإجراء المقارنات مباشرة بطريقة بيانية.

٤ – التعاون مع الصناعة المصرية لبناء "نموذج أوّلي" يتيح إجراء القياسات العملية المختلفة لتأكيد صلاحية البرنامج لتصميم العديد من المحرّكات ذات القدرات وأعداد الأوجه المختلفة، ويكون تصميم وبناء محرّك المعاوقة للتيّار المستمر المقطّع مصرياً بحتاً وبدء استخدامه في شتي المجالات لما يعطيه من مزايا عديدة.

Abstract

The thesis presents an integrated computer program ***SRMCAD****, which takes over the design problem of the switched reluctance motor (SRM). This program simulates an integrated algorithm which is combined of a proposed design algorithm and a machine analysis algorithm. The computation processing of the integrated algorithm is executed in two stages. In the first stage, the program determines a preliminary design according to the given rating and design specification. Also in this stage, all the magnetization characteristics are calculated in tabulated form according to the dimensions of the preliminary design. In the second stage, the expected performance is determined for each couple,* O_{on} *and* O_s*, picked from the switching condition list. This performance is represented by the average torque, the rms current, and the efficiency. If this performance satisfies the machine rating as a motor, it will be stored in a permanent list. Having the expected performance for all couples included in the switching conditions list, starts a search process within the permanent list to pick up the best performance in this design iteration cycle. The best performance is that performance which ensures the required motor rating at a highest efficiency. If the efficiency of the best performance is closed to the given expected efficiency the deign iteration stops. The program algorithm and logic have been tested using a reference design example. Results are verified partially by hand and are found very close to those of the reference example. The program is applied to study the effects of phase voltage, speed, and the number of phases on the dimensions and performance of the machine. The obtained results satisfy the expected results.*

Summary

The thesis presents an integrated computer program SRM$_{CAD}$, which takes over the design problem of the switched reluctance motor (SRM). Input data is the required motor specification; rated power, rated voltage, rated (or base) speed, and the number of phases. This program simulates an integrated algorithm which is combined of: a proposed design algorithm and a machine analysis algorithm. The first algorithm is suggested by the author. It carries out the magnetic and electric design of regular SRMs; in an iterative manner. The second algorithm, suggested by Dr. El-Sersawy, implements a nonlinear method of calculating the expected performance.

The computation processing of the integrated algorithm is executed in two stages. In the first stage, the program determines a preliminary design according to the given rating and design specification. This specification is modified and adjusted internally, within the permissible ranges, to suit the motor rating. Interaction between the user and computer is minimized; but the last decision is taken by the user.

Also in the first stage, all the magnetization characteristics are calculated in tabulated form according to the dimensions of the preliminary design. These characteristics are the inductance List L (O,i), the flux-linkage List ψ (O,i) and the inverted List i(O,ψ). Also in this stage, the list of the proposed switching conditions is formulated; either self by the program or given by the user. These lists are required in the second stage.

In the second stage, the expected performance is determined for each couple, O_{on} and O_c, picked from the switching condition list. Here the computation process starts with the numerical solution of the voltage equation. The form of this equation varies from interval to interval according to the state of the electronic switches controlling the applied voltage. Each interval, instantaneous values of flux-linkage and current are stored to get the current and flux-linkage wave worms, torque pulse and the energy loop.

Having the above transient performance, the steady-state performance can be calculated. This performance is represented by the average torque, the rms current, and the efficiency. If this performance satisfies the machine rating as a motor, it will be stored in a permanent list.

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the design iteration stops, else starts a new design iteration cycle. A new design iteration cycle starts with the design specifications; modified according to the best performance data.

The program stops calculations when the efficiencies of best performances are closed to each other. In this case, a print out of best performances and the corresponding transient behaviors are given. In this print out, the user has to chose the more suitable proper design.

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In accordance with the future work, the author wishes to load the program with different magnetic materials having different properties and B-H curves. In this case, the user will be able to study the effect of magnetic material on the proper design and the corresponding performance.

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Mansoura University
Faculty of Engineering
Elect. Power & Machines Dept.

COMPUTER AIDED DESIGN OF SWITCHED RELUCTANCE MOTOR

A THESIS

SUBMITTED TO THE FACULTY OF ENGINEERING
MANSOURA UNIVERSITY

In partial fullfillment for the requirement of the degree of
Master of Science in Electrical Engineering

By
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In accordance with the future work, the author wishes to load the program with different magnetic materials having different properties and B-H curves. In this case, the user will be able to study the effect of magnetic material on the proper design and the corresponding performance.

LIST OF SYMPOLS

a_c := cross-sectional area of conductor , (m^2)

ag := Area of rotor pole (m^2)

A_{slot} := slot area , (m^2)

Asp := Specific electric loading (Amp.cond./ m)

B := Specific magnetic loading (tesla)

B_s := saturation flux density of the used core steel ; (tesla)

b_r := Rotor pole width (m)

b_s := Stator pole width (m)

C_o := Output coefficient (KW.min / m^3)

C_o := Torque output coefficient (KN.m / m^3)

D := stator bore diameter , (m)

D_o := The outer stator diameter (m)

D_r := rotor diameter , (m)

D_{sh} := Shaft diameter (m)

d_r := The rotor slot depth (m)

d_s := The stator slot depth (m)

g := Airgap length (mm)

G_r := The rotor weight (Kg)

I : = Phase current, (Amp.)

I_{peak} : = Phase-current; peak value, (Amp.)

$I_{r.m.s}$: = Phase-current; r.m.s value, (Amp.)

I_{sat} : = The current at which saturation begins (Amp.)

$J_{r.m.s}$: = current-density ; r.m.s value , (Amp./ m^2)

K *: = Ratio between the length and bore diameter*

K_d *: = Duty cycle coefficient*

K_{Ipeak} : = ratio of peak current to r.m.s current ,

K_l : = Ratio of inductance overlap of two adjacent phases to the angle over which inductance is changing.

K_{sf} : = slot fill factor (ratio of copper area to slot area) ,

K_{spr} *: = stator pole arc as aratio of stator pole pitch*

K_{Tpeak} := ratio of peak torque to mean torque ,

L_a := Unsaturated inductance in the aligned position /phase (H)

La^{u} := Unsaturated aligned inductance (H)

L_i := The effective core length (m)

L_u := Perphase inductance in the unaligned position (H)

l := Length between bearings (m)

l_e := Overall length (m)

l_{oh} := End turn overhangs length (m)

l_{ph} := The total length of the phase winding (m)

l_{mt} := The mean length of one turn (m)

m := number of phases that conduct simultaneously ,

N_c := The first cridical speed (r.p.m)

N_r := number of rotor poles ,

N_s := number of stator poles ,

P := Half of stator pole width

P_m := Mechanical output power (watt)

P_{out} := Output power (watt)

q := number of phases ,

R_{ph} := Resistance of phase winding (ohm)

r_1 := Stator bore radius (m)

St := number of strokes or torque pulses

T := mean torque (N.m)

T_p := number of turns per pole ,

T_{ph} := number of turns in series per phase ,

T_{peak} := Peak torque (N.m)

T_{Rv} := The torque per unit rotor bore volume (K.N.m/m^3)

V := Supply voltage (volt)

v := Height of pole –coil (m)

W := Energy converted due to one loop which is produced by one phase (Joules)

W_{mt} := The mechanical workdone (Joules)

W_{fc} := Stored magnetic energy (Joules)

$Y_{r.}$:= Rotor yoke thickness (m)

Y_s := stator yoke thickness (m)

β_r : = Rotor pole-arc (rad.mech.)

β_s : = Stator pole-arc (rad.mech.)

σ := The airgap shear stress ($K.N/m^2$)

Δ : = The conduction angle in radians (rad(mech.)

$\in$: = Stroke angle (electrical deg.)

η := Efficiency

θ_c : = Commutation angle (electrical deg.)

θ_{on} : = Conduction angle (electrical deg.)

θ_i := current conduction angle for each rising Inductance profile (electrical deg.)

λ_a^u := Phase unsaturated inductance in aligned position (H)

λ_u := The unsaturated inductance ratio

λ_s := Saturated inductance ratio

ρ_A :=The absolute overlap ratio ,

ρ_E :=The effective overlap ratio ,

τ := Time taken by the rotor pole to move from the unaligned To the aligned position, (sec.)

ϕ : = Rotor pole pitch (electrical deg.)

ψ := Fluxlinkage (wib.turn)

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CHAPTER 1

INTRODUCTION

1.1 DEFINITION

A reluctance motor can be defined as an electric motor in which torque is produced by the tendency of its moveable part to move to the position (the aligned or equilibrium position) where the inductance of the excited winding is maximized.

The “ winding “ usually consists of a number of electrically separate circuits or phases. These circuits may be excited separately or together . In motoring mode of operation each phase is usually excited when its inductance is increasing/, and is unexcited when its inductance is decreasing . In the generation mode, the opposite is true.

This definition is broad enough to include both the switched reluctance motor (SRM), the variable reluctance (VR) stepper motor, and the poly-phase synchronous reluctance motor, as seen in Fig.(1.1) and Fig.(1.2).

1.2 SWITCHED RELUCTANCE MOTOR

The switched reluctance motor is a kind of stepper motor. It operates on the variable reluctance principle and has been developed to provide high efficiency and high specific output. The SRM has salient poles (named also teeth) on both stator and rotor. Excitation is only on one side ; usually the stator and the rotor has no windings, bars, or squirrel cage. Therefore, the SRM is sometimes described as a doubly-salient, singly-excited reluctance motor.

Simple concentrated stator coils are wound around main poles, with diametrically opposite windings connected in series to form a single phase. Position sensors feed rotor position information to an electronic controller which maintains the stator mmf excitation pattern in step with the rotating rotor, ensuring optimum torque production.

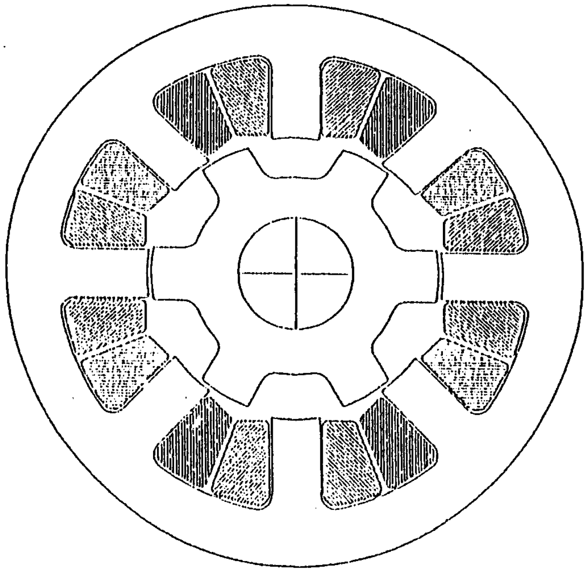

Fig.(1-1): Switched reluctance motor with 8 stator poles and 6 rotor poles Each phase winding comprises two coils wound on opposite poles

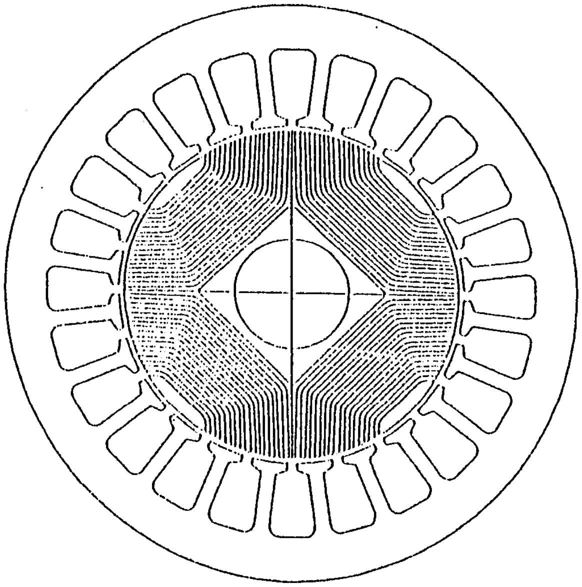

Fig.(1-2): Axially -laminated sychronous reluctance motor . This is a true AC motor . The stator is the same as that of the induction motor , and the supply is sinusoidal .

Additional feedback loop can adjust the nature of the inherent speed torque characteristics to simulate that of the d.c. series motor or even that of the shunt motor. As the phase currents are switched, the SRM can be used as a variable speed drive over a wide range of speed by controlling the switching parameters.

The SRMs have gained attention in the variable-speed drive market. The saving in manufacturing cost of the motor due to its simplicity of construction and use of minimum number of switching devices in the drive circuit are two important factors in its favor compared to any other motor drive. Modern power semiconductor switching devices, such as the power transistor and the gate turn-off thyristor are now capable of bringing out the optimum performance from the motor. At the same time the electromagnetic analysis of doubly salient motors has progressed to the point where the geometry of laminations can be optimized for particular applications.

The term switched reluctance dose not means that the reluctance itself is switched, but it clearly refers to the switching of phase currents, essential to operation. This switching is more precisely called " commutation ", so ECR (Electronically Commutated Reluctance) is an even more precise term than switched reluctance.

1.3 BASIC OPERATION PRINCIPLE OF SRM

The rotation occurs principally by getting the rotor in a condition of continuous seeking for the equilibrium position. This position is found when a rotor-pole is in alignment with an excited stator-pole. Of course, the rotor will never go to standstill when the machine is excited due to the difference in pole numbers on both machine sides.

Figure(1-3) shows a simple 3-phase SRM with six poles on the stator and four poles on the rotor. When any one phase AA' , BB' or CC', of the windings is energized with a dc current, the mmf developed will position the rotor such that the teeth of the rotor section under the excited phase are aligned opposite the teeth on the excited phase of the stator. This is the position of maximum permeance which is the stable equilibrium position. If phase AA' is

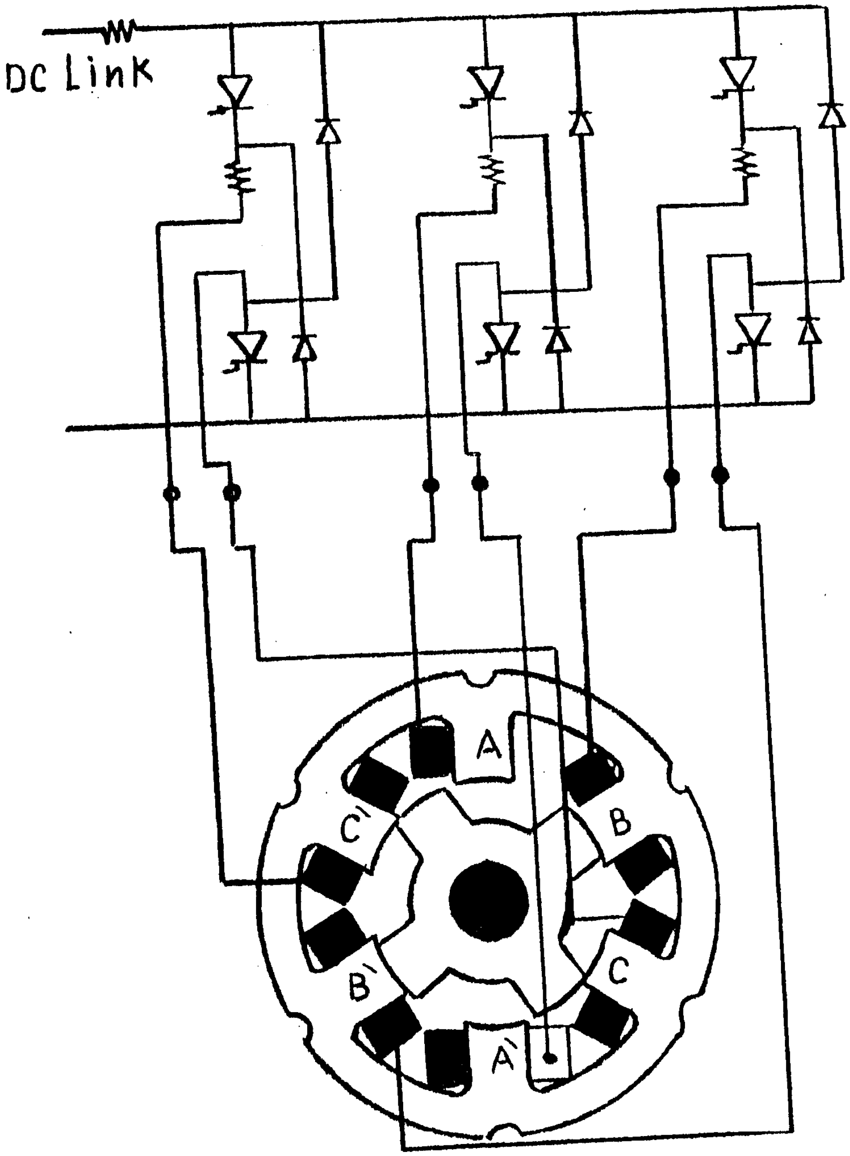

Fig. (1-3): a simple -3- phase SRM and control circuit energized the rotor would positioned as shown in Fig(1-3). When the dc current is switched to phase BB' the rotor will rotate clockwise, and the rotor teeth will be aligned opposite the teeth of phase BB' of the stator. Continuing in the same way, the sequence ABCAB..., the rotor will rotate clockwise in 30 degree steps.

During movement of the rotor-pole under the stator-pole the reluctance of the magnetic circuit varies and therefore the inductance of the phase-winding.

During one revolution of the rotor, each stator coil experiences the passage of 4 identical rotor teeth, and 4 pulses must be applied, that is the phase winding frequency has to be 4 times the rotational frequency. For a range of speed between 300 rpm., and 2100 rpm., the corresponding stator switching frequencies are between 20Hz and 140Hz.

1. 4 IDEALIZED FORMS OF SWITCHED AND SYNCHRONOUS RELUCTANCE MOTORS

As a comparison between switched and synchronous reluctance motors, the idealized features of both machines are defined and given as follows :

SWITCHED RELUCTANCE	SYNCHRONOUS RELUCTANCE
1. Both stator and rotor have salient poles	1.The stator has a smooth bore except for slotting.
2.The stator winding comprises a set of coils, each of which is wound on one pole.	2.The stator has a poly-phase winding with approximately sine-distributed coils
3.Excitation is a sequence of current pulses applied each phase in turn.	3.Excitation is a set of poly-phase balanced sine-wave currents.
4.As the rotor rotates, the phase flux-linkage should have a triangular or sawtooth wave-form but not vary with current.	4.The phase self-inductance should vary sinusoidal with rotor position but not vary with current.

The above schedule summarizes the mean differences between the SRM and the synchronous reluctance motor.

1.5 THE RELATIONSHIP BETWEEN SRM AND VR STEPPERS

The switched reluctance motor is topologically and electromagnetically identical to the variable reluctance stepper motor. The difference are in the engineering design, in the control method , and in the performance and application characteristics .

There are two essentials that distinguish the switched reluctance motor from the variable reluctance stepper :

One is that the conduction angle for phase current is controlled and synchronized with the rotor position .Usually by means of a shaft position sensor. In this respect the switched reluctance motor is exactly like the PM brush-less d.c. motor but unlike the stepper motor. Which is usually fed with a square wave of phase current without rotor position feedback.

The second distinction between switched reluctance and stepper motors is that the switched reluctance motor is designed for efficient power conversion at high speed comparable with those of the P.M brush-less motor, the stepper on the other hand is usually designed as a torque motor with a limited speed range.

Although this may seem a fine distinction , it leads to fundamental differences in the geometry power electronics, control, and design technique . The switched reluctance motor is more than high- speed stepper motor. It combines many of the desirable qualities of induction motor drives and d.c commutator motor drives as well as P.M brush-less disc system.

The above differences that distinguish the SRM from the VR stepper motor can be summarized as follows in the next Table.

SWITCHED RELUCTANCE MOTOR	VR STEPPER MOTOR
1.Normally operated , with shaft-position feedback to synchronize the commutation of phase currents with precise rotor positions.	1.Normally runs open loop ,i.e. .with out shaft-position feedback.
2.Normally designed for efficient conversion of power up to at least 300 kW.	2.Normally designed to maintain step-integrity rather than to achieve efficient power conversion .

1.6 HISTORY OF THE SWITCHED RELUCTANCE MOTOR

The earliest recorded switched reluctance motor was the one built by Davidson in Scotland in 1838 and used to propel a locomotive on the Glasgow-Edinburgh railway near Falkirk. Dr.Fulton of SRDL recently described Davidson's locomotive in a seminar of the UK Magnetic Club , pointing out that the locomotive weighted several tons yet the top speed was less than could be achieved with one man pushing [1].

The Lucas Ledex rotary actuator dates back to World War II, and continues in production today , but this is a limited rotation actuator rather than a motor.

The stepper motor, invented and patented in the 20's by C.L. Walker in Aberdeen, included many of the features of modern VR stepper motors and therefore of the switched inductance motor.

Apart from the well-known work by Lawrenson and his colleagues at the University of Leeds, UK and subsequently at switched reluctance Drives Ltd , there have been many other substantial contributions to the technology since the mid-1950s.

Two US patents field by Bedford and Hoft in 1971 and 1972 describe many of the essential features of the modern SRM, with true electronic commutation positively synchronized with rotor position [1]. Bedford and Hoft discussed rotor geometry as well as the circuit topology of the power electronic controller. However, this cannot be regarded as a master patent because the same electromagnetic and control principles were used on Davidson's machine.

Important milestones in the recent history include the axial-gab, thyristor-controlled motor built by Unnewehr and Koch of Ford Motor Company , and other works by Bausch [1].

In Europe the commercial potential of switched reluctance motor was realized by Byrne and Lawrenson [2,1] but the rapid exploitation and technical development by SRDL probably played the leading role in exciting interest in the technology especially in the early 80's. Among SRDL's early licensees, the best known is *Tasc Drives* (now Graseby Controls) who manufacture arange of general-purpose variable-speed switched-reluctance drives for industrial applications. These cast-iron framed motor have explosion- proof certification in the UK, and cover the range from 4kW to 80kW.

More recently products have been announced by *Allenwest Electrical, Prestwick, Scotland* (the *Motionmaster* range of industrial cast-iron framed motors from 4KW to 75KW, with Toshiba IGBT phaseleg modules developed specially for switched reluctance motors); and by *British Jeffrey Diamond*, a subsidiary of Dresser (flame proof mining motors and controllers at 35KW and 150KW,1100V). These products were displayed at the 1991 Total Solutions Exhibition at the UK National Exhibition center in Brimingham. *Raadioenergie* in France has also announced a switched reluctance drive for Low-voltage DC application [1].

In the United States the first commercial application was the *Hewlett-Packard* servo drive used in the *Draftmaster* Computer-Plotter. Konecny's description of this motor includes an account of the use of controlled saturation at the air gab to decrease the torque ripple. Later work by Stephenson confirmed the theoretical validity of this principle. The Hewlett-Packard motors are controlled by a special integrated circuit (the HCTL1000, subsequently replaced by the HCTL1100) which incorporates many advanced features and can also control brushless d.c. motors. *Semifusion* in Santa Clara, CA, subsequently developed several switched reluctance servo-drives using this IC.

It is difficult to be certain about the origin of the term "switched reluctance" but one of the earliest occurrences (1969) is in Nasar [3] in relation to a rudimentary disk motor employing switched direct current. Professor Lawrenson (1980) was perhaps the first to adopt the term in relation to the radial-air-gap motor [2] which is the focus of attention today. It may be also stated that terms such as "brushless reluctance motor" , "variable reluctance" , and "Commutated reluctance motor are among several equally acceptable alternatives that were in use long before this time. It could perhaps be most accurately described as a "statically Commutated doubly-salient vernier reluctance motor".

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COMPUTER AIDED DESIGN OF SWITCHED RELUCTANCE MOTOR

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