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Switched Reluctance Machine For A Starter-Alternator Micro-Hybrid Car

Sihem Saidani, Moez Ghariani
Laboratory of Electronics and Information Technology (LETI)
Electric Vehicle and Power Electronics Group (VEEP)
National School of Engineers of Sfax
B.P. 1173 3038 Sfax Tunisia
e-mail: sihem.saidani@yahoo.fr, moez.ghariani@isecs.rnu.tn

ABSTRACT

Living in a world where environment protection and energy conservation are the first worries, the development of hybrid vehicle seems to be an accelerated pace. There for, recent efforts are directed toward developing an improved propulsion system. One of the most valuable solutions is the starter alternators [19]. This paper presents an advanced development of a switched reluctance starter-alternator for a micro-hybrid vehicle. The performance, efficiency and torque characteristics of switched reluctance machines combined with its robust, low cost construction makes that technology an interesting alternative to other machine types chosen for traction applications especially starter/generator. This paper will provide an overview of the present status of hybrid vehicles worldwide and their state of the art, with emphasis on the engineering philosophy and key technologies. Using the Finite element method by the program FEMM we also present a model of switched reluctance machine 12/8 proposed for starter-alternator application.
Keywords—Hybrid Vehicle, Starter-Alternator, Switched Reluctance Machine, FEMM.

I. INTRODUCTION

The necessity to decrease fuel emissions and improve fuel economy of cars requires a big change in conventional structure used[20]. There for, the automotive industry has been investigating alternatives to conventional internal combustion engine powered vehicles in order to improve their fuel efficiency and to reduce their greenhouse gas emissions. In several instances, electric machines are integrated into the power train for the sole purpose of optimizing the energy delivery and recovery during vehicle propulsion. Hybrid electric vehicles are a key-piece of the future of the automotive industry. It has been demonstrated that Hybrid Vehicle (HV) offers benefits to fuel consumption, durability, and drivability to the end-user. The most realized version of the HV is the starter/alternator coupled to the internal combustion engine [10].

The starter generator replaces the conventional starter motor and the alternator (generator). It provides, beside its two basic functions (starter and alternator), an auxiliary one, as a convenient automatic vehicle start-stop system for further improved fuel efficiency.[11]

The following characteristics of the Switched Reluctance Machine [13] (SRM) had attracted researchers to investigate its potential for variable speed applications:

-Simplified construction with rotor consisting only a laminated steel

-Concentrated phase winding for only on the stator poles (independent phases command)

-Absence of permanent magnet, which gives high cost and low manufacturing

The fact of using a machine in such conditions, we can operate at high speed and high temperature operation since the rotor can act as a cooling source to the stator as higher reliability since each phase is electrically and magnetically independent.

For the first time we will describe the technology of hybrid vehicle and the use of starter alternator system. Next , we

As known; the finite element method (FEM) has been a powerful tool to solve many complex problems in electromagnetic especially for modeling machines. For the optimum design of switched reluctance motors, this paper presents the methods and results, which are calculated by the finite element analysis. First, the geometry and mechanical parameters of the machine are established, when a finite-element modeling (FEM) approach is initially developed to obtain the flux linkage/current/rotor position relationship so that the proper and mutual inductances and also its torque and field distribution characteristics can then be computed.

II. HYBRID VEHICLE

A hybrid electric vehicle is the kind of vehicle which combines conventional propulsion system, such as an internal combustion engine (ICE) and an electric propulsion system with a rechargeable energy storage system, such as batteries. Thus, Fuel consumption is minimized by turning off the internal combustion engine during idle and low of the car; we can recapture energy through regenerative breaking, which converts a portion of the vehicle's kinetic energy into electrical energy during breaking and stop events. These benefits lead to improved durability of the engine as a whole due to elimination of the strain on the internal combustion engine during idle events and braking [10]. The use of HV benefits the environment by reducing emissions, caused by reducing fuel consumption, and reducing noise pollution, by

using the electric motor at low speeds. Hybrid power trains use a conventional ICE in combination with an electric motor, a battery, and an electronic controller.
HV have two basic configurations: series and parallel hybrids.
In the series variant, the ICE is used to drive an alternator to generate electricity stored then in a battery system or sent directly to the electric motor in order to power the wheels. The efficiency of the engine is maximized because it operates within a narrow range of speeds. . Despite, the parallel hybrid vehicle has two power paths, so that either the IEC or the electric motor (or both) can be used to power the wheels directly. Like the series configuration, it can operate in zero-emission mode (power supplied solely via the electric motor).The Fig.1 describes the basic configurations of HV:

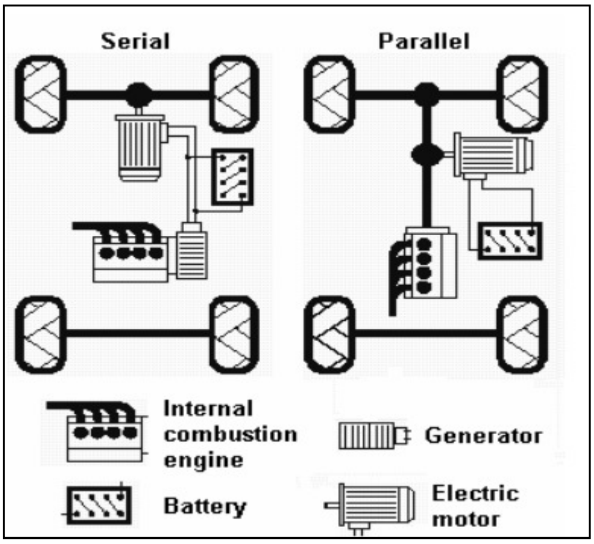

Fig . 1. The basic configurations of HV

As the electric motor and the battery provide additional power to the ICE, the fuel consumption is reduced without affecting power output. To further save fuel, the engine automatically stops when the vehicle comes to a stop, and starts again automatically when the accelerator is depressed. The battery is recharged using the energy captured during regenerative braking, relieving the IEC of doing all that work, and saving more fuel. A hybrid power train is completely self-sufficient, it doesn't need to be plugged in and charged up overnight. The mild hybrid cars are operated in a same manner as the full hybrids. Unlike a full hybrid, a mild hybrid has a much smaller battery than a full hybrid and cannot run on battery power alone.[12]

Clearly, a less expensive hybrid system is more likely to appeal to a greater number of mainstream consumers than would more robust and more expensive hybrid systems, at least in the initial phases of market development. As consumers gain a greater understanding of the differences in hybrid technologies, they will be better able to match their need for increased fuel mileage with the most cost-effective system. [21]

The concept of starter-alternator to the flywheel has been forwarded over the past several years. It is intended to provide the following functions:
-Starter for the thermal engine

-Generator for charging the car battery and supplying the on board equipment

-Acceleration assisting for the thermal engine

-Stop and go function to minimize the polluting emissions in urban traffic.

Because of their robustness, low price, good efficiency , high torque and speed capability, the doubly salient switched reluctance machines seems to be a good choice in comparison to classical synchronous or asynchronous machines for such application.

III. MOTOR SELECTION

The electric motor of a starter alternator system is desired to have a high starting torque for initial acceleration and then and high efficiency to extend the battery range and a wide operating speed range as generator. Some motors types have the inherent property of operating with large extended speeds such as excited dc motors is an but its the principal problems especially the commutators and brushes, that limit the maximum speed of the motor and create sparks which require expected maintenance.
With development of the power electronics and microprocessors, the frequency variable inverter/converter makes multiphase AC machines dominate the starter alternator system applications. Many types of machines have been used such as claw pole Lundell machine, induction machine, switched reluctance machine, permanent magnet machines.

III.1 The Lundell claw-pole machines

Having the same operating principle, the Lundell machine are synchronous machines. The stator is similar to other multiphase AC machines and a rotor consists of claw pole segments .The Lundell claw-pole machines are widely used as alternators in the automotive industry. The air gap flux can be adjusted by controlling field current..The power limitation (up to 2.5Kw AT 5000rpm) is caused by high-rotor leakage flux between claw poles when the axial-lamination length is increased. The classical Lundell machines still suffers from a power electromechanical efficiency, skin effect and high losses. Next , a comparison between other types of machines will show that starter-alternator application needs induction machine, permanent magnet and especially switched reluctance motors. [17]

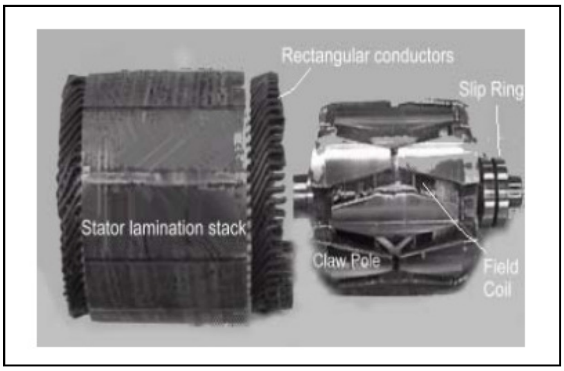

Fig.1 Lundell machine with dual field coils

III.2 Permanent Magnet Machines

The PM is a synchronous machine having the most efficient (due to the absence of field-coil losses) but the highest cost than the others motors used in drive applications. The PM has tow types a surface-mounted Pm and interior PM (IPM) which is better suited for starter alternator applications. The IPM machine can be can be used with Ld<Lq and Ld>Lq are shown in *Fig.2*, respectively. Due to the saliency, this machine is also called PM reluctance machine because it produces a reluctance torque in addition to main electromagnetic torque.[15]

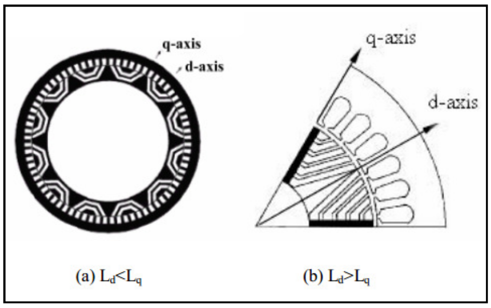

Fig.2 Interior Permanent Machine

III.3 Induction Machine (IM)

The induction machine has a high efficiency and smooth torque which able it usually used like a three-phase candidate for starter alternator application throw a dc inverter/converter. Despite her size and compared to PM and SRM, the IM seems to have the lowest power and efficiency.

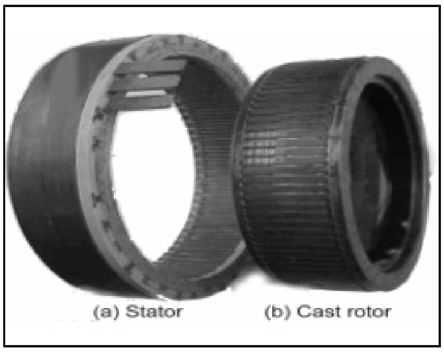

Fig.3 Induction Machine (IM)

The induction machine is allowed to run at the slip values corresponding to the maximum torques with frequency variation during cranking procedure because the cranking procedure is very short (0.2~3s). But the slip at the maximum torque causes low power factor and high machine losses .Thus, high reliability and low technological risk will make it the primary technology in the near future.

III.2 Switched Reluctance Machine (SRM)

The switched reluctance machine has high-speed operation capability with a wide constant power region. This motor is characterized by a high starting torque and efficiency similar to a high-efficiency IM.[5]
The rotor is so simple: without any windings or magnets, and is usually made by steel laminations in order to minimize the core losses. The SRM a is machine suited for harsh environments. Thus, the torque ripple, vibration, and acoustic noise are the most disadvantages of the SRM. The acoustic noise in SRMs are caused by the radial forces that increase inversely with the air gap and especially when the force frequency is near the stator resonant frequency.[16]
The switched reluctance machine is excited by current pulses applied independently to each phase. The current pulses are applied on precise rotor position and the motor creates torque in the direction of increasing inductance.
In Fig.4, we represent :the torque is positive when $dL/d\theta>0$ from θ1 to θ2, and the SRM so it is the motoring mode. shown in Fig.4.[17]

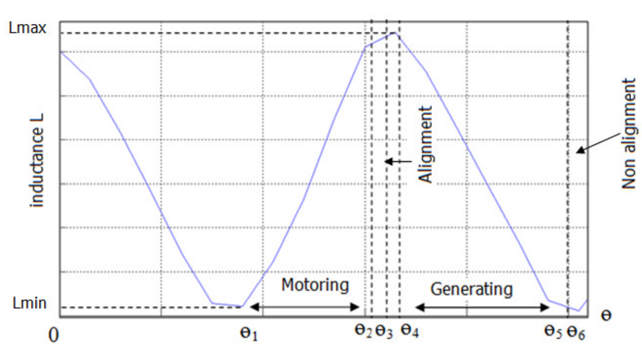

Fig.4 Inductance vs. rotor position angle

The torque ripple, vibration and acoustic noise are the most disadvantages of the SRM. The torque ripple can be reduced via controlling the current by the switching angles where we

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include conduction angle, switching-on and –off position. A wide choice of pole configurations and phase numbers are possible with SRMs. Lower number of phases even it can reduce the converter cost, but it increases the torque ripple for example as three phases 12/8 poles is better than 3 phases 6/4 poles .

IV. FINITE-ELEMENT ANALYSIS OF SRM

Determining the magnetic characteristics is the key of optimization and controlling a switched reluctance machine. We define next the method used and the

IV.1 FINITE ELEMENT METHOD (FEM)

THE finite element method has become a practical method for solving electromagnetic problems. It has been one method of the widely methods used to study the SR machines [1]. Thus, to simplify complex geometries such us motors, we have to break down the problem into small regions (Fig. 5*)*.

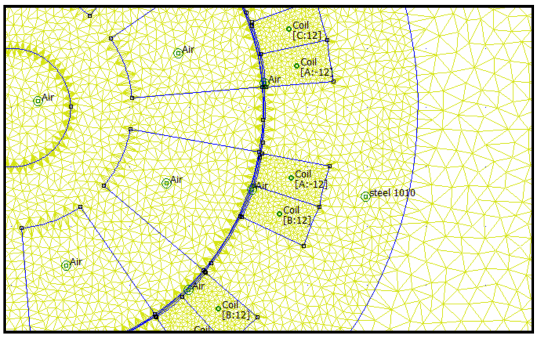

Fig.5 triangulation of the SR machine

Many tools of finite elements have been developed last years in order to compute the accurate properties and magnetic characteristics of machine without constructing a real prototype. FEMME is a program that can solve electromagnetic problems on 2D (two –dimensional planar). Thus, we can resolve linear and nonlinear magnetostatic, harmonic magnetic, linear electrostatic and steady state heat problems. The determination of magnetic characteristics facilitates the optimization and control of switched reluctance machine. [3]

In particular, the switched reluctance machine phase magnetization characteristics vary hardly as a function of both excitation current and rotor position. Thus, numerical methods must be used in order to calculate the magnetic field and to predict the magnetization characteristics.[4]

IV.2 RESULTS

The switched reluctance machine has both salient poles in stator and rotor. Each phase has a number of combinations from those we choose 12/8. Every winding phase are mounted around stator poles diametrically opposite: A-A,B-B,C-C…(*Fig.6*).

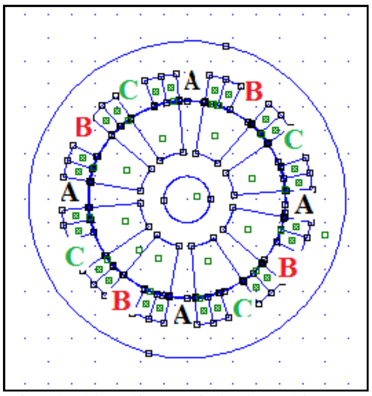

Fig.6 A double salient switched machine (12/8)

We have to name air gap as "air" (Fig.7). Also it must be emphasized that in each phase input and outputs *shown* (Fig.6) as A+, B+, C-, C+…[1]and the number of winding must also be written such *as 10,50,…(12 in our cas:Fig.7)* Each part of the machine (Fig.7) are named according to the metals used such as M–45 steel, stainless steel...(show in Fig.8) and the windings must also be marked as "coil" since the drawings.

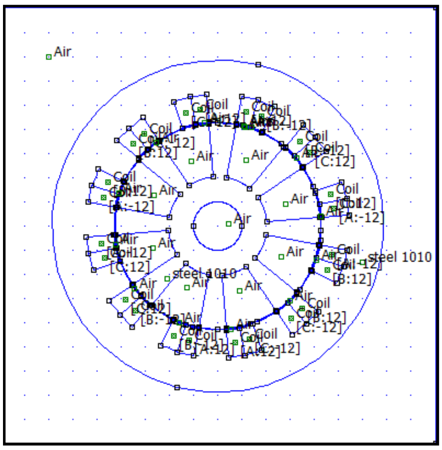

Fig.7 A 12/8- pole switched reluctance machine

The dimensions of the switched reluctance motor are next in table 1. :

Table1.geometry of SR machine 12/8

	SR machine Model
Stator outer diameter	137(mm)
Stator inner diameter	85(mm)
Stator teeth length	22(mm)
Rotor outer diameter	42.48(mm)
Air gap	0.325(mm)
Number of turns	12
Stator pole arc	30(°)
Rotor pole arc	45(°)
Rotor teeth length	18.02(mm)

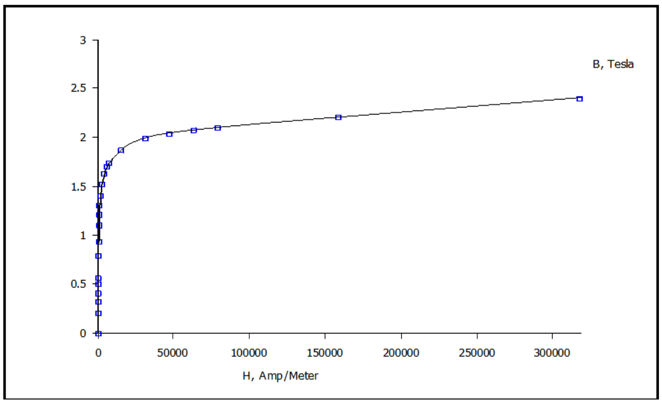

Fig.8 Magnetization cure of 1010 Steel

The SR machine has neither winding nor magnet on the rotor. The SR machine tends to operate on the minimum reluctance law [2]. The torque is produced when we have an reluctance variation among the magnetic circuit: the stator windings are excited of voltage or current at each phase independently so that each tries to attract the closest rotor pole toward the alignment of the poles.

The induction L(□) is calculated by using the coenergy W stored of the machine given by the next equation:

$$W=1/2*L(\square).i^2$$

The inductance profile for on phase is shown in Fig. 9. The current excitation of the phases is synchronized with the inductance region for climbing positive (motoring) torque and with the decreasing inductance region (generating). [8]

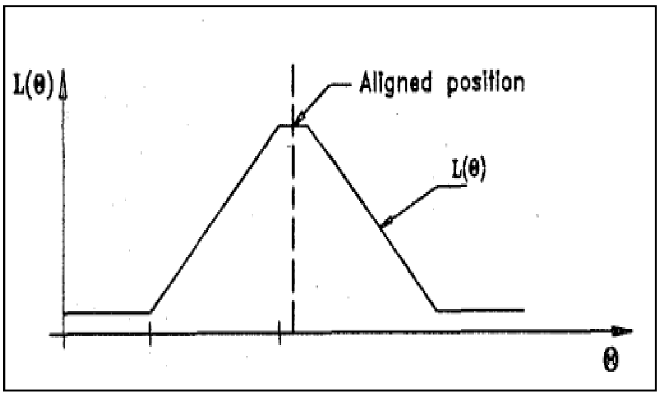

Fig.9the idealized inductance profile

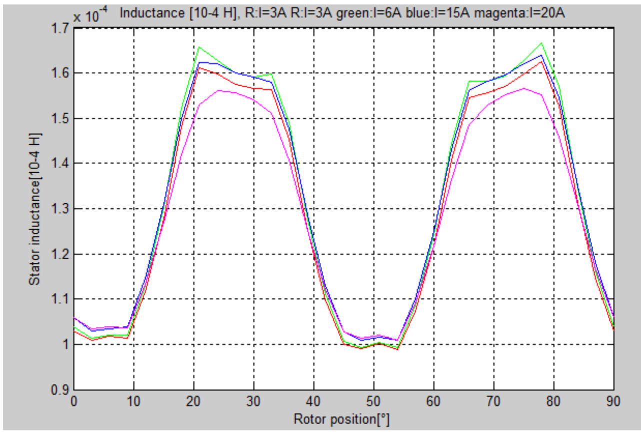

Fig.10 Inductance profiles for different currents

To control the operating mode of the switched machine (motor or generator) we have to calculate the maximum L_{max} and the minimum inductance L_{min} using the relations:

$L_{max}=3/2Ld$
$L_{min}=3/2Lq$

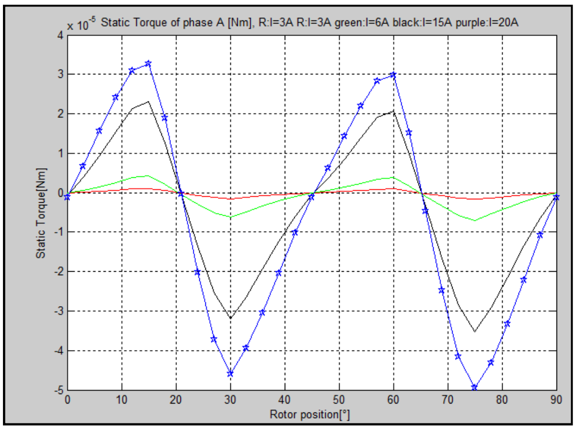

Fig.11 Static Torque (phase A) for different current excitation

Looking at Fig.11, the torque is positive (motoring) between 0° and 22.5° and negative between 22.5 and 45°.We can use these result to control each operating mode.

The simulation of the machine with alternative currents we represent next the flux distribution (Fig.12).

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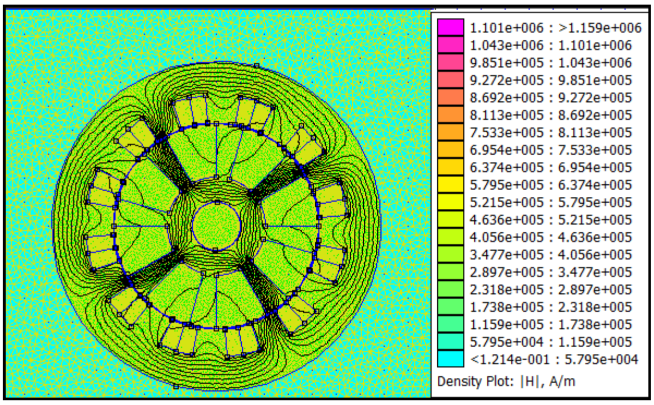

Fig.12 The flux distribution due to an excitation of one phase

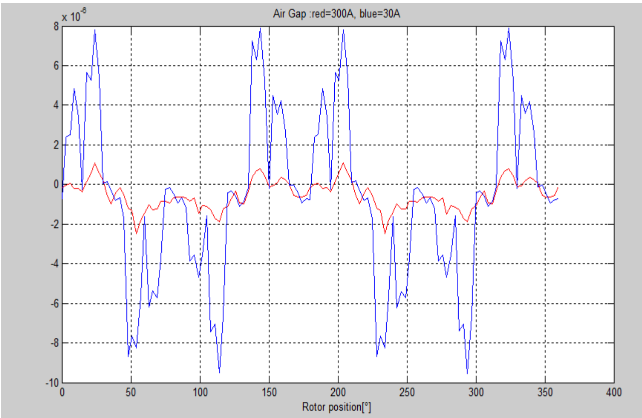

Fig.13 The flux in air gap

V. CONCLUSION

This paper presented the use of the switched reluctance in hybrid vehicle as a starter alternator application. The control of such machine leads to a study its electromagnetic characteristics from its two-dimensional finite element method using FEMM. The model of 12/8 SR machine will enable us in the next work to develop a control strategy in a SIMULINK /MATLAB to optimize the characteristics of the alternator in order to avoid the acoustic noise produced by stator vibrations in operating mode.[6]

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