DESIGN, COMPARISON AND OPTIMISATION OF PERMANENT MAGNET FLUX SWITCHING MOTOR (PMFSM) WITH VARIOUS SLOT POLE CONFIGURATION

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DEDICATION

Dedicated to

My beloved family father and mother,

Sisters, brothers, uncles and my friends.

Thank you for your love, prayer, and support.

I love you all deeply

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ABSTRACT

This project report is about comparison between conventional permanent magnet flux switching machine (PMFSM) with double stator flux switching machine (DS-PMFSM). Due to the unique design of double stator single rotor motor itself, many research has been developed but not being compare to different kind of motor. The purpose of this study is to observe the capability of each different motor. The test will be also conducted in no load and load situations. Result each of the motor will be compare. JMAG design 16 is being use as a platform to develop both motor. Although both machine is silent pole type motor, each of them have a different topology and characteristic. By using JMAG, each of the motor is been constructed, starting from JMAG sketch that are used to sketch the motor topology. The both motor topology need to be almost the same with different in stator design. After that, by using JMAG designer, both electrical motor material, condition circuit, mesh value and properties have to be exactly the same as dimmed variable. Thus an in depth study is about the performance of both motor is conducted. Result shows that under no load condition the DS-PMFSM has a lower cogging torque then conventional PMFSM. Beside that went compare with flux line, flux density and induce EMF conventional PMFSM have advantage over DS-PMFSM. Went both motor is test with load test, it is show a large performance gap. Load test shown that conventional PMFSM has a higher torque, power and speed went compare. Result conclude that conventional PMFSM has a better performance in all the load test and in flux line, flux density, induce EMF for no load. However, DS-PMFSM has an advantage in cogging torque with lower cogging and reduce noise. Although the 12S/14P motor is selected for securing the initial highest torque of 11.5 Nm and achieved the target average torque/power after using parameter optimisation method (POM).

ABSTRAK

Memandangkan motors magnet kekal (PM) telah menarik perhatian penyelidikan yang ketara kerana ketumpatan kuasa tinggi mereka, prestasi cemerlang, kebolehpercayaan yang rendah, kebolehpercayaan yang tinggi, kawalan yang sangat baik dan telah digunakan secara meluas dalam pelbagai aplikasi sedia ada dan yang baru muncul. Laporan projek ini adalah mengenai perbandingan antara motor bergigi salient dan segmen. Reka bentuk slot tersebut dipanggil PMFSM 12S / 10P salient dan segmen PMFSM 12S / 14P. Kedua-dua kombinasi ini dipilih dengan menganalisis nilai kuasa tertinggi dan tork melalui analisis pada tiang. Reka bentuk yang dicadangkan telah dibincangkan secara ringkas mengenai pembangunan topologi, penetapan bahan dan ciri-ciri bahan yang digunakan.Beberapa analisis telah dijalankan seperti menggerakkan emf, tork cogging, kuasa keluaran dan tork, dan kelajuan motor yang dicadangkan. Kajian ini dijalankan dengang menggunakan perisian JMAG Designer versi 16 Kedua-dua motor yang mempunyai saiz stator yang sama. Ujian ini dilakukan di bawah keadaan ada beban dan tiada beban untuk menilai prestasi awal reka bentuk yang dicadangkan. Hasil simulasi menunjukkan bahawa motor bergigi 12S / 10P salient menghasilkan tork yang lebih tinggi, kerana kita tahu bahawa semakin tinggi fluk terhasil maka semakin tinggi nilai tork pada motor tersebut. Oleh itu, matlamat kami untuk projek ini adalah untuk mencadangkan motor segmen PMFSM 12S / 14P bagi mengurangkan back-emf, dan cogging tork. Beberapa kelebihan rotor Segmental adalah laluan fluks yang pendek, pautan fluks yang tinggi, dan prestasi yang lebih baik dari segi kelebihan emf dan tork cogging yang rendah. Walau yang demikian,, motor 12S/14P terpilih kerana tork permulaan yang tertinggi iaitu 11.5Nm dan mencapai tahap purata tork setelah mengaplikasikan kaedah pengoptimum parameter (POM).

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Flux-switching machine (FSM) is a novel kind of machine in which both excitation flux and armature windings are located on the stator, its rotor is a single piece of iron. Flux switching machines can be divided into three permanent groups such as permanent magnet (PM) FSMs, field excitation (FE) FSMs as well hybrid excitation (HE) FSMs. While PMFSM utilizes PM flux source, Field excitation utilizes field coil and hybrid utilizes both PM and FE flux source as main and secondary source. Between these FSMs FEFSM offers benefits of less cost-effective, simple designs and variable flux Control capabilities options for various services. [1][2]. The Flux- Switching Permanent magnet (PM) motor is a new brushless machine with magnets in the stator. For brushless alternating current (BLAC) operation, it is desirable to make the machine with the back EMF waveform as sinusoidal as possible to eliminate torque ripple [3]. Some special steps are usually applied to PM-rotor motors, for example to create magnets that produce complexity and cost generation, to eject throwing magnets or slits [4]. However, especially for stator-PM motors in Doubly Salient Permanent Magnet (DSPM) motors, since the magnets are present in the stator, there is no winding or magnet in the rotor and the rotor can easily be tilted to change the back-EMF waveform, but the back-EMF peak is reduced. Fortunately, for the (PM) FSM motor developed, the rear EMF can be naturally sinusoidal without any additional steps that have the advantage of this motor.

Nowadays, permanent magnet (PM) machine has attracted considerable interest in research and has been widely used in various existing and emerging applications, due to their advantages such as high power density, excellent performance, low reliability, high reliability and superior control.[5,6] There are generally two types of electromagnetic torque in PM-PM machines. The PM torque generated by the interaction between the PM Field and the armature winding and the reluctance torque generated by the variation of the inductance of the PM winding with the rotor position due to rotor [7, 8]: For this reason, PM- brushless machines are preferred to ensure that both the PM and the break torque are suitably used to improve overall machine performance [10]. In most conventional PM machines, the armature windings are mounted on the stator, while the PM is positioned differently on the rotor to carry a wide range of machines, [9]. However, new brushless PM machines with both armature winding and PMs are also proposed and developed. The three-phase version was first reported in 1997, but in 1955 the PM flux switching machine (PFMS) was first introduced as a single-phase alternator. PMFS machine inherits the highest benefits Traditional PM brushless machines. In the PMFS machine a typical double remarkable building with a simple passive rotor but rather a complex stator. The mechanically robust rotor is identical to that of a switched reluctance machine, resulting in a rapid dynamic response [11].

Motors and generators are very similar. Generators convert the mechanical energy into electricity and the motor converts the electrical energy into mechanical energy. In addition, motors and generators have the same structure [12]. Nevertheless the back EMF is the voltage generated during operation of a rotating machine [13]. In a generator motor, when the voltage (an electromotive force) is applied to the armature of a motor, it starts to rotate and an electrical resistance is generated by the rotating magnetic field. [14] Furthermore the back EMF is proportional to the acceleration of free load, it also creates opposing forces that limits the engine speed, the higher the armature, the greater the back EMF is made [15].

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1.2 Problem Statement

The Design of 12S/10P PMFSM in salient pole with various slot pole configuration has been and will be developed in inner rotor configuration; it as well had been optimized for improved induced EMF. It embraced all stator teeth armature winding with permanent magnets sandwiched between stator teeth in circumferential magnetisation direction [16]. One of the advantages of this motor is that the phase back EMF waveform tends to be naturally sinusoidal without any such measures. The performance in terms of power and efficiency of this motor seems to be low due to high iron loss, high copper loss. In addition, stator design is complex while it embraced high volume of PM which might make the construction of the motor costing. In order to overcome these challenges associated with the above-mentioned motor, 12S/14P PMFSM in segmental rotor is proposed. It consists of alternate armature winding and embracing alternate permanent magnet radial magnetisation direction [17]. Segmental rotor has the advantages of short flux path generating high flux linkage, for better performance in terms of low cogging torque and favourable induced back EMF.

1.3 Objectives of Project

In this project, the main objectives have been formed as follows;

(i) To design a three phase 12S/10P PMFSM salient and 12S/14P PMFSM SegIR-PMFSM.
(ii) To analyse and compare the three phase 12S/10P PMFSM salient and 12S/14P SegIR-PMFSM.
(iii) To optimise 12S/14P SegIR-PMFSM using parameter optimisation method (POM) for better average torque and power, torque-speed characteristics.

1.4 Scope of Study

The scopes of this project are as follows:

(i) This project is designed by using JMAG Design Version 16 software, released by Japan Research Institute (JRI) was utilized for this design.

(ii) A three phase 12S/10P PMFSM in salient and 12S/14P SegIR- PMFSM will be designed.

(iii) Analyse and compare three phase of 12S/10P PMFSM in salient and 12S/14P SegIR- PMFSM will be analysed.

(iv) Optimise of SegIR-PMFSM is detected using parameter optimisation method (POM) for better average torque and power.

(v) The rated speed of the drive machine is approximately 1500rpm as mentioned in table1.1.

Table 1.1: Specifications of parameters of both motors and optimised

Items	Units	12S/10P PMFSM Salient pole	12S/14P SegIR-PMFSM	Optimised 12S/14P SegIR-PMFSM
Rated speed, nr	rpm	1500	1500	1500
dc-link voltage,	V	440	440	440
Phase number,	m	3	3	3
Air-gap length	mm	0.35	0.35	0.35
PM height	mm	28.8	28.8	29.8
PM width	mm	4.6	4.6	4.44
Stator outer diameter	mm	128	128	128
Active stack length	mm	25	25	25
Rotor inner radius	mm	22	22	21
Rotor outer radius	mm	34.85	34.85	33.85
Stator tooth number	mm	12	12	12
RMS current density, Ja	A/mm2	30	30	30

CHAPTER 2

REVIEW OF FLUX SWITCHING MOTORS

2.1 Introduction to electrical Motors

Electric motors are electromechanical devices that convert electrical energy into mechanical energy. This transformation is usually obtained by the generation of a Magnetic field by means of a current flowing in one or more coils. It is the interface between the electrical and mechanical systems of a facility. Electric motors are an important part of any electrical system. They consumed in every production plant, every office, houses and consumed about 64% of the total electricity. Electric motors are devices that carry one of the greatest advances in engineering and technology since the creation of electricity. There are various motor types that have been developed for specific purposes; different types of electrical motors can be classified according to the shown figure 2.1. In principles, electric motors are divided into two groups, such as direct current (DC) and alternating current (AC). There are four types in alternating currents which are flux switching machine (FSM), switch reluctance motor (SRM), synchronous motor (SM), induction motor (IM). Synchronous motors are divided into three hybrid excitation (HE), field excitation (FE), permanent magnet (PM). While flux switching machine (FSM) are separated into three as well which are Permanent Magnet Flux Switching Machine (PMFSM), Hybrid Excitation Flux Switching Machine (HEFSM), and Field Excitation Flux Switching Machine (FEFSM).

Electromagnetic is the basis of an electric motor. Electric motors are completely motors of magnets and electric motors do usually operate based on the interaction between electric motor's with magnetic fields and electricity generating energy in the motor.

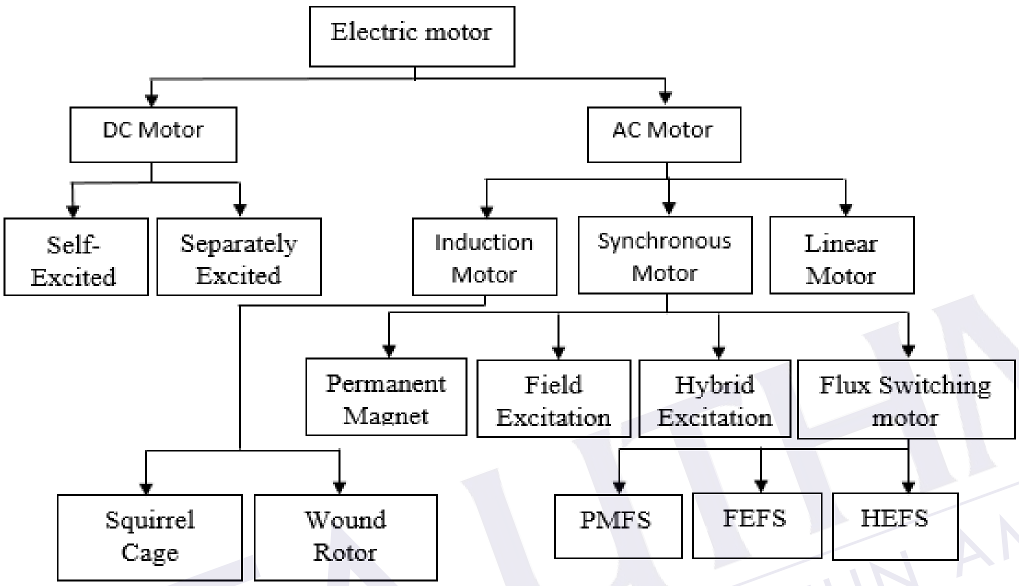

Figure 2.1: classification of electric motor.

2.2 Flux switching motor and operation principle

In search of an electric machine with improved performance and high frequency, Rauch & Johnson [18] developed a flux switch generator using a PM flux source located on a flux switch stator [19], which is known as a "flux switch machine. '. The FSM is a synchronous machine in which the armature flux linkage changes with the rotor position due to the change in presence seen by the armature windings [20].

This machine consists of a pair of stator windings, a double set of laminated yokes and a pair of PMs located on the stator, while the rotor is a double pole plate on the shaft, as shown in Figure 2.2. The flow paths shown by arrows in Figure 2.2 (a) show the flow from left to right in both windings. However, when the rotor position moves half an electrical cycle, as in Figure 2.2 (b), the flux linkage had the same magnitude, but the direction was reversed, as in Figure 2.2 (a). A complete reversal of the flow direction was achieved with each revolution of the rotor. Consequently, the salient pole of the stationary part and the rotor operated in the usual pulsating flow regime. In the proposed motor, without changing the basic characteristics, the protruding rotor of the PM inductor is replaced by a segmented rotor. Therefore, the principle of operation based on the original design and development of the PMFSM, which locates the PM flux source and the stator armature winding in the inductor generator, is the same.

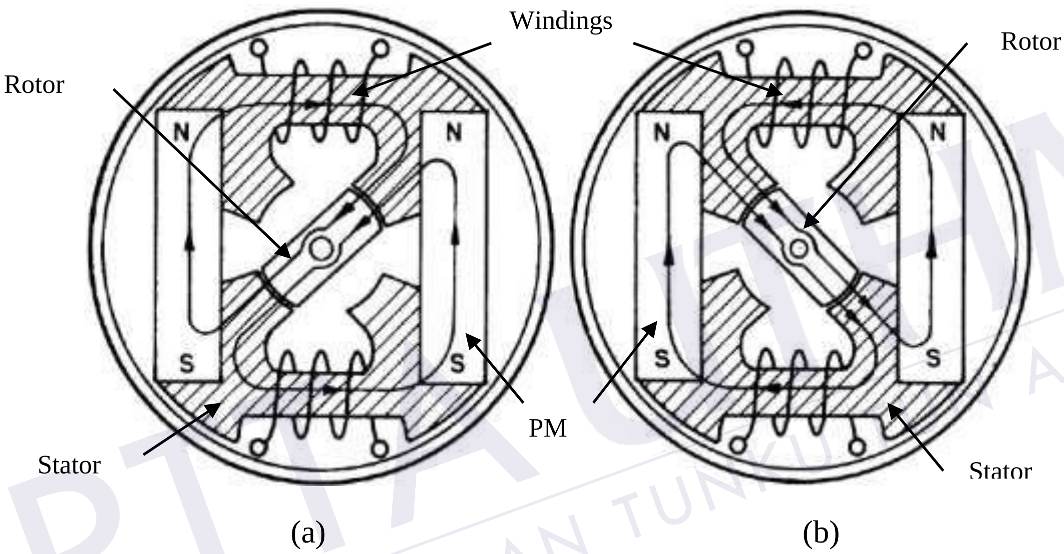

Figure 2.2: Single-phase 4S/2P flux switch alternator (inner rotor).

The automaton has three internal types arising from sources of excitation, which are designated as; Permanent magnet state machine, field excited state machine, and hybrid excited state machine. The PMFSM uses a permanent magnet (PM) as the excitation source, the FEFSM uses an n-field excitation coil, and the HEFSM uses both PM and FE as primary and secondary sources. In addition, both the FEFSM and HEFSM require external circuitry and DC excitation. Interestingly, the FSM was founded with good advantages in terms of design, torque, efficiency and thermal management. Unlike machines in which materials are on the rotor, in this machine all materials are placed on the stator [21]. Taking into account the favourable characteristics of state machines, research and development thus continue to improve the performance of electric motors in terms of high torque, increased accuracy, less starting energy use, and less heat loss for efficient output.

2.3 Review of flux switching motors (FSMs)

The concept of permanent magnet switch flux (FSPM) was published in the 1950s. Over the last decade many new topologies and new FSMs has been developed for a variety of applications, ranging from financial devices, cars, wind and aviation as well [22]. The FSPM machine offers several potential advantages over conventional PM concrete machines that use a magnet on the rotor. The structure of the FSPM engine is relatively simple and consists of steel piles with salient poles. FSPM machines have shown advantages over SPM engines for high-speed generator applications, due mainly to a reduction in magnetic retention problems during high-speed operation [23]. In addition, FSPM machines have been engineered to achieve attractive torque densities that are superior to other types of PM doubly-salient motors [24]. The advantages and disadvantages of FSM are considered and listed in table 2.1.

Table 2.1: Advantages and disadvantages of FSM

Advantages	Disadvantages
i. Simple and robust rotor structure suitable for high speed applications.	i. Reduced copper slot area in stator.
ii. Easy to manage magnet temperature rise as all active parts are located in the stator.	ii. Low over-load capability due to heavy saturation.
iii. Flux focusing / low cost ferrite magnets can also be used.	iii. Complicated stator.
iv. Sinusoidal back-emf waveform which is suitable for brushless AC operation.	iv. Flux leakage outside stator.
	v. High magnet volume for PMFSM

2.4 Classification of flux switching machine (FSM)

In general, the FSMs can be divided into three groups, permanent magnet flux switching machine (PMFSM), field excitation flux switching machine (FEFSM), and hybrid excitation flux switching machine (HEFSM). Both PMFSM and FEFSM has only PM and field excitation coil (FEC), respectively as their main flux sources, while HEFSM combines both PM and FEC as their main flux sources. Figure 2.3 shows the general classification of FSM.

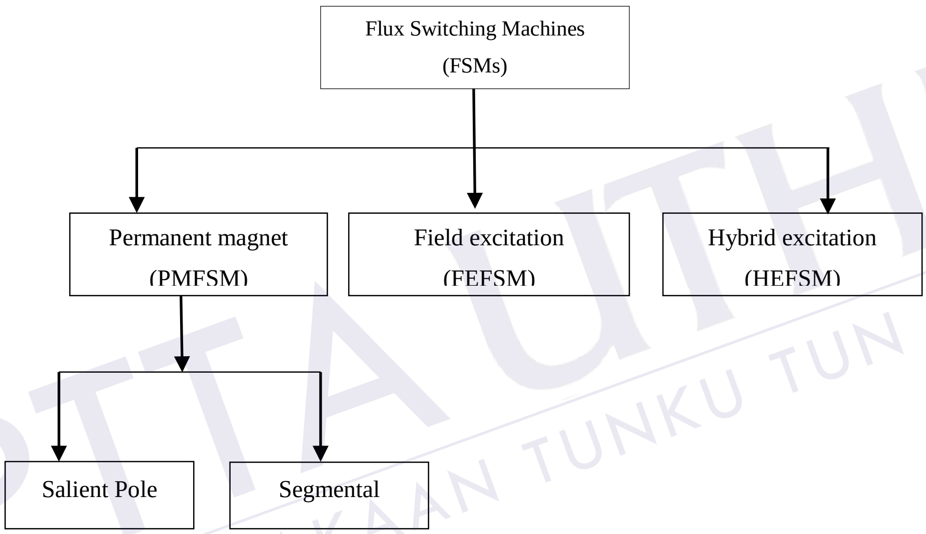

Figure 2.3: Classification of flux switching machine (FSMs)

2.4.1 Permanent Magnet Flux Switching Machine (PMFSM)

Permanent magnet flux machines (PMFSM) have a short history and have been researched for several decades. And this is a relatively new category of electric motors. The main PMFSM model was described in [25]. Where Rauch and Johnson proposed a new type of motor with permanent magnets placed in the stator. Typically, these machines have an important salient rotor with poles and PMs, which are stationed in the stator. PMFSM is very similar to the (DSPM) machine (Double salient Permanent magnet) or to the (FRM) flux reversal machine [26]. However, the conventional

PMFSM has a relatively weak flux weakness due to fixed magnetic flux, which requires existing armature winding current controllers to work in an increasingly weak range. By using a negative d-axis current, the PM flux can be overcome, thereby reducing the density of the magnetic flux. However, the disadvantages of increasing the loss of copper can reduce efficiency, and the possibility of non-recoverable demagnetization by the PM is difficult to overcome. A new 12S-10P PMFSM structure to provide interesting features [27].

Permanent magnet motors based on the principle of flux switching have been studied for decades. Generally, such a machine has a salient pole rotor and PM housed in the stator. [28] And [29] describe three-phase FSM based on the principle of homopolar flux and bipolar flux, respectively, in [30], new types of single-phase and three-phase PMFSM were reported respectively, in which a pair of PMs are embedded in the stator. In addition, in [31], the performance of the Law relay is proposed, a limited angle actuator type magnetic flux actuator. Various examples of three-phase PMFSM are shown in Figure 2.4.

Figure 2.4 (a) shows a special three-phase 12S-10P PMFSM, in which the salient pole stator core is composed of a modular U-shaped lamination, the lamination and the circular magnetic PM phase placed between them adjacent. For the principle of magnetic flux transfer, the polarity of PM magnetization is reversed from one magnet to another. The stator armature winding consists of a thicker coil, and each coil is wounded around the stator tooth formed by two adjacent laminations parts and a magnet. In the same figure, all phases of the armature coil (for example, A1, B1, C1, A2, B2 and C2) have the same winding configuration and are placed in the stator core to form 12 winding slots. Salient pole rotor is similar to SRMs, which is stronger and more suitable for high-speed applications, and the difference between the number of rotor poles and the number of stator teeth is two. Compared with conventional IPMSM, when the magnet moves from the rotor to the stator, the gap area is reduced, it is easier to remove heat from the stator, and the temperature rise in the magnet can be controlled by a suitable cooling system. In addition, because the armature windings, the flux path generated by the PM are connected magnetically in parallel, and not in series like traditional IPMSM, the effect of the armature reaction field at the PM operating point is almost eliminated. And to that, the electrical load and torque of PMFSM can be increased. On top of that, high pre-unit winding inductance can be easily obtained. Therefore, such a machine is very suitable for running with constant power operation strength at various speed range, that is, it can have a high flux-weakening ability [32]. Just like fractional PM motors without overlapping windings, spare pole wound windings can also be used in the three-phase PMFSM 12S-10P to achieve tolerable PMFSM. The armature windings from Fig. 2.4 (a) are reduced by releasing A2, B2 and C2 to form a total of 6 armature windings as shown in Fig. 2.2(b) [33].

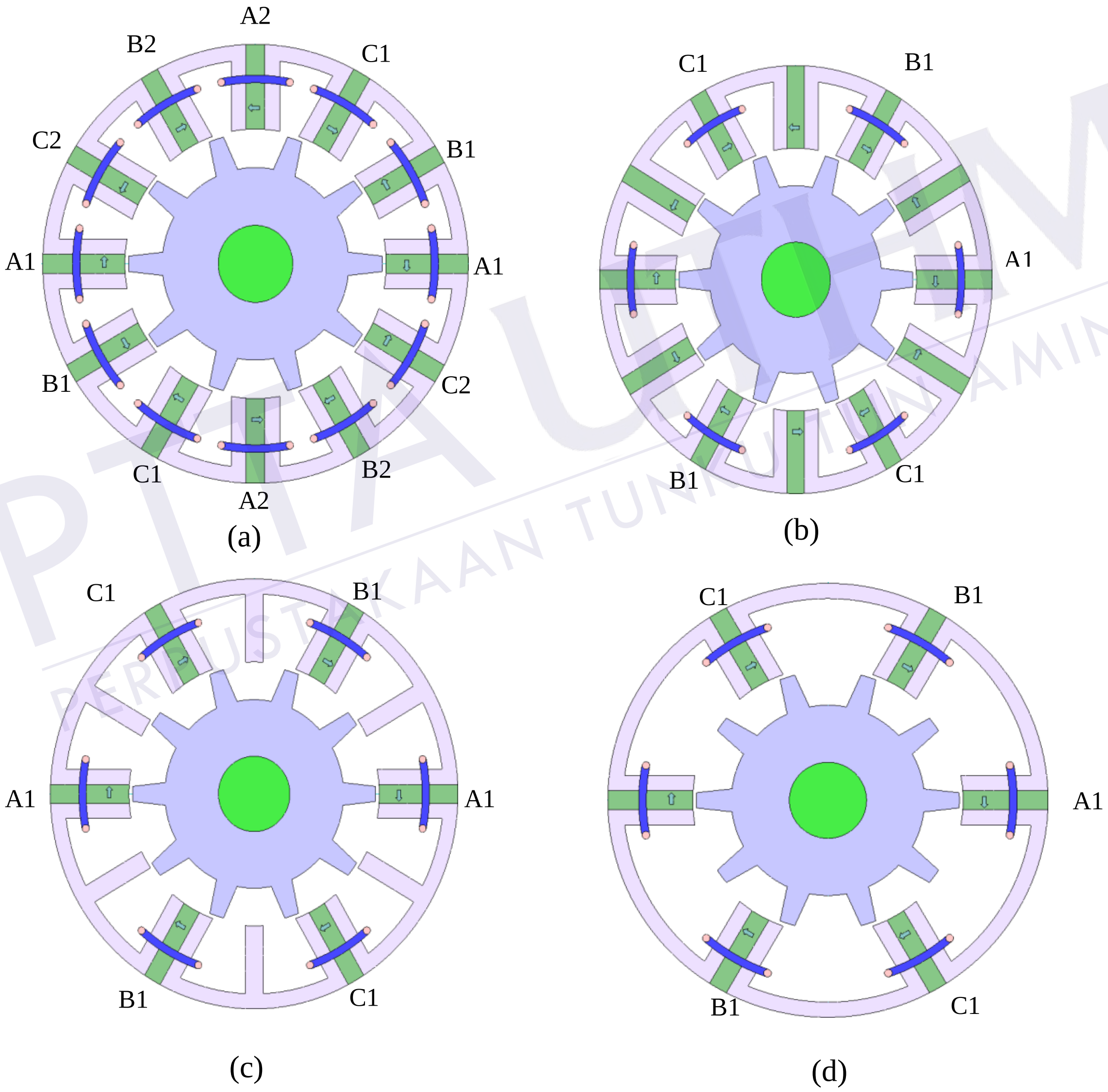

Figure 2.4: Examples of PMFSMs (a) 12S-10P PMFSM (b) Fault-tolerance PMFSM (c) E-core PMFSM (d) C-core PMFSM

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