Design of an Integrated Modular Motor Drive

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Abstract

**In this study, design of an Integrated Modular Motor Drive (IMMD) is performed. The design is based on a modular fractional slot concentrated winding permanent magnet synchronous machine (FSCW-PMSM) and power stage with gallium nitride (GaN) power field effect transistors (FETs). Suitable slot/pole combination and winding configuration are obtained to maximize the stator winding factor as well as reduce the space harmonics on the modular motor. Optimum selection of number of series and parallel motor drive modules is achieved and power device selection is performed based on loss characterization. The performance of the system is obtained with Ansys/Maxwell for the motor and with MATLAB/Simulink for the power stage. The efficiency of the motor drive is enhanced by 2% compared to a conventional motor drive power stage. Power density values larger than 15 W/cm3 has been achieved which is not attainable with conventional motor drive systems.**

# 1. Introduction

In conventional motor drive systems, the drive units are placed in separate cabinets which increases the overall weight and volume of the system and decreases the power density of the system. Furthermore, the drive units are connected to the motor by means of long cables which causes transient voltage overshoots due to the high frequency pulse width modulation (PWM) operation.

A novel concept called Integrated Modular Motor Drives (IMMDs) has been proposed in the last few years suggesting that all the components of the motor drive system can be integrated onto the motor including power electronics, control electronics, passive components and heat sink (ref). By doing so, the power density of the system can be enhanced significantly which is very critical in aerospace and electric traction applications (ref). In addition to that, cost reduction up to 20% is possible thanks to the elimination of enclosures and connection equipment (ref). Moreover, the absence of connection cables yields less leakage current on the winding insulation which will extend the lifespan of the motor as well as minimize electromagnetic interference (EMI) problems (ref).

In addition, the overall system is segmented with modules sharing the total power equally. By this way, the fault tolerance of the system is increased (ref). The current and voltage ratings of the power semiconductor devices can also be decreased by modularization. Moreover, the components which produce heat due to power loss are spread and distributed in a wider surface area which makes the thermal design more convenient as well as decreases the possible of hot spot formation (ref). Finally, the manufacturing, installation and maintenance costs are considered to decrease thanks to the modular structure (ref).

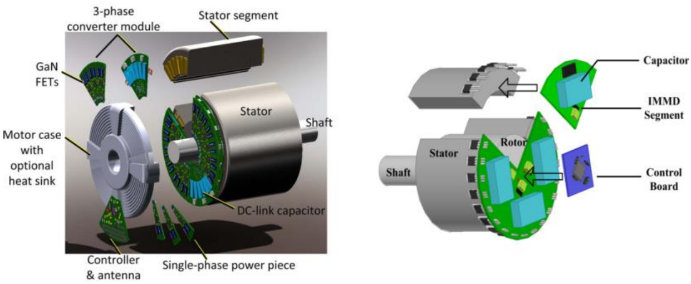
Integration of the motor and drive also brings several challenges. Firstly, fitting all the drive components to the available space requires size optimization and careful layout design (ref). Second, it is difficult to cool the motor and drive simultaneously since they both produce heat (ref). Furthermore, all the electronic components are subjected to a higher ambient temperature and continuous vibration and should be selected accordingly (ref).

To overcome these challenges, it has been proposed in the literature that wide band gap (WBG) power semiconductor devices such as Gallium Nitride (GaN) can be used which are capable of operating at high frequencies (ref). By doing so, the size of the passive components can be reduced as well as the size of the heat sink thanks to superior efficiency values (ref). On the other hand, high frequency operation highlights the parasitic components on the power stage and gate drive circuits which makes layout design critical (ref).

In this paper, design of an IMMD system is presented with enhanced power density, increased efficiency and enhanced fault tolerance capability. In Section 2, basic structure and current technology prospects of IMMDs are introduced. In section 3, design of the system including the motor and the drive is explained. In section 4, simulation results are presented and in section 5, conclusions are given.

**2. Basic Structure of IMMD**

There are several types of integration of the motor drive onto the motor. In this paper, integration into the stator back iron is considered, which also allows the modularization of the system. In this configuration, one module is composed of a stator pole piece, a concentrated coil and a power converter dedicated to its own winding along with its controller. Examples of such a structure can be seen in Fig. 1 (ref).



**Fig. 1.** IMMDs with stator back-iron integration (ref)

Each stator winding belonging to different pole pairs on the stator are usually connected in series to form one phase of the stator in conventional motors. On the other hand, the windings in different poles can be connected to separate motor drive units in modular motors. These types of motors are also called split-winding motors (ref) and the redundancy and fault tolerance of the system is enhanced thanks to this modularization. Moreover, the motor drive modules can be connected with different configurations which makes the design more flexible.

A general block diagram of one module of an IMMD system is shown in Fig. 2 (ref).

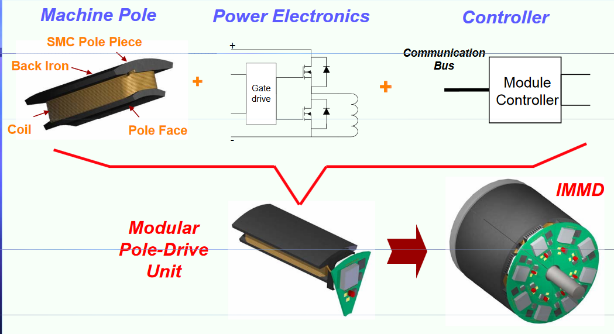


Fig. 2. A general block diagram of an IMMD (ref)

Concentrated windings are preferred for their easy manufacturing and suitability for split-winding stators, especially in modular motors. Fractional slot concentrated winding (FSCW) permanent magnet synchronous motors (PMSMs) are very common in IMMD studies thanks to their high power density, high torque density, low cogging torque and good fault tolerance capability (ref).

Motor sürücü çeviricileri için, sistemin çalışma değerlerine bağlı olarak çeşitli topolojiler ortaya atılmıştır. TMMS’lerde çok sayıdaki motor sürücü parçalarının DA bara üzerinde seri ve/veya paralel olarak bağlanabilmesi ile bu topolojiler büyük oranda çeşitlendirilebilmektedir. Şekil 2’de geleneksel motor sürücü yapısı ve ayrık sargılı motor yapısı farklı tipte çevirici bağlantıları için gösterilmiştir [8]. Ayrıca, ayrık sargı yapısından dolayı sürücülerin bağlandığı yükün doğası gereği izole olması sayesinde çeviriciler arasında dolaşım akımları oluşmamaktadır. Yüksek DA bara gerilimi olduğu durumda bu özellik kullanılarak, düşük gerilim değerlerine sahip yarıiletken anahtarların kullanılması ile oluşturulan sürücü parçaları DA bara üzerinde seri bağlanabilmektedir. Bu durum, yeni nesil yüksek güç yarıiletkenlerinin (GaN gibi) motor sürücülerde kullanılmasına olanak vermiştir.

TMMS uygulamaları WBG yarıiletkenlerinin kullanımına oldukça uygundur, çünkü bu tip yarıiletkenler düşük iletim durumu direncine, yüksek anahtarlama hızına ve yüksek maksimum jonksiyon sıcaklığına sahiptirler. Geleneksel yarıiletkenlerle (IGBT gibi) yapılan yüksek güç uygulamalarında anahtarlama frekansı 20 kHz ile sınırlı iken Silikon Karbür (SiC) veya GaN gibi yarıiletkenlerde kW mertebesinde dahi 100 kHz’e kadar çıkılabilmektedir. Düşük iletim direncinden dolayı iletim kayıplarının düşürülebilmesi, yüksek anahtarlama hızlarından dolayı yüksek anahtarlama frekanslarında çalıştırılabilmesi ve böylece sürücü sistemi pasif elemanlarının boyutlarının küçültülebilmesi ve ısıl başarımlarının iyi olmasından dolayı TMMS uygulamalarına yönelik ilk örnek çalışmalarında GaN transistorları sıklıkla tercih edilmiştir [8], [10]. GaN ile geliştirilen TMMS sistemlerinin verimleri de, hem anma değerlerinde hem de tüm güç çıkışı aralığında yüksek olmuştur [10].

TMMS uygulamalarında DA baranın modellenmesi ve DA bara kondansatörü seçimi özellikle kritiktir çünkü bu kondansatörler sistemin hacminin %20’sini, ağırlığının ise %30’unu oluşturmaktadır [1]. Ayrıca motor sürücü devresinin yüksekliğini yine bu elemanlar belirlemektedir. Motor sürücü uygulamalarında alüminyum elektrolitik kondansatörler ucuz olmaları ve hacim başıma sığa değerlerinin yüksek olması sebebiyle tercih edilmektedir. Ancak bu kondansatör tipinin ömrü çalışma değerlerine bağımlıdır ve görece kısadır [11]. Ayrıca hacim başına akım dayanma değerleri düşüktür. Diğer bir taraftan, metal film tipi kondansatörler ömür ve akım değerleri açısından daha iyidir. Bu sebeple TMMS sistemleri için daha uygun oldukları söylenebilir. Standart uygulamaların aksine, TMMS’lerde kondansatör bankası tasarımında gerilim, sığa ve dalgalanma akımına ek olarak güç yoğunluğu, maliyet, kondansatör yüksekliği, ısıl model ve çalışma sıcaklığının kondansatör ömrü üzerine etkileri gibi parametreler de incelenmelidir.

**3. Design of the IMMD System**

Figures and tables should be not more than 8.25 cm wide and ought to be centered in column. If possible, position figures and tables at the tops and bottoms of columns. Large figures and tables (maximum 17 cm width) may span across both columns. In such cases they should be centered on the full width of page together with captions or headings.

**3.1. Fundamental decisions**

Captions example, write "Time (s) ". Do not label axes only with units.

**3.2. Design of the motor**

Every table mu

**3.3. Design of the drive**

Every table mu

**4. Simulation Results**

Equations

**3.1. 2D FEM simulations of the motor**

Captions example, write "Time (s) ". Do not label axes only with units.

**3.2. Power stage simulations**

Every table mu

**3.3. Results**

Every table mu

**5. Conclusions**

Define abbreviations and

**6. References**

[1] J. K. Author, "Name of paper", *Abbrev. Title of Periodical*, vol. *x,* no. *x,* pp*. x-x,* Abbrev. Month, year.

[2] J. K. Author, "Title of book", Abbrev. of Publisher, City of Publisher, Country, year*.*

[3] J. K. Author, "Title of paper", in *Unabbreviated Name of Conf.*, City of Conf., Abbrev. State (if given), year, pp. *x-x.*

[4] J. K. Author, "Title of thesis", M.S. thesis, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

[5] *Title of Standard*, Standard number, date.

[6] J. K. Author. (year, month day). *Title* (edition) [Type of medium]. Available: http://www.(URL)