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 usedwhich 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, current technology prospects 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. Current IMMD Technology**

The manuscripts must be prepared in a two-column format on A4 size paper. The margins on the first page must be as follows: top = 3 cm, bottom = 3.7 cm, left = 2 cm, right = 2 cm. All margins on the second and subsequent pages: top = 2.5 cm, bottom = 3.7 cm, left = 2 cm, right = 2 cm. The text of the paper must be written in two columns with a space of 0.5 cm between them (Fig. 1). The width of each column must be 8.25 cm. On the last page of the paper, the lengths of the columns must be adjusted so that they are equal. Do not add page numbers.

All the text must be written in Times New Roman fonts, single line spacing. The exception may be done for the contents of tables and figures, where Arial as well as Times New Roman font may be used. Font sizes and styles are listed in Table 1.

All paragraphs should be indented 0.4 mm. Please do not place any additional blank lines between paragraphs. Be sure your text is fully justified.



*1 blank line using 6-point font with single spacing*

**Fig. 1.** Arrangement of printing area on an A4 size page for the first and subsequent pages of the manuscript

*1 blank line using 9-point font with single spacing*

**Table 1.** Font sizes and styles

*1 blank line using 6-point font with single spacing*

|  |  |  |
| --- | --- | --- |
|  | Size | Style |
| Title of the Paper | 14 pt\* | **Bold**, Initially capitalized |
| Name of Author(s) | 11 pt | Regular |
| Affiliation(s) | 10 pt | Regular |
| Text of the Abstract | 9 pt | **Bold** |
| Text of the Paper | 9 pt | Regular |
| Headings of chapters and subsections | 10 pt | **Bold**, Initially capitalized |
| Caption of Table | 9 pt | Regular (The word “Table” and number – **Bold**) |
| Contents of Table | 9 pt | Regular |
| Caption of Figure | 9 pt | Regular (The word “Fig.” and number – **Bold**) |
| Subscripts and Superscripts | 7 pt | Regular |

\* 1 point (pt) is about 0.35 mm.

*1 blank line using 9-point font with single spacing*

**2.1. First Page**

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The first page of the manuscript must contain the title of the paper, author(s) name(s) and affiliation(s) all centered on the top of the page and spanning both columns. The title should be written using 14-point Times, boldface type with single spacing. Initially capitalize nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word).

Full names of authors are preferred, but initials may be used instead. There must be one-line separations between the title and author name(s), and between the authors and their affiliation(s). A two-line separation is required between the author affiliation(s) and the start of the main text.

**2.2. Headings**

Headings of chapters should be written in 10-point bold type font with single spacing. They should be numbered by successive Arabic numerals and centered in lines. Titles of subsections are to be written in 10-point bold type font with single-spacing as well, but they should be aligned with the left edge of the column. Full-stop symbol follows the number of chapter or subsection. All titles must be separated from the text by one (9-point) blank line above, and one (9-point) blank line below the title.

**3. Figures and Tables**

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. Figures**

Captions of figures should be aligned with both edges of the column below the figures, in 9-point font, single spacing. The word "Fig." and the successive Arabic number with the full-stop symbol (".") must be written in bold. There should not be a full-stop symbol in the end of the caption of figure or table. Above each figure and below its caption should be 1 blank line spacing (9-point). The space between figure and its caption should have the size of approximately 6-point font.

All figures must be cited in the text in a consecutive order using abbreviations, e.g. "Fig. 1". In figure axis labels, use words rather than symbols. Put units in parentheses. For example, write "Time (s) ". Do not label axes only with units.

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Every table must have a descriptive title. Captions of tables should be aligned with both edges of the column above the tables, in 9-point font, single spacing. The word "Table" and the successive Arabic number with the full-stop symbol (".") must be written in bold. Below each table and above its caption should be 1 blank line spacing (9-point). The caption should be separated from the table by one 6-point empty line. Tables must be cited consecutively in the text, e.g. "Table 1".

**4. Equations**

Equations ought to be centrally arranged in lines and numbered by successive Arabic numerals using parentheses aligned with the right-side edge of the column. Symbols and variables in the equations as well as in the text should be written in italics, while vectors and matrices in ordinary bold type.

The equations ought to be separated from the text by 1 blank line (9-point):

*u*(*t*) *= U*m*·*sin ω*t*. (1)

Symbols in the equation should be defined before the equation appears or immediately following.

**5. Abbreviations and Units**

Define abbreviations and acronyms the first time they are used in the text, even if they have been defined in the abstract. Commonly used abbreviations such as IEC, IEEE, SI, AC, and RMS do not have to be defined. Use SI units where possible.

**6. Conclusions**

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

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