2. Макаренко М.Г., Калашник Є.А. Роль інформаційних технологій у вдосконаленні функціональних можливостей блочно-модульних тракторів. // Технічний прогрес в АПВ: матеріали міжнародної науково-практичної конференції, 21-22 травня 2024 року / Державний біотехнологічний університет. Харків, 2024. С. 67-68.

3. Макаренко М. Г, Пиріжок В. І. Використання штучного інтелекту у вбудованих системах сільськогосподарських тракторів. // Матеріали XX міжнародного форуму молоді "Молодь і індустрія 4.0 в XXI столітті" 04-05. 04. 2024. Харків: ДБТУ, 2024 С. 192.

4. Макаренко М. Г., Шевченко І. О., Хейло В. О., Пиріжок В. І. Електронні системи керування та діагностики сучасних автомобілів: проблеми і рішення. // Збірник тез та доповідей міжнародної конференції «Енергетичні установки та альтернативні джерела енергії». 11–12 березня 2024 року, ХНАДУ, Харків, 2024. С. 274-278.

DEVELOPMENT OF AN ELECTRONIC POWER SUPPLY SYSTEM FOR A SWITCHED RELUCTANCE MOTOR WITH HYBRID EXCITATION AS PART OF THE POWERTRAIN OF AN ELECTRIC VEHICLE

Andrii Nechaus, PhD, Associate Professor of Department of Automobile Electronics, Kharkiv National Automobile and Highway University,
e-mail: nechaus@ukr.net, ORCID: 0000-0001-8833-0802
Mykhailo Kadnai, student, Kharkiv National Automobile and Highway University,
e-mail: mikadnaj@gmail.com

During the execution of a student scientific competition project, a comparison of the design of promising types of electric motors for the powertrain of an electric vehicle was conducted. In particular, switched reluctance machines (SRM), Flux Switching PM Machines (FSPMM), Flux Switching Winding Excitation Machines (FSWFM), and Flux Switching Hybrid Excitation Machines (FSHEM) [1-3] were considered. Based on the analysis, a conclusion was made regarding the structural similarity of the magnetic systems of these motor types. This suggests the possibility of unifying the manufacturing process for mass production of electric motors that essentially belong to different types (Figure 1).

The application of winding excitation or hybrid excitation significantly expands the control capabilities of SRM. In the case of an FSWFM, it becomes possible to regulate the magnetic flux by adjusting the excitation current. In the case of an FSHEM, the magnetic flux of the permanent magnets (PM) can be strengthened or weakened by varying the magnitude and direction of the excitation current. Increasing the magnetic flux allows for a higher torque output when acceleration is needed, while reducing the flux at cruising speeds improves motor efficiency [4-11].

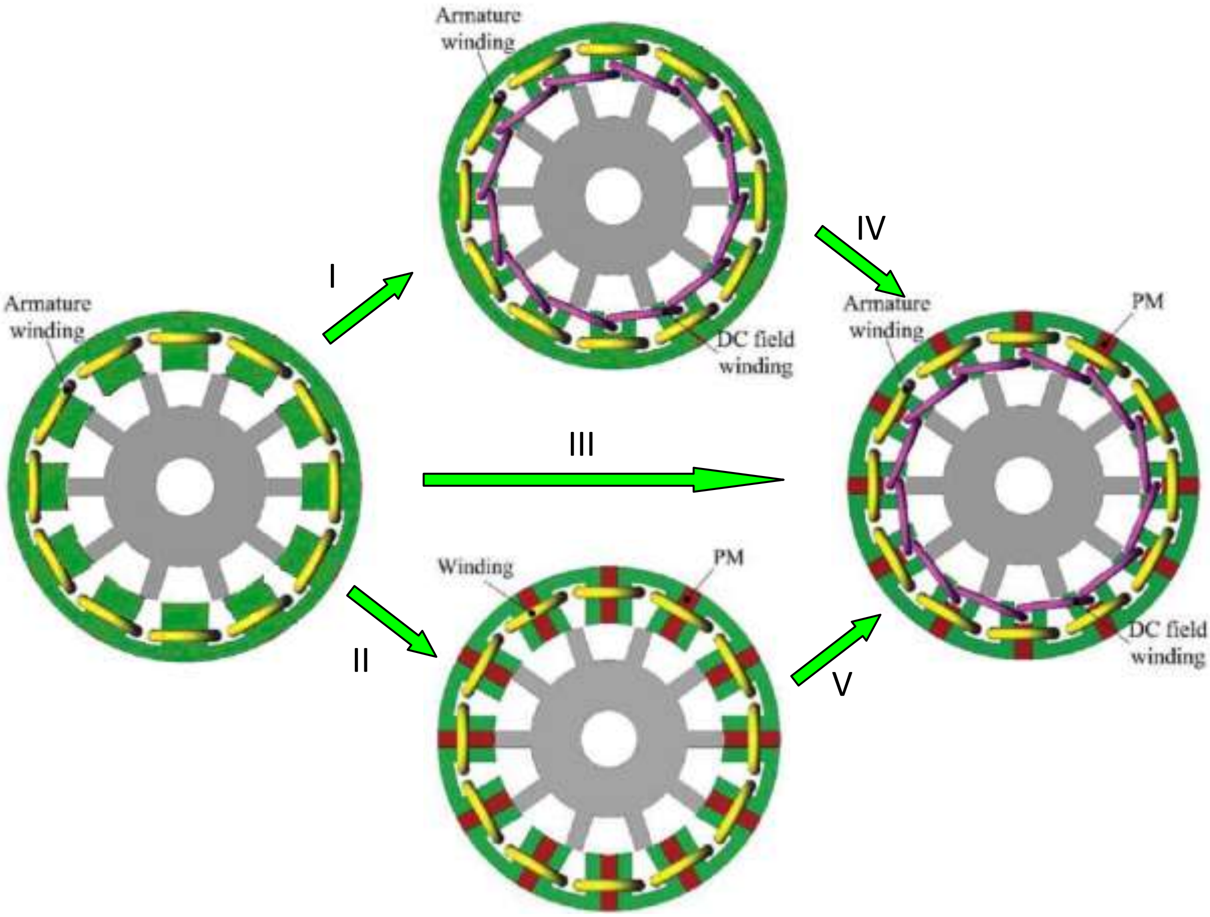
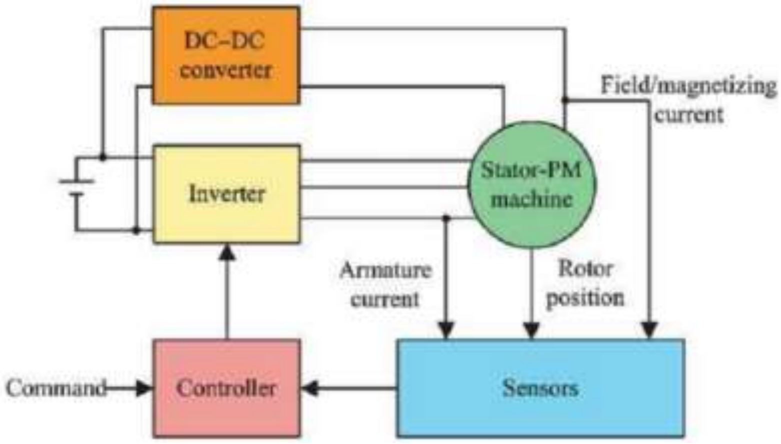


Figure 1 – Transformation SRM to FSWFM, FSPMM and FSHEM

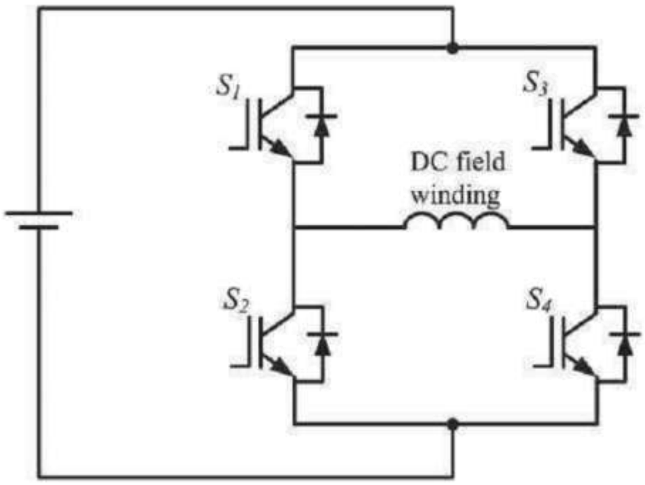
However, generating the excitation current requires an additional DC power source. This source must be capable of controlling both the magnitude and direction of the current. As a result, the motor control system becomes more complex due to the inclusion of an additional DC/DC converter (Figure 2, a).

In Figure 2, b, the simplest and most common converter circuit based on a typical H-bridge converter is presented. A key aspect of this converter's operation within a hybrid excitation system is that the magnetic flux generated by the excitation winding must be comparable in magnitude to both the working magnetic flux of the motor and that of the permanent magnets (PM). This means that the excitation winding current is comparable to the working current of the motor.

To ensure smooth regulation of the excitation current, the power transistors of the DC/DC converter must operate over a wide range of states, from fully off to fully on. Consequently, this results in significant power dissipation in the switches, leading to substantial energy losses.



a



b

Figure 2 – Coniguration of doubly-fed FSWFM (a),
power circuit for DC field winding (b) [2]

The use of pulse-width modulation (PWM) in the operation of the H-bridge converter leads to additional magnetic flux ripple in the FSHEM, which is one of its main drawbacks. Therefore, additional measures are required to reduce magnetic flux ripple and minimize energy losses in the switching elements.

Conclusion

An electrical circuit and an operating algorithm for the power switch driver of the DC/DC converter in the FSHEM hybrid excitation system have been proposed. This solution minimizes energy losses in the excitation circuit by utilizing PWM and smoothing the current ripple of the H-bridge converter.

References

1. El Hadraoui, H., Zegrari, M., Chebak, A., Laayati, O., & Guennouni, N. (2022). A Multi-Criteria Analysis and Trends of Electric Motors for Electric Vehicles. World Electric Vehicle Journal, 13(4), 65. https://doi.org/10.3390/wevj13040065.

2. Chau, K.T. (2015). Electric Vehicle Machines and Drives: Design, Analysis and Application. 10.1002/9781118752555.

3. Hillary, Idoko & Akuru, Udochukwu & Wang, Rong-Jie & Popoola, Olawale. (2022). Potentials of Brushless Stator-Mounted Machines in Electric Vehicle Drives – A Literature Review. World Electric Vehicle Journal. 13. 93. 10.3390/wevj13050093.

4. Jenal, Mahyuzie & Sulaiman, Erwan & Omar, Mohd Fairoz & Romalan, Gadafi & Soomro, Hassan. (2015). Development of a novel permanent magnet flux switching machine prototype for light weight electric vehicles. 739-744. 10.1109/SCORED.2015.7449436.

5. Chiweta E. Abunike, Milad Dowlatshahi, Aliakbar Jamshidi Far, Ogbonnaya I. Okoro, Sumeet S. Aphale, Multi-objective optimization of a flux switching wound field machine using a response surface-based multi-level design approach, Results in Engineering, Volume 25, 2025, 103988, https://doi.org/10.1016/j.rineng.2025.103988.

6. Khan, F., Sulaiman, E., Ahmad, Z., & Husin, Z.A. (2015). Design and analysis of wound field three-phase flux switching machine with non-overlap windings and salient rotor. 10.15676/ijeei.2015.7.2.12.

7. Diab, H., Amara, Y., Hlioui, S., & Paulides, J. J. H. (2021). Design and Realization of a Hybrid Excited Flux Switching Vernier Machine for Renewable Energy Conversion. Energies, 14(19), 6060. https://doi.org/10.3390/en14196060.

8. Nasr, Andre & Hlioui, Sami & Gabsi, Mohamed & Mairie, Mathieu & Lalevee, Didier. (2017). Design Optimization of a Hybrid-Excited Flux-Switching Machine for Aircraft-Safe DC Power Generation Using a Diode Bridge Rectifier. IEEE Transactions on Industrial Electronics. PP. 1-1. 10.1109/TIE.2017.2726974.

9. Cinti, Luca & Bianchi, Nicola. (2021). Hybrid-Excited PM Motor for Electric Vehicle. Energies. 14. 916. https://doi.org/10.3390/en14040916.

10. Ma, J., Gu, F., Wang, L., Ma, S., Golmohammadi, A.-M., & Zhang, S. (2024). The Design and Optimization of a Novel Hybrid Excitation Generator for Vehicles. World Electric Vehicle Journal, 15(4), 139. https://doi.org/10.3390/wevj15040139.

11. Wang, Shensheng & Zhu, Ziqiang & Pride, Adam & Shi, Juntao & Deodhar, Rajesh & Umemura, Chiaki. (2022). Comparison of Different Winding Configurations for Dual Three-Phase Interior PM Machines in Electric Vehicles. World Electric Vehicle Journal. 13. 51. https://doi.org/10.3390/wevj13030051.