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A NEW MULTI-MOTOR DRIVE SYSTEM BASED ON FOUR-SWITCH THREE-PHASE INVERTER TOPOLOGIES

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Abstract. Vietnam encourages greenhouse technology applications for high-tech agricultural production. The microclimate of greenhouses is the key factor for better plant growth. The greenhouse microclimate can be improved by control actions, such as heating, ventilation, and carbon dioxide enrichment to provide appropriate environmental conditions for crops. The multi-motor drive systems using six-switch three-phase inverter topologies are applied for greenhouse fans. In order to decrease to size and cost of effectiveness drive systems, the paper proposes a new multi-motor drive system based on four-switch three-phase inverter topologies which are applied to two-level hysteresis current controllers. The proposed solution has been tested to a four-permanent-magnet synchronous motor (PMSM) drive system. The simulation results are carried out to show the effectiveness of the proposed solution.

Keywords. Six-switch three-phase (SSTP) inverter, four-switch three-phase inverter (FSTP), inverter, multi-motor drive system, greenhouse fans.

1 INTRODUCTION

Normally, a motor drive system or a multi-motor drive system using six-switch three-phase (SSTP) inverter topologies is almost universally considered as the industry standard [1-3]. However, for economic, control complexity, size reasons, reducing the cost of a drive system, the inverter topologies are still under investigation, and one way to achieve this aim is to decrease the number of inverter switching devices. Low-cost inverter topologies with the reduced number of switching devices for an induction machine drive system has been suggested and demonstrated in [4,5]. In [4] proposed using a three-switch three-phase inverter with an extra connection from neutral point to dc-link midpoint to control torque and speed of an induction machine. In [5], a four-switch three-phase (FSTP) inverter was presented, where one of the three-phase machine terminals was connected to the dc-link midpoint and control was achieved by manipulating the voltages and currents of the two active phases. In [6-7], a work is proposed the application of sensorless induction motor drives to high performance industrial applications where multi-drive synchronisation is required. In [8], control of multi-motors electric drives with high dynamic, with rapid changes in torque and speed, with rigid coupling of motors, where the control strategy is FOC (Field Oriented Control) for each drives and the distributed control in local network using the CanOpen protocol is tested. In [9], multi-motor drive system based on a two-stage direct power conversion topology for aerospace applications.

In this paper, a new multi-motor drive system includes a hardware and a software. The hardware uses four-switch three-phase inverter topology. The software uses two-level hysteresis current controllers. The proposed solution has applied to greenhouse fans.

The organization of the paper is briefly given as follows: Section 1 gives information on overview of a one/multi-motor drive system. Then, conventional multi-motor drive system is reviewed in Section 2. A new multi-motor drive system is shown in Section 3. Section 4 gives numerical results. Conclusions are given in Section 5.

2 CONVENTIONAL MULTI-MOTOR DRIVE SYSTEMS

In this section, the conventional multi-motor drive systems, which include the inverter topology and the inverter control method will be reviewed.

2.1 Inverter topology

Figure 1 shows the schematic diagram of n SSTP inverter module which each them includes a rectifier and a SSTP. The ideal SSTP having the power devices is considered as ideal switch, there are no snubbers and gate drive circuits. Each phase leg of the SSTP inverter is represented by a “switch” that has three input terminals and one output terminal [2].

Each phase leg of the SSTP inverter is represented by a “switch” that has three input terminals and one output terminal [2]:

$$v_{as} = \frac{V_{dc}(2S_1 - S_3 - S_5)}{3} \tag{1}$$

$$v_{as} = \frac{V_{dc}(2S_3 - S_5 - S_1)}{3} \tag{2}$$

$$v_{as} = \frac{V_{dc}(2S_5 - S_1 - S_3)}{3} \tag{3}$$

where v_{as}, v_{bs}, and v_{cs} are the phase-to-neutral voltages.

2.2 Inverter control method

There are two inverter control method, current-controled inverter and voltage-controled inverter [2]. For economic, control complexity, size reasons, reducing the cost of a drive system. The current-controled inverter method is best solution [2]. Each controller uses three two-level hysteresis current controllers. So this drive system needs three current sensors.

The theory of hysteresis current control is the error between control references and control variables crosses either the positive or negative hysteresis band's boundary, a significant change in the controller's output (S_1, S_3, and S_5)

3 PROPSED MULTI-MOTOR DRIVE SYSTEMS

In this section, proposed inverter topology and proposed control method will be presented.

3.1 Proposed inverter topology

Figure 3 shows the schematic diagram of n FSTP inverter module which each them includes only a rectifier and a FSTP. The ideal FSTP having the power devices is considered as ideal switch, there are no snubbers and gate drive circuits. Each phase leg of the FSTP inverter is represented by a “switch” that has three input terminals and one output terminal [4,5].

Each phase leg of the FSTP inverter is represented by a “switch” that has three input terminals and one output terminal [4,5]:

$$v_{as} = \frac{V_{dc}(1 - S_3 - S_5)}{3} \tag{4}$$

$$v_{bs} = \frac{V_{dc}(4S_3 - 2S_5 - 1)}{6} \tag{5}$$

$$v_{cs} = \frac{V_{dc}(4S_5 - 2S_3 - 1)}{6} \tag{6}$$

3.2 Proposed control method

Figure 4 shows a proposed n-motor controller which each controller is applied to two-level hysteresis current controllers. So this drive system needs two current sensors.

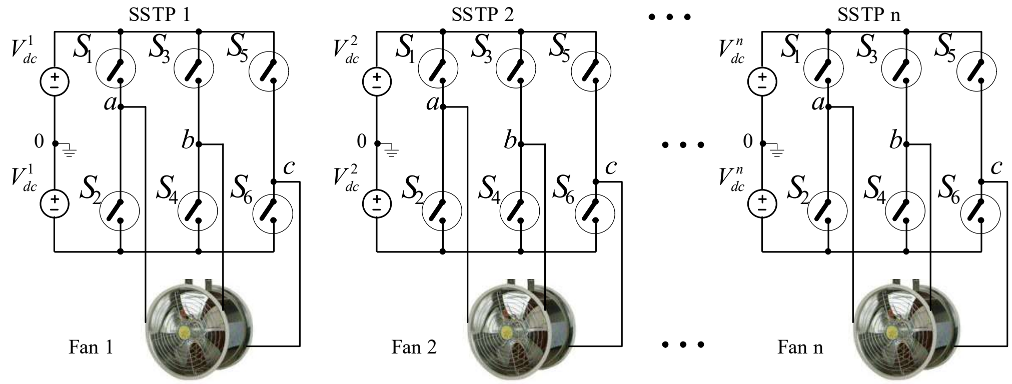


Figure 1: SSTP inverter topology

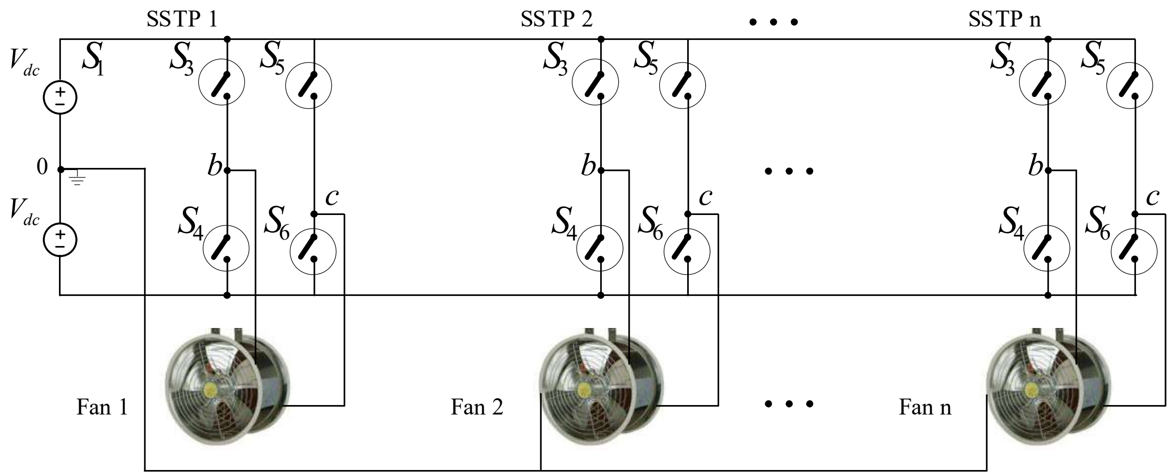


Figure 2: FSTP inverter topology

4 SIMULATION RESULTS

Most pumps and fans operating in industrial and commercial applications are currently driven by AC induction motors, which stands for “alternating current induction motor”, is an asynchronous type of motor that relies on electric current to turn the rotor. But are often installed with variable frequency drives (VFD) in pump systems or fan systems in an effort to improve system efficiency. Permanent magnet synchronous motors require a drive to operate. A VFD is required to precisely control the speed of the PMSM to meet the application requirements for pressure, flow, volume, etc. Some new VFDs already come with permanent magnet motor control options as a standard feature, allowing operators to control the permanent magnet motor to drive the fan and/or pump more efficiently [10].

The proposed solution has been applied successfully to a four-permanent-magnet synchronous motor (PMSM) drive system which each motor has the parameter shown in Table 1. The operating condition of the motors is shown in Table 2. The hysteresis band is set to 0.05 A and the dc-link voltage is 300 V.

The proposed drive solution is applied to greenhouse fans, the test results of speed, torque, and current will be shown.

Figure 5 and Figure 6 have the shape of speed and torque waveforms which resulted in satisfactory in Table 2. Fig. 7 has the shape of current waveforms and resulted in satisfactory balanced current magnitudes.

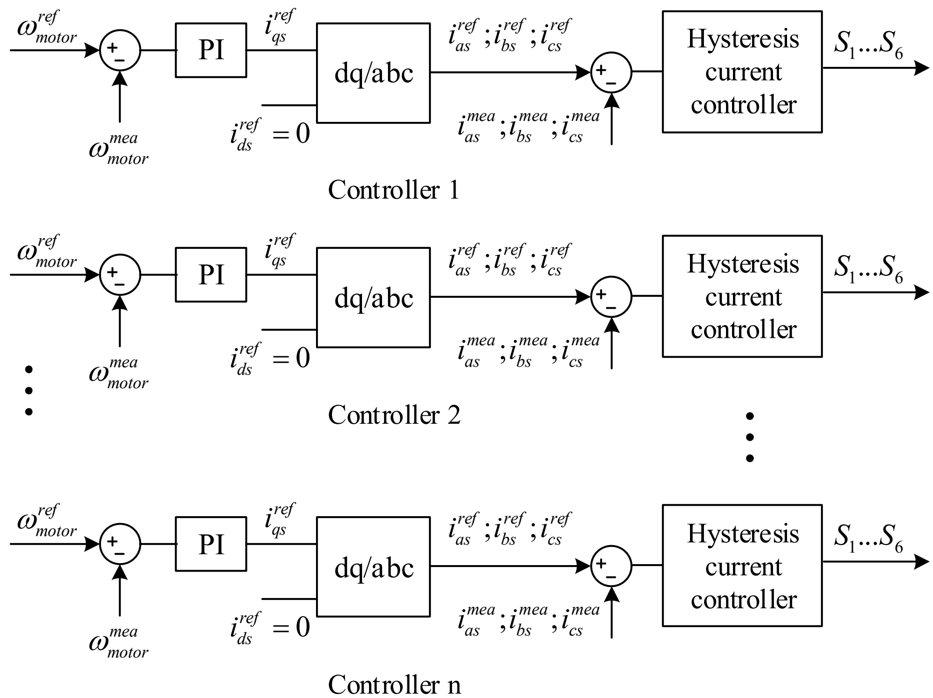


Figure 3: n-fan system

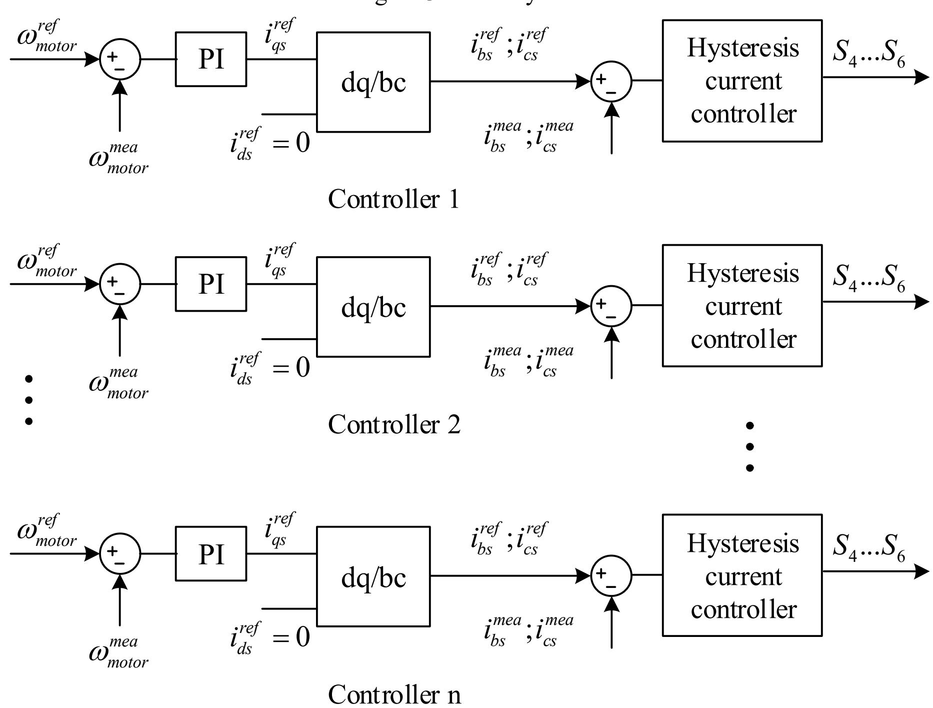


Figure 4: A proposed n-fan drive system

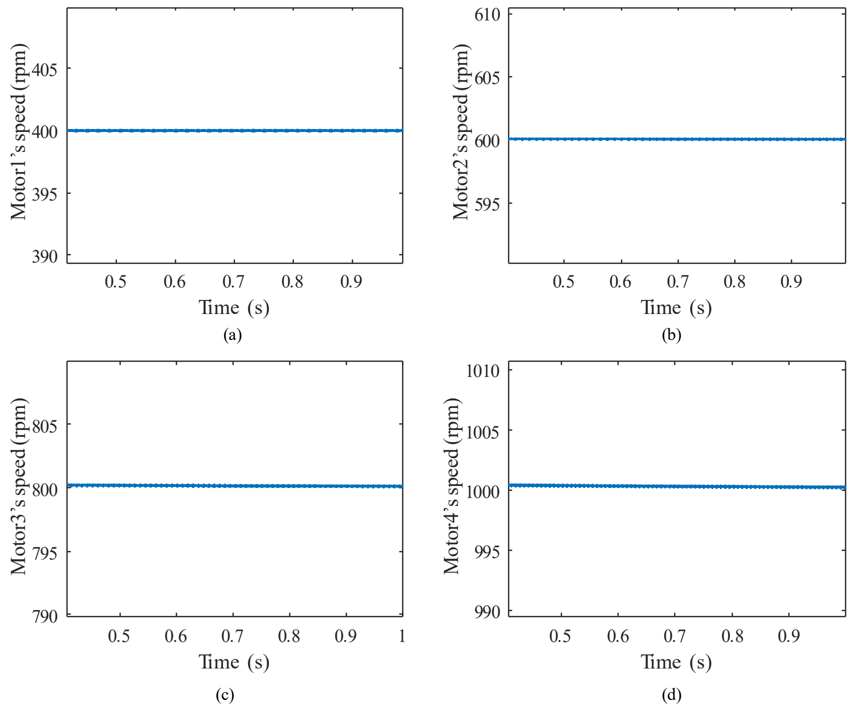


Figure 5: Speed performance of 4-motor, (a) speed performance of motor 1 with speed reference is 400 rpm and load torque is 0.508 Nm, (b) speed performance of motor 2 with speed reference is 600 rpm and load torque is 0.762 Nm, (c) speed performance of motor 3 with speed reference is 800 rpm and load torque is 1.016 Nm, (d) speed performance of motor 4 with speed reference is 1000 rpm and load torque is 1.27 Nm.

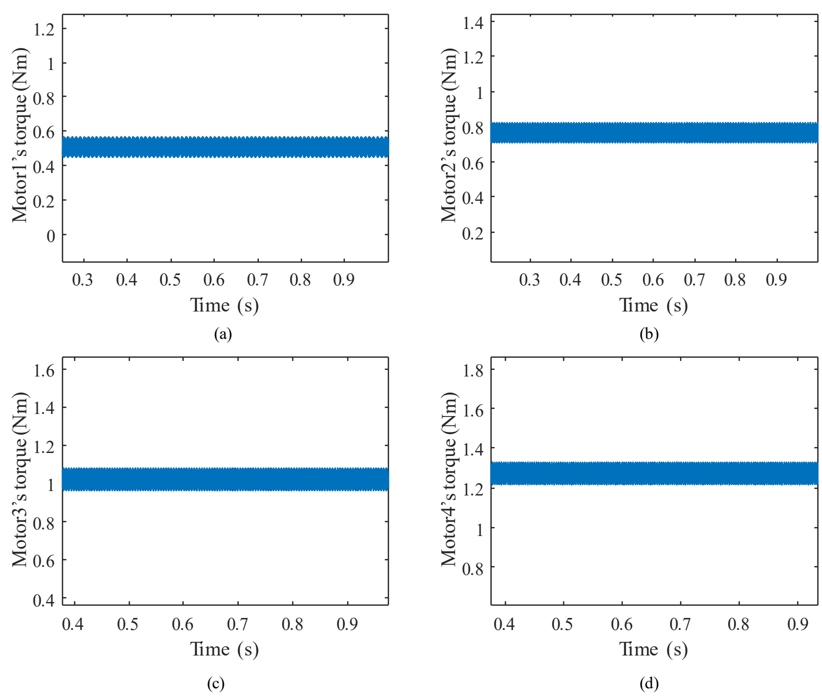
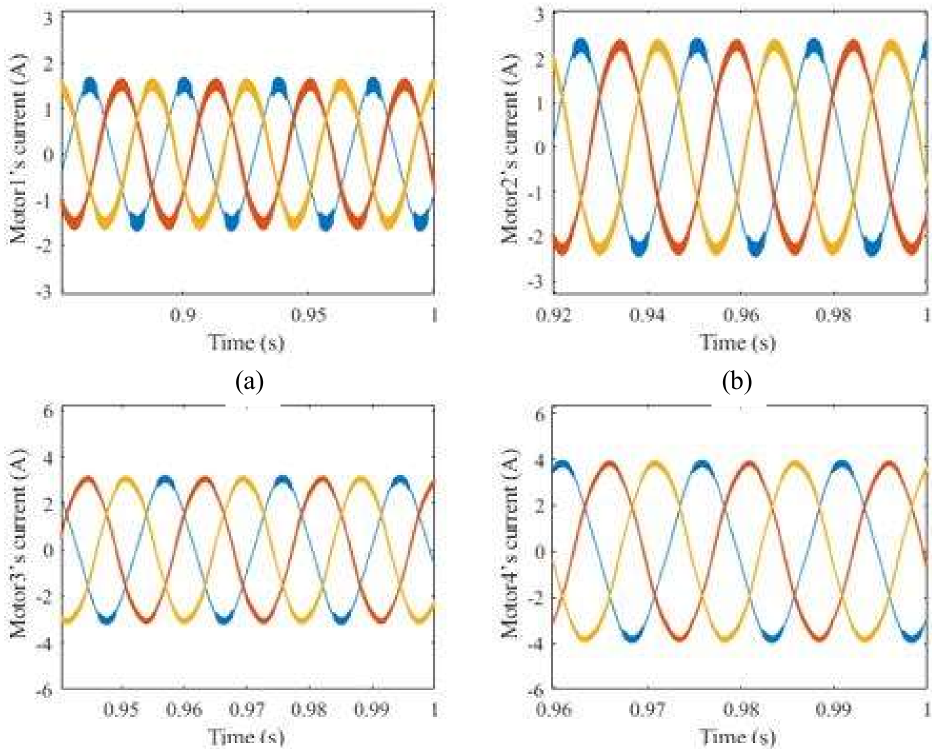


Figure 6: Torque performance of 4-motor, (a) torque performance of motor 1 with speed reference is 400 rpm and load torque is 0.508 Nm, (b) torque performance of motor 2 with speed reference is 600 rpm and load torque is 0.762

Nm, (c) torque performance of motor 3 with speed reference is 800 rpm and load torque is 1.016 Nm, (d) torque performance of motor 4 with speed reference is 1000 rpm and load torque is 1.27 Nm.



(c) (d)

Figure 7: Current performance of 4-motor, (a) current performance of motor 1 with speed reference is 400 rpm and load torque is 0.508 Nm, (b) current performance of motor 2 with speed reference is 600 rpm and load torque is 0.762 Nm, (c) current performance of motor 3 with speed reference is 800 rpm and load torque is 1.016 Nm, (d) current performance of motor 4 with speed reference is 1000 rpm and load torque is 1.27 Nm.

Figure 5 shows the speed performance of 4-motor, motor 1 has speed performance of 400rpm, motor 2 has speed performance of 600rpm, motor 3 has speed performance of 800rpm, motor 4 has speed performance of 1000rpm. Figure 6 shows torque performance of 4-motor, motor 1 has torque performance of 0.508 Nm, motor 2 has torque performance of 0.762 Nm, motor 3 has speed performance of 1.016 Nm, motor 4 has speed performance of 1.27 Nm. Figure 7 shows current performance of 4-motor, motor 1 has current performance of 1.2 A, motor 2 has current performance of 1.74 A, motor 3 has current performance of 2.28 A, motor 4 has current performance of 2.7 A. Figure 8 shows volatge performance of 4-motor, all motor have good volatge performances.

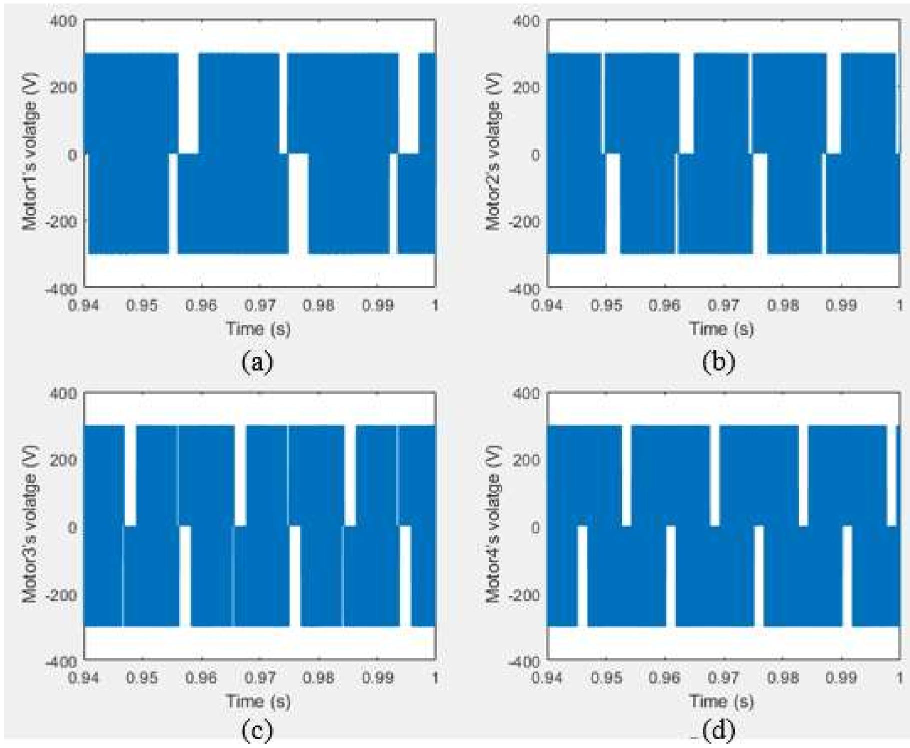


Figure 8: Volatge performance of 4-motor, (a) voltage performance of motor 1 with speed reference is 400 rpm and load torque is 0.508 Nm, (b) voltage performance of motor 2 with speed reference is 600 rpm and load torque is 0.762 Nm, (c) voltage performance of motor 3 with speed reference is 800 rpm and load torque is 1.016 Nm, (d) voltage performance of motor 4 with speed reference is 1000 rpm and load torque is 1.27 Nm.

Table 1: Parameter of PMSM

Description	Parameter	Value
Rated Power	P_n	400 W
Rated Torque	T_n	1.27 N.m
Rated Voltage	U_{ll}	200 V
Rated Current	I_n	2.7 A
Rated speed	n	3000 rpm
dc-link voltage	V_{dc}	300 V
Stator phase resistance	R_s	2.35 Ω
Stator phase inductance	L_s	6.5 mH
Permanent magnet rotor flux linkage	λ_r	0.0555 Wb
Rotor moment of inertia	J	0.00003495kg.m^2
Viscous friction coefficient	B	5.3×10-5 Nms
Number of pole pairs	p	4

Table 2: Reference parameters of four-PMSM

Motor	Speed reference (rpm)	Load torque (Nm)
Motor 1	400	0.508
Motor 2	600	0.762
Motor 3	800	1.016
Motor 4	1000	1.27

5 CONCLUSIONS

This paper has presented a new multi-motor drive system for greenhouse fan applications. The proposed drive system has been applied successfully to a four-permanent-magnet synchronous motor (PMSM) which is operated under the different speed and torque conditions. It has been shown the shape of speed and torque waveforms which resulted in satisfactory with references and the shape of current waveforms and resulted in satisfactory balanced current magnitudes. In addition, this solution can also be extended for high-tech shrimp farming applications that controls dissolved oxygen in water for shrimp farming. Further works are experimental evaluation of the proposed drive.

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REFERENCES

[1] N. Mohan, T. M. Underland and W.P. Robbins, *Power electronics: converters, applications and design*. New York: Wiley, 3rd, 2003

[2] Bimal Bose, Power Electronics and Motor Drives Advances and Trends, 2nd Edition, 2020, Academic Press.

[3] J. I. Leon, S. Kouro, L. G. Franquelo, J. Rodriguez, and Bin Wu, *The Essential role and the continuous evolution of modulation techniques for voltage source inverters in past, present and future power electronics*, IEEE Transactions on Industrial Electronics, Volume 63, Issue 5, May 2016.

[4] B. A. Welchko and T. A. Lipo, “A novel variable-frequency three-phase induction motor drive system using only three controlled switches,” IEEE Trans. Ind. Appl., vol. 37, no. 6, pp. 1739–1745, Nov./Dec. 2001.

[5] H. W. van der Broeck and J. D. van Wyk, “A comparative investigation of a three-phase induction machine drive with a component minimized voltage-fed inverter under different control options,” IEEE Trans. Ind. Appl., vol. IA-20, no. 2, pp. 309–320, Mar./Apr. 1984.

[6] G. Turl, M. Sumner, G.M. Asher, A multi induction-motor drive strategy operating in the sensorless mode, 2001 IEEE Industry Applications Conference. 36th IAS Annual Meeting (Cat. No.01CH37248), 30 Sept.-4 Oct. 2001.

[7] G. Turl, M. Sumner, G.M. Asher, A synchronised multi-motor control system using sensorless induction motor drives, 2002 International Conference on Power Electronics, Machines and Drives, 4-7 June 2002.

[8] Marcel Nicola, Dumitru Sacerdotianu, Adrian Hurezeanu, Sensorless control in multi-motors electric drives with high dynamic and rigid coupling, 2017 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM) & 2017 Intl Aegean Conference on Electrical Machines and Power Electronics (ACEMP), 25-27 May 2017.

[9] Dinesh Kumar, Patrick Wheeler, Jon Clare, Tae-Woong Kim, Multi-motor drive system based on a two-stage direct power conversion topology for aerospace applications, 2008 4th IET Conference on Power Electronics, Machines and Drives, 2-4 April 2008.

[10] https://empoweringpumps.com/ac-induction-motors-versus-permanent-magnet-synchronous-motors-fuji

MỘT HỆ THỐNG TRUYỀN ĐỘNG NHIỀU ĐỘNG CƠ MỚI TỰA VÀO KIỂU BIẾN TẦN 3 PHA 4 KHÓA

Tóm tắt. Việt Nam khuyến kích ứng dụng công nghệ nhà kính cho nông nghiệp công nghệ cao. Tiểu khí hậu của nhà kính là nhân tố chính yếu cho cây trồng phát triển tốt hơn. Tiểu khí hậu nhà kính có thể được cải thiện bởi các hành động điều khiển, như là nhiệt, thông gió và làm giàu CO_2 để cung cấp các điều kiện thích hợp cho vụ mùa. Hệ thống truyền động nhiều động cơ sử dụng kiểu biến tần 6 khóa được ứng dụng cho quạt nhà kính. Để giảm kích thước và giá thành cho các hệ thống truyền động hiệu quả, bài báo đề xuất một hệ thống truyền động nhiều động cơ tựa vào kiểu biến tần 3 pha 4 khóa sử dụng bộ điều khiển trễ hai bậc. Giải pháp đề xuất đã được kiểm chứng cho một hệ thống truyền động điện bốn động cơ đồng bộ nam châm vĩnh cửu (PMSM). Kết quả mô phỏng chỉ ra tính hiệu quả của giải pháp truyền động đề xuất.

Từ khóa. Biến tần 3 pha 6 khóa (SSTP), Biến tần 3 pha 4 khóa (FSTP), biến tần, hệ thống truyền động nhiều động cơ, quạt nhà kính.

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