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 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].

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

\[ v_{as} = \frac{V_{dc}}{3} (2S_1 - S_3 - S_5) \]  
\[ v_{bs} = \frac{V_{dc}}{3} (2S_3 - S_5 - S_1) \]  
\[ v_{cs} = \frac{V_{dc}}{3} (2S_5 - S_1 - S_3) \]

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-controlled inverter and voltage-controlled inverter [2]. For economic, control complexity, size reasons, reducing the cost of a drive system. The current-controlled 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 Proposed 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]:

\[ v_{as} = \frac{V_{dc}}{3} (1 - S_3 - S_5) \]  
\[ v_{bs} = \frac{V_{dc}}{6} (4S_3 - 2S_5 - 1) \]  
\[ v_{cs} = \frac{V_{dc}}{6} (4S_5 - 2S_3 - 1) \]

#### 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.
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.
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Figure 3: n-fan system

Controller 1

Controller 2

Controller n

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.

Figure 5 shows the speed performance of 4-motor, motor 1 has speed performance of 400 rpm, motor 2 has speed performance of 600 rpm, motor 3 has speed performance of 800 rpm, motor 4 has speed performance of 1000 rpm. 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 voltage performance of 4-motor, all motor have good voltage performances.
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Figure 8: Voltage 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

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>$P_n$</td>
<td>400 W</td>
</tr>
<tr>
<td>Rated Torque</td>
<td>$T_n$</td>
<td>1.27 N.m</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>$U_{ll}$</td>
<td>200 V</td>
</tr>
<tr>
<td>Rated Current</td>
<td>$I_n$</td>
<td>2.7 A</td>
</tr>
<tr>
<td>Rated speed</td>
<td>$n$</td>
<td>3000 rpm</td>
</tr>
<tr>
<td>dc-link voltage</td>
<td>$V_{dc}$</td>
<td>300 V</td>
</tr>
<tr>
<td>Stator phase resistance</td>
<td>$R_s$</td>
<td>2.35 Ω</td>
</tr>
<tr>
<td>Stator phase inductance</td>
<td>$L_s$</td>
<td>6.5 mH</td>
</tr>
<tr>
<td>Permanent magnet rotor flux linkage</td>
<td>$\lambda_r$</td>
<td>0.0555 Wb</td>
</tr>
<tr>
<td>Rotor moment of inertia</td>
<td>$J$</td>
<td>0.00003495 kg.m²</td>
</tr>
<tr>
<td>Viscous friction coefficient</td>
<td>$B$</td>
<td>5.3×10-5 Nms</td>
</tr>
<tr>
<td>Number of pole pairs</td>
<td>$p$</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2: Reference parameters of four-PMSM

<table>
<thead>
<tr>
<th>Motor</th>
<th>Speed reference (rpm)</th>
<th>Load torque (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor 1</td>
<td>400</td>
<td>0.508</td>
</tr>
<tr>
<td>Motor 2</td>
<td>600</td>
<td>0.762</td>
</tr>
<tr>
<td>Motor 3</td>
<td>800</td>
<td>1.016</td>
</tr>
<tr>
<td>Motor 4</td>
<td>1000</td>
<td>1.27</td>
</tr>
</tbody>
</table>

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**


