PERFORMANCE ANALYSIS OF MODIFIED VARIABLE FREQUENCY DRIVE (VFD) WITH IMPROVED EFFICIENCY

S. Gowtham¹, K. Karthikeyan²,
¹Assistant Professor, ²Associate Professor
Department of EEE,
KCG College of Technology,
Chennai, India

June 25, 2018

Abstract

This paper details a study performed to determine motor performances under varying speed induced by a variable frequency drive (VFD) controller to the load [2]. Further goal of the study is to improve the design to provide sufficient information to designers so that an improved performance of motors with a modified VFD-controller is achieved [1]-[3]. Motors were tested with a conventional VFD as well as with the modified version. On an average, the efficiency of the motor with a modified VFD was found to be approximately 2 - 10% higher than the conventional VFD system. In an industrial scale this 2% is a huge save in power especially in a variable speed load system. This further adds on to energy savings that can be obtained with VFDs due to their ability to properly adjust speeds to meet actual field conditions [4]-[6].
1 INTRODUCTION

In the industry starting from pumps, conveyors, compressors, fans, mixers, grinders, and other material handling or processing equipment, accounts for about 50 to 70% of electricity consumption. These are driven by electrical motors, and they are the integral parts of heating, ventilating and air conditioning (HVAC) systems [5]-[9]. A lot of research has been dedicated to improve the efficiency of them. Recent developments have increased the complexity of these systems which made them hard to study and model.

Many applications require variable speed drives, so AC motors are usually combined with various types of speed adjustment devices. These devices include gears, belts, eddy-current couplings, hydraulic couplings, VFDs, etc [10], [11], [12]. Recent method of controlling speed is to use induction motors combined with pulse-width modulated variable frequency drives (VFDs). To improve the energy efficiency of the system, variable frequency drives (VFDs) are widely applied on the electric motors of pumps and fans to reduce energy consumption. VFDs have two functions: reducing frequency to reduce the speed and match the reduced load and reducing voltage to reduce motor power [13]-[19]. VFDs change voltage and frequency together, and they use some preset ratios to do that. The ratio of voltage to frequency squared, called the squared ratio, is applied for centrifugal fans and pumps, which are considered to have a cubic correlation between the motor load and speed [20]-[22].

2 EXISTING SYSTEM

A Variable Frequency Drive (VFD) also termed as adjustable frequency drive is a type of motor controller used in electromechanical drive system that drives an electric motor by varying by the frequency and voltage supplied to the electric motor. VFD’s can be operated based on the need of the application. If the application is for different speed other than the rated speed, then VFD’s can be used to simply turn up or down the speed by varying the frequency and voltage to meet the requirements of the electric motor’s load. The biggest advantage of using a VFD is that the energy cost can
be cut down by controlling the motor speed when the application requirement is not for full speed [14]-[17]. VFDs allows to match the speed of the motor-driven equipment to the load requirement. Electric motor systems are responsible for more than 65% of the power consumption in industry today. Optimizing motor control systems by installing or upgrading to VFDs can reduce energy consumption in a facility by as much as 70%. Additionally, the utilization of VFDs improves product quality, and reduces production cost. The conventional VFD’s use an uncontrolled rectifier at the input side. The uncontrolled rectifier produces a pulsating dc with more losses, so by replacing it with controlled rectifier the supply voltage utilized can be reduced as per the load demand.

![Figure 1 Block diagram of uncontrolled rectifier fed variable frequency drive](image)

**3 PROPOSED SYSTEM**

Fig. 2 Shows the block diagram of the proposed system. Here the ac voltage source supplies a Phase controlled rectifier. The purpose of the controlled rectifier is to minimize the use of supply voltage. The supply voltage can be controlled by varying the firing angle of the controlled switch, so that when the load requirement is less, the voltage can be controlled at the supply point itself. With the addition of phase controlled rectifier the losses at the output can be reduced, so the level of output voltage can be increased, there by efficiency can be increased. For the same value of capacitive filter
the ripple content at the output of the controlled rectifier is very less compared to the output of an uncontrolled rectifier.

4 SIMULATION RESULTS

The simulation is performed for the variable frequency drive. The speed control of output is done by varying the motor speed. This is performed by controlling the firing pulses to the inverter using space vector modulation (SVM). Simulation is performed for the typical VFD drive and our proposed modified VFD drive as follows.
space vector modulation technique. So the output of the inverter is precisely controlled, which makes the system to be stable for variations in load. Fig. 4 shows the simulation circuit of controlled rectifier coupled with inverter feeding induction motor. Comparing the input power and output power of both the topologies, the controlled rectifier minimizes the use of input power thus providing better efficiency.

Figure 4 Circuit diagram of Controlled rectifier fed variable frequency drive

Fig 5 shows the waveform for efficiency comparison between uncontrolled and controlled rectifier at 1440rpm. From the waveform we can clearly see the difference in efficiency between controlled and uncontrolled rectifier. The same is repeated for different speeds and tabulated below.
Figure 5 Circuit diagram of Controlled rectifier fed variable frequency drive

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Speed (rpm)</th>
<th>Uncontrolled Rectifier</th>
<th>Controlled Rectifier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Input Power(W)</td>
<td>Output Power(W)</td>
</tr>
<tr>
<td>1</td>
<td>400</td>
<td>911</td>
<td>210</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
<td>924</td>
<td>265</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>876</td>
<td>327</td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
<td>830</td>
<td>390</td>
</tr>
<tr>
<td>5</td>
<td>1200</td>
<td>805</td>
<td>405</td>
</tr>
<tr>
<td>6</td>
<td>1400</td>
<td>773</td>
<td>585</td>
</tr>
</tbody>
</table>

Table 1 shows the results for input and output power with efficiency at different speeds. From the table we can clearly see the difference in efficiency between the controlled and uncontrolled rectifier. The difference is more at lower speeds and it reduces at rated speed. So it is clearly evident that the proposed system consumes less power at lower speed and increased load. This increases the stability of the system.

5 HARDWARE RESULTS

The hardware setup of the proposed modified VFD system is shown below in Fig. 6. The controlled DC input to the Variable Voltage Variable Frequency (VVVF) Inverter is supplied by using a three phase controlled rectifier that is fed to the motor for a controlled RPM. Specifications of the hardware are shown in Fig. 6. The Experiment was conducted in two phase one by directly feeding the VVVF with 3 phase supply which has an uncontrolled rectifier to feed DC output to the inverter. The second one is by externally feeding the DC supply to the Inverter from a 3 phase controlled rectifier. The following tests were performed in hardware setup.
Fig. 7 shows the transient part of the output. We can see that the output voltage and current has a small distortion in the beginning but it settles in a very short time. The transient part is measured for the system at rated speed of 1440rpm. By varying the firing angle of the controlled rectifier at the start the transient part will increase, but settles to the required value in a short time.

Fig. 8 shows the output waveform of the proposed system at rated speed. The output power depends on the type of load used. The load that has been considered here is having a constant torque

---

**Figure 6 Hardware setup & its specifications**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Hardware Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Three Phase Induction Motor</td>
</tr>
<tr>
<td></td>
<td>415V, 5.5A, 3HP, 2.2 kW</td>
</tr>
<tr>
<td>2.</td>
<td>Variable Voltage Variable Frequency (VVVF) drive</td>
</tr>
<tr>
<td></td>
<td>415V, 5.5A, 3HP, 2.2 kW, 0 to 50 Hz</td>
</tr>
<tr>
<td>3.</td>
<td>Three Phase Controlled Rectifier</td>
</tr>
<tr>
<td></td>
<td>415V, 6A, 3.5 kW</td>
</tr>
</tbody>
</table>

---

**Figure 7 Transient waveform for Input current**

Fig. 8 shows the output waveform of the proposed system at rated speed. The output power depends on the type of load used. The load that has been considered here is having a constant torque
characteristic. Fig. 9 shows the input waveform of the proposed system. At rated speed the current drawn by the system is will be minimum. So the power obtained is minimum at the start. From the waveforms we can clearly see the values of voltage and current obtained are minimum as the current drawn by the load is minimum.

Figure 8 Output waveform for current, voltage and power

Figure 9 Input voltage and current waveform

TABLE II Power - Efficiency for Uncontrolled and Controlled rectifier at different speeds using Hardware results
6 DISCUSSION ON RESULTS

The Industrial application of VFD drive here in this paper was considered for a load where the torque characteristic is assumed to be constant. Table 2. Shows the hardware results of power and efficiency. Fig. 10 shows the efficiency plot for both simulation and hardware results.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Speed (rpm)</th>
<th>Uncontrolled Rectifier</th>
<th></th>
<th></th>
<th>Controlled Rectifier</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Input Power (W)</td>
<td>Output Power (W)</td>
<td>Efficiency (%)</td>
<td>Input Power (W)</td>
<td>Output Power (W)</td>
<td>Efficiency (%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>400</td>
<td>905</td>
<td>187</td>
<td>19.44</td>
<td>730</td>
<td>231</td>
<td>28.90</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
<td>763</td>
<td>193</td>
<td>25.97</td>
<td>695</td>
<td>230</td>
<td>33.09</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>722</td>
<td>235</td>
<td>32.46</td>
<td>662</td>
<td>258</td>
<td>38.67</td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
<td>671</td>
<td>280</td>
<td>41.79</td>
<td>641</td>
<td>295</td>
<td>48.98</td>
</tr>
<tr>
<td>5</td>
<td>1200</td>
<td>624</td>
<td>335</td>
<td>54.17</td>
<td>587</td>
<td>310</td>
<td>57.73</td>
</tr>
<tr>
<td>6</td>
<td>1440</td>
<td>585</td>
<td>420</td>
<td>71.79</td>
<td>481</td>
<td>358</td>
<td>74.45</td>
</tr>
</tbody>
</table>

Figure 10 Efficiency comparison between Simulation and Hardware result

On comparison between simulation and experimental results from Table. 1, Table. 2 and efficiency plot, we can clearly see that for conventional VFD and Modified VFD drive there is a difference of about 2 to 10% in efficiency with decrease in speed. Thus the concept of improved efficiency with our modified topology is shown in the results above. The above proposed system is done for 2.2kW machine, this can extended to higher power machines in industries where increase in efficiency increases the lifetime of the machine.
References


