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POWER QUALITY MEASUREMENTS OF A DC MOTOR DRIVE

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ABSTRACT
This paper presents the results of power quality measurements performed on a DC motor drive. The power quality measurements involve a laboratory setup to investigate how various loading conditions on DC drive affect the efficiency, input power factor and total harmonic distortion of output armature current of a DC drive. Through the capture of this information, ways to minimize losses associated with the DC motor drive could be achieved based on finding an optimal operating point or region.

KEY WORDS
DC motor drive, power quality

1. Introduction

The DC motor is a device that is used through many industries in order to convert electrical energy into mechanical energy. One of the primary reasons for choosing DC motors over their AC counterparts is due to the simplicity of their speed control; a higher voltage at the armature input translates into a higher speed. The overall simplicity of the approach allows DC motors to be common in devices ranging from toys, robotics to industrial applications in steel, metal shredding and other material handling industries [1].

In addition, DC motors provide continuous operation available over a speed range of 8:1. Smooth speed control down to zero for short durations or reduced load is also common with DC motors. Often, DC motors are applied where they momentarily deliver three or more times their rated torque. In emergency situations, for example, DC motors can supply over five times rated torque without stalling. Dynamic braking (DC motor-generated energy is fed to a resistor grid) or regenerative braking (DC motor-generated energy is fed back into the DC motor supply) can be obtained with DC motors on applications requiring quick stops, thus eliminating the need for, or reducing the size of, a mechanical brake [2].

In applications where variable speed is required, DC motor drives are being used. DC drive is a device which typically uses power electronics to convert incoming AC power into DC power with as little loss as possible. In general, DC motor drives have the following advantages over ac motor drives [3]:

- DC drives are less complex with a single power conversion from AC to DC
- DC drives are normally less expensive for most horsepower ratings
- DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose
- DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive
- Some AC drives may produce audible motor noise which is undesirable in some applications
- Dynamic braking (DC motor-generated energy is fed to a resistor grid) or regenerative braking (DC motor-generated energy is fed back into the DC motor supply) can be obtained with DC motors on applications requiring quick stops, thus eliminating the need for, or reducing the size of, a mechanical brake.

Medium and high power DC drives in industrial applications are connected to the ac grid through a rectifier. The drive serves as both the controller and safety check for the DC motor. Additionally DC drives provide methods to improve efficiency when slowing down the motor with features like regeneration which returns energy back to the ac line during motor slow down. With the existence of these DC motor drives in industry it is imperative, especially for utility companies, to understand the power quality impact of having such drives on their system under various motor loadings. Through this knowledge, both utility and consumers may use the information to maximize efficiency which in turn maximizes profit.

2. Background

This study will be looking at controlled rectifier drives, in particular a three-phase controlled drive. This means the three phase ac input will have to be rectified through typically a three-phase bridge thyristor rectifier. The DC output voltage of this rectifier is being adjusted based on how much firing angle is applied to the thyristors. This will inherently produce harmonics on both input (ac) and output (DC) sides [4] with harmonic locations h at:

$$\text{Output Voltage waveform: } h = n \cdot f_{in} \tag{1}$$

$$\text{Input Current waveform: } (mn \pm 1) \cdot f_{in} \tag{2}$$

where:

n = 1, 2, 3, …

f_{in} = Input ac frequency

m = pulse type of the bridge used in the drive

In this investigation, the input ac voltage has its frequency at 60 Hz, and since the DC drive is a six-pulse type, hence (1) and (2) become:

$$\text{Output Voltage waveform: } h = 60n \tag{3}$$

$$\text{Input Current waveform: } (6n \pm 1) \cdot 60 \tag{4}$$

In terms of the output voltage waveform, the following equations describe its average and rms values [5]:

$$V_{dc} = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha \tag{5}$$

$$V_{rms} = \sqrt{3}V_m\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}\cos 2\alpha} \tag{6}$$

where:

V_m is the peak value of the ac input voltage

α is the firing angle

Total harmonic distortion (THD) of an ac waveform is defined to be how close the waveform is to a pure sinusoidal waveform. When DC component is present, the THD is computed as follows [6]:

$$THD_V = \frac{\sqrt{V_{rms}^2 - V_{1,rms}^2}}{V_{1,rms}} \tag{7}$$

where:

V_{rms} is the total rms of the waveform including the DC

V_{1rms} is the rms of the fundamental component of the waveform

The input total power factor is the product of distortion power factor and displacement power factor. Distortion power factor is mainly affected by how much distortion or THD, while the displacement power factor is affected by how much firing angle is applied to the thyristors of the bridge.

3. Lab Setup

As previously mentioned, in assessing the power quality of the ac or input side of the DC drive, three main parameters were measured empirically: input power factor, rectifier efficiency and total harmonic distortion (THD). These measurements were conducted when the DC drive is loaded at three different loading conditions, from low to high load.

To perform the measurements, a lab setup consisting of a Siemens SIMOREG DC drive rated at 5hp and power resistors was established. The input to the drive came in the form of three phase ac power at $240V_{rms}$. The drive was found to be a six-pulse controller type capable of outputting 240VDC at 20A along with a field voltage of 150 VDC at 3 A, see Fig. 1.

Since the power quality measurements focused on the DC drive itself, and not on the entire drive-motor system, therefore the main goal was be able to draw currents at the output of the DC drive. This eliminates the need of using an elaborate DC drive-motor-load configuration. Instead, a simple power resistor load bank was used to load the DC drive, see Fig. 2. By changing the resistance values, armature current which is one of the output currents produced by the DC drive could be varied, hence simulating the effects of loading at the input or armature terminals of the DC motor.

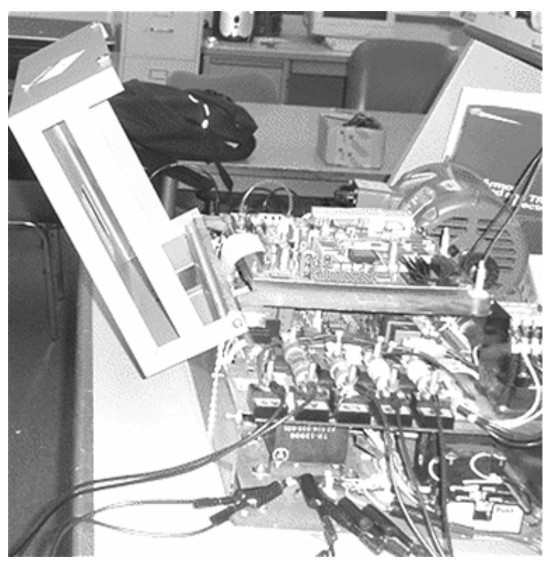

Figure 1. Front view of the DC Drive

Figure 2. DC Drive (top) is connected to resistor load bank (bottom)

In order to measure the total input power factor, total harmonic distortion (THD), and real power at the input terminal of the DC drive, a power analyzer (Power Sight) was used. The power analyzer uses clamp meters to measure currents and voltage probes for voltages.

When conducting the load test, the DC drive was connected to a resistor bank as previously mentioned, but with the field winding resistance of the drive was held constant at full rated current. This in turn simulates the maximum rated magnetic field applied to a DC motor. The armature was initially started at 240VDC at 20A and then adjusted down to achieve the desired armature current to correspond to a certain percentage of motor torque.

4. Test Results

Results of the efficiency measurement are summarized in Fig. 3 for three loading conditions. The low load was defined to be the load at which the DC drive outputted about 4.5A armature current, or roughly 22.5% of its maximum armature current capability. The mid load was achieved when the armature current produced by the DC drive was about 8.5A equivalent to about 42.5% of its maximum capability. The high load was determined once the output armature current was measured at about 20A or 100%. Due to the limited resistor values of the load bank, seven measurement points were taken for each loading case.

As Fig. 3 shows, the efficiency of the DC drive while armature voltage was varied from low to high follows an increasing pattern. Moreover, the efficiency for the high load case is always higher than those of the other two cases. This is an interesting finding since one would think that the higher the output current, the larger the conduction losses of the thyristors in the bridge configuration inside the DC drive, and hence the lower the overall efficiency of the DC drive. This may be explained from the fact that energy required to turn on the thyristors inside the DC drive is the same regardless of the load, and that for every single point of measurement the output field current was kept the same. This should explain the overall consistency of the difference in efficiency from low armature voltage to high armature voltage at the three loading conditions.

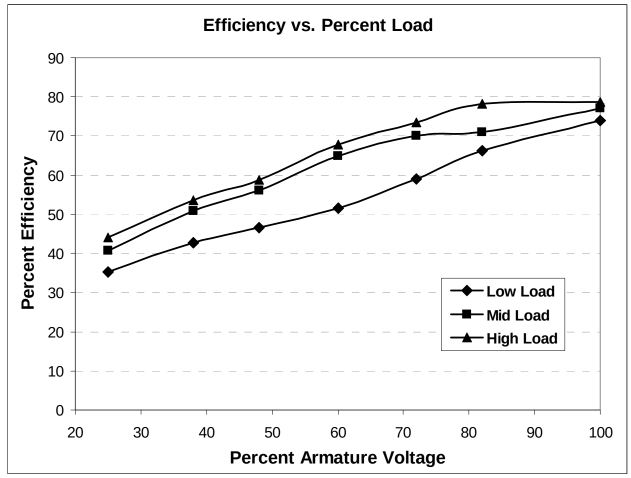

Figure 3. Efficiency of the DC Drive

Results of input power factor measurements with varying DC drive's output voltage at three different loadings are illustrated in Fig. 4. It is clear from the Figure that as the armature voltage is increased, the input power factor decreases. This is true for all three loading cases. This is again an interesting finding since one would think that input power factor should be higher as the output voltage is increased due to the smaller firing angle, hence bigger displacement input power factor.

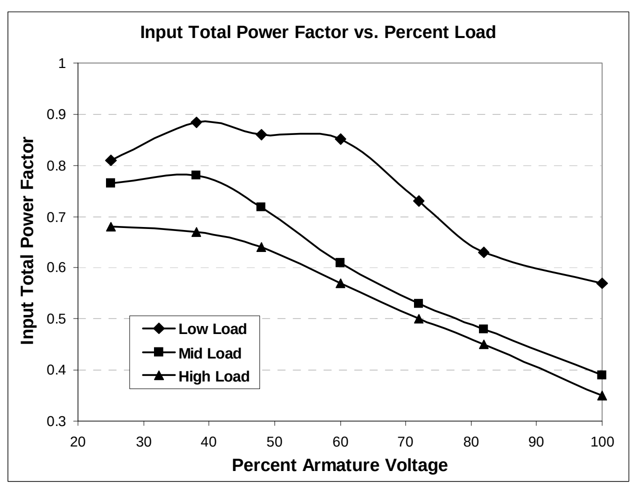

Figure 4. Total input power factor of the DC Drive

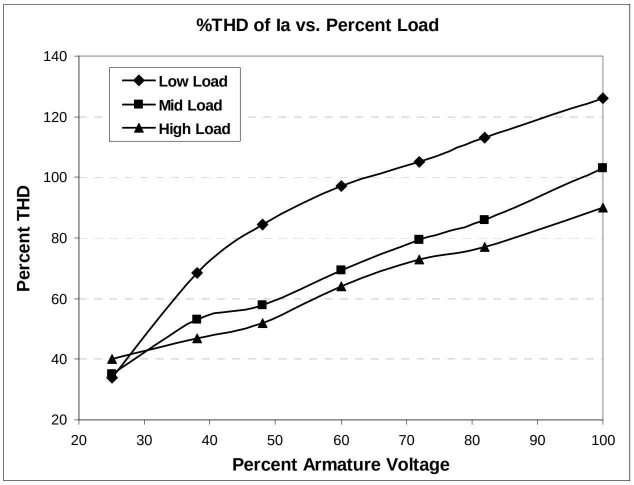

Figure 5. THD of armature current of the DC Drive

Therefore, the decreasing total input power factor must be contributed from the increasing distortion input power factor and the constant firing angle power that would impact the total apparent power at the input. It is also interesting to note that the input power factor, in general, is highest at about 35% load for this particular DC drive. At the lower end, the input power factor is as high as about 0.8 at high load, while at the higher end, the value is as low as 0.35 at low load. The difference in total input power factor is seen to be biggest at about 60% of the armature voltage, whereas the smallest different was measured at the lower armature voltage.

THD measurements at the output (armature) current are shown in Fig. 5. Understanding the THD of the output or armature current, though may seem useless, is actually crucial due to the fact that the armature current serves as an input current to the DC motor. Thus, the quality of the armature current greatly impact for example efficiency of the DC motor.

Figure 5 shows, for each loading case, the THD of armature current increases as the armature voltage increases. This phenomenon could be understood by the fact that as the armature voltage is increased, the average (or DC) component of the output voltage waveform increases. Hence, the THD of the output voltage will accordingly be larger with the larger value of DC component, see (7).

Overall, the high loading case is shown to be at lower THDs. The THD values are smallest at lower output voltage, e.g. about 40%; while the values are in between 90% to 125% at full armature voltage. The difference in THDs throughout the armature voltage range is in between 5% to 35% with the worst case occurring at the low load.

5. Conclusion

In this paper, power quality measurements for a DC drive were presented. A lab setup consisting of a 5 hp DC drive connected to a load resistor bank was established to conduct the measurements. Results from the measurements of the drive's efficiency, input power factor to the DC drive, and the total harmonic distortion (THD) of the armature current of the DC drive were discussed and described. In conducting these measurements, three different loading conditions were investigated while the output (armature) voltage of the DC drive was increased from about 25% to 100%. Two interesting results were observed: the increasing efficiency as the armature voltage is increased and the decreasing total input power factor as the armature voltage is increased. The result of THD measurements done on armature current agrees with the expectation due to the increasing DC component of the armature voltage waveform.

Data from these measurements will be useful for both the utilities and consumers to give them the broad picture of how various operating conditions of a DC drive may affect the power quality differently at both its input and output. This in turn will encourage both utilities and consumers to perform power quality measurements of DC drive in their electrical system such that information could be obtained where the operation of their DC drive system may be optimized.

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