*pq brief*

EPRI

# Evaluation of Losses in ASD/Motor System

## Background

In search of ways to increase production efficiency, many industrial facilities rely on adjustable-speed drives (ASDs) to control production processes that are driven by electric motors. Motors that drive variable-torque loads such as pumps and fans sometimes operate significantly below their full-load ratings. For example, during extreme temperature changes, a heating, ventilation, and air-conditioning system may require full air flow to heat or cool a building. During normal operation, the HVAC system may require only moderate air flow to maintain steady temperature. In the past, dampers, vanes, clutches, brakes, and flow-control valves were used to control the speed and flow of motor-driven processes. Today, ASDs can provide improved system efficiency and flexible control schemes by using electronic rather than mechanical means for controlling motor-driven processes.

When evaluating the benefit of using an ASD, additional system losses must be considered . Not only do losses in the ASD inverter add to the system losses, but motor losses will increase when the motor is driven by an ASD. Quantifying the ASD losses and total motor losses in the system enables a more accurate estimation of savings when comparing ASD operation to other mechanical controls.

## Objective

The objective of the tests performed at LTEE Hydro-Quebec Motor Testing Laboratory was to determine the additional system losses resulting from the use of an ASD in a motor-driven process.

## Test Setup

A voltage-source inverter (VSI), pulse-width modulated (PWM) ASD rated at 150 horsepower was tested with a 150-horsepower, 460-volt motor. The motor was loaded using a 250-horsepower hydraulic brake. Figure 1 shows the test setup. Input voltage to the ASD was fed from a power amplifier, which supplied three-phase voltage (460 volts) with harmonic distortion maintained below 1 percent. All measurements were taken both with and without the ASD in the circuit. During each trial, technicians took power measurements from the ASD input ($P_{\text{ASD-in}}$) and output ($P_{\text{motor-in}}$) with a digital power analyzer, which recorded power consumption in kilowatts. Mechanical load power ($P_{\text{mech}}$) was derived by measuring the output torque and speed, and then multiplying the torque and speed measurements. For each trial with and without the ASD in the circuit, the motor load was set at either 25, 50, 75, or 100 percent of the rated full-load torque. For each trial with the ASD in the circuit, the ASD frequency was set at either 15, 30, 45, or 60 hertz. The ASD output frequency determined the system speed: 60 hertz equaled 100-percent speed, 45 hertz equaled 75-percent speed, 30 hertz equaled 50-percent speed, and 15 hertz equaled 25-percent speed.

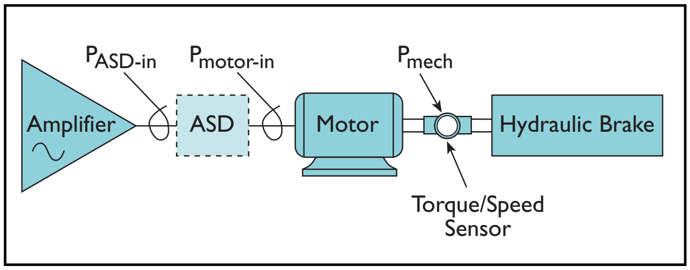

Figure 1. Test setup

## Results

Table 1 shows the measurements taken for each trial. The measurements were used to calculate losses and efficiency for the ASD, the motor, and the ASD/motor as a system. Motor efficiency was calculated by dividing $P_{\text{mech}}$ by $P_{\text{motor-in}}$. For trials with the ASD in the system, the ASD efficiency was calculated by dividing $P_{\text{motor-in}}$ by $P_{\text{ASD-in}}$. In both cases, system efficiency was calculated by dividing $P_{\text{mech}}$ by $P_{\text{ASD-in}}$ ($P_{\text{motor-in}}$ when the ASD was not in the system).

Figure 2 shows how load level and ASD frequency affected motor efficiency with and without the ASD in the circuit. Figure 3 shows how load level and ASD frequency affected system efficiency with and without the ASD in the circuit. Figure 4

Table 1. Test results for motor, ASD, and ASD/motor system

| Freq. (Hz) | Load Torque (%) | $P_{ASD-in}$ (kW) | $P_{motor-in}$ (kW) | $P_{mech}$ (kW) | ASD Losses (kW) | Motor Losses (kW) | ASD Efficiency (%) | Motor Efficiency (%) | System Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|
| 60 (No Drive) | 100 | - | 119.6 | 112.4 | - | 7.2 | - | 94 | 94 |
| | 75 | - | 89.5 | 84.0 | - | 5.5 | - | 94 | 94 |
| | 50 | - | 60.8 | 56.4 | - | 4.4 | - | 93 | 93 |
| | 25 | - | 31.8 | 28.1 | - | 3.7 | - | 88 | 88 |
| 60 (Drive) | 100 | 128.5 | 126.1 | 111.4 | 2.4 | 14.7 | 98 | 88 | 87 |
| | 75 | 99.2 | 97.5 | 84.9 | 1.7 | 12.6 | 98 | 87 | 86 |
| | 50 | 68.6 | 67.4 | 56.5 | 1.2 | 10.9 | 98 | 84 | 82 |
| | 25 | 37.8 | 37.0 | 28.4 | 0.8 | 8.6 | 98 | 77 | 75 |
| 45 (Drive) | 100 | 94.8 | 92.7 | 84.0 | 2.1 | 8.7 | 98 | 91 | 89 |
| | 75 | 72.0 | 70.5 | 63.4 | 1.5 | 7.1 | 98 | 90 | 88 |
| | 50 | 49.1 | 48.1 | 42.3 | 1.0 | 5.8 | 98 | 88 | 86 |
| | 25 | 26.6 | 26.1 | 21.5 | 0.5 | 4.6 | 98 | 82 | 81 |
| 30 (Drive) | 100 | 65.0 | 63.1 | 55.7 | 1.9 | 7.4 | 97 | 88 | 86 |
| | 75 | 49.1 | 47.7 | 42.0 | 1.4 | 5.7 | 97 | 88 | 86 |
| | 50 | 33.7 | 32.8 | 28.3 | 0.9 | 4.5 | 97 | 86 | 84 |
| | 25 | 18.4 | 18.0 | 14.3 | 0.4 | 3.7 | 98 | 79 | 78 |
| 15 (Drive) | 100 | 34.7 | 33.0 | 27.4 | 1.7 | 5.6 | 95 | 83 | 79 |
| | 75 | 26.0 | 24.9 | 21.2 | 1.1 | 3.7 | 96 | 85 | 82 |
| | 50 | 17.5 | 16.6 | 14.2 | 0.9 | 2.4 | 95 | 86 | 81 |
| | 25 | 9.4 | 9.0 | 7.2 | 0.4 | 1.8 | 96 | 80 | 77 |

shows how the load level and ASD frequency affected total power consumption of the system with and without the ASD in the circuit.

## Discussion

The data from Table 1 reveals that the motor had a lower efficiency when it was connected to an ASD than when it was directly connected to line voltage. This lower motor efficiency resulted from the non-sinusoidal voltages and currents characteristic of ASDs. At 60 hertz, motor efficiency was lower when the ASD was in the circuit, anywhere from 6 to 11 percent lower depending on the motor load.

The ASD also contributed to system losses. As shown in Table 1, the losses in the ASD at 60-hertz operation were between 2.4 kW at full load and 0.8 kW at 25-percent load, with an efficiency of 98 percent. The losses in the ASD were the result of the switching and conducting of the power-electronic components in the ASD. At lower speeds, the efficiency of both the motor and the ASD dropped, as shown in Table 1. However, at

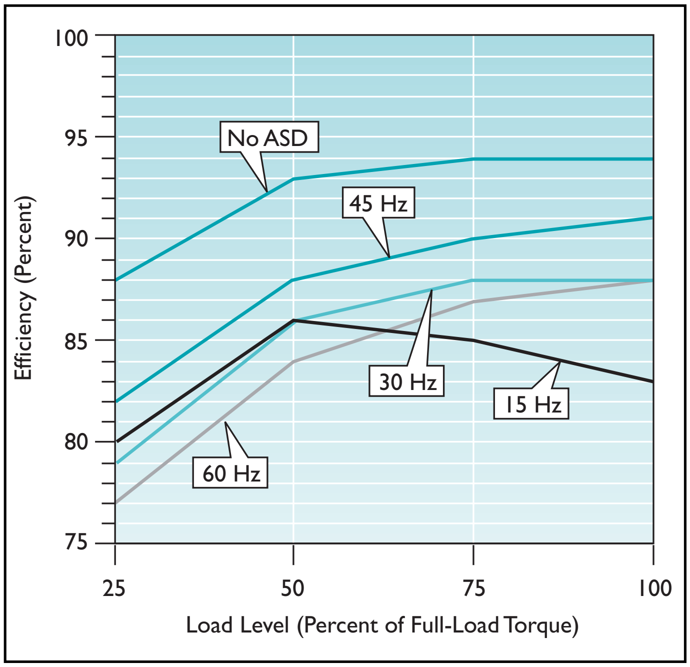

Figure 2. Motor efficiency based on motor load and ASD frequency

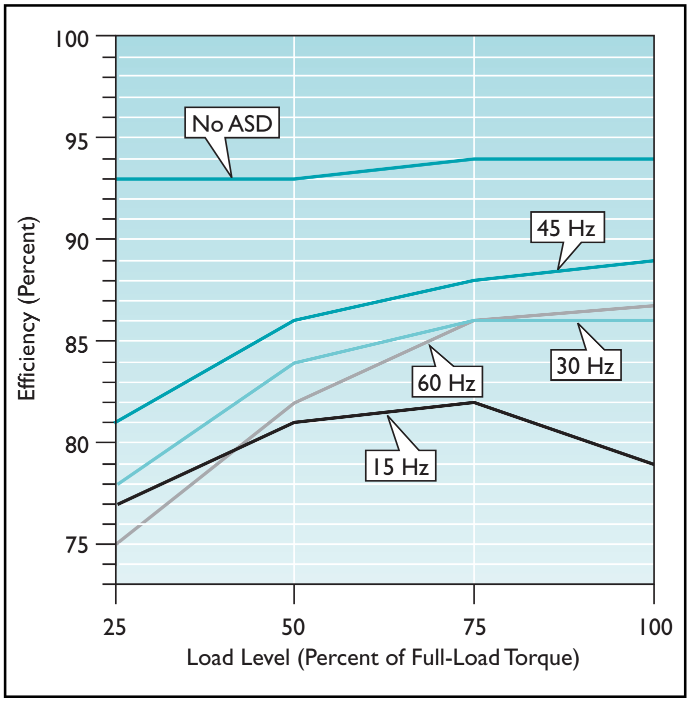

Figure 3. Efficiency of the motor alone (no ASD) and the ASD/motor system based on load level and ASD frequency

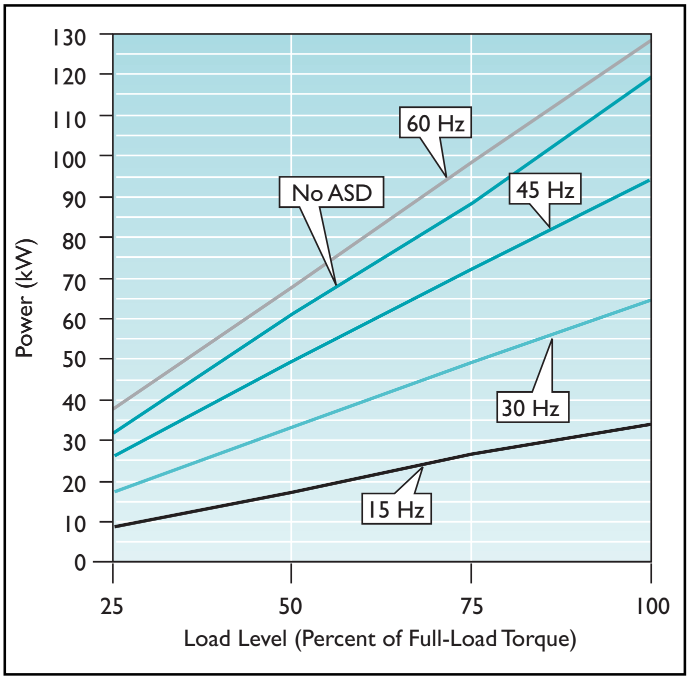

Figure 4. Power consumption of the motor alone (no ASD) and the ASD/motor system based on load level and ASD frequency

lower ASD frequencies, the ASD/motor system consumed less power for the same load-torque level as the line-connected motor operating at 60 hertz. The tutorial on the back page illustrates how an ASD/motor system may use less power than a line-connected motor when the motor is operated at less than rated speed.

## Significance

Manufacturing companies continually seek ways to trim operating costs and increase production efficiency. Small energy savings incurred within one production process over the course of one day can be multiplied to reap significant savings throughout the year. When mechanical controls such as dampers and valves are replaced by ASDs, the system energy performance usually improves, especially for processes that require a partially closed damper or valve for a large portion of the total operation time. Determining whether an ASD will save energy requires careful consideration of process characteristics. In addition, quantifying all the losses incurred by adding an ASD to a motor-driven process will enable a more accurate estimate of potential energy savings.

## Acknowledgments

The work published here is part of an EPRI system compatibility initiative. Special recognition goes to LTEE Hydro Quebec for conducting these ASD/motor efficiency tests.

## Tutorial: Potential Energy Savings with ASD Control

The efficiency of motor driven by an ASD is always lower than a line-connected motor. Also, an ASD will contribute to system losses. So why use an ASD? Consider the motor-driven process illustrated in Figure A. The liquid-coolant pump in this process is a variable-torque load on the motor. The flow rate of the liquid coolant transported by the pump is controlled by a flow-control valve. However, when the flow-control valve restricts flow, system efficiency decreases.

The function of a flow-control valve can be achieved with an ASD. By changing the output frequency of the ASD, the motor speed, and thus rate of flow, can be controlled. However, while losses in the flow-control valve are eliminated, additional losses in the motor and the ASD are introduced. As shown in Figure B, these additional losses are small when compared with the losses in the mechanical control, especially at reduced flow rates. Therefore, if the process is operated at a reduced flow rate for most of the time, using an ASD instead of a mechanical control will likely yield significant energy savings, notwithstanding the additional losses in the ASD and motor.

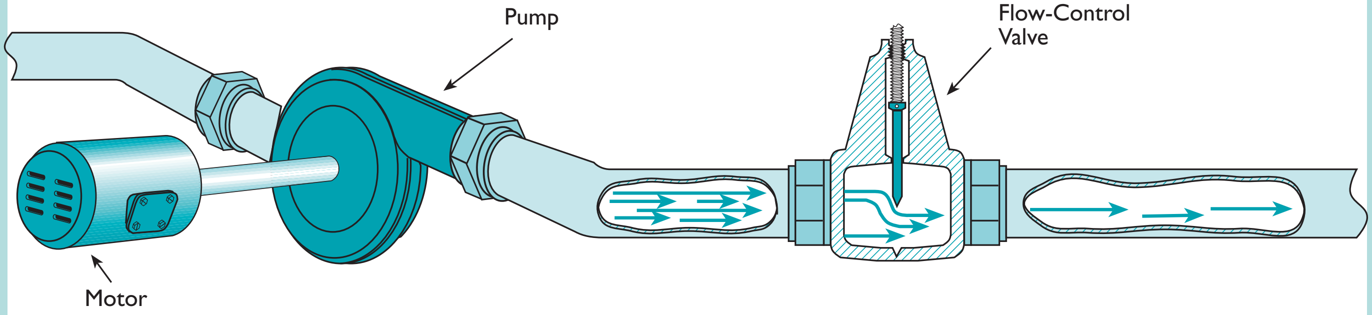

Figure A. Motor-driven process using a flow-control valve to control the rate of flow of a liquid coolant

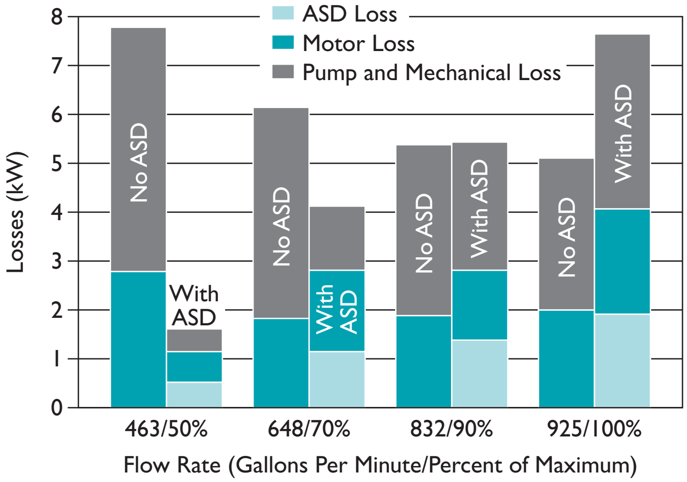

Figure B. Losses in system elements with mechanical control versus ASD control at four different flow rates

---

The EPRI Power Electronics Applications Center (PEAC) supports electric utilities in their efforts to understand and resolve power quality problems and system compatibility issues; help utilities solidify durable, beneficial relationships with their customers, manufacturers, and standards organizations; and empower utilities with knowledge via power quality training and publications.

For information about the EPRI Power Electronics Applications Center, call 423-974-8288. To order EPRI publications, call the EPRI Customer Assistance Center at 800-313-3774 or, if outside the U.S., 1-650-855-2121.

PB-112127

♻ *Printed on recycled paper in the United States of America.*

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304
PO Box 10412, Palo Alto, California 94303 USA
askepri@epri.com • www.epri.com

Brief Number 47, December 1998