Efficiency Study of Adjustable Speed Drive with Dual Motor Connection

C. Mitsui, *Member, IEEE*, S. Tu, Taufik, *Senior Member, IEEE*, and M. Anwari, *Member, IEEE*

***Abstract*-- This paper presents a study of AC Adjustable Speed Drive when used to operate two induction motors. The impact of running the two motors under various loading conditions and operating output frequency to overall efficiency of the Adjustable Speed Drives under room temperature will be discussed. Data obtained from laboratory and their analysis will be presented.**

***Index Terms*-- Adjustable Speed Drives, Power Quality.**

I. Introduction

Power electronics is the new and optimized method to process and control energy flow by controlling supplied voltage and currents. An upgrade to a power electronics circuit raises performance by reducing power loss, thus increasing energy efficiency within a power conversion process. Studies show that by the year of 2000, at least 50% of all electrical loads were supplied through Power Electronics systems [1]. The expectation should be much higher in the years to come. The main reason of the shift toward power electronics is due to the more efficient and cost effective features of power electronics as compared to the previous power processing technology. In addition, power electronics can be implemented anywhere power conversion occurs. This conversion can be in the form of DC-to-AC, AC-to-DC, DC-to-DC, and AC-to-AC. Frequencies, voltage levels, and current levels may also be converted and processed with power electronics. Power electronic devices are practically used in almost every electrical system from small-scale power distribution system found in portable devices to high power conversion system used in high-voltage DC power transmission.

The DC-to-AC conversion process with power electronics is commonly known as the switched-mode inversion; hence the power converter is called switched-mode inverter. One major application of switched-mode inverter is Adjustable Speed Drives (ASD). Their job is to convert ac input with a fixed rms and frequency (ac line input) to ac output with variable rms and frequency. ASDs are normally used to control the speed of ac induction motor and they are also called Variable Frequency Drives (VFDs). Traditionally, motors were operated uncontrolled, running at constant speed and at part or variable load. This means the motors either run at constant speed bypassing the excess capacity, or use some form of capacity regulation (dampers, valves) which is very inefficient. ASD controls the motor speed to match the flow or load requirement; hence the motoring system is easier to automate, more energy efficient and requires lower maintenance. In water pumping system, for example, the use of ASD will result in a reduction of up to 50% flow results which translates to an 88% reduction of energy input; hence reducing energy cost [2].

Manufacturers want faster, more efficient machines that are more productive. The electrical utilities encourage this because it reduces the aggregate rate of growth electrical load and helps defer large investment for substations and generation. This results in systems which depend on precise control of motors through adjustable speed drives (ASD) and complex control systems. This trend towards greater control of energy intensive process is supported by the rate of growth in the AC and DC drives market as shown in Fig. 1. In 1988 DC drives held close to 60% of the market. Between 1988 and 1995 there has been a 50% increase in the number of drives with most of the growth in AC drives. Equivalent growth can be found in the use of programmable logic controllers.

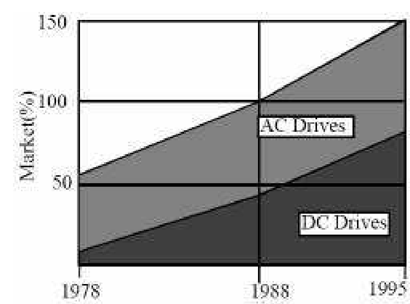

Fig. 1. Market growth of AC and DC Drives [3].

Due to their economic benefits, ASDs become increasingly popular for motor control applications. In 1997 ASD was a US $20 billion industry in the world and the increasing trend continues since [4].

ASDs using power electronics technology, however, possesses several drawbacks. In particular, ASDs cause Power Quality issues both at their input and output. At the output side, the pulsating output voltage may cause significant harmonics and may introduce additional stresses to the motors

C. Mitsui is with San Diego Gas & Electric, San Diego, CA 92112, USA (e-mail: cmitsui@semprautilities.com).

S. Tu is with Anheuser Busch, Fort Collins, CO 80524, USA.

Taufik is with the Electrical Engineering Department, Cal Poly State University, San Luis Obispo, CA 93407, USA (e-mail: taufik@)calpoly.edu).

M. Anwari is with the Energy Conversion Department, Faculty of Electrical Engineering, University Teknologi Malaysia, 81310 Johor, Malaysia (e-mail: makbul@ieee.org).

978-981-05-9423-7 © 2007 RPS

connected to them. At the input, it has been known that ASDs are significant harmonic sources and thus mitigating these harmonics has become crucial in power systems.

The power quality impact of a single ASD connected to a single motor has been well understood and its qualitative and quantitative study has been presented in many papers such as [5] and [6]. However, one important use of ASDs is in the HVAC (Heating Ventilating and Air Conditioning) applications such as those found in buildings. In this application, there are typically more than one motor connected to an individual ASD. The harmonic impact of having one ASD connected to multiple motors has not yet been studied. This paper reports a harmonic study to characterize the impact on harmonics and overall efficiency of one ASD connected to two motors at varying loads. A laboratory setup was established to perform the measurements. Data obtained from this study would provide the preliminary understanding on how multi-motor connection in ASD impacts the Power Quality.

II. Laboratory Setup and Results

Fig. 2 shows the block diagram of laboratory setup to perform the harmonic and efficiency measurements. All measurements were performed under room temperature.

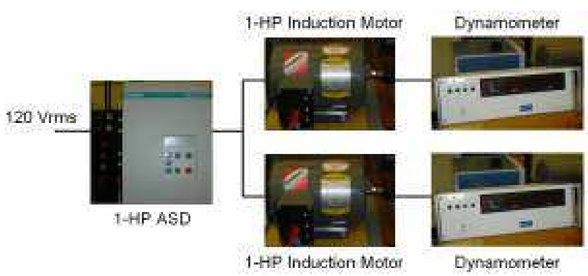

Fig. 2. Block diagram of lab setup.

The adjustable speed drive was chosen to be a 1-HP Siemens' SIMOVERT P 6SE21, and each motor is a 1-HP Baldor's inverter-rated induction motor. The Siemens drives used in this setup incorporate the V/F type control. Moreover, each drive was operated under one single switching frequency of 5 kHz to obtain measured data. As for the motor, each was connected to a dynamometer such that the load for each motor can be varied. Efficiency was measured from the single phase ac input to the drive (electrical power) to the mechanical output power of the ac motor as measured by the dynamometer readings. Since the ASD is rated at 1-HP while each motor is rated at 1 HP, it was understood that the total horse-power of both motors at any given time had to be less than 1 HP.

A single motor connection was also setup whose data were later compared with the dual connection. To find the mechanical output power in Watts, the following equation is used

$$P_{out} \quad \left(1.184*10^{-2}\right)*(n)(T) \tag{1}$$

where n is the motor speed in rpm and T is the load torque in lb-in as read from the dynamometer displays.

Figs. 3 to 4 show the results of efficiency measurements. Comparisons between efficiencies obtained from single and dual connections are shown in Fig. 3 for 50 Hz ASD's output and in Fig. 4 for 60 Hz ASD's output. It is evident from both figures that the efficiency of single connection outperforms those of the dual connections at the three different motor 2 (M2) loadings. Within the dual connection themselves, we can observe that in general the lowest loading yields the lower efficiency. This is consistent with the data typically provided by ASD's manufacturers.

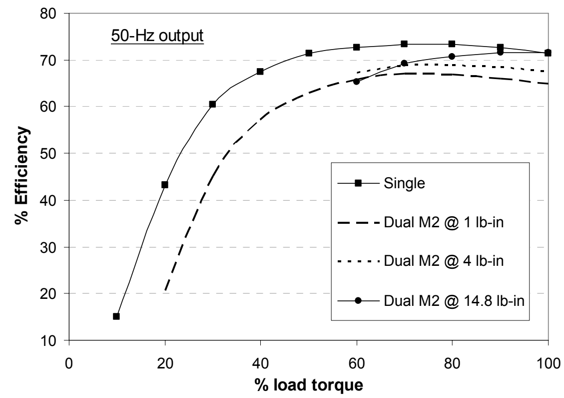

Fig. 3. Efficiency at 50-Hz output: single vs. dual connections when motor 1 load is varied while motor load 2 (M2) was kept constant at a certain value.

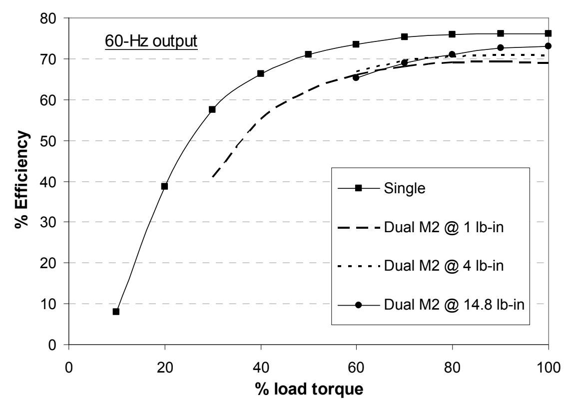

Fig. 4. Efficiency at 60-Hz output: single vs. dual connections when motor 1 load is varied while motor load 2 (M2) was kept constant at a certain value.

Figs. 5 to 7 show the results where the frequency output of the ASD was kept at a constant value. For each frequency, motor 1 load was varied while motor load 2 (M2) was kept at a constant value. The measurements were repeated for 4 different constant loading values of motor 2 (M2). In all three frequencies, one common pattern that is found from all curves is that above approximately 70% motor 1 loading, the higher loading of motor M2 gives higher efficiency. Interestingly, at about below 70% motor 1 loading, the highest loading drops drastically in all three cases. At some loading value, the efficiency at the highest motor 1 loading will actually be less than the rest of the motor 1 loading.

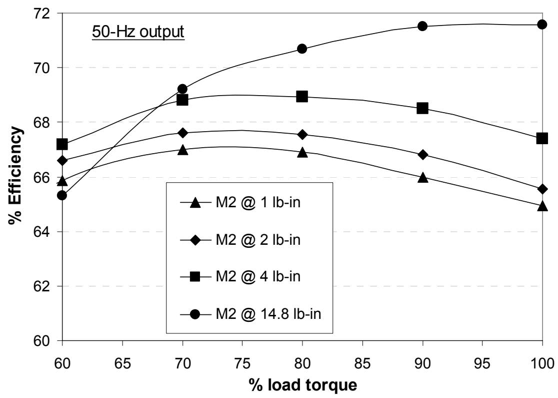

Fig. 5. Overall efficiency at 50-Hz output for dual connections when motor 1 load is varied while motor load 2 (M2) was kept constant at a certain value

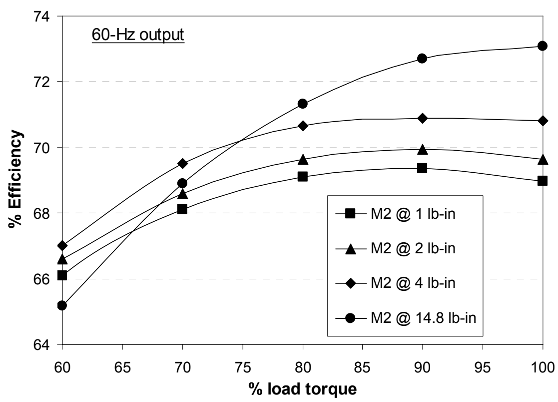

Fig. 6. Overall efficiency at 60-Hz output for dual connections when motor 1 load is varied while motor load 2 (M2) was kept constant at a certain value.

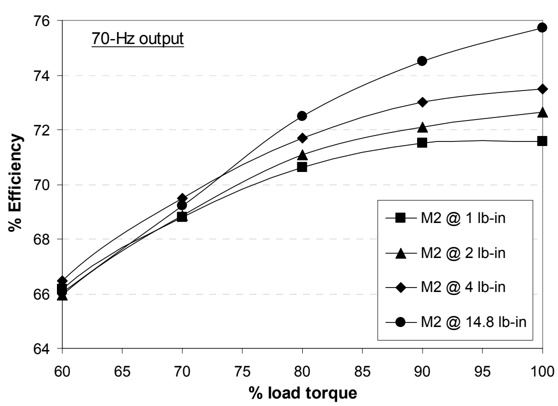

Fig. 7. Overall efficiency at 70-Hz output for dual connections when motor 1 load is varied while motor load 2 (M2) was kept constant at a certain value.

Fig. 8 depicts another interesting result of this study. The four curves were obtained when motor 2 was loaded at 14.8 lb-in while motor 1 load was varied from 60% to 100%. The measurements were repeated for four frequencies of ASD's output. All four curves interestingly intersect each other at about 70% motor 1 loading. Beyond the 70% loading, the efficiency is higher at the faster frequency (70 Hz) and lower the smaller the frequency. However, below 70% the situation is reversed; that is the higher the frequency of the ASD's output the less the efficiency.

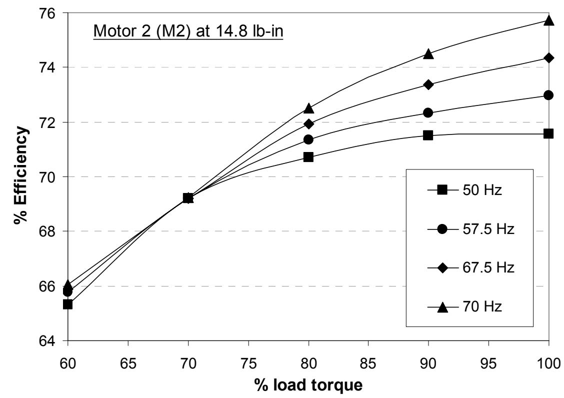

Fig. 8. Overall efficiency at 4 different frequencies for dual connections when motor 1 load is varied while motor load 2 (M2) was kept at 14.8 lb-in.

III. CONCLUSIONS

Analysis of the single motor configuration shows that efficiency increases as the motor approaches full load. The efficiency is also higher when the motor is operating at the rated frequency of 60 Hz. Efficiency decreases as the frequency is moved away from the rated value.

Analysis of the dual motor configuration shows more complicated relationships and results. The efficiency increases as the motor approaches full load similar to the single motor configuration. One point worth mentioning is that with respect to loading the two motors at a given frequency, the results suggest that the higher loading of one of the motors does not guarantee the most efficient operation of the drive-motor system. It was found that below at around 70% loading of motor 1, overall efficiency suffers when motor 2 is heavily loaded. 70% motor 1 loading turned out to be the point of interest as well when it comes to characterizing efficiency with respect to the output frequency of the ASD. A higher frequency seemed to be more beneficial for energy savings but only when motor 1 is loaded at 70%. Below the 70% loading point, the efficiency at higher frequency becomes lower.

Further study of the dual connection of ASD involves measurements of the total harmonic distortion (THD) of the input current to the ASD. The effect that is of interest here would be whether or not the use of two motors under one ASD impacts the level of harmonics produced by the drives. Information obtained from such study will be useful in further determining the size of line reactor needed for one-drive dual-motor applications. Finally, another interest would be to investigate the efficiency performance of the same dual connection setup but under different temperature settings.

IV. References

[1] N. Mohan, T. Undeland, and W. Robbins, *Power Electronics: Converters, Applications and Design*, 3rd edition, John Wiley & Sons, 2003, p. 3.

[2] A. T. de Almeida, F.J.T.E Ferreira, and D. Both, "Technical and economical considerations in the application of variable speed drives with electric motor systems," in *Proc. 2004 IEEE Industrial and Commercial Power Systems Technical Conference,* Issue May 2004, pp. 136 – 144.

[3] V. Hyvarinin and J.P. Makinen, "Digital Drive Systems with Variable Speed AC Motors," ABB Review 4/90, pp. 3-10.

[4] Online Drives Magazine, http://www.drivesmag.com

[5] A. Zobaa, "Harmonic problems produced from the use of adjustable speed drives in industrial plants: case study," in *Proc. 2004 11th International Conference on Harmonics and Quality of Power*, Issue Sept. 2004, pp. 6 – 10.

[6] A.K. Wallace, R. Spee, and L.G. Martin, "Current harmonics and acoustic noise in AC adjustable speed drives," in *Proc. 1988 IEEE Industry Applications Society Annual Meeting*, Issue Oct 1988, pp. 483-488.

V. Biographies

Cory Mitsui (M' 2005) attended California Polytechnic State University in San Luis Obispo, California, USA studying Electrical Engineering with an emphasis in power engineering. He graduated from Cal Poly in June 2005 with a Bachelor of Science degree in Electrical Engineering. He is currently working as an electrical engineer at San Diego Gas and Electric in San Diego, California, USA.

Sherman Tu studied electrical engineering with power engineering as his area of concentration at California Polytechnic State University, San Luis Obispo, California, USA. He received his Bachelor of Science degree in Electrical Engineering in June 2005 and since then he joined Anheuser Busch in Fort Collins, Colorado, USA as an electrical engineer.

Taufik (M'1997, SM'2007) was born in Jakarta, Indonesia. He received his BSEE degree with minor in Computer Science from Northern Arizona University in 1993. He then continued his study and received his MS degree in Electrical Engineering and Computer Science from the University of Illinois at Chicago in 1995. Following this, he spent one year working as a research assistant at the Microelectronics Fabrications lab at the University of Illinois at Chicago before pursuing his Doctoral degree in electrical engineering at Cleveland State University which he received in 1999. Since then, Dr. Taufik joined the Electrical Engineering Department at California Polytechnic State University in San Luis Obispo where he is currently an Associate Professor.

Dr. Taufik has had industrial experience working with engineering companies such as Capstone Microturbine, Picker International (currently Philips Medical System), Allen-Bradley (Rockwell Automation), Rantec Power Systems, San Diego Gas & Electric, and APD Semiconductor (currently Diodes Inc.). Dr. Taufik's main areas of interests are in power electronics and engineering education.

Makbul Anwari (S'2004-M'2006) was born in Pontianak, Indonesia. He received the B.Eng. degree in Electrical Engineering from University of Tanjungpura, Indonesia, in 1995, the M.Eng. degree in electrical engineering from Bandung Institute of Technology, Indonesia, in 2000, and the Dr.Eng. degree from Nagaoka University of Technology, Japan, in 2005.

From 1995 to 2006, he joined the Electrical Engineering Department at University of Tanjungpura, Indonesia, where he was a Lecturer. Currently, he is a Lecturer at the Department of Energy Conversion, Faculty of Electrical Engineering, Universiti Teknologi Malaysia.

Dr. Anwari is a member of the IEEE Power Engineering and Industry Application Societies.