SURVEY OF USERS' EXPERIENCE WITH ADJUSTABLE SPEED DRIVES RATED 500 HP AND ABOVE

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1.0 ABSTRACT

Many utilities in Canada, including Ontario Hydro are encouraging their customers to review their processes and applications to identify opportunities for saving energy. Cash incentives are being offered towards conducting feasibility studies and project implementation when energy paybacks are attractive. This paper describes the work which was sponsored by Ontario Hydro to survey users' experience with Adjustable Speed Drives (ASD) rated 500 HP and above. The purpose of the survey was to gather field data on the performance of the ASD, its associated equipment and the process. This information will enable Ontario Hydro to better meet the needs of customers who are using or considering employing ASD, and to provide suppliers with market intelligence to improve the products and services.

This paper reviews the questionnaire sent to users and analyzes the survey findings for AC ASD's. It also offers conclusions and suggestions based on the responses gathered in the study.

2.0 SURVEY BACKGROUND

ASD's have the potential to offer substantial advantages to industrial users through improved process control, and higher efficiency. The use of ASD has been increasing over the last few years and this trend is expected to continue. The ASD technology has been undergoing continuous improvement and development to better meet industry requirements for greater reliability and performance. In spite of these advancements there are still several ongoing technical issues and barriers that might be impeding the widespread use of ASD's. These concerns include:

- motor related problems, namely: overheating, insulation breakdown, vibration, bearings, rotor and stator failure.
- Inverter related problems, namely: blown fuse, tripping out, components and logic boards failure.
- Harmonic effect on motors, driven mechanical load, other electrical equipment and incoming power supply.
- Power factor capacitor failure.
- Torsional vibration.
- Complying with utility harmonic guidelines.
- Additional space and cooling requirements.
- User misconception about the status of ASD technology.

In 1991 the Canadian Electrical Association (CEA) sponsored a Canada-wide project (#8923 U736) to survey users' experience with ASD rated 5 to 500 HP for both commercial and industrial sectors. Ontario Hydro identified the need to conduct a survey beyond the scope of the CEA work and considerably expand on specific areas of interest related to 500 HP and above in Province of Ontario.

3.0 STUDY OBJECTIVES

The study is geared to investigate the effect of the ASD on the performance of motor, driven equipment, process, incoming power supply and other connected electrical equipment. In March 1992, Ontario Hydro initiated the survey of existing ASD industrial users to achieve the following objectives:

1 - Establish the magnitude and extent of the technical concerns that appear to be limiting increased use of ASD's.

2 - Provide Ontario Hydro with first hand operating experience and information on ASD reliability, performance, maintenance record and any other concerns. This will help Ontario Hydro to address the needs of their customers that are using or considering employing ASD's.

3 - Provide manufacturers and suppliers of motor, pump, fan, blower and ASD with field experience data which will assist them to better address end users' needs.

4.0 METHODOLOGY

The project methodology included the identification of users, the selection of issues to be addressed, the analysis of the survey data and the development of conclusions and recommendations.

For purpose of this study the ASD users were divided into eight sectors depending on the type of industry. These were mining, Petro-chemical, steel, pulp and paper, cement, utility, municipal and general.

In all, a total of 22 users were identified in Ontario and every one of them received a copy of a two-part questionnaire. Users participation and co-operation were excellent and 18 returned a completed questionnaire reporting on 42 AC ASD installations. This

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represents 82% rate of return, and indicates that the methodology followed here was very successful. In addition, plant visit and key personal interviews were conducted with six pre-selected users representing the various sectors of industry to ensure maximum users' input on their ASD design, selection and operating experience.

5.0 SURVEY QUESTIONNAIRE

The quality of the information acquired from a survey is limited by the questions asked in the survey and its clarity. It is essential for a survey of this type that all important issues to users are properly represented and be user-friendly, to solicit information from very busy industrial users.

The survey questionnaire consisted of two parts. Part A, which is comprised of 42 questions, requested specific information on each ASD used by the Company. If the Company had many drives, it was given the option of either reporting on all its drives or selecting a representative sample of a minimum of five of its drives. Most companies reported on all the drives they had in operation. Part B, which is comprised of 10 questions, asked more general questions with the intent of obtaining the company's overall experience with all ASD's.

The following is a summary of the questions asked in Part A and B grouped under several sections:

1 - Motor Design.

- Motor size.
- Voltage rating.
- Nominal speed.
- Overspeed capability.
- New or retrofit (state derating factor). Standard or custom built.
- Service factor.

2 - Motor Testing.

- Heat run test at 60 HZ and when connected to inverter.
- Efficiency at operating speed range and expected loading conditions.

3 - Motor Features and Selected Options.

- Manufacturer.
- Year purchased.
- Years in service.
- Solid state overload.
- Auto restart.
- External cooling.
- Temperature sensors.
- Bypass control (60 HZ operation).

4 - ASD Application.

- Variable torque.
- Constant torque.
- Motor rotation direction.
- Load duty cycle: steady, continuously changing, slightly changing, other.
- Type of service: continuous (24 hr/day), intermittent (4 hr/day), normal (8 hr/day).
- Operating speed range.
- Type of driven load: pump, fan/blower, compressor, other.

5 - ASD Sizing Guidelines.

- Starting torque.
- Required horsepower.
- Motor size.

6 - Inverter Features and Selected Options.

- Manufacturer.
- Year purchased.
- Years in service.
- Type: Variable Voltage Inverter (VVI), Current Source Inverter (CSI), Pulse Width Modulated (PWM).
- Input isolating transformer.
- Output transformer to match motor voltage.
- Input and output harmonic filters.

7 - ASD Selection.

- Feasibility study conducted by Consultant, Company personnel, Other.
- ASD selection/design by Consultant, Company personnel, Other.
- ASD compatible with the load torque requirements.
- ASD purchased from a Manufacturer, Distributor, Contractor or supplied part of an equipment package.

8 - Environmental Control.

- Additional humidity/temperature control.
- Space limitation.

9 - ASD Start-up and Commissioning duration.

<3 days, <7 days, <one month.

10 - Training and Documentation.

- Operating/maintenance instruction package provided.
- Operating/maintenance training.
- Preventative maintenance contract.

11 - Nature of any problems that are attributed to the use of ASD's.

- Motor.
- Inverter.
- Driven equipment.
- Process.

12 - ASD Reliability.

- Average time interval between failures.
- Average down time for repair.
- Average cost to repair failure.

13 - Reasons for Selecting ASD.

- Reliability.
- Maintenance.
- Efficiency.
- Soft start.
- Price.
- Process requirement.
- Ontario Hydro incentive program.

14 - Harmonic Analysis.

- Harmonic study performed.
- Harmonic filter used.
- Complying with Ontario harmonic guidelines for THD and IT product.
- Voltage notching.
- Power factor correction capacitors failure.
- Motor overheating.
- Torsional analysis.

15 - Suitability of ASD Application.

- Successful application.
- Purchase again a new ASD.

6.0- SURVEY RESPONSE AND ANALYSES

A total of 18 out of 22 users responded to the survey reporting on 42 AC drives. The data gathered were analyzed using the frequency tabulation method. This method counts the response to each of the possible answers to each question in the questionnaire and the reporting of this number is compared to the total responses as a percent. Considerable observations and conclusions can be formed from this information alone. The following is a summary of the responses, findings and general observations.

1 - Motor Design.

- Motor sizes reported on were mainly between 500 - 1000 HP (90.5%), the largest being 9000 HP (synchronous motor).

- 600V is the most common motor voltage rating (47.6%), followed by 4160V (33.3%), and 2300V (11.9%). In the case of 4160V and 2300V power conversion is carried at 600V, but a step up transformer is used at the inverter output to match motor voltage.

- Over 45% of the motors are rated at 1200 rpm or less, 40.5% at 1800 rpm and 14.3% at 3600 rpm.

- Only one user reported running the motors at 110% rated speed; a few had the capability but had not used it.

- Less than 10% of the motors used were retrofit and no derating factor was employed.

- About 71% specified standard motor and 29% custom built.
- 80% of the motors were specified with service factor equal to 1.15. Users, in general, selected 1.15 service factor to accommodate additional temperature rise caused by harmonics. This assumption should be used with caution especially for constant torque load application operating at reduced speed. Service factor is meant to drive loads above nameplate HP for <u>limited</u> amount of time without incurring thermal damage, and is not intended for extended period of operation at reduced speed.

2 - Motor Testing.

- 52.4% of the users stated that their motor underwent heat run test at 60 HZ and when connected to an inverter. One user reported that motor temperature rise exceeded specified 80°C rise when tested with PWM inverter running at 50% speed and constant torque.

3 - Motor Features.

- Induction motors are commonly used. Only one user reported using synchronous machines rated 9,000 HP with load commutated inverter (LCI) drive.

- Over 60% of motors were put in service in the last 5 years and over 1/3 in the last 12 months.

- The use of solid state overload relay and temperature protection was fairly common.

- Bypass control is not widely employed. This indicates that the majority of users have established that ASD is fairly reliable and elected not to specify the bypass feature.

- External cooling used on 25% of the motors mainly when operating at lower speed range to overcome reduced cooling and additional harmonic loss problems. This feature is strongly recommended in constant torque load applications and operating speed range below 50% of rated speed.

- Auto restart not considered significant feature, nor was it considered to be particularly desirable. The 3 responses referring to auto-start stated it had been defeated, because of conflict with associated equipment or process features. Some users consider this feature unsafe as the drive could start by itself when a process shutdown permissive is reset. The auto restart feature should be defeated unless specifically requested by user.

4 - Problems with driven equipment attributable to the use of ASD.

- Two respondents reported experiencing mechanical problems. One, who had 5 drives, reported on increased wear of bearings when operating at 110% of rated speed.

  The other, who had 4 drives, reported that mechanical vibration resulted in one case from harmonic resonance. Also the drive sensitivity to voltage dips was too great, and the subsequent auto re-starts after tripping could cause operational problems.

Mechanical problems, although few reported, should not be lightly evaluated when employing ASD especially for large HP drives. It is costly to rectify mechanical problems, and if not properly addressed at the design stage, they could cause substantial equipment damage and extended loss of production.

5 - ASD Application.

- 73% are of variable torque and the remaining are constant torque applications with majority (83%) in 24 hr/day continuous operation.

- All motors operate in one direction.

- Drive duty cycle is mostly steady or slightly changing (67%), and 31% is continuously changing.

- Majority of the drives (46%) are employed to control speed from 70-100%. Considerable energy saving is achieved even with a low speed turndown, because the HP requirements of fans, blowers and pumps vary with the cube of the speed.

- Pump constitutes 48% of the driven loads, followed closely by fan/blower (45%), and by compressor (5%).

6 - ASD Sizing Guidelines.

- Majority (71%) report on sizing based on required HP.

7 - Inverter Features.

- As for motors, over 64% of inverters were put in service in the last five years.

- Overall use of PWM inverter is 2:1 that of VVI. The use of CSI is less common at 600V inverters, and is more popular at medium voltage level. More recently (last three years) PWM inverter technology has practically dominated the market (90%) for ASD's rated at 500 - 1000 HP.

- Almost all inverters were rated at 600V and output transformer was used to match motor voltage at 4160V or 2300V. Only one recent installation reported having 4160V inverter connected directly to induction motor. This inverter used the CSI principle of power conversion.

- 62% of the inverters surveyed were put in service in the last three years, indicating substantial increase in users' interest in this technology.

8 - ASD Selection and Procurement.

- Feasibility study and drive selection was almost equally done by either a consultant or company personnel.

- 50% of ASD's were purchased directly from a manufacturer, 24% from contractor and 19% as part of equipment package.

9 - Environmental Control.

- Additional temperature control was needed for one-half of the ASD installations, because of generated heat.

- Space limitation was not considered a problem as provision was made in the design stage. However, some reported no room was left for future expansion. Typically, a 500 HP drive with bypass could occupy a space of up 9 ft. long, 3 ft. deep and 8 ft. high.

10 - Commissioning Period.

- 13 drives were commissioned in less than 3 days, 7 in less than 7 days and 22 in less than a month. One user reported 3-6 months commissioning period, because of many manufacturing design and process problems.

11 - Training and Operating Instructions.

- An Operation manual was mainly provided and generally considered adequate.

- In almost in all cases, training was provided and conducted by ASD manufacturer. Maximum system benefits are achieved when operations and maintenance personnel are trained. Proper ASD component labelling and system familiarizations is strongly recommended.

- 100% reported having no preventative maintenance contract on their ASD. This feature does not appear to be of great desire to users, probably they are satisfied with the level of services offered by the support groups including the manufacturer.

12 - ASD Problems Reported.

(a) Motor.

- Three users had vibration problems reporting on 9 drives.

- Two users had bearing problems reporting on 9 drives.

- One user had stator/rotor failure reporting on 4 drives.

- Motor failures, although reported minimal, they are considered very serious, because of their impact. Adequate motor overtemperature and vibration monitoring and protection is recommended.

(b) Inverter.

- Almost all users (84%) reported having inverter problems. The majority were attributed to component failure (60%) followed by logic boards (48%), blown fuse (48%) and tripping out (41%). Most users reported having more than one kind of a problem with their drives.

- Inverter component failure was rated very serious among all the other problems. Inverter tripping was rated serious.

- 67% of users reported that the logic boards presented the most problem.

- ASD manufacture should be conducting more research and developing more rigorous testing into the performance of the inverter circuit. Inverter is considered the weakest link in the whole electrical/mechanical system.

13 - ASD Reliability.

- 72% reported ASD failures within first 12 months of operation, 7% in second year, 26% after second year. This highlights that the electronic devices are very susceptible to failures in their infancy.

- Downtime of less than one day was reported by 45% of respondents and between 1-4 days by 26% of respondents.

- A significant item reported was the cost per repair (outside warranty period). 38% of responses indicated the burden to be $1,000 - $5,000, with some reporting repair costs to be $5,000 - $10,000.

- 50% of the users rated poor design, poor quality and improper installation as being "very significant" in causing most ASD problems.

- 22% of the users considered inadequate training as being "significant" cause for ASD problems.

14 - Reasons for Selecting ASD.

- About 81% for process requirements, 52% for improved efficiency, and 21% for price. Most users listed more than one reason for selecting ASD.

- About 31% of total drives were purchased because of Ontario Hydro incentive program which was introduced in 1990.

15 - Harmonic Analysis.

- Torsional and/or spectrum analysis was conducted on 36% of the drives.

- Harmonic study to ensure resonance is not present was carried out on 41% of the drives.

- 18% reported having voltage notching, power factor correction capacitor and audible noise problems. One user reported using reactors on 600V input bus to reduce voltage notching, but this resulted in very high audible noise.

- 20% reported using input filters to control harmonics injected back to power supply.

16 - General Satisfaction.

- 95% of responses indicated installations were successful and that further installations would be favoured.

7.0 USERS SUGGESTIONS AND RECOMMENDATIONS

The users were asked to offer suggestions to any or all the parties involved in design, selection and manufacturing of ASD to improve its performance. The following is an overview of observations arising from the responses to the questionnaire.

1 - ASD manufacturer to advise harmonic content to motor manufacturer.
2 - Include surge protection.
3 - If ride through not required, it should be defeated.
4 - Overspeed protection for driven equipment.
5 - Filter air intake to inverter for dust control. Ready access to be made for replacing filter element without having to shut down equipment.
6 - Complete documentation is required for ASD system.
7 - Proper training important.
8 - Study application closely.
9 - Generous equipment ratings.
10 - Separate power from control wiring and components to reduce the exposure of maintenance personnel to live parts.
11 - Dead front design.
12 - Accessible components.
13 - Adequate start torque for high inertia loads.
14 - Heat run tests to determine effect of harmonics.
15 - Improve reliability of electornic components.
16 - Ensure that all mechanically related problems are addressed, such as vibration (torsional), lubrication and bearings.

8.0 CONCLUSIONS

The use of ASD is increasing in Ontario judging by the number of new installations over the last three years. The trend is expected to continue, because of their great potential for saving energy, Ontario Hydro incentive program and continued development and advancement by the ASD manufacturers. The users have accepted this technology and are employing it to control critical processes. There is a good overall satisfaction by the users and most would consider using ASD again for future applications.

The following are the main conclusions arising from the survey conducted in April 1992 for users of ASD's rated 500 HP and above in the Province of Ontario.

1. 90% of ASD installations are rate 500 - 1,000 HP. Induction motors are commonly used. All motors operated in one direction.

2. Almost all inverters reported on are rated 600V. Output transformers were used for 2300V/4160V motors. There was only one recently commissioned inverter operating at 4160V and rated 1750 HP.

3. 80% of responses indicated using motors with service factor 1.15 to accommodate additional temperature rise caused by harmonics.

4. Variable torque applications are more prevalent than constant torque with 2:1 ratio.

5. Duty cycle and service shows mostly steady or slight change of speed.

6. PWM inverters are predominantly used, particularly over the last three years (90%) when compared with VVI inverters. One user reported using load commutated inverter (LCI) with synchronous motor rated 9000 HP. No user reported using slip-ring recovery drive principle.

7. By-pass feature on ASD was not widely specified.

8. Auto restart feature neither considered significant nor desirable.

9. Additional temperature control was needed for one-half of the ASD installations, because of generated heat.

10. Space limitation was not considered a problem as provision was made in the design stage.

11. 50% of the drives were commissioned in less than 7 days and the rest in less than one month.

12. 81% of respondents indicated the main reason for selecting ASD was process requirement followed by 52% for improved efficiency.

13. Almost all users (84%) reported having inverter problems. The majority were attributed to component failure (60%), followed by logic board (48%), blown fuse (48%) and tripping out (41%). Most users reported having more than one problem with their inverter.

14. Inverter component failure was rated very serious among all other categories.

15. 67% of users reported that the logic board presented the most problem.

16. 72% reported ASD failure within first 12 months of operation, which indicates that electronic devices are very susceptible to failures during their infancy.

17. Average downtime for repair of inverter reported to be less than 1 day by 45% of drives and between 1-4 days by 26% of drives.

18. A significant item reported was the cost per repair (outside warranty period). 38% of responses indicated the burden to be $1,000 - $5,0000, with some reporting repair costs to be $5,000 - $10,000.

19. Majority of users reported having no harmonic problems. 18% reported having voltage notching, power factor correction capacitor and audible noise problems. Harmonic study was conducted on 41% of the drives to ensure resonance is not present. Torsional analysis was carried out by 36%. 20% reported using input filters to control harmonics injected back to power supply. Majority indicated being familiar with Ontario Hydro harmonic guidelines.

20. Since Hydro performance optimization for pumps, fans and blower systems program was initiated two years ago, about one-half of the installations were purchased as a result of this program.

21. Majority reported that they refer to ASD manufacturer for outside assistance to resolve problems encountered with the use of ASD's.

22. Users reported that the most probable causes of ASD failures in order of importance were:

    Poor design, inadequate training, improper installation, poor workmanship, mis-application, mis-operation, surge protection and harmonics.

23. 60% of users reported that the ASD load represents less than 5% of their total electrical load, and 24% stated between 5% - 20%, and 17% indicated greater than 20%.

24. Municipal industry represents the largest user (22%) of ASD rated 500 HP and above, followed equally by petro-chemical (16.7%) and pulp and paper (16.7%).

25. Majority (89%) of users stated that the most important parameter when purchasing an ASD is reliability followed by efficiency.

9.0 SUGGESTIONS AND RECOMMENDATIONS

1. Increase communication between motor and ASD manufacturers to ensure overall "system" performance is optimized.

2. Provide better accessibility to equipment for troubleshooting and repair. Reduce exposure to live parts.

3. Investigate provision of test-jack for checking input/output waveforms, etc. without having to open cabinet doors.

4. Develop data for effect of harmonics on motor, driven equipment and incoming power supply. Continue to develop system that produces less harmonics injected to motor and power supply.

5. Develop 4160V ASD for 1000 HP and above to capture much wider industry applications and associated energy saving.

6. Improve longevity and reliability of components and logic boards by continuously examining quality control procedures.

7. Endeavour to reduce cost of systems.

8. Produce drive efficiency curves at various operating frequencies to permit conducting more accurately energy saving calculations.

9. A failure of electronics should under no circumstances cause drive run away as this will result in catastrophic damage to driven equipment.