MAINTAINING ADJUSTABLE SPEED DRIVE RELIABILITY AFTER OBSOLECENCE: REPLACE OR REFURBISH?

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ABSTRACT

The installed base of electronic high capacity adjustable speed drives (ASD) has grown over the past 30 years. This growth was made possible due to the development of power semiconductor devices like thyristors that made the ASD an attractive commercial solution. Technological advances in communications, micro processing, high-speed switching and cooling systems have made these products more reliable, smaller, and more commercially accepted in industry. With technological advancement, invariably there is obsolescence of older equipment. Maintaining older adjustable speed drives becomes commercially less attractive and sometimes impossible as parts become scarce. This paper presents a case study in which an ASD operator was faced with decisions on how to maintain their equipment after obsolescence was announced. Potential solutions and alternative options are evaluated against cost and facility downtime. The paper concludes with the options available to ASD operators that eliminate the concern of maintaining the adjustable speed drive and obsolescence after 20 years of operation. It will help the operator make the decision based on the application.

INTRODUCTION

Users of adjustable speed drives are often faced with the challenge of maintaining electronics that were installed in the 1980’s. For operators, the adjustable speed drive is just a “black box.” The operator is heavily dependent on the ASD manufacturer for service and support. Many times the manufacturer might have very limited resources available to support the “as installed” ASD. Because engineers retire and a supplier stops making components, the question arises, “How do I maintain adjustable speed drive reliability after obsolescence?” A case study is used in which an ASD operator was confronted with the question after obsolescence was announced. The decision-making process, evaluation of alternatives and potential final solutions are discussed. It is the intent that the study covers a broad range of application considerations that are taken into account in order to realize the final solution.

THE GENERAL PROBLEM

Ever since the invention of power semiconductor devices, adjustable speed drives have been used in several industrial complexes to regulate the speed and torque of motors. Many ASD installations date back to the 1980’s. Over the course of years, many industry changes have taken place and have created concerns about how these old ASD installations can be maintained. The authors have identified five key problematic areas and industrial changes that have taken place as shown in Table 1.

Table 1: Current ASD problems and industrial changes

The General Problem	Industry changes in the last 20 years
Uncertain product life beyond 20 years	These drives were installed in the 1980’s and are past their useful life
Obsolescence of components due to technology advances	Major shift from analog to digital
Increased cost of maintenance as the end of life nears	Classic “bath tub” reliability curve for product life shows increased maintenance

The General Problem	Industry changes in the last 20 years
Dwindling professionals to service and support the older technology	Workforce retirements, younger professionals who more familiar with contemporary technology
Changing industry expectations	Push for higher productivity, connectivity requirements and commercial justification to use VFD in process control
Compatibility of old ASD's with new motor types	Movement from synchronous to induction motors for applications below 20,000 HP

Large ASD systems are expensive initially and represent a major capital expense if they need to be completely replaced. The need to keep the ASD reliable, with decreasing availability of replacement parts and ever-increasing prices, add to the pressure of making a change.

CASE STUDY

Background – This paper employs a case study evaluating a motor and ASD system that was installed in the late 1980's in a plant in Texas, USA.

History of the installation – In the late 1980's, a new synchronous motor and adjustable speed drive system had been installed on an extruder line. The reliability of the motor and ASD is extremely critical, the drive and motor must run for the operator to meet their production goals. Table 2 outlines high level details of the application and Figure 1 shows an electrical illustration of the installation.

Table 2: Case study application details

Item	Description
Service	Extruder
Year Commissioned	1989
Power (HP)	3000
Voltage (V)	2300
ASD Type	Load Commutated Inverter
Motor Type	Synchronous
Drive Cooling	Air

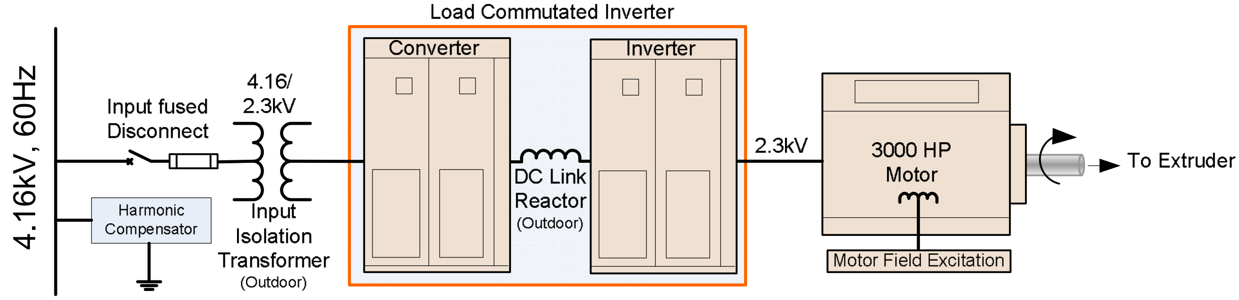

Fig. 1 Electrical illustration for the case study

As shown in figure 1, the system consists of a 4.16kV feed into the incoming circuit breaker. This power is then fed to the 4.16/2.3 kV step-down transformer so that it is suitable for the 6-pulse LCI drive and finally to the synchronous motor. The motor field excitation is also supplied by the LCI drive. An outdoor DC link reactor is needed which is the primary energy storage device in the LCI ASD.

This was a common system configuration for the time period between 1980 and 1995. Applications of 1000 HP or more would use a synchronous motor, since the adjustable speed drive technology available in the 1980's could only be applied to a synchronous motor.

As technology has progressed over the years, it is very common to find induction motors rated up to 26,000 HP and synchronous motors up to 120,000 HP. In many cases, an induction motor is the preferred choice for up to 13,000 HP. At the same time, drive technology has progressed and with the advent of Voltage Source Inverter (VSI), the type of motor used is inconsequential to the ASD operation. VSI based ASD are capable of running an induction or synchronous motor.

Problem – In 2004, the installed 3000 HP synchronous motor was sent to a motor shop and completely serviced and rewound. This procedure gave the motor another 15 – 20 year life. In 2009, the LCI ASD developed reliability issues. Replacement parts were very expensive to procure and service/support from experienced technicians was difficult to find. This issue could lead to lengthy downtimes in the plant and lost productivity. The goal of the operator was to maintain ASD reliability. It was preferred that the solution have no unscheduled downtime.

The extruder drive analog controls are currently not connected to the Distributed Control System (DCS); hence, any proposed solution would have provisions to connect the ASD to the plant DCS system. From a reliability standpoint, this would give the plant internal communications to the drive and if necessary, would allow the ASD vendor to diagnose the drive remotely via the internet.

Problem Solution – Whenever an ASD operator is faced with a motor and ASD issue, the first course to solve the failures is by repairing as required. This may require the operator to look for spares to "stock pile" ahead of break down. Generally, maintenance budgets are more flexible and easier to access than a capital spending for a project of this size and scope.

At some point, the ASD operators investigate ways of solving the issue permanently. The operator initially may believe that they have only two choices to replace the installation:

Option A) Replace the motor and ASD completely, OR
Option B) Replace the ASD only

However, many operators are not familiar with a third option known as "refurbishment", which is as follows:

Option C) Replace/refurbish critical components of the adjustable speed drive.

In the following sections, options A, B and C will be discussed in detail and specific application considerations will be presented for the case study in observation. Even though the explanations are case study specific, the application concepts can be applied to other system configurations as well.

Option A – Replace motor and adjustable speed drive

Replacing both the motor and ASD completely is perhaps the most expensive option available to end users. Under certain cases, it may make economic sense to replace the system completely. Below is the scope of work, pros, cons and application considerations when selecting option A

Scope of work

When planning to replace the motor and ASD completely, the scope of work involves electrical modifications as well as extensive civil and mechanical work. A simplified electrical illustration is shown in Figure 2.

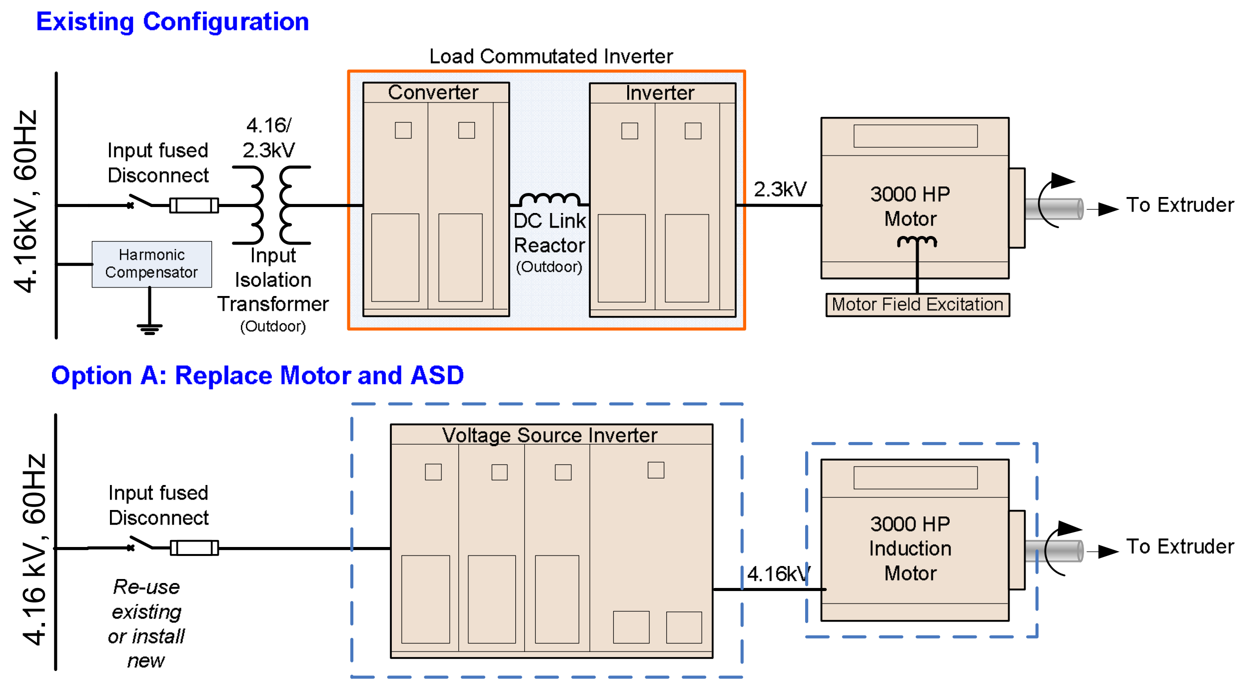

Fig. 2 Scope of work: electrical one-line diagram for replacing motor and drive

Electrical: The existing configuration is a 2.3kV system, where the ASD and the motor are designed to run at that voltage level. This is because the LCI at the time used switching devices that were rated for maximum of 2.5 – 3kV. Higher voltage levels were not available. A 2.3kV ASD system was very common 25 years ago. Today, it is very easy to find ASDs in a whole range of medium voltage levels ranging from 2.3kV up to 11kV. Hence, any new system that is to be installed today would be able to utilize 4.16kV directly. The electrical scope of work includes:

1) Procuring a 4.16kV input and output ASD as per motor rating and required over-load
2) Procuring a 3000 HP 4.16kV induction motor based on the speed-torque curve of the driven load

Mechanical: From a mechanical/civil perspective, replacing the motor and the ASD is extensive. The general scope of work involves the following:

1) Removal and disposal of old motor and adjustable speed drive
2) Removal and disposal of outdoor DC link reactor and associated electrical cables
3) Inspection and preparation of the foundation for the new motor
4) Redesign and planning of the Motor Control Center (MCC) room to accommodate the new ASD
5) Upgrading the HVAC system to account for the new heat load

<u>Advantages</u>

1) The current motor is specific for use with an LCI drive. It is expensive to repair and with no stock availability. Changing the motor to a standard induction motor can be used to lower the cost of future repair and replacement
2) Eliminating the input isolation transformer and operating on the plant line voltage is simpler
3) Connecting the ASD directly to the 4.16kV line
4) Lower motor amps due to operating at a higher voltage means less cable will be used
5) A field exciter will no longer be needed which eliminates a piece of equipment
6) Spares are readily available
7) Operating and diagnostics information would be available to the DCS or plant historian
8) Resources are readily available for service and repair

9) Scrap value can be gained by disposing of copper and metal
10) Since the new ASD is a voltage source inverter, a high power factor (> 0.96) is achieved across the entire speed range. This was not possible with the LCI drive
11) The use of a multi-pulse converter enables the ASD to comply with the IEEE 519 harmonic specifications for power systems. The existing LCI is a 6-pulse converter, whereas a new ASD would have a 24 – pulse or higher converter
12) The motor and the ASD can be optimized and matched to process conditions for lower long term energy usage and lifetime costs

Disadvantages

1) This solution has the highest initial cost
2) The motor base and mounting modifications are needed to match the frame size
3) Structural modifications are necessary around the extruder motor
4) Extended downtime
5) Upstream protection relays need to be coordinated with the ASD due to the new full load amps that will be drawn by the ASD

Application considerations

1) The induction motor will operate similar to the existing system. A review of the actual operating full load amps and motor speed-torque curve is necessary. This is important for applications where a high starting torque is required to break free from inertia
2) Verify that the existing cables are rated for PWM based waveforms and will not induce voltages on adjacent cables or circuitry
3) Proper sizing of HVAC since the new ASD will have the isolation transformer integral to the inverter as a single package
4) Ethernet connectivity in the motor control center is required for advanced diagnostics

Option B – Replace Adjustable Speed Drive ONLY

Replacing just the adjustable speed drive offers several advantages in terms of cost effectiveness and reliability.

Scope of work

Option B has similar requirements for the ASD replacement as Option A. However, the work associated with motor replacement is eliminated. The scope of work can be divided into the following:

Electrical: The existing configuration is a 2.3kV system, where the ASD and the motor are designed to run at that voltage level. The new ASD will also utilize a 2.3kV system voltage. The electrical scope of work includes:

1) Procuring a 2.3kV input and output ASD as per motor rating and required over-load

Mechanical: From a mechanical/civil standpoint, replacing the ASD involves the following:

1) Removal and disposal of adjustable speed drive
2) Redesign and planning of the Motor Control Center (MCC) room to accommodate the new ASD
3) Upgrading the HVAC system to account for the new heat load

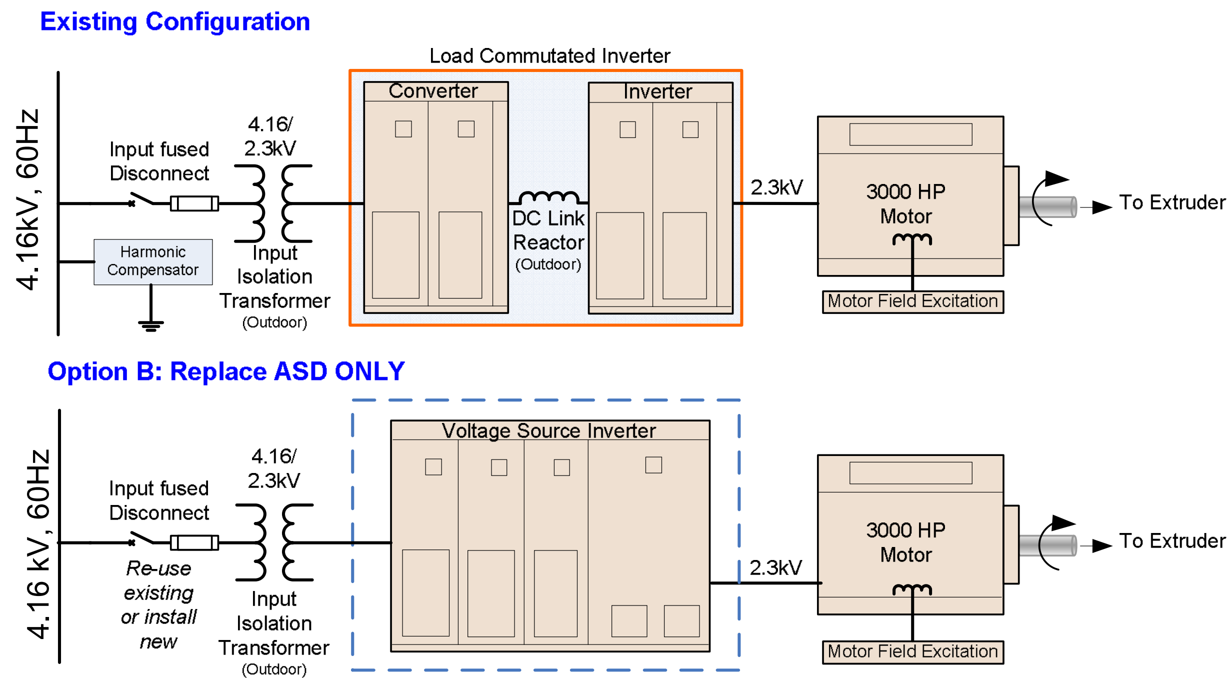

Fig. 3 Scope of work electrical one-line diagram for replacing drive only

Advantages

1) Capital spending is less compared to option A
2) ASD can be applied as a drop-in replacement for the old LCI ASD, without worrying about upstream gear and relay coordination
3) Spares are readily available
4) Increased operating and diagnostics information available to the DCS and plant historian
5) Resources are readily available for service and repair
6) Scrap value can be gained by disposing of copper and metal
7) Since the new ASD is a voltage source inverter, a high power factor (> 0.96) is achieved across the entire speed range. This was not possible with the LCI drive
8) The use of a multi-pulse converter enables the ASD to comply with the IEEE 519 harmonic specifications for power systems. The existing LCI is a 6-pulse converter, whereas a new ASD would have a 24 – pulse or higher converter

Disadvantages

1) Capital expense is still substantial and the price of the ASD is typically more than maintenance budgets will allow
2) Since the input isolation transformer is not eliminated, the operator is tied to a 2.3kV system which implies higher ASD current for a given power rating
3) The current LCI is located in the center of the equipment room. A new drive cannot be worked around the existing equipment without major building modification and rearrangement
4) The new ASD has more heat loss inside the equipment room implying that the HVAC system would need to be replaced adding to the capital cost of the project

Application considerations

1) Verify that the existing cables are rated for PWM based waveforms and will not induce voltages on adjacent cables or circuitry
2) Proper sizing of HVAC since the new ASD will have the isolation transformer integral to the inverter as a single package
3) Ethernet connectivity in the motor control center is required for advanced diagnostics

Option C – Replace/Refurbish critical components of the adjustable speed drive

Option C is relatively new to the ASD industry. Many operators are not familiar with this method of extending life to their existing ASD systems. On a high level, option C is an ASD “refurbishment” where only the drive controls are upgraded. The refurbishment philosophy indicates that power components like transformers, switchgear, motors, cooling systems, power bridges and inductors are designed to last for at least 30 years. However, the ASD controls become obsolete at a faster pace than the power components. This is because analog circuit boards have migrated to microprocessor based digital technology. It has been field proven that a majority of issues that are faced by operators of old ASDs is due to outdated technology and no access to the internal ASD parameters.

Scope of work

The scope of work in performing an ASD refurbishment is electrical in nature and very little mechanical work is required. The work can be divided into three major categories as follows (See Figure 4):

Pre-outage Tasks: During this phase, an initial assessment of the performance issues and equipment condition is done. This includes checking equipment like the input switchgear, transformer, reactor, cables, power-bridge, cooling system and the motor. Infrared hot-spot analysis and measurement analysis of drive system response is done. Finally, a vibration analysis of the motor and load system is completed. The pre-outage task is important since this gives a clear indication whether the ASD is a good candidate for the refurbishment process. Any abnormalities or an imminent component failure will be discovered in the pre-outage period

Outage Tasks: During this stage, the actual replacement is performed. Some of the key steps include lock out/tag out and cleaning of the switchgear, transformer, and power conversion enclosures. Then the old control components are removed and the new control, circuit boards and I/Os are installed. Wires and cables are terminated and motor and transformer insulation resistances are checked. The ASD is then commissioned and a final tune-up and load matching is done to put the ASD into service.

Post-outage Tasks: The post-outage tasks monitor the system performance. This is done to verify that the ASD has the same or better performance than the old controls. The upgrade is concluded by documenting the changes and training the operators on the new control.

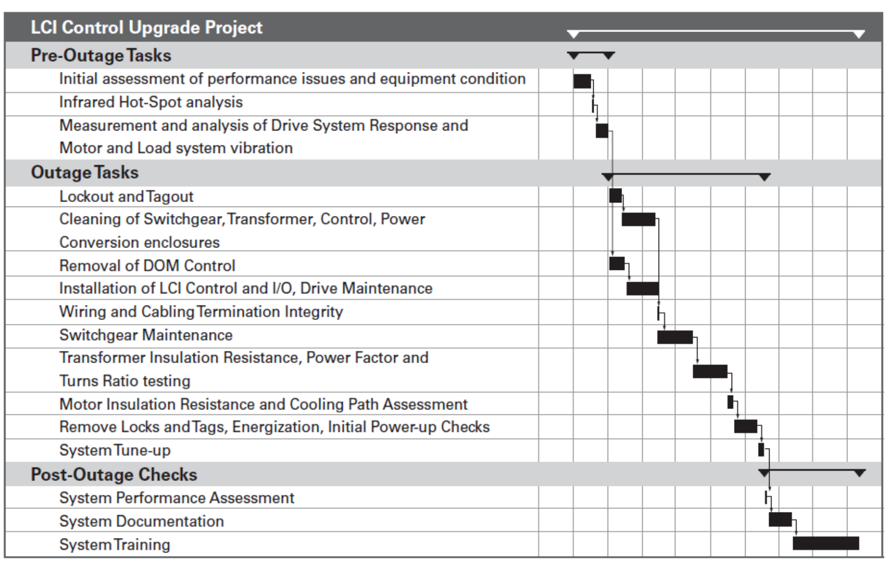

Fig. 4 Scope of work ASD control upgrade

Figure 5 shows the electrical illustration of the case study under investigation. Since no power components are touched, there is no change in the system configuration.

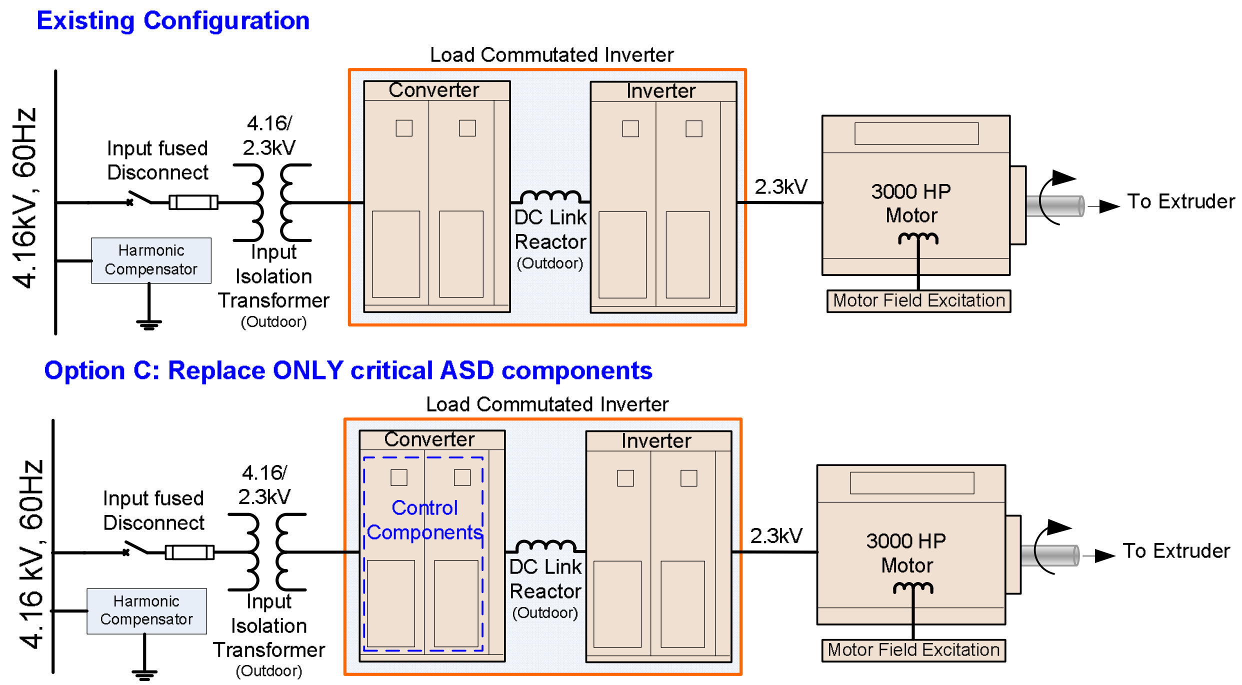

Fig. 5 Scope of work electrical one-line diagram for upgrading drive "controls" only

Advantages

1) The least expensive option and requires the shortest time for installation
2) Installation does not require external resources or craft labor
3) Equipment installation can be done with basic hand-tools and plant technicians
4) ASD can be connected to the DCS system for monitoring and diagnostics
5) Drive spare parts are readily available if needed
6) Reduced environmental burden since most of the components are reused or refurbished
7) Next generation controls and drives software
8) Capital cost of a drive upgrade is less than 25% of complete ASD replacement
9) Improved system uptime

Disadvantages

1) The upgrade package is ASD manufacturer specific. Since control cards, algorithm, and firing circuits are proprietary to the original ASD manufacturer, it is difficult for a third party vendor to perform this upgrade
2) The performance of the ASD is unchanged. It is a common misconception that upgrading the ASD will eliminate pre-existing issues, for example in the Power Bridge, transformer, switchgear, motor, etc
3) The upgrade is typically done during a regular "maintenance" outage period, therefore, timing is critical and limited
4) Once the upgrade is performed, it is impossible to revert back to the old system. The ASD vendor and the end user must be committed to upgrade and successfully commission the ASD
5) It is difficult to accurately forecast when power components could fail
6) At some point during the plant life, the ASD will have to be replaced

When to choose option C

It is important to note that not all installed ASDs are good candidates for refurbishment or upgrade. The effectiveness of upgrade is dependent on the voltage and power rating of the ASD. For example, upgrading a 2.3kV, 1000 HP ASD is more expensive than replacing the entire ASD with a new one. Figure 6 shows the voltage and power ratings of ASD that are suitable for refurbishment.

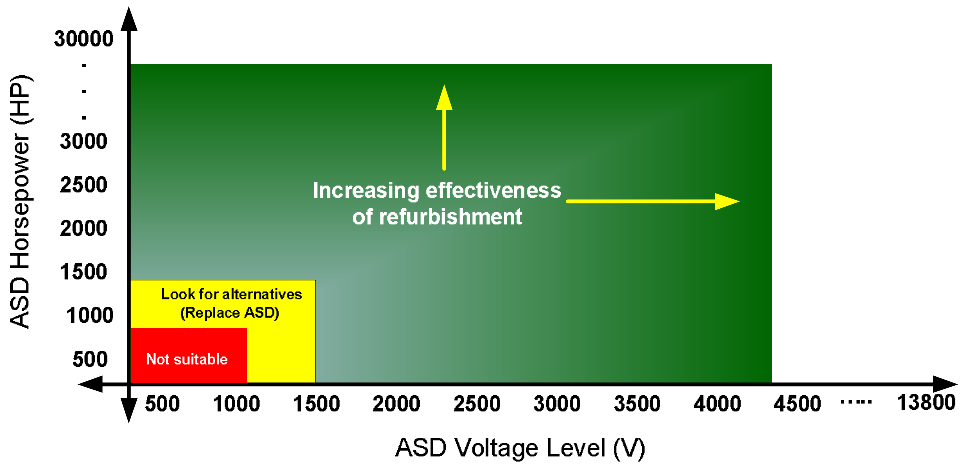

Fig. 6 Dimensions of ASD suitable for Option C: Replace critical components of adjustable speed drives

Figure 6 indicates that any ASD below 1500V and 1500 HP are not cost effective to refurbish. This is because presently, ASDs less than 1500 HP are considered commodity drives and are available at reasonable prices in a compact package with short lead times. However, as the voltage level and power ratings increase, the upgrade/refurbishment option becomes attractive because the drives get larger in size, have long lead times and are critical to overall plant productivity.

Figure 7 shows an estimate of the cost-effectiveness of the refurbishment option. It can be seen that at lower power levels, the refurbishment would cost almost 60% of a new drive. As the power level starts to increase, the percentage drops significantly and large ASDs can gain new life for as low as 15% of the new drive cost.

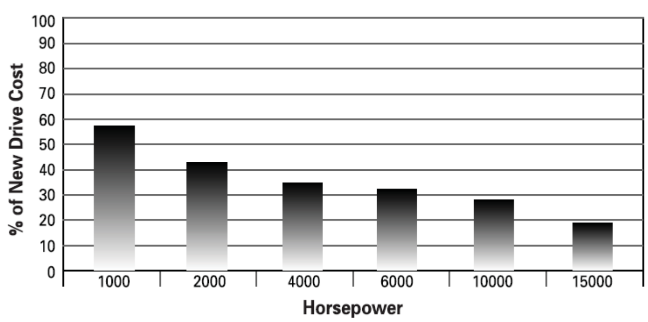

Fig. 7 ASD power versus % of new drive cost

COMPARITIVE STUDY – OPTION A, B, & C

This section compares options A, B and C from a cost standpoint. Table 3 shows the major line item cost associated with each of the options. Not all costs can be accounted for, but this chart gives a good overview of the type of expenses that can be expected. The numbers shown in Table 3 are estimates based on 3000 HP extruder system.

Table 3: Cost comparison between option A, B and C

Parameter	Option A Replace Motor and ASD	Option B Replace ASD ONLY	Option C Refurbish ASD "Controls" ONLY
Motor Equipment price	$160,000.00	$0.00	$0.00
ASD Equipment price	$220,000.00	$220,000.00	$0.00
Control Equipment price	$0.00	$0.00	$130,000.00
Start-up & commissioning of motor	$10,000	$0.00	$0.00
Start-up & commissioning of ASD	$13,000	$13,000	$13,000
Old motor removal	$4,000.00	$0.00	$0.00
Old ASD removal	$5,000.00	$5,000.00	$1,000.00
HVAC Upgrading	$14,000.00	$14,000.00	$0.00
Estimated labor cost	$20,000.00	$15,000.00	$10,000.00
New ASD installation and labor	$200,000.00	$200,000.00	$50,000.00
New motor installation labor	$200,000.00	$0.00	$0.00
Estimated Total Expense	$846,000.00	$467,000.00	$204,000.00
Other Considerations			
HVAC upgrading	Yes	Yes	No
Electrical Cabling	Optional	Optional	No
MCC Room rearrangement	Yes	Yes	No
Expected project turnaround	20 - 30 days	10 - 12 days	70 hours
Expected Life expectancy	25 - 30 years	15 - 20 years	10 - 15 years

From Table 3, it can be seen that when evaluating the options, several costs add up quickly and prove extremely expensive. However, the goal of the table is to give an indication of the cost multiplier of upgrade versus modernization. For example: Option C is 44% cost of option B and 23% cost of option A. Field experience indicates that there are cost overruns in 95% of installations, irrespective of the industry segment.

CASE STUDY – Making the final decision

The above sections gave an overview regarding the scope of work, advantages and disadvantages associated with each of the options, namely: replacing the motor and the ASD, replacing the ASD only and replacing/refurbishing only critical components of the ASD.

After reviewing the three options, the complete change out of the motor and drive (option A) was rejected. As mentioned before, the synchronous motor was rewound in 2004 and removing and reinstalling a new motor would have no economic advantage. The motor was good for at least 15 years.

Option B (replacing the ASD) was considered since this would allow the plant to control expenses and also get a brand new ASD. In addition, the operator could have the flexibility to install a stock induction motor sometime in the future, if the existing synchronous motor failed. However, finding space in the existing MCC room and reviewing the physical dimensions of the new ASD made this option very expensive. Moving the new ASD in place would require a substantial rearrangement of existing electrical gear, structural modifications, widening doorways, and relocating equipment. A preliminary cost estimate indicated a total expense of roughly three to four times of the ASD cost. At the time of writing, this option is still being investigated.

Option C (replace/refurbish critical components of the ASD) is the simplest and stands in reserve. Initially it was thought there only solution was to replace the drive. The modernization program updates the drives to digital control and adds the connectivity expected in today's process plants.

CONCLUSIONS

As adjustable speed drives start to age, there is a growing concern regarding the reliability and longevity of these installed drives. This paper outlined the pros and cons of three options that are available to end users of ASD's. In addition, special application considerations were outlined for each of the described options that need to be considered before undertaking any activity. Finally, a comparative study was presented that compared each of the options side-by-side to give an overview of the costs that would be associated with each of them.

The conclusion of this paper is that each user situation is unique in terms of complexity, requirements, expectations and available budgets. The final choice lies with the operations and maintenance personnel as to which option is best suited for them to maintain adjustable speed reliability after obsolescence.