Implementing Advanced Predictive Maintenance Functions

SUMMARY OF REVISIONS

Introduction

The cost of unplanned downtime is high. Depending on the industry and industrial application affected, an hour of unplanned downtime can be more expensive than the cost to replace the automation equipment related to the issue.

This paper is intended to illustrate the magnitude of those costs associated with unplanned downtime and demonstrate the value of implementing Advanced Predictive Maintenance functions in your Variable Frequency Drives to proactively monitor component life and prevent unscheduled replacements or failures in your facility.

Reason and benefits

In many cases, automation equipment fails because the lifespan of the individual components inside the equipment is not as long as the whole of the equipment.

This lifespan can vary based on how the equipment is used and what the operating environment is like.

Managers in industrial production have some choices for dealing with the lifespans of these components:

- Just react to component failures when they occur.
- Replace components on a fixed schedule that does not account for use and environment.
- Use advanced Predictive Maintenance functions to replace the components, as needed, before they expire.

The first approach is probably most costly and unpredictable. These component failures will likely cause unplanned downtime. The cost of downtime can only be limited by time to troubleshoot, the availability of replacement components and equipment, and the serviceability of the equipment. This approach creates a chaotic environment. The primary role of the maintenance professional becomes "fireman".

The second approach is better, but not optimal. Printed static service intervals cannot adjust for the changing way the equipment is used or the changing environment around the equipment. Using this approach will lead to overspending on maintenance and replacement components. This happens when the mode of operation or operating environment is less harsh than the one that dictates the static service interval. It can also lead to some unplanned downtime. This happens when the mode of operation or environment is harsher than the one dictating the static service interval.

The third approach is most cost effective. It reduces unplanned downtime. It optimizes spending on maintenance and replacement components. It makes the workloads of the maintenance professionals more professional and predictable.

Example: A perfect production day

Let's look at a simplified example. Our example company runs its production line eight hours per day. The production line makes $25,000 worth of sellable goods per hour on $5,000 worth of material per hour. The fixed costs (depreciation, facility costs and so forth) are $500 per hour. The production staff costs $500 per hour to run the machine. On a perfect day, our production line makes $144,000 in profit. Figure 1 illustrates this example.

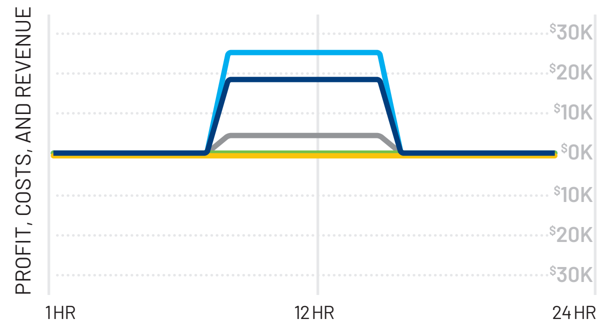

FIG. 1
A perfect production day

Example: A bad production day without predictive maintenance

On this example day, the bearings in the heat sink fan of a large drive wear out and the fan stops turning. This causes the drive to overheat a power module and results in an hour of lost production. The production staff remains in place during the outage. Two maintenance technicians work for an hour to troubleshoot the machine, procure a replacement power module and then install it. The power module costs $25,000. The maintenance technicians cost $125 per hour. Compared to the Perfect Day example, the lost profits are $45,250. Figure 2 illustrates this example.

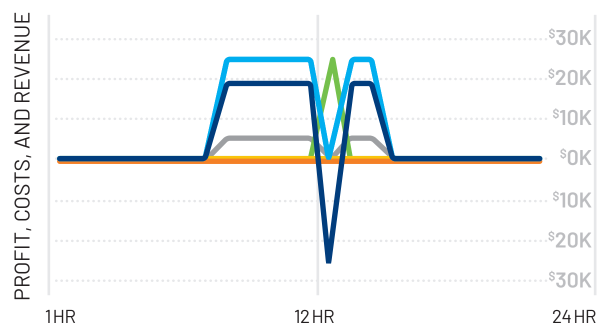

FIG. 2
A bad production day without predictive maintenance

Example: A bad production day with predictive maintenance

The Predictive Maintenance firmware feature predicts the fan wear-out ahead of time. The maintenance staff has the replacement heat sink fan on hand. One maintenance technician replaces the fan, in one hour, before the start of scheduled production. The cost of the replacement fan is $2,210. There is no unplanned downtime and no loss of production. Compared to the Perfect Day example, the lost profits are $2,335. This is a $42,915 improvement over the scenario without Predictive Maintenance. Figure 3 illustrates this example.

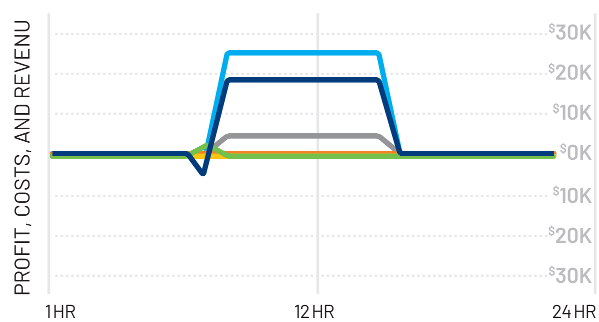

FIG. 3
A bad production day with predictive maintenance

● REVENUE ● FIXED COST ● MATERIAL ● PRODUCTION STAFF
● REPAIR STAFF ● REPAIR PARTS ● PROFIT

How predictive maintenance firmware features work

The new, patented, predictive maintenance models are built around a common framework where the amount of life consumed by each component is tracked by the drive. Advanced physics-of-failure models are incorporated into the drive to convert actual stressors (e.g., voltage, current, speed, switching frequency, and temperature) into life consumption for critical components like fans, power semiconductors, capacitors, and breakers. When the consumed life exceeds the user-defined event level (default is 80%), an alarm is generated indicating that preventative maintenance is required for the specific component. The common model framework is shown in Figure 4.

The rate of life consumption is also tracked in the firmware for each component on a pseudo rolling average. This rate is unique to each drive and depends on how the drive is actually used. Based on the rolling rate of life consumption, the new predictive models will calculate how many hours remain until the percentage of consumed life reaches the alarm level. This remaining life calculation allows for proactive scheduling of preventative maintenance and minimum downtime.

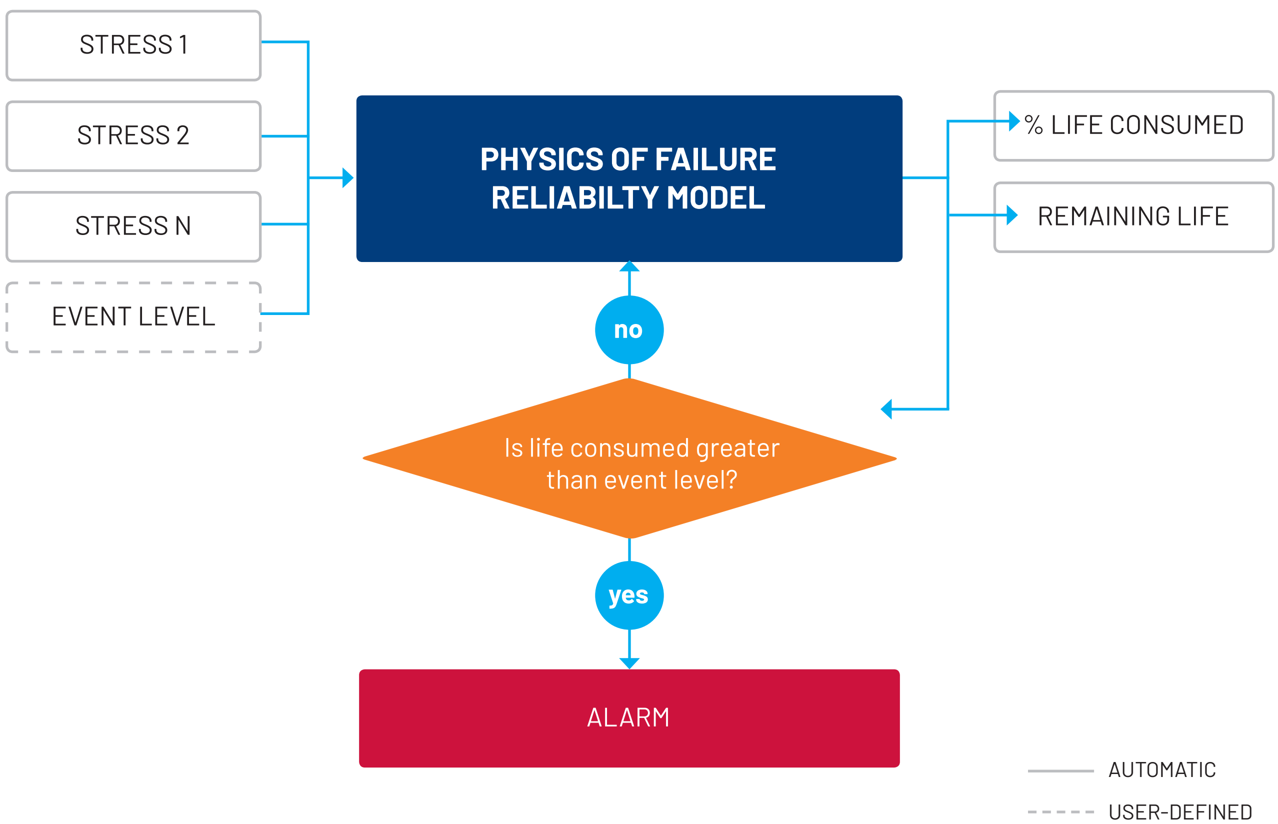

FIG 4. A common framework for the new predictive maintenance models.

Component life consumption is affected by actual stress parameters like current, speed, switching frequency, and external air temperature. Higher stresses will lead to a more rapid life consumption (see Figure 5a). The intent of the event level, or maximum life consumed before an alarm is generated, is to allow the end-user to control the risk of unplanned downtime. Figure 5b shows that higher stresses will accelerate the replacement time. Finally, as the new predictive maintenance algorithms adapt to how the drive is being used, it will take about 30 days for the models to learn about the application stresses (see Figure 5c).

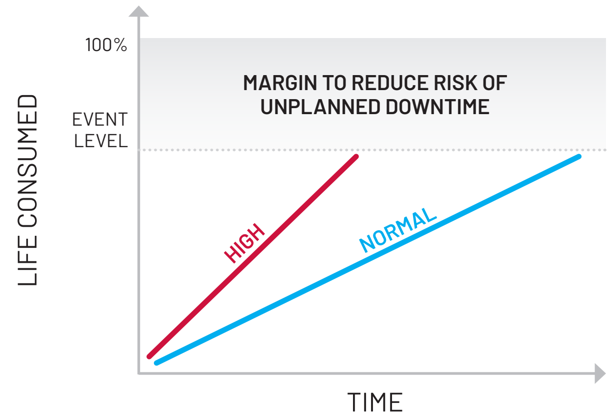

FIG. 5A
Effect of stresses on Life Consumption

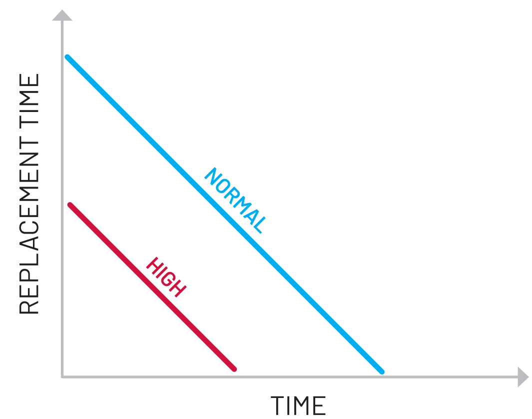

FIG. 5B
Effect of stresses on Replacement Time

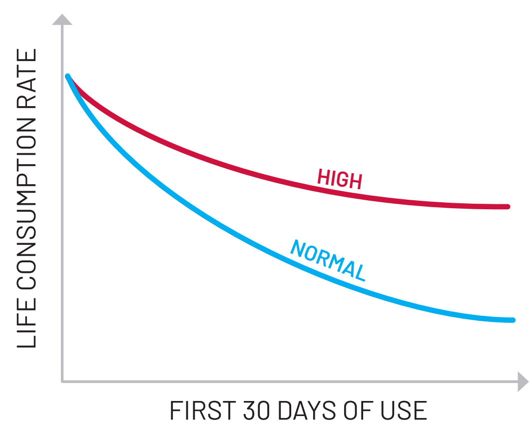

FIG. 5C
Effect of stresses on Life Consumption Rate

The sections below provide additional information on the predictive models for each component.

Power Semiconductors

The predictive maintenance models for the power semiconductors (IGBTs) in the drive are based on a custom physics of failure model created from both IGBT manufacturer data and extensive testing performed by Rockwell Automation® engineers. The IGBT model takes into account two failure modes: bond wire fatigue and solder fatigue. Applications that have high internal IGBT temperature cycles will consume life faster than applications with low internal IGBT temperature cycles. These temperature cycles are accurately calculated using internal sensors, control parameters, and advanced thermal models extracted from extensive Rockwell Automation testing as shown in Figure 6. Since the IGBT predictive maintenance models rely on real drive operation, they take into account the dynamic nature of the drive operation to capture actual life consumption. Elapsed and remaining life calculations are updated every minute and the remaining life calculation is based on the user-defined event level.

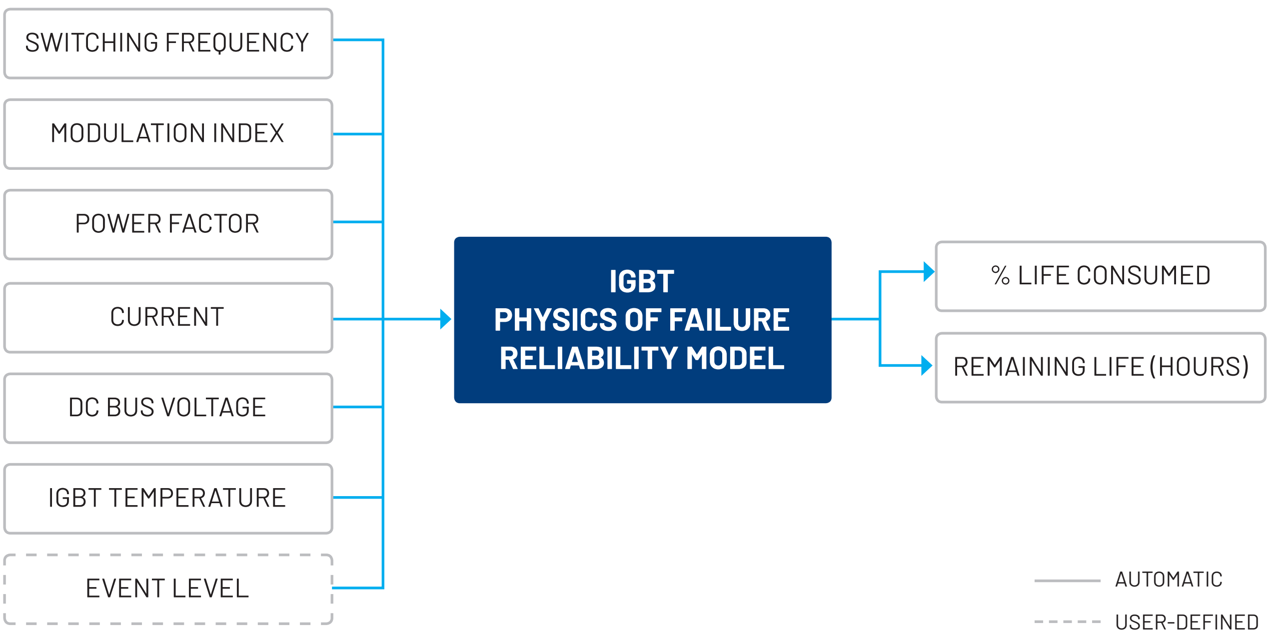

Figure 6. Diagram of the power semiconductor predictive maintenance model.

Fans

Each fan has a predictive maintenance model associated with it that is based on physics of failure models for bearing life and any life-limiting electronics that were fitted to reliability data obtained from the fan manufacturer or life testing performed by Rockwell Automation engineers. The fan life is mostly affected by the local air temperature around the fan as well as the total rotation time. This local air temperature is either directly measured or accurately estimated from one or more air temperature sensors as shown in the figure below and table. When the fan is not rotating, life is no longer being consumed and the predicted fan replacement time easily adapts to such cases where the fan may only run a few hours each day. Elapsed and remaining life calculations are updated every minute and the remaining life calculation is based on the user-defined event level. The fan derating parameter reduces the calculated remaining life. This accounts for other stresses, like environmental contamination, that reduce actual fan life.

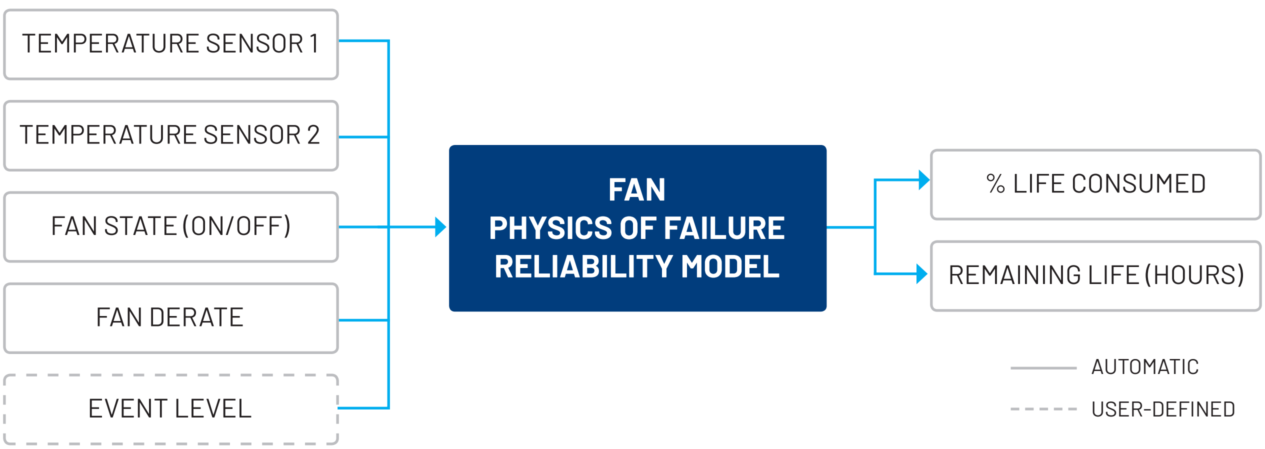

Figure 7. Diagram of the fan predictive maintenance models.

Table 1. Temperature sensors used to calculate air temperature around fan.

Fan	Temperature sensor 1	Temperature sensor 2
Heat sink	Inlet air temperature	—
Control pod	Control pod air temperature	—
Power roof	Inlet air temperature	Heat sink temperature
Input bay	Inlet air temperature	—
Control bay	Control pod temperature	—
Wiring bay	Inlet air temperature	—

DC Bus Capacitors

A DC bus capacitor's life is a function of the internal temperature of the capacitor and applied voltage. This predictive model uses several sensor and control values to calculate the heat generated inside the capacitors. The internal temperature is accurately calculated from two temperature sensors and the heat generation estimates using an empirical model derived from extensive thermal testing by Rockwell Automation engineers (see Figure 8). The capacitor life consumption is based on a physics-of-failure model obtained from the manufacturer. Elapsed and remaining life calculations are updated RELIABILITY and the remaining life calculation is based on the user-defined event level.

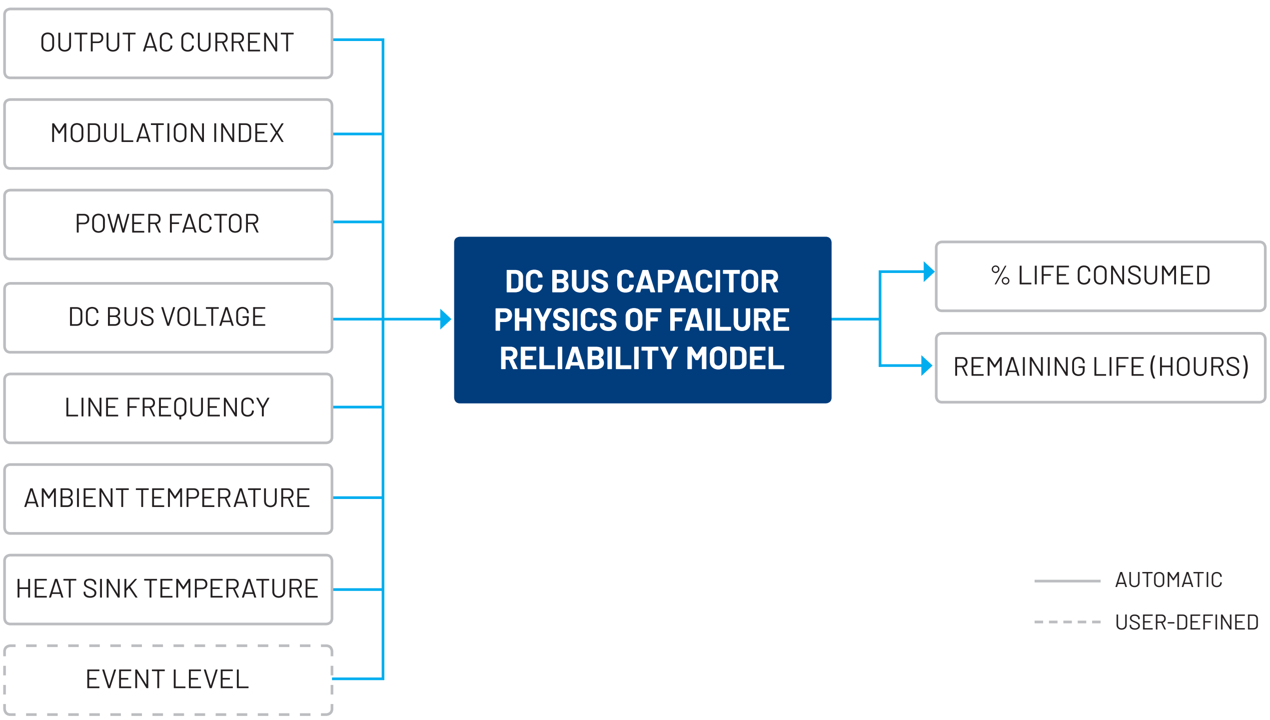

Figure 8. Diagram of the DC bus capacitor predictive maintenance model.

Contactors and Switches

The life span model for the main circuit breaker, precharge contactor, and molded case switch are all based on the actual number of no-load disconnect actions as depicted in Figure 9. Each action consumes life from the total available life. The rate of life consumption is used to estimate the remaining life for the contactors and switches. Elapsed and remaining life calculations are updated every minute and the remaining life calculation is based on the user-defined event level.

Figure 9. Diagram of the contactor and switch predictive maintenance models.

Line Capacitors

The line capacitor life in the LCL Filter is most affected by the temperature of the capacitor. Data provided by the manufacturer was fitted to physics-of-failure model that uses the temperature as an input (see Fig. 10). The capacitor temperature is accurately calculated from a model developed by Rockwell Automation engineers using data obtained during extensive thermal testing. The life consumption rate increases as the ambient temperature increases. Elapsed and remaining life calculations are updated every minute and the remaining life calculation is based on the user-defined event level.

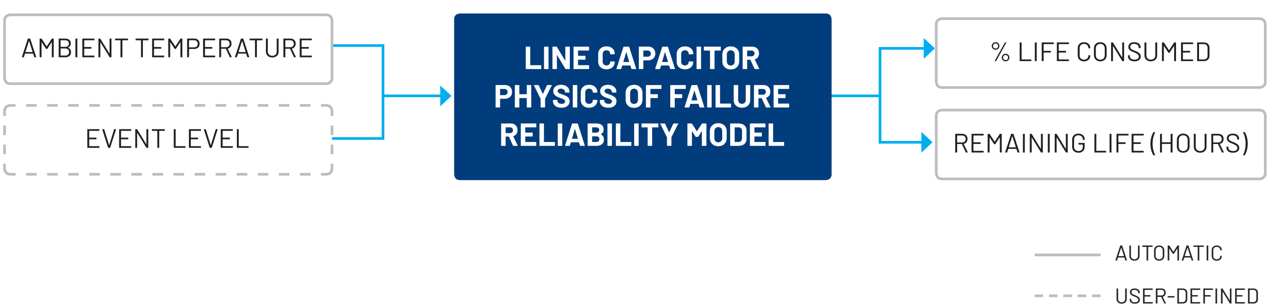

Figure 10. Diagram of the LCL filter capacitor predictive maintenance model.

How to Use Predictive Maintenance

First, develop a predictive maintenance plan for critical drive components like fans, capacitors, IGBTs, etc. In the plan, define the process for monitoring the remaining life predictive maintenance function on these components. You can accomplish this locally or remotely. Use the data and notifications from the function to schedule when to perform maintenance to minimize downtime. Take preventative action at the planned time to reduce unexpected downtime.

For detailed information see publication 750-PM100, Programming Manual for PowerFlex® Drives with TotalFORCE® Control.

Conclusion

Unplanned downtime can be very expensive, as it encompasses not only the cost of lost production time but that of material, capital depreciation, parts and staff.

The examples modeled in this paper were intended to illustrate the magnitude of those costs and demonstrate the value of implementing Advanced Predictive Maintenance functions.

Advanced Predictive Maintenance functions help prevent unplanned downtime and improve overall productivity of the equipment by using advanced physics-of-failure models that take equipment use and surrounding environmental conditions into consideration.

These Advanced Predictive Maintenance functions are included in the firmware of every PowerFlex 755T drive product. To learn more please see **Publication 755T-BR001_** or **http://www.ab.com/drives**

AMERICAS: Rockwell Automation, 1201 South Second Street, Milwaukee, WI 53204-2496 USA, Tel: (1) 414.382.2000, Fax: (1) 414.382.4444
EUROPE/MIDDLE EAST/AFRICA: Rockwell Automation NV, Pegasus Park, De Kleetlaan 12a, 1831 Diegem, Belgium, Tel: (32) 2 663 0600, Fax: (32) 2 663 0640
ASIA PACIFIC: Rockwell Automation, Level 14, Core F, Cyberport 3, 100 Cyberport Road, Hong Kong, Tel: (852) 2887 4788, Fax: (852) 2508 1846

Publication PFLEX-WP002A-EN-P - August 2019