Assessing PROFIenergy‘s potential

Quantifying the energy saving possibilities of PI‘s PROFIenergy profile for PROFINET and assessing its deployment opportunities

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PROFIenergy

Smarter energy management in automation

1. Executive Summary

PROFIenergy is a Profile of the real-time Industrial Ethernet protocol PROFINET. It was developed in response to calls from the AIDA group of automotive manufacturing companies (Audi, BMW, Daimler, Porsche and Volkswagen) for an open standardized method of controlling energy consumption in automation systems.

The Profile, published in 2010, enables the deployment of more effective energy management strategies over PROFINET architectures. Its function is to place energy consuming devices such as robots, laser systems, conveyors, handling systems and IO into 'sleep' modes during equipment idle times (i.e. non-productive periods) in order to prevent the wastage of energy.

The Profile requires firmware to be embedded in vendor-supplied devices and equipment so that these can respond to PROFIenergy commands and status requests sent from a central control point (e.g. a PLC or supervisory computer).

Early calculations suggested that energy savings could be dramatic. To assess the actual potential, a 'real world' study of some typical automation systems was undertaken to analyze and understand their energy use profiles and assess the potential for energy saving during non-productive periods.

The analysis concluded that savings of up to 30% are possible. In chosen 'typical' cases this could result in plant-wide cost savings of €1,400,000 p.a. The potential 'Green' savings are substantial as well.

The analysis also concluded that, for optimum benefit, the PROFIenergy concept should be designed into automation systems at an early engineering stage, requiring close collaboration between end users, device vendors, system integrators and OEMs.

PROFINET is the enabler for ***intelligent energy management*** in automation systems. As experience grows, the concept is expected to become more tightly integrated into plant-level energy management systems.

2. The PROFIenergy Concept

The aim of the PROFIenergy Profile is to enable easier and more efficient energy management of automation systems, by intelligently placing individual devices or sub-systems into energy-saving modes during idle times.

Various degrees of energy saving are possible, ranging from the device equivalent of the 'sleep' (hibernation) mode of a PC through to the complete standstill of a production line. PROFIenergy can also be used to control interactions between equipment (such as conveyor drives, water/wastewater drives, HVAC drives or drives in production machines), by taking them through pre-determined slow down and re-start sequences.

The real-time Industrial Ethernet protocol PROFINET is the well-proven medium by which PROFIenergy commands are transmitted to energy-consuming devices and equipment. PROFIenergy can be fully integrated into standard automation systems based on PROFINET. It utilizes the acyclic PROFINET communication slots and therefore does not interfere with normal process control activity. Energy management utilizing PROFIenergy can therefore be managed by the same controller as used in the automation process. Alternatively, it can be managed by a dedicated controller on the same network.

COMMANDS
Start_Pause, Tpause - used to switch a device from an operational mode to an energy-saving state (sleep mode), or from one energy-saving state to another (which can be either higher or lower power). The parameter includes the time stamp **Tpause** indicating either the precise idle time or an indeterminate period dependent on other factors (for example, the sum of any run-down, sleep and re-start periods, or the minimum duration in power saving mode). The device can adapt the optimum energy saving mode for this period.
End_Pause - used to force a re-start after a period of energy-saving.

STATUS QUERIES:
PE_Identify - the services and commands available from the device.
PEM_Status - the current status of the device (for example 'fully operational' or 'in energy saving mode').
Query_Modes - return overview of the device's supported energy-saving modes and their time requirements.
Query_Measurement: - return energy-relevant data from the device (for example, phase, current, power).

The PROFIenergy commands and status queries

With PROFIenergy, the mechanisms controlling the 'sleep' modes of equipment reside inside end devices. These respond to PROFIenergy commands issued at predictable idle times (such as lunchtimes), or at dynamically-decided times that depend on circumstances - for example the deliberate slow-down of a production line to match material input conditions, a product change, or a line breakdown.

It's important to recognize that many devices and equipments in automation systems operate interdependently. That is, they react to operations taking place in advance of, during and after the process in which they are involved. However, smooth production flows are usually the principle goal for maximizing productivity. As a result, not all production equipment is active all the time. In other words, non-productive time is built-in to most production processes. It's either hidden (e.g. when an IO device has nothing to do) or it's overt (e.g. when a robot waits for material to arrive).

During non-productive periods energy is wasted. The situation is compounded by random faults due to, for example, breakdowns or delivery failures when large sections of a process may be halted. It is the goal of PROFIenergy to put non-productive devices and equipment into energy-saving modes during these periods using a simple, standardized technique.

As well as basic 'sleep modes', energy consumption can be reduced in other ways - for example by adapting process cycle times to production rates. Equipment interdependencies can be taken into account - for example a conveyor may need to be run down to idle over a 30 second period before a robot can be put into its 'sleep' mode. Restarts may need converse run-up procedures. Pneumatic and thermal energy usage could also be considered.

Since a wide variety of pauses can be expected, a range of approaches is required. Each production process is different, and each device or sub-system may need a different approach to energy-management. Implementing PROFIenergy is therefore the responsibility of equipment vendors, OEMs, system integrators and end users acting together. All need to have a common understanding of the objectives for each automation process.

PROFIenergy is the enabling technology for deploying the chosen energy management strategy. It enables ***intelligent energy management***.

3. Typical Use Cases

Four 'use cases' were considered during the development of the PROFIenergy Profile. The three main ones are:

- Brief pauses - usually planned and lasting up to one hour.
- Longer pauses - typically measured in hours or days.
- Unscheduled pauses - typically caused by equipment failures.

The fourth 'use case' is that of gathering energy consumption data from automation devices and returning that data to the controller so that energy consumption can be managed in real-time using, say, a SCADA system.

4. Study Overview

Until now only limited empirical data and hardly any actual data have been available about the relationship between energy consumption and equipment operating modes. Therefore, a detailed measurement study was initiated to record quantitative data, with the aim of allowing better analysis and understanding of the energy saving potential of PROFIenergy.

The Institute for Automation & Industrial IT, Cologne University of Applied Sciences, was commissioned by PI to perform this study. The institute is a member of the PI Working Group that developed the PROFIenergy specification. It also serves as a PROFINET Competence Center. It specializes in PROFINET diagnostics and in performing energy consumption measurements and analyses for production plants.

The goal of the PROFIenergy study was to quantify the benefits that could result from using PROFIenergy. These include the direct cost savings associated with improved energy efficiency as well as any indirect benefits, for example from extended service lifetimes.

The main tasks included:

- Recording and analyzing load curves in typical production processes.
- Determining the relevance of idle times for energy savings, and identifying the exploitable idle periods.
- Quantifying the potential savings.

To achieve representative results, the study covered applications in industry sectors in which PROFINET is already being used, where the benefits from PROFIenergy are particularly relevant.

5. The Measurement Project

The PROFIenergy study was undertaken on production lines in Germany - at Daimler's Sindelfingen plant and at Volkswagen Commercial Vehicles in Hanover (Panamera production). The behavior of the plants and their components was analyzed with respect to load curve, load distribution, and the types of idle time encountered. In addition, the influence of operating modes on energy consumption was analyzed. Production pauses were analyzed with respect to frequency and duration.

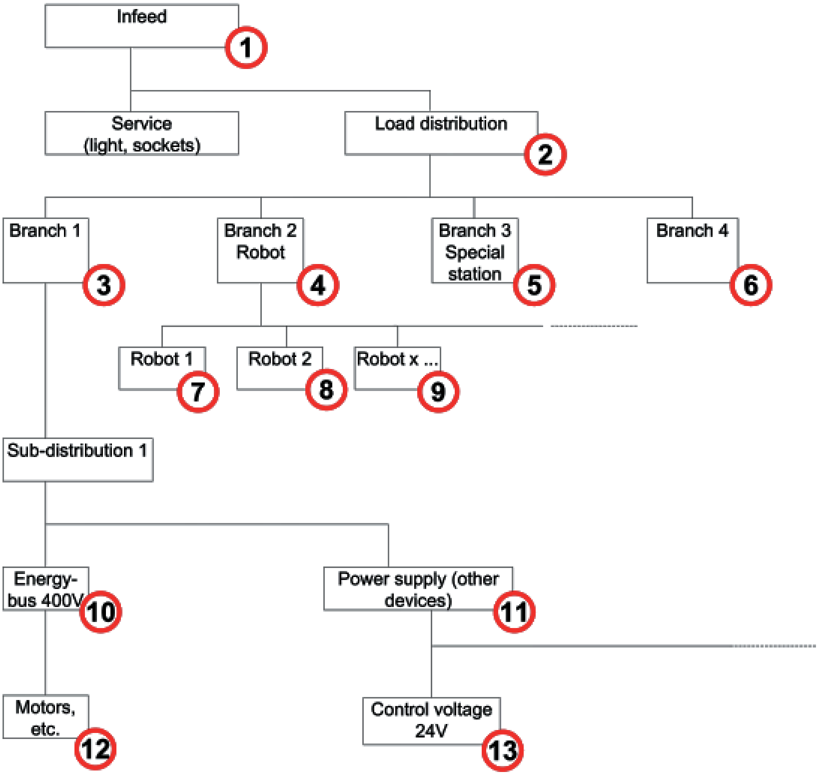
A variety of production cells was monitored during the measurement program. For commercial reasons, detailed descriptions of these lines cannot be published here but for the purposes of this White Paper we can provide representative results from 'typical' plant processes. We characterize a 'typical' cell as containing several assembly robots, a conveyor, a controlling device connected to adjacent production cells and various actuators and sensors. The cell, and the rest of the plant, are networked using PROFINET.

In the automotive manufacturing context, this describes a typical car body construction and assembly cell. An automotive plant may comprise 200 or more examples of this 'typical' cell.

Power measurements were taken at up to 15 different points in each cell (see diagram on next page), making it possible to record load curves and determine characteristic power consumption values (including voltage, harmonics, and phase offsets) at different levels in the automation architecture of the cell, ranging from the main incoming power supply down to individual devices.

Continuous recordings were taken over a seven day period, at one second intervals. At the same time, synchronous data on equipment status and operating modes were

Energy meter used during the audit



The measurement point architecture used during the study

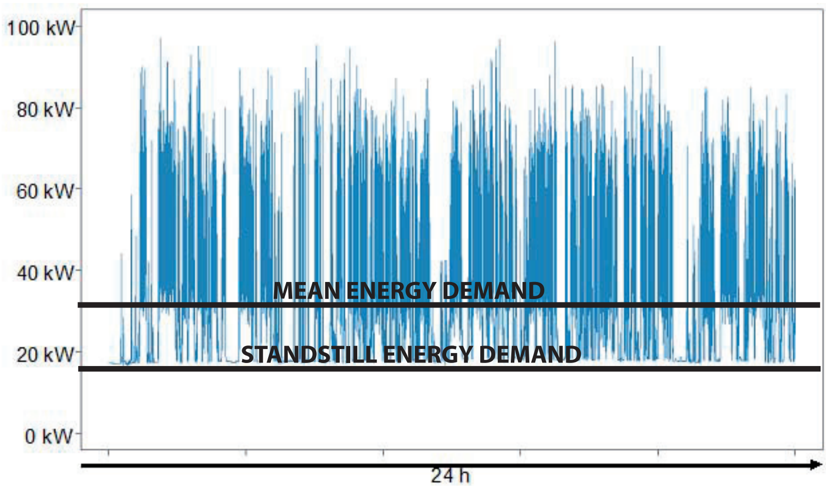
acquired from PLC logs to ensure that the measured values at each individual measurement point could be attributed explicitly to control events.

6. Measurement Results

The measurements showed clearly that load curves in the analyzed production cells exhibited regularly recurring load profiles that are the direct result of the discrete production steps (see load profile curve, right). The profiles are the result of chronological overlapping of individual devices and plant components and their functions. Due to variations in material stores at infeed or between plant units, there are often no rigid process sequences. Load profiles vary – particularly during the transition to a temporary equipment standstill in which not all plant components are necessarily affected at the same time (due to run-on, idling of certain stations, re-filling of buffers, etc.)

A noticeable feature of the load curve below is the high load peaks over a 24 hour period. While the maximum load level during operation is around 80kW, the base (i.e. standstill) load is only around 17kW.

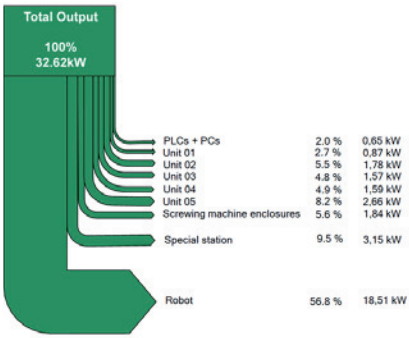
At first glance this standstill load (around 20% of the peak) does not seem particularly relevant in the hunt for energy savings. But that is a misinterpretation. The high peak load figures conceal the fact that the actual consumption value (that is, the energy that is actually paid for) is the mean value of the load profile, which in this example is around 32 kW. It follows that the base load during non-productive periods can be at least 50% of the total energy consumed, which suggests that significant savings are possible.



Standstill energy demand v. mean energy demand over a 24 hour period

7. Load Distribution and Energy Flow

Another aspect of the study was the analysis of the load distribution within a production cell. Due to the structured distribution of the measurement points – from the incoming supply down to the terminal level – it was possible to analyze individual energy consumers and to identify their typical energy-consuming characteristics.



Energy demand distribution in a 'typical' cell

The diagram right indicates that the largest proportion of energy consumed - perhaps up to 60% - is used by robots. Robot systems are also predominant energy consumers during idle times, when up to 300 watts of non-productive energy may be consumed per unit. Individual components such as IO and controllers account for relatively small amounts of the overall energy demand.

In a world of cheap energy, such wastage may be tolerable. However, as energy costs rise, the non-productive energy consumed during idle periods becomes significant and therefore worthy of exploitation.

8. Analysis of Idle Times

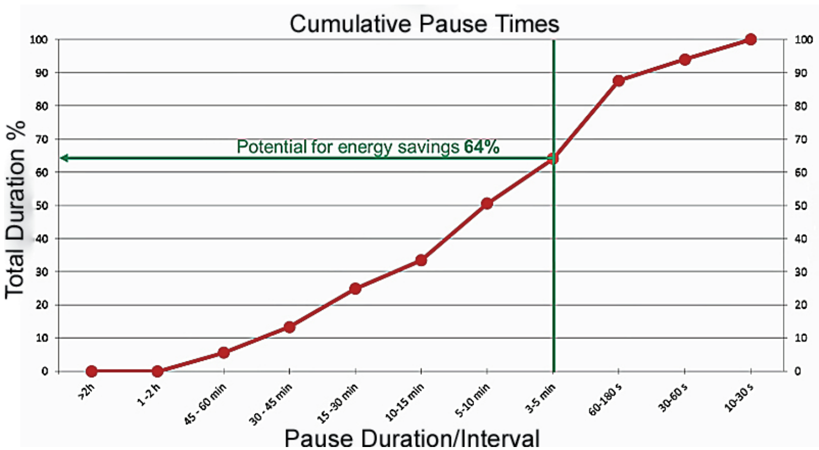
Idle times occur for many reasons. As well as planned pauses - for example, lunchtimes and holidays - there may be unplanned pauses caused by material shortages or breakdowns. It's common to find product-related factors too. For example, one robot may stand idle while standard versions of a product pass by on a conveyor system until a special version of the product arrives (say, a 'hatchback' instead of a sedan/saloon) when it carries out a slightly different production task.

Energy wastage may also occur for human reasons. For example, many plant engineers know that line problems are most likely to occur during equipment restarts. As a result, operators are often reluctant to switch off production equipment even during extended standstills, for example overnight or during weekends.

The data obtained during the study provided many clues to the true operating behavior of automation systems. While brief standstills may relate to equipment synchronization and/or material store issues, longer standstills generally take place during planned pauses and shutdowns, or when line problems occur. Special attention was therefore given to analyzing the duration of idle periods and comparing that with the cumulative duration of all individual events, leading to the analysis of idle times shown in the graph below.

Industry experts generally accept that idle times of short duration (these occur frequently) are not candidates for energy saving because of the time required to restart equipment from standby. Moreover, rapid stops and starts of electronic equipment can introduce unreliability. However, it is generally agreed that a transition to energy saving modes is appropriate for idle times lasting 5 minutes or more.

From the graph we can see that 64% of idle time falls into this category and is therefore exploitable by PROFIenergy. Idle time profiles will differ for each process and therefore a full understanding of idle time distribution in each production cell may be needed for optimal deployment of PROFIenergy.



Idle time distribution: pauses of less than 5 minutes may not be exploitable

9. The Energy Savings Potential

Based on the study it can be stated that, for typical automotive production plants engaged in body construction and assembly, a production plant with a typical two-shift strategy will consume about half (47%) of its total energy during idle periods. This means only 53% of the energy consumed is productive!

If we assume that PROFIenergy can facilitate energy savings of up to 70% during exploitable idle times the result is a potential saving of 33% of the total energy consumption of a plant. As our 'typical' production cell may be consuming 210,000 kWh per year overall, this suggests savings in the order of 7,000 € per annum are available (based on €0.10 per kWh). Multiplying by the number of cells in a typical plant therefore gives a total possible saving of 7,000 x 200 = €1,400,000.

10. ROI (Return on Investment)

But what about the costs of implementation? Can a €7,000 saving be justified if the extra engineering input required when designing the plant is taken into account?

Feedback from car plant operators suggests that the engineering costs required to deploy PROFIenergy in the ways described above could be up to twice the annual saved amount. This means that an ROI of 2 years or less is realistic.

Further cost benefits arise from extending the lifetimes of mechanical systems such as conveyors because their length of time in operation is reduced. Equipment lifetimes may also be longer for specialized equipment such as laser-based systems whose life cycles are directly dependent on operational duration.

11. Green Advantages

Thus far, this White Paper has dealt only with the more obvious financial benefits. What are the 'green' benefits of reducing energy consumption?

European industries are becoming more and more sensitive to 'green' argumentation. Partly this is because of regulatory factors but increasingly it is for reasons of social responsibility. It is interesting to note that if an automation system is already being designed to reduce energy usage in the manner described above, no additional engineering costs are involved in gaining CO^2 reductions. Hence, 'green' ROI is immediate!

The financial benefits of managing energy consumption are paramount in many countries at the moment. Social responsibility arguments are bound to become more and more compelling over time.

12. Benefits and Opportunities

For device vendors, the opportunity to gain competitive advantage by offering PROFIenergy in their devices is clear.

OEMs are ideally positioned to profit from PROFIenergy since offering PROFIenergy functionality to end users is a way to demonstrate competitive advantage. OEMs may well find themselves pioneering more effective energy-management strategies, particularly as PROFIenergy is likely to become a standard requirement of the automotive industries.

For end users, there are many cost benefits over the life cycle of a plant, not just from direct energy reductions but also from less downtime and fewer replacement issues.

As well as enabling intelligent energy management in automation, PROFIenergy is likely to promote a wider energy efficiency review, for example by encouraging a deeper understanding of energy saving potentials across other sectors of a plant.

For both vendors and users, PROFIenergy offers enormous potential as a contributor to company-wide energy management policies. PROFIenergy could also become part of a plant's energy recovery mechanisms.

13. Applications Potential

So far, the main focus for PROFIenergy has been on automotive manufacturing because that's where the biggest demand currently is. Could other end users or equipment vendors benefit? Are there opportunities for low end systems such as remote IO?

The quick answer of course is 'yes', particularly where large numbers of devices are involved. But each plant situation will be different and an energy audit will be needed in every case to understand the implications and potential benefits.

An industry that might benefit significantly is intralogistics (e.g. automated warehousing and distribution) where equipment such as automated mechanical handling systems, automatic guided vehicles and multiple conveyors are widely used. A further energy study has been commissioned by PI for this sector to understand the implications. The results will be published in a future White Paper.

There may be justification for employing PROFIenergy with other energy consuming systems - for example, hydraulics and pneumatics. The latter in particular could be a rich source of savings because of the constant problem of air leakage, together with the natural human tendency to leave pneumatic power sources on during expected idle periods (such as overnight and weekends) because "it's easier." If those energy-consuming sources could be controlled centrally, say from a supervisory system or a local PLC, then further large savings might be achievable.

One high energy consumption sector is the process industries. Could PROFIenergy be used there? It's thought unlikely at present because continuous processes can't be shut down and restarted in the way that discrete manufacturing systems can. In any case, process industry operators are already acutely energy conscious and are well used to minimizing energy usage wherever possible. Nevertheless, many process industries are hybrid (i.e. they include discrete-like functions such as bottling and packaging) so it is possible that PROFIenergy will find application in those areas in due course.

The ability of PROFIenergy to transmit energy use data back from devices to a controller has not been fully investigated or exploited yet, in any sector. The possibilities include active energy management of equipment to help avoid overload penalties.

14. Prerequisites of Deployment

End users, OEMs and device vendors need to work closely together to maximize the benefits of PROFIenergy. Changes to the way plants are conceived, engineered and built may be necessary. Careful design of plant architectures and a macro-economic view of energy management are key factors in the optimization of savings. It can be anticipated that smart energy management systems originating outside local PLC loops - perhaps at an IT level - will eventually evolve.

To achieve all this, plant owners need to understand and clearly define their requirements in advance with suppliers so that PROFIenergy can be built into plant concepts from the outset. As a result, PROFIenergy may encourage changes in the design philosophy of plants and processes as end users will become used to designing with energy efficiency in mind. We can even imagine that, in time, software simulations of plants and processes will identify even more innovative ways in which energy consumption can be minimized.

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