Control Technologies for Reducing Demand in Induction Heating Systems

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ABSTRACT

Foundries are energy intensive facilities where a high percentage of energy use is attributable to melting metals. Industrial melting equipment is typically powered electrically through inductive or resistive technologies. These melters or furnaces are most often controlled locally and operate independent of each other. Several melting units are often independently employed in a given facility and are operated simultaneously to meet production demands. Implementing a state-of-the-art control system for the entire facility can significantly reduce demand with associated energy savings, thereby lowering overall operational costs. Such a system employs both a monitoring data acquisition system and a control output module. The monitoring system acquires real-time data from the utility meter(s) for the entire facility and employs control strategies to key energy intensive equipment to meet the target demand and energy consumption goals of the plant. Such a system facilitates understanding of the facility load profiles, overall energy consumption, tariff comparisons based on actual usage, and an overall knowledge of how the facility consumes energy as a function of production. Having this data and the tools to understand it can result in greater efficiency and substantive improvements in operating costs through reduced equipment demand and lower overall facility demand. This paper will discuss the technologies associated with demand control systems and present a case study of a casting facility.

Introduction

Induction heating systems are used in foundry facilities to produce molten metals for subsequent casting processes. Such systems typically utilize silicon-controlled rectifiers (SCR) to control electric energy used for induction heating in the melting process. Further, these units usually have local control systems that govern operation based on input from foundry employees. Multiple melting systems are often present in foundry operations. Although independent, these units often operate simultaneously for melting processes and thus contribute significantly to overall facility electrical demand. Without real-time monitoring and control on a plant wide level, there is no means to regulate induction-heating equipment to maintain the facility's energy consumption and peak demand goals. Such automatic control systems are often referred to as "demand limiting" control systems.

Implementation of a demand limiting control system provides both demand monitoring capabilities and equipment control functions. They monitor overall facility real-time demand from the main utility meter(s) and, based on defined limits, implement control be developed with cooperation from facility and operations staff to ensure that the control is cost-effective and consistent with production requirements. Such actions ensure that the peak demand target established for the facility is maintained and that production goals are not adversely impacted.

Discussion of Foundry Operations

The primary purpose of foundries is to liquefy metals and cast or mold those metals into desired shapes. A variety of metals and alloys are used and the types of casting and molding processes are numerous. The size and shapes of parts developed range from tiny to huge. Even with all the variables, one aspect remains constant; the process requires considerable energy input to liquefy the metals involved.

Most foundries utilize induction or resistance melting equipment for this purpose that often can consume several megawatts (MW) of power for each piece of melting equipment. Resistance melting systems use electric resistance to indirectly heat the metal that must be melted. Conversion of electrical energy to heat energy is 100 percent efficient. While the high cost of electricity for heating and heat loss to the environment is often a concern, electric resistance is appropriate for high temperature, well-insulated applications like melting at foundries for specific materials.

Induction heating is also commonly used in foundry melting systems. Induction heating system melters use a coil or conductor to induce an electrical current in the material to be melted (generally ferrous). Internal resistance heat then melts the material and brings it to the desired temperature. Like resistance heating, this process of heating and melting can be highly effective and efficient with appropriate melter insulation and safeguards to limit heat loss to the surroundings.

These process-heating systems will typically amount to far greater than 50% of the energy consumed in a foundry facility. With the cost of energy on the rise, it is increasingly important to maximize the efficiency of melting systems and minimize energy consumption. This goal can best be achieved by implementing a real-time monitoring and control system that evaluates facility energy use and controls facility equipment to optimize production while reducing energy consumption.

Conventional Control Systems

Typical process melting control systems in foundries provide localized control specific to an individual piece of equipment. Programmable controllers are commonly integrated into the equipment package and provide various levels of customizable functions. Although adequate for certain types of equipment and applications, this control type does not provide or receive information from any other equipment in the facility. Thus, individual equipment pieces operate independently of all others, and automated facility-wide energy control strategies are not available.

As a consequence of conventional control limitations, facilities often consume excessive energy and set demand peaks that are not necessary to ensure high productivity. It is common to find multiple melters operating at peak load concurrently. Generally, it is possible to stagger system operation and still have melt available at the correct time for molding operations. We focus on this inappropriate establishment of excessively high demand in much of this paper.

Conceptual Discussion of State-of-the-Art Control Systems

A state-of-the-art control system for foundry operations must contain features that allow it to centrally monitor the individual and integrated status of each major foundry system, and use that information to effectively develop and implement control strategies that reduce energy operating costs while maintaining productivity. While the discussion here is conceptual, we do describe an actual control system application in our case study discussion of an iron foundry.

Note that the control system described here is not limited only to foundries, but would have applicability in controlling energy and demand in other facility types. In general, the control approaches and protocols described can be effective where significant loads can be intermittently scheduled to reduce energy use or demand.

State-of-the-art systems provide the ability to gather electrical energy consumption data on a real-time basis and modify equipment usage accordingly to achieve usage targets. Additionally, a state-of-the-art system will provide extensive analysis, graphing, and reporting tools as well as alarm monitoring.

There are two primary system components—monitoring and control. Monitoring is the ability to capture data that informs the operator about the current system status. This task is performed in real-time and subsequently provides a dynamic status of system parameters. Once the current status is known via monitoring, a change can be induced by the control system based on previously developed strategies. These aspects are discreet functions of such a system, but when combined, provide an operationally efficient and very powerful energy management system.

The system described below provides both monitoring and control functions utilizing real time and historical data relating to energy, demand, and associated costs. Systems of this type can be equipped with multiple operator stations allowing various networked users to simultaneously access real-time and historical data, and make manipulations to control strategies.

Overall System Design and Concept

State-of-the-art foundry control systems are designed to reliably collect, analyze, and report data on a real-time basis and to automatically control peak demand. In their simplest form, these PC-based systems collect and store real time information from metering signals duplicated from the plant's incoming utility meters. From this information, the software is able to build the facility's load profile and to predict the facility load through the end of the current utility billing period window. Different utilities use different windows, but they are typically between 15 and 30 minutes. The predicted peak demand data, operating energy costs, and plant profiles are continuously available to the plant operators on computer monitors.

The software also uses these predictions to generate control signals that are dispatched to control selected plant equipment at the appropriate times to manage peak demand load, thereby limiting overall facility kW or kVA to a pre-determined level. The demand limiting system may range in size from a single personal computer controlling limited equipment to an array of industrial quality computers on local area networks that permit users in different parts of the plant (or other buildings) to simultaneously access the data.

Demand Limiting and Energy Saving System Operation

Basic demand limiting system operation is achieved by comparing the actual predicted demand to that of an operator entered demand target during periods when demand control is necessary as determined by the tariff. Depending on the facility's rate structure, control may be needed only during on-peak periods or in both off- and on-peak periods, which may or may not include weekends and holidays. During an active billing window, the system collects data from the utility meters and analytically forecasts what the load will be at the end of that billing window. By comparing the forecast load to the target, the control program will automatically generate output load control signals that can be used for plant control. The system has multiple levels of output signals that can be generated at various percentage levels of predicted load versus target, allowing systems to be easily tuned to match individual end user needs.

In addition to peak demand savings, this type of system can be used effectively to reduce annual energy consumption in a facility. If target goals are defined to lower the average operating demand in the plant, the system can employ control strategies based on these criteria and limit demand and overall energy consumption. For example, if the baseline energy consumption and load profile for a facility is known, a target demand reduction can be established for various operating periods that will cut the average demand by a defined percentage. When done throughout the year over long operating hours, this form of demand control will result in considerable energy savings.

Data Acquisition

General. The data acquisition system associated with the discussed state-of-the-art control system is based upon use of distributed remote terminal units (RTU's) located throughout the facility. Metering, status, and alarm signals are hardwired into the RTU's using shielded instrument cable and fiber optic cabling. The RTU's are interconnected using RS422 communication cable and fiber optics back to the data acquisition computer or are connected to the computer via the local area network.

Metered points. The system monitors both digital and analog signals from a combination of kWh, kVARh, kQh, water, gas, and air meters located throughout the facility. Meters applied here can be from a variety of manufacturers and types and are individually configured in the software. Each digital metering signal is wired into a local RTU using twisted and shielded pair or fiber optic cabling depending on location. The inputs are all volt-free contacts provided with a 24-volt DC interrogation voltage from the associated RTU.

Analog metered points. Analog transducers using 4-20 ma and 0-5V signals provide the analog metered signals. The power supplies to drive the current through the transmitters are provided by the RTU's or by the transducers themselves. Each analog input is connected to its RTU using twisted and shielded pair wiring.

Digital status points. The system also monitors and reports on the status change of digital input points from devices such as circuit breakers or protective relay devices. Each digital status input is a volt-free contact suitable for use at 24V DC in a similar manner to the digital metered points.

Smart meters. The system also monitors smart meters that use RS485 communications with Modbus RTU protocol. Typically these devices are connected on main feeder circuits and provide the ability to snapshot voltage and current waveforms and provide harmonic analysis as well as digital readouts from the front of the meter. Smart meters are connected to their local RTU's using RS485 twisted and shielded cable. Each smart meter provides information on phase voltage, current, total kW, kVAR, kVA, power factor, harmonic distortion, and waveform data to the operator through system software.

Control outputs. The system provides digital output points to be connected to various types of field devices. For demand and cost control purposes in foundry applications, the output points are connected into the set point controllers of furnace variable frequency power supplies or as digital inputs into the furnace control PLC's. The number of control points and their location must be determined by facility management and engineering. The output points located in the RTU units are controlled by the load control program. Typically each digital control output point is either a dry, volt-free contact suitable for use at 24V DC, or a solid state output for use with voltages up to 60V DC or 120V AC.

Remote terminal units (RTU's). The system RTU's must contain intelligent processors, input/output interface modules, and power supplies. These RTU's provide the interface between the field metering devices and the computer equipment. The number of RTU's, their location, number and type of input/output modules, and power supply requirements are determined during the design phase. Each RTU consists of a NEMA 12 wall mount cabinet containing an intelligent processor with a unique serial communications or IP address, up to 32 digital I/O, up to 16 analog inputs, and associated power supplies. Additionally, each RTU is equipped with an internal UPS unit of an electrical rating determined by the RTU internal configuration.

State-of-the-Art Control System Software

System software optimized for foundry energy management must have several components as described below.

- Data acquisition
- Data archiving
- Load predictions
- Automatic load control

- Data analysis and reports
- Configuration

The data acquisition aspects of the software must provide communication with the RTU and remote data acquisition equipment. Duplicated utility metering signals are connected to the data acquisition hardware devices. The computer polls the RTU's at regular intervals using serial or network communications and brings back the metered information from the remote data acquisition units. The resulting data is suitably scaled and passed to the prediction and data archiving routines. The prediction program reads in the target set points and compares the metered data to the target. This process is usually performed on a minute-by-minute basis. The target set points may be related to the current hourly price of electrical energy or they may be fixed targets depending on the supply tariff. If the predicted load is greater than the configured percentage of the target set point, the control program will turn on outputs placed at specific points in the plant using the same data highway as used by the data acquisition equipment and software. The configuration program allows the system to be configured to match the industrial plant both in terms of electrical tariff, type of metered signal, and load.

The data archiving software saves the metered data, control logs, hourly energy costs, and other non-electrical data. This saved data can be accessed using onboard data analysis tools. Graphs and tables relating to peak demand, energy usage, load factors, load profiles, flows, and other measurements can be generated from the system archives through use of the analytical tools provided. The saved data can also be exported into spreadsheets or transported into other databases.

Multiple plant control. Where there are several facilities whose electrical utility bills are aggregated, the state-of-the-art system can be particularly useful in providing demand control, analysis of data from each plant, and allocation of costs. By using the Internet, historical data can be uploaded from the systems to a central database location at regular intervals. Overall demand control is achieved by having one of the computers act as a master and collecting the metering information from the other plants in real time. Control signals are then sent out to each plant to mange the demand according to the overall summated demand.

Control strategies and results. The real time load forecasting provided with this type of system allows facilities with the appropriate tariff to take advantage of the automatic peak demand control programs. Demand limiting control can result in substantial savings (5-25%) on power bills. Facilities with high peak rates can frequently implement actions that reduce their utility costs dramatically. Those customers on real time pricing save through managing their hourly peaks, reducing consumption when the price is high, and buying power intelligently by knowing their load profiles. Customers using the system have negotiated better rates and tariffs as a result of being able to shed load and demonstrate that they can maintain that load when asked to do so by the utility in times of tight supply. When using smart meters, customers are able to monitor phase voltages and currents, and read harmonic data and waveforms remotely through the system.

Additionally, this type of system can facilitate verification of customer billing accuracy and allows errors to be spotted. The system can also allocate costs between departments and associate energy costs to production costs, eliminating guesswork.

Case Study: Diversa Cast Technologies Control System

System Overview

The E2MS power management system (conceptually discussed in the preceding sections) was selected for installation at the Diversa Cast Technologies plant in Guelph, Ontario. Diversa Cast Technologies is a Linamar Company specializing in producing aluminum, gray, and ductile iron automotive lost foam castings. The power management system is a real time demand control system that allows plant staff to reduce operating costs through automatic control of plant furnace loads with minimum interference to production levels. Based on demand control savings alone, the payback for this system was less than 8 months. Experience with this system has proven that the overall demand can be reduced while improving productivity and energy consumption efficiency. The system is fully integrated with the Linamar plant's wide area network, permitting multiple users to access the system's real time and historical data from their existing desktop computers.

The Diversa Cast plant has an installed potential load of approximately 5,000 kW made up of two ABB coreless induction melters and supporting equipment. The first melter is rated at 2,750 kW with an 8,000 lb. capacity and is used for iron batch melting in the off peak periods from 11pm to 7am. The second melter is rated at 1,250 kW with a 2,700 lb. capacity and is used for aluminum melting during on-peak periods. The plant operates 3 shifts per day, 5 days per week. The utility power contract provides power using a time-of-use (TOU) contract with on-peak demand charges. A schematic of the system is shown in Figure 1.

Computer equipment is installed in a free standing panel located in the plant's office area and is linked by an RS422 instrument cable to an RTU panel located in the vicinity of the two melters. The RTU contains data acquisition equipment consisting of a data processor, digital input/output modules, and power supplies.

The plant has two utility power feeds and two sets of meters. One feed supplies the plant auxiliary equipment, while the other supplies the two melters. Each meter has two isolated output contacts providing kWh and kVARh pulse signals proportional to the energy being used. These pulse signals are wired to the RTU panel and are supplied by 24V DC power from the power supply in the RTU.

Power consumption of the two melters is monitored by power transducers mounted on the melter power supply units. These transducers provide pulse outputs that are also wired to the RTU panel. The E2MS computers control the load on each melter by effectively changing the operator set points through adjustment of the potentiometer load control settings. The degree of control required at any time is calculated by comparing the utility metering input information with the plant's desired demand limit set point.

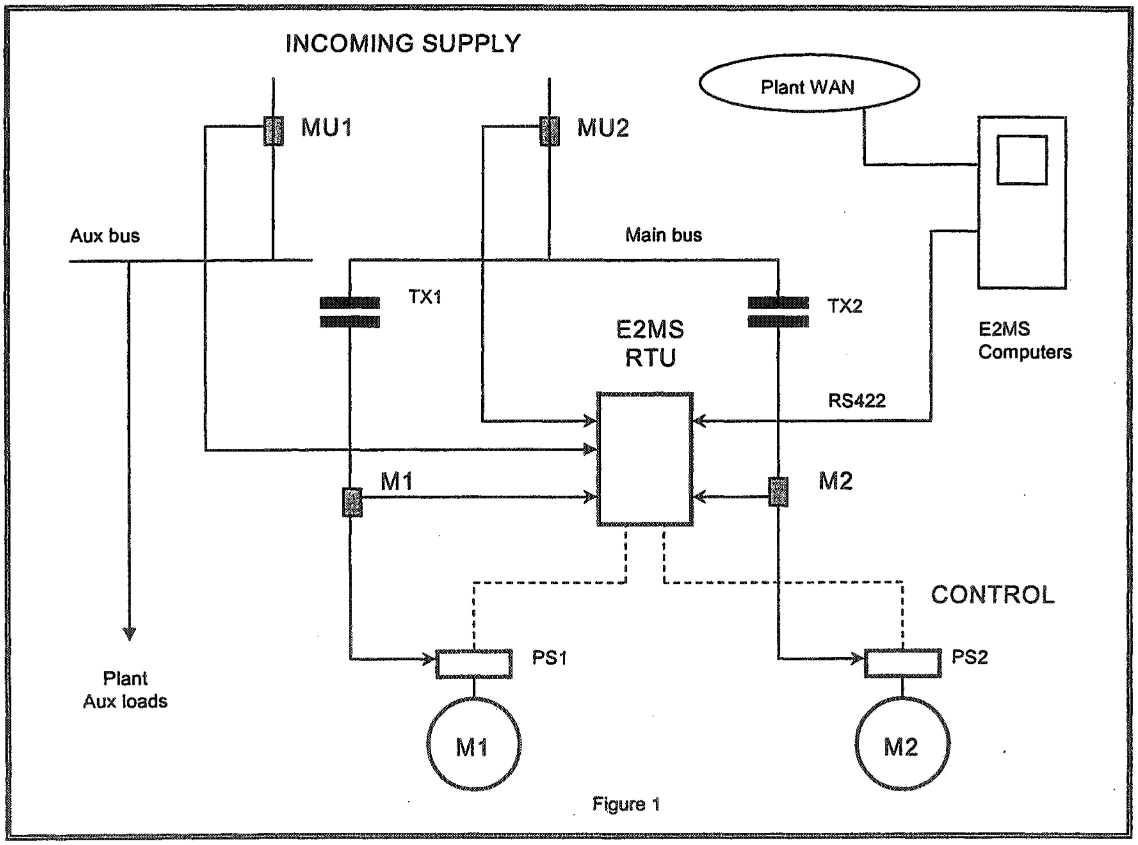

Figure 1. Schematic of Diversa Plant Foundry Control System

System Operation

The control system RTU continuously obtains electrical information from the plant's two main utility meters, MU1 and MU2, and from the kWh transducers M1 and M2 on the two melters. The E2MS control software module monitors the energy being used and forecasts the plant's demand in accordance with the power utility billing algorithm used at the plant. By comparing the forecast demand with the desired set point demand as determined by plant management, the computers issues control command outputs to raise or lower melter loads. These output signals are sent to the RTU panel where they operate digital output modules. These modules in turn are connected to E2MS demand control modules mounted in the control sections of the melter power supply units PS1 and PS2. Resistance is inserted or removed from each of the melter's electronic control circuits by the RTU output modules to control the frequency of the power applied to the melter, thereby controlling demand.

System operators are provided with a real time graph of overall plant load versus time, set target load display, and full analysis tools for historical and cost analysis. In addition to the overall plant total, the load on each individual melter is also shown. Control of demand is smooth and is applied equally to both melters in three stages. Reloading of the melters is automatic after the load has fallen to the restart level as defined in the system configuration. Every time a control operation takes place, the activity is written into a control log together with the time, date, and demand at that time.

The load target is password protected and may be changed at any time by authorized users when on the control screen. The output control levels are computed on a minute-by-minute basis using the utility metering signals. The system has several major communication routines.

The data values returned to the computers are scaled and stored in files ready for display and analysis. Menu driven routines provide access to the stored data and logs for analysis purposes. The on-line and historical Diversa Cast data may be accessed by any authorized user whose PC is connected to the Linamar wide area network

System Software

The real-time core module contains all the functions necessary to provide data acquisition and analysis as follows.

- **Communications Module:** This module provides the data acquisition functions and interface with the control equipment via the RTU.
- **Display Module:** Provides the user interface with the system both in graphical and spreadsheet format using Windows 98/NT system software.
- **Analysis Module:** Provides graphical and spreadsheet analysis of the stored data including maximums, minimums, coincident demand data, energy use, and load factors.
- **Report Module:** Provides reports on power use and plant running costs, including bill verification by generating utility bill.
- **Database Filer:** Stores the data and configuration parameters in ODBC compliant database.
- **System and Cost Configuration Module:** This module allows the number of points to be entered and identified, and utility metering algorithms assigned together with energy and demand costs.
- **Automatic Demand Control Module:** This module is installed and used to automatically invoke control strategies based on demand monitoring.

The E2MS software consists of the major modules shown in Figure 2, which presents a schematic breakdown of the software system.

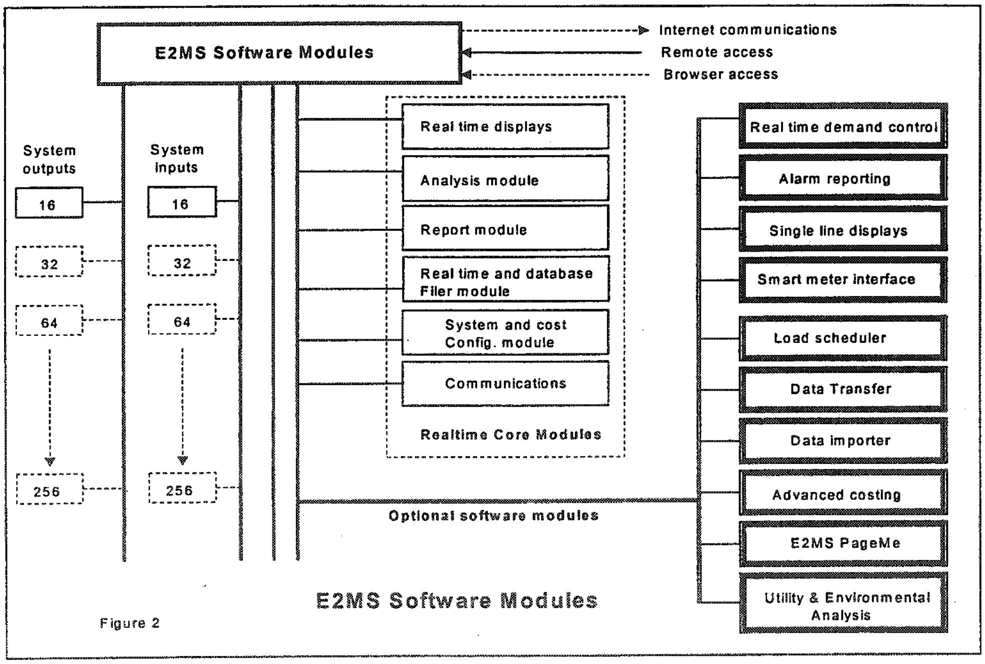

Figure 2. E2MS Software Modules

Figure 3 shows a portion of the load control screen. Users can set the maximum target for load control. Updated once per minute, the display shows how the load is being controlled using the billing window as a time base.

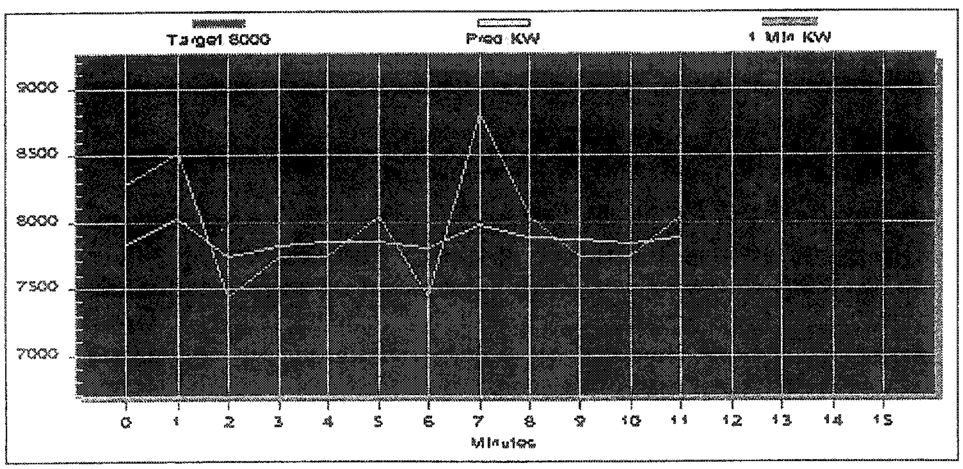

Figure 3. Load Control Screen Output

Plant Experience with the System

The installation proceeded around production with minimal interference or delays in the melting and pouring schedules. The software has been fully operational without any unscheduled downtime.

The system was started in a monitoring mode for the first two weeks of operation to allow Diversa Cast Technologies to establish a baseline of energy demand and consumption for the plant. The demand control was then turned on based on initial measurements for the plant melt requirements and base load.

Initial reaction from plant operators was hesitant, as it appeared to limit their ability to meet production melting requirements. This was due to the fact that operators were constantly adjusting power levels of the furnaces to meet a shared combined kW requirement between the two furnaces. Also, power was added to the system until the bath achieved the appropriate release temperature.

By modifying furnace operating procedures and appropriate operator training Diversa Cast Technologies was able to take advantage of the available power to melt quicker and more efficiently. Operators now utilize the E2MS system along with the furnace power management system to input a preset energy kWh count along with a total kW power input. This allows the E2MS system to monitor and control the overall power input based on the demand target while allowing the furnace power management system to input the appropriate amount of energy count to the melt bringing the heat to the necessary release temperature. The overall benefit of this procedural change is that operators can now input more power over shorter periods of time to achieve higher melt rates.

Many benefits have been realized beyond the initial project justification based on demand control alone. One of the indirect benefits of limiting demand energy is that the overall Load Factor or efficiency in the way energy is used has improved. Since commissioning for the on peak periods, average load factor has increased from an average of 70% utilization to and average of over 80%.

Another tangible benefit is that power factor penalties can be significantly reduced by controlling when and how the peak for the plant is set. For instance, if the plant power factor is low, the peak can be reset at the end of the month using the furnaces, which are more efficient, to balance the plant power factor. This power factor savings also occurs now because the furnace operators are able to apply higher power to the melt without worrying about accidentally resetting the peak for the month.

The software is accessible from anywhere on the WAN, which allows anyone with the appropriate authorization to access and view the plant energy, cost and control information. Cost accountants as well as production managers now have the ability to get an instantaneous calculation of the electrical demand and consumption billing for budgeting and planning purposes. This system is also a valuable tool to measure productivity and effectiveness of the plant and melting operations.

Conclusion

In summary, foundries are typically highly energy intensive facilities, with a substantial percentage of energy use attributable to melting metals. It is quite common for the melting equipment to be electrically powered through inductive or resistive technologies. These melters or furnaces are most often controlled locally and operate independent of each other. Several melting units are often employed in a given facility and are operated simultaneously to meet production demands. The connected load of these units can collectively represent megawatts of demand in a foundry and likely define the peak demand in the plant.

Implementing a state-of-the-art demand limiting control system for the entire facility can save significant energy and therefore lower overall operational costs. As presented in the case study, such a system employs both a monitoring data acquisition system and a control output module. The monitoring system acquires real-time data from the utility meter(s) for the entire facility and employs control strategies to key energy intensive equipment to meet the target demand and energy consumption goals of the plant. Such a system facilitates understanding of the facility load profiles, overall energy consumption, tariff comparisons based on actual usage, and an overall knowledge of how the facility consumes energy as a function of production. Having this data and the tools to understand them facilitates greater efficiency and reduced demand and energy consumption.