* * *

COST EFFECTIVE STRATEGIES FOR INDUSTRIAL ELECTRIC POWER MANAGEMENT SYSTEMS

Copyright Material IEEE
Paper No. PCIC - 98 - 24

Kenneth E. Nicholson, P.E.
Senior Member, IEEE
Syzegph Engineering, Inc.
P.O. Box 1790
Wilmington, DE 19899

Richard L. Doughty
Fellow, IEEE
Dupont Engineering
P.O. Box 80840
Wilmington, DE 19880

Luan Mane
General Electric
41 Woodford Ave.
Plainville, CT 06062

Gregory Miranda
Member, IEEE
General Electric
P. O Box 327
Allentown, PA 18106

Frank D. Pulaski
Cutler Hammer
240 Vista Park Drive
Pittsburgh, PA 15205

Abstract: The current use of power management systems for industrial electrical power distribution and utilization systems is examined and the benefits, functionality and costs are presented with examples. The functionality in commercially available systems is mapped against the recommended location of devices within the industrial electrical power system. System architecture considerations and equipment and installation costs are discussed; venture guidance analysis costs are given. An argument is made that all potential users must be involved in the system for it to have the maximum return on investment. A process flow chart to facilitate cost effective implementation of the power management system is also provided.

Index Terms – electrical power management system, power management system, power monitoring

I. INTRODUCTION

Electrical power system management technology is readily available to the chemical and petroleum industry at a reasonable cost, but the value of the benefits from these systems is not well understood. While some research and survey work has been done [1], [2], few comprehensive guides exist for their effective selection and implementation and much of the potential of these management systems has not been realized.

Much of the potential of industrial power management systems has not been realized due to the lack of site wide and corporate wide strategies and architectures for power management implementation. The typical “project by project” selection, design and implementation of power management systems in many companies has led not to a growing network of power management systems gathering more and more useful information within a site and a company, but to isolated pockets of power management systems, each attempting to stand on its limited merits and in danger of becoming obsolete as technology advances.

Few, if any, installed power management systems use all of the functionality available as advocated by this paper. Although some power management systems can be justified on individual application, it is the authors’ belief that the real potential of power management systems can only be realized by their full application on a site wide or corporate wide basis.

II. BENEFITS

Capital expenditures for power management systems must be justified by documenting savings or avoided business costs. These savings include direct costs in manpower savings, reduced inventory, reduced capital equipment costs, and reduced energy costs. Indirect cost “avoidance”, usually of significantly more value, includes avoided downtime, improved system analysis, and improved electrical system reliability. The resulting cost savings can be used to calculate the return on investment and thus justify the power management system expenditure.

This paper builds on previous work in this area [3], [4] and further details the benefits available to the industrial user. Table 1 shows a list of common benefits derived from a power management system.

A. Monitoring & Data Collection

The power management system provides the ability to gather system information accurately and reliably without tying up the time of valuable maintenance personnel. The system typically provides RMS values of basic electrical parameters, power, energy, power quality disturbances and distortions, as well as device status, alarms, and time stamped event information. The metered data is typically accurate to better than 1% of full scale, and is gathered automatically, eliminating transcription errors and providing information for plant analysis.

In a chemical plant or refinery, it may take 1 to 5 man-days per month to gather and store the basic routine data. This labor can be eliminated. In addition, the data gathered automatically by the power management system can be more comprehensive and easier to analyze than that which is gathered manually.

B. Protection, Coordination & Studies

In addition to the metering information, protective relays, trip units and other protection devices are usually part of the power management system. These microprocessor-based devices allow significantly more sophisticated protection algorithms, providing better protection while increasing

TABLE I
POWER MANAGEMENT SYSTEM BENEFITS

Function Category	Benefit Description
Monitoring	• Reduces data collection manpower • Reduces personnel exposure to hazards • Provides higher data sampling rate • Reduces data transmission time • Improves data accuracy • Provides more data at lower cost per unit
Protection	• Enables more sophisticated protection algorithms • Enables protection system integration • Provides data for electrical system studies • Provides remote setting capability
Analysis	• Enables routine power quality analysis • Provides routine sequence of events record • Provides data for root cause failure analysis • Identifies capacity & downtime bottlenecks • Enables more accurate cost allocation • Allows full capacity utilization of the electrical power distribution system • Identifies inefficient electrical equipment • Enables load aggregation • Enables more accurate demand prediction • Improves capital planning for electrical system
Operations	• Reduces operating manpower due to centralized control and monitoring • Enables display of data at multiple locations • Reduces trouble shooting time • Reduces switching errors • Provides tools to continuously monitor & reduce energy demand and consumption • Allows better optimization of work practices & procedures
Maintenance	• Enables maintenance scheduling based on actual device operating history • Eliminates unnecessary maintenance work & related production outages • Reduces spare parts requirements due to accurate equipment history • Reduces overall maintenance cost

system availability.

For example, motor protective relays can model motor thermal damage curves as well as take into account negative sequence currents and motor RTD values in their protection calculations. This allows the relay to adjust the trip time (in either direction) based on rotor health or motor temperature, maximizing motor and thus system uptime. Benefits are not limited to large motors, even starters for motors below 200 hp can economically incorporate ground fault or phase unbalance protection along with adjustable overload protection [5].

Switchgear relays typically incorporate integrated 3 phase protection algorithms, essentially infinite adjustment settings and time current curve shapes, and the capacity to interlock protection with other relays downstream or upstream. These features help to insure that the circuit is adequately protected from damage and that protective functions are coordinated.

In addition, these relays can have the ability to communicate their trip settings and min/max values across the power management network and receive new settings in return. Automatic gathering of these settings virtually eliminates the time required to gather nameplate data and trip settings for coordination studies and min/max values required for load flow studies. Given the time and cost involved in using portable recording meters to acquire this information, the ability to gather data can automatically save a refinery or chemical facility from $20,000 - $40,000 per power system study. Setting the protective devices from a central computer saves additional engineering field time.

C. Operations

The largest return on a power management system is often maintaining plant uptime. Downtime costs in the petrochemical industry in the range of $400,000 — $900,000 per hour are not unusual. The ability to alert plant operators or maintenance personnel to equipment operating out of normal range or a protective device timing out toward a trip can result in the problem being corrected without a downtime incident [6].

An example is a chemical facility with a high resistance grounded substation. Ground fault alarms on motor starters or circuit breakers alert users to ground faults. The fault location is identified immediately; maintenance is dispatched to identify and fix the problem before the condition results in a trip condition.

Similarly, an overload condition on a breaker may be sensed by the power management system. The system identifies the circuit, the magnitude of the overload, and non-critical loads on that circuit and their loading — all the information the operator needs to shed the minimum non-critical load. He then dispatches maintenance to determine what caused the overload, the problem is fixed and the system is put back on line with only the loss of predetermined, non-essential load. If the circuit does trip, the power management system identifies the circuit that interrupted, the reason for the trip, and the magnitude of the problem, providing enough information to reduce troubleshooting time and resulting downtime significantly.

There are also times when a plant needs to switch between feeders, turn on or off generators or loads, etc. for energy management, maintenance or loading balance reasons. A high percentage of the time, this occurs when the operator is under stress. The power management system is not affected by stress and assists the operator in making an optimum choice by providing system loading information, status, options or even predetermined instructions.

A primary concern of plant operations is managing operating costs. One significant cost component is often the demand charge of the energy bill. The demand charge typically represents 40-60% of the bill for sites without peak shaving generation.

A single “unmanaged” demand can cause a very large increase in the bill each month, and with “ratcheting” demand charges the effect remains for up to a year. The power management system can help manage that peak demand by measuring and presenting the current and predicted demand. Then, either manually or automatically, through the power management system, loads can be shed, peak shaving generators can be started, processes can be delayed, or the penalty can be paid, depending on the needs helps to pinpoint a mechanical problem that caused the electrical system disturbance.

Cost Allocation: Costs are allocated to a logical business segment (such as department, work shift, machine cell, etc.) or to a process or product. This may involve electrical energy, total energy, or total electrical service costs. Another term currently in use is ABC (Activity Based Costing).

C. Maintenance

Preventive/Predictive Maintenance: By analyzing historical data on the operation of the power system, maintenance personnel can better schedule maintenance based on what duty each piece of equipment has had. The future trend is toward on-line diagnostics of equipment to predict what and when equipment might fail so that maintenance can be performed before a failure causes an unscheduled outage.

D. Operation

Alarm Initiated Instructions: A power management system can be configured to display instructions for the operator when there is a problem with the power system. There might be instructions on how to reroute power to a critical area that has lost power, to reduce loading on a particular machine before the protective device trips it off line, or instructions as simple as who to call in a particular situation.

System Switching Control: Electrical circuit devices, such as circuit breakers, contactors, or motor operated switches can be operated remotely by a power management system.

Overload Capacity Advisement: This function advises an operator when a load device (motor, transformer, etc.) is operating above its rated load or temperature rating. It can also be configured to advise the amount of time before the protective device will trip the load at the current loading.

Load Shedding: The ability to shed non-critical loads or segregate loads to minimize process interruptions can be included in a power management system. Peak demand shaving can be used to reduce utility demand charges.

Electric Rate Based Scheduling: A power management system allows the user to schedule the plant production to take advantage of attractive utility rates that might be available, such as off peak, interruptible power or time-of-use rates. The load aggregation capabilities of a power management system will take on more importance with the deregulation of utilities.

E. Protection

Protective Device Function: Any alarm or “trip” by a protective device can be displayed. In addition to merely reporting that an “event” has taken place, the system can indicate the magnitude and sequence of key parameters associated with the event.

Protective Device Settings: Existing protective device settings can be verified remotely and new device settings can be implemented remotely by an operator. The ability to change protective device settings can be restricted by several layers of password protection.

The present case for the implementation of power management systems will look even better in the future.

VII. ACKNOWLEDGEMENTS

The authors would like to thank Basler Electric, Cutler Hammer Westinghouse, General Electric, Power Measurements Limited and Siemens Automation for their contribution of data and examples to this paper.

VIII. REFERENCES

[1] K. E. Nicholson and I. J. Becnel, Jr., “Industrial Power Monitoring and Control - Review of Commercial Technology and A Survey of Its Application In Use,” *Energy and Environmental Visions for the New Millenium*, 20th World Energy Engineering Conference, 1997.

[2] K. E. Nicholson, *Power Monitoring & Supervisory Control Systems: Survey of Systems in Production and Use*, Wilmington, DE: Integrated Technology Research, A Division of Syzegph Corporation, 1997.

[3] M. Seifert, “Can Power Monitoring Provide A Real Economic Advantage To An informed User?” in *IEEE PCIC Conference Record*, 1993, pp 233-239.

[4] A. P. Stublen, C. M. Wellman, S. A. Kell and T. W. Langston, “Justifying and Planning An Energy Monitoring System In An Existing Plant,” in *IEEE PCIC Conference Record*, 1995, pp 13-19.

[5] P. E. Alwin, “Solid State Motor Protective Devices Provide Sophisticated Motor Protection and Communications,” in *IEEE PCIC Conference Record, 1994*, pp 35-44.

[6] M. Dhalla, C. Fredericks and W. Wielebski, “Integration of the Electrical System With Process Control For Petrochemical Plants,” in *IEEE PCIC Conference Record, 1994*, pp 169-182.

[7] K. E. Nicholson, “Industrial Vs. Utility Power Monitoring and Control - Review of Commercial Technology, A Survey of its Application in Use and Potential in a Deregulated Marketplace,” *Proceedings - T&D World Expo 97*, 1997.

[8] IEEE Std 493-1980, Recommended Practice for the Design of Reliable Industrial and Commercial Power systems (ANSI).

APPENDIX

FUNCTIONALITY DEFINITIONS

The functions available in power management systems that are mapped in the Power Management System Matrix, Fig. 2, are further defined below.

Site Wide System: The site system includes the personal computer, PC based communication cards, basic communication software, application specific software (such as energy billing/cost allocation, PQ display, time current curve modeling, etc.) and any repeaters or data concentrators required for the site wide communications.

A. *Monitoring*

Harmonic Distortion (%THD): Total Harmonic Distortion (%THD) is the ratio of total harmonic content (voltage or current) to the fundamental (60 Hz) component, usually expressed in percent and is a measure of the amount of harmonics present in a power system.

System Operating Status Display: For a site wide display, this is typically a graphical display, such as an active one-line showing the operating status of the system. The one line might show the status (open, closed, tripped, out of service) of the switching devices as well as key operating parameters (amps, % load, kW, demand, etc.) associated with the distribution components. The buses and switching devices may change color to indicate where power is present in the system. For local displays, this may be as simple as a local monitor through which the individual devices on a lineup of equipment can be viewed.

B. *Analysis*

Sample Waveform Capture: This is a manually or routinely triggered snapshot of a parameter or parameters. High-resolution data, usually one full cycle of any voltage or current input sampled at a high rate, 64 samples or more per cycle, is typically used by the power management system for detailed power quality analysis of harmonics and transients. Lower resolution data, usually involving simultaneous samples of multiple inputs for several cycles at a lower samples per cycle rate, provides data for disturbance analysis, aids in locating faults and records current and voltage variations.

Setpoint-Triggered Waveform Capture: Similar to Sample Waveform Capture, this is triggered by a programmed set point of a parameter such as current or voltage exceeding a threshold value due to an abnormal condition in the system.

Distortion Analysis: A power management system can perform a Fast Fourier Transform on any waveform data to indicate total harmonic distortion as well as a breakdown of individual harmonic components both in graphical and tabular form. The ability to determine the direction of the distortion can be used to aid in locating the source of the distortion. Calculated values, such as Crest Factor and K-Factor are also typically available.

Disturbance Analysis: Disturbance analysis is power quality analysis of conditions occurring before, during and after a power fluctuation or failure, such as power line faults, swells, sags and transients. Data recordings can also be used to help analyze mechanical or process problems.

Electrical Availability: Electrical availability is the percent of the time that a circuit is energized or not energized, but could be if required. Not available is defined as tripped, under maintenance or any other condition preventing the circuit from being energized.

Event Logging: The event logging function of a power management system can document when portions of the electrical system are available (or unavailable). The power system operator can use this information to help determine any trends that might cause lower availability and therefore can improve the reliability of the system

Efficiency of Motors & Transformers: Efficiency is the ratio of outgoing power over incoming power, allowing the identification of losses. For motors the effect of motor rewinds or replacing standard efficiency motors with high efficiency motors can be verified.

Failure & Event Analysis: This is a method for reviewing the time stamped sequence of events data to accurately determine the root cause of a power system problem. By knowing the exact order of events, it is possible to determine what was the cause and what events were the result of the root cause event. This allows faster trouble shooting and a means to improve the system reliability by correcting the cause of the problem and not just reacting to the symptoms. Many times a failure and event analysis of the electrical data of the business.

This is illustrated by a manufacturing firm in Louisiana who had just received a large motor from the rewind shop. They decided to run a 30-minute full load test before putting the unit back into inventory. The motor tested out perfectly. At the end of the month, the purchasing department brought the utility bill to the attention of the operations manager. The bill was up by 7% ($20,000). The motor test run had set a new peak demand — extremely bad news since the utility contract had a “ratcheted” demand clause, setting a new, higher demand for the next 12 months — an easily avoidable $250,000 mistake.

D. System Analysis

In addition to the operational benefits of the power management system, analysis of the collected data can provide other significant benefits. One such area is capital expenditures. In evaluating capacity for plant expansion or process changes, the engineer must decide whether additional distribution equipment is required.

In major plant expansions, more electrical capacity than is actually needed is often installed. While this may be an economically justified installation of future capacity, more often it is due to overestimating both new and existing loads. Power management systems can give the engineer the information he needs to evaluate the available capacity, redistribute existing loads and more accurately extrapolate the new loads.

A major domestic refinery saved over $1 million in a recent expansion by not installing a new substation as originally planned, partially based on power management system information. Similarly, an automotive assembly plant failed to avoid a $2 million investment in a second purchased power substation at the site, primarily because accurate information about the existing and future loads was not available. After the expansion, no increase over the previous site demand was experienced.

Power quality analysis by the power management system can also lead to significant savings. The system can provide disturbance and distortion information, both events driven and logged over time. Typical disturbance information available includes voltage sags and swells or subcycle transients, available as summary values or in graphical waveform depiction. Typical harmonic information includes %THD or Fourier analysis with magnitude and phase angle.

An example of the benefit of power quality monitoring involved a plant incinerator for a domestic glass plant that had shut down on several occasions. The EPA was on the verge of requiring the plant to install standby generation to insure that the incinerator power would continue to be available. The local utility insisted that during the time period in question they had experienced slight voltage sags, but that these were within the contract limits. Using the event analysis capability of a power management system, the manufacturer proved to the EPA and the utility that there was a complete loss of voltage for several microseconds, causing a PLC to malfunction. The utility investigated and corrected their problem and the EPA withdrew both the fine and the requirement for standby generation, resulting in significant avoided costs.

Harmonics can also cause significant problems in petrochemical facilities. They may cause transformers, generators, motors, and cables to overheat, capacitors to fail, relays or circuit breakers to nuisance trip and PLCs, DCSs or personal computers to malfunction. Many petrochemical facilities have a significant number of adjustable frequency and DC drives and/or are on the same utility lines with other facilities that have drives or harmonic causing devices. As harmonics can travel down the utility line into the plant, even if the plant has its internal harmonic generation problem under control, neighbors with problems can affect the site.

Power management systems can analyze the magnitude and direction of the harmonics, alarming or performing a plant wide synchronized capture of waveform when the magnitude reaches levels that will affect plant operations. By analyzing the origin of the harmonics (internal to the plant vs. external, etc.), the “fingerprint’ of the waveform and any changes in plant operation, the site can quickly isolate the cause of the problem and address it.

Maintaining uptime is critical. A power management system can help by providing time stamped event recording, complete with metering data and status information, time and date stamped. This information provides sequence of event recording enabling root cause failure analysis. An event may not be preventable; analyzing the cause and implementing corrective action minimizes the chances it will occur again. Sequence of event recording has provided significant improvement in plant wide load shedding schemes during utility outages as well as isolating instances of the root cause of multiple breaker trips, isolating the cause quickly, so that corrective action can be implemented.

One of the significant benefits of power management systems is in energy cost management. First is verification of the energy bill. Some facilities also have more than one utility meter. Utilities may issue a separate bill for each meter, which usually is a significant disadvantage to the site. Combining multiple meters generally reduces co-incident demand and leads to cost savings of 8-10%.

Second, using the power management system to record and allocate energy costs to individual plants, processes or users almost always results in savings. The automated meter reading and bill generation reduces manpower costs. By allocating costs, the local production team takes ownership of the costs, much like other costs under their control. This “ownership” has resulted in plants saving up to 14% of total energy costs. This is accomplished by analyzing energy usage to insure that loads are shut off when not needed, by performing energy intensive tasks sequentially instead of concurrently, by performing non-critical processes during off peak demand hours, etc.

Third, the power management system is an important part of a plant’s energy conservation program. It provides load profiles for major loads and helps users prioritize the order of projects to maximize return on investment. It can also verify that the project is delivering the savings promised, essential to the process of justifying the next project or verifying an energy service vendor’s promises and contract obligations.

Fourth, by developing a plant wide energy profile, different utility rate schedules can be evaluated and the best rate schedule for the facility can be determined. For example, interruptible load plans can be considered for less critical processes. The power management system provides the current consumption of the sheddable loads, the generator statistics, etc. necessary to make an informed decision as to how to respond when an interruption request is made. Cost savings can be considerable, such as a $900,000 annual saving seen at an automotive plant in Detroit. This saving resulted from the combination of entering into a voluntary load shedding agreement which lowered the demand charge and reducing energy consumption through conservation and more effective operating procedures.

Finally, the power management system can provide either a site wide or corporate wide energy profile. An energy profile is a time based (hourly, daily, weekly, monthly, yearly) energy usage profile necessary to aggregate loads and negotiate the best contract with a power broker under deregulation of the utility industry [7]. Cost savings estimates have ranged from a low of 10% to a high of 30% of overall energy costs.

E. Maintenance

Another critical aspect to reducing downtime and controlling costs in a facility is managing maintenance activities. Providing maintenance for power system equipment when needed as opposed to when it is scheduled helps strike the proper balance between maintaining uptime and controlling cost. This is the concept of “predictive maintenance”. Power management systems monitor equipment runtime, temperature/pressure, operations counts, basic electrical parameters, and trip history (number of trips, magnitude of current, etc.). The combination of those parameters provides the information basis for condition based predictive maintenance. Cost savings include reduced overtime, reduced inventory, reduced repair cost (bid vs. emergency), and increased avoidance of downtime.

The reliability of the power distribution system can be increased through the use of power management systems. Automatic switching, reduced frequency and duration of scheduled maintenance, reduced time to locate and troubleshoot equipment failures and maintenance information databases can all lead to higher system reliability. Standardized reliability evaluation methods are available for calculating system reliability [8].

III. SELECTING POWER MANAGEMENT SYSTEM FUNCTIONALITY

A. Power Distribution Organization

The functions required of a power management system vary with the type of equipment or circuit to be monitored, its voltage level and its location within the power system. Since different functions are required of the power management system at different locations in the power system, the single line diagram is divided into sections. The single line diagram shown in Fig. 1 depicts a generic industrial electric power distribution and utilization system.

This division into sections allows us to determine which power management system functions have value at which points in the power system and to locate them in the specific section of the single line diagram. It also assists in estimating costs of the system during the front end loading portion of a project by providing a methodology to estimate quantity and cost of equipment components.

B. Function Mapping

The Power System Management Function Matrix (Fig. 2) shows the functions commercially available in power management systems mapped in a matrix against the locations of circuits and equipment in the power system. Locations where the functions have been shown to be valuable are indicated by the “X”s. Definitions for the complex functions used in the matrix are defined in the Appendix. This matrix is central to the development of an effective power management system because it facilitates the determination of what functionality to provide at what point.

Several functions are considered to be basic to power management systems and are not listed separately. These functions are: determination of minimum and maximum values, alarm and event logging, trending, system device or communications failure, deviations of values from normal parameters and auxiliary I/O for control and additional data acquisition from field devices.

One of the more recent additions to power management system functionality offerings supports power system engineering studies, particularly load flow, loading and protective device coordination. The most recent technology also supports the remote setting of protective device set points.

In the application of power management systems to a specific site, the designer of the system should evaluate the value for that site and business of power management at each of the points indicated. Each system needs to be analyzed and the unique needs of the business and site addressed by the design of the power management system.

IV. ESTIMATING THE COST OF POWER MANAGEMENT SYSTEMS

The cost of installing electrical power management systems in industrial facilities depends on many factors. Obviously the approach to a green field facility will be different from addressing a long established plant. The presence or absence of communications networks adequate to handle the power management system’s requirements and the architecture of existing networks also plays a role.

A. New and Retrofit

Installation of a power management system in an existing plant is generally more complex than installation in a new facility, but the potential savings generally justify the extra effort. In order to cost effectively retrofit an existing plant with a power management system, it is necessary first to define a vision of what the final system will include. An important part of that vision is the communication infrastructure. If the existing communication infrastructure is adequate to provide for future needs, then the most economical solution is generally to expand the existing communication system as required to implement the power management system. In some cases, the communications infrastructure may need to be upgraded to provide increased data handling capacity and response time.

Another important aspect of retrofit installations deals with existing plant data displays. The vision for the power management system needs to define if the location of existing data displays will be adequate to provide the full benefits of the power management system, or if new data display locations are desirable. Even if the locations of

single line diagram of the system. In the example in the previous section on equipment cost the number of functional blocks would be 30. The number is determined as sitewide (1); service entrance (1); transformer feeders (4); medium voltage substation mains (1) and motors (2); and low voltage substation mains (3) and feeders (18).

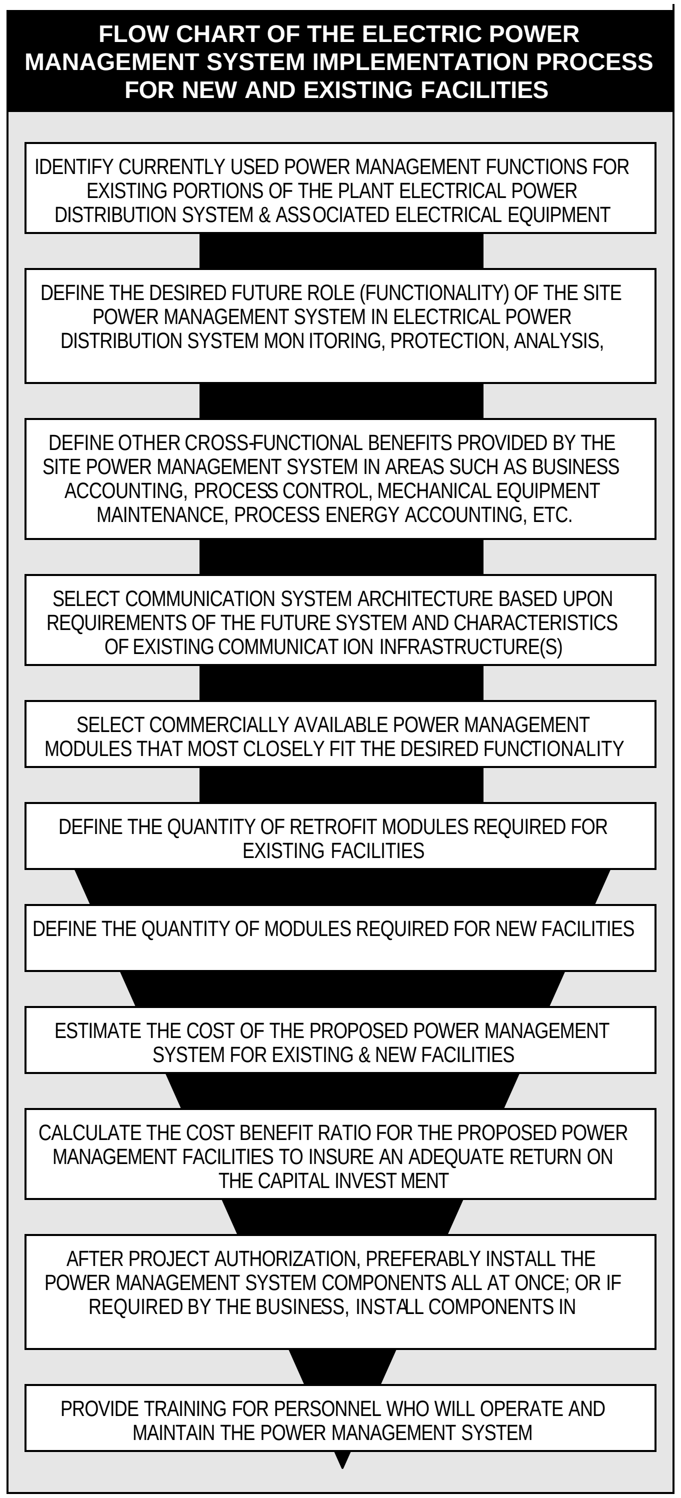


Fig. 5

Care should be taken in interpreting this data as both site specific situations (existing equipment, existing communications infrastructure, project accounting methodology, etc.) and the level of sophistication of the power management system will impact the costs reported. These actual costs will define an envelope of costs that can provide guidance at the inception of a project.

The total installed cost of power management systems varies with several factors. One of the major factors is a green field installation versus the retrofit of an existing power system.

In a retrofit, the addition of current and potential transformers, the duplication of already present (usually analog) devices, field wiring of equipment, modification of existing equipment to accept new devices, and especially downtime to accommodate the retrofit all contribute to additional cost.

Other factors are the voltage level(s) of the system monitored, the presence of multiple sources including primary and stand by generation, large single loads such as large horsepower motors, etc.

V. IMPLEMENTATION PROCESS FLOW CHART

Whether a power management system is being installed in a new or existing facility, it is important to approach the implementation of the system in a logical manner. This will promote ownership of the system by all stakeholders (production, operations, accounting, project engineering, management, etc.), help avoid unnecessary disruptions to an existing plant, insure that the installed system meets business needs, and minimize total installed cost. The flow chart shown in Fig. 5 summarizes the essential steps that need to be followed to optimize the implementation process for a power management system. The process is designed for installation of a power management system in either existing or new facilities. Note that it includes the essential steps of first defining the long range vision for the system as well as calculating the cost benefit ratio for management before the project is submitted for authorization.

VI. CONCLUSION

Maximum system benefits can be obtained from your power management system by employing the full spectrum of available functions and involving all of the potential users, traditional and non-traditional, in the development and implementation of the system. The successful system designer will take a systems approach, involve technical and business representatives from all functions, advocate site wide ownership of the system and integrate corporate direction into the energy management system vision.

Commercially available power management systems have matured and all of the functionality required for a viable and economically justified industrial system is readily available. The return on investment (ROI) should be well above the hurdle for most businesses and the available benefits will continue to grow with the twin dynamics of the continued progression of technology and the introduction of the deregulated marketplace for electrical energy.

Power quality, cost and “up time” — the “new” issues for electrical power systems — all require a robust power management system in order to be effectively addressed.

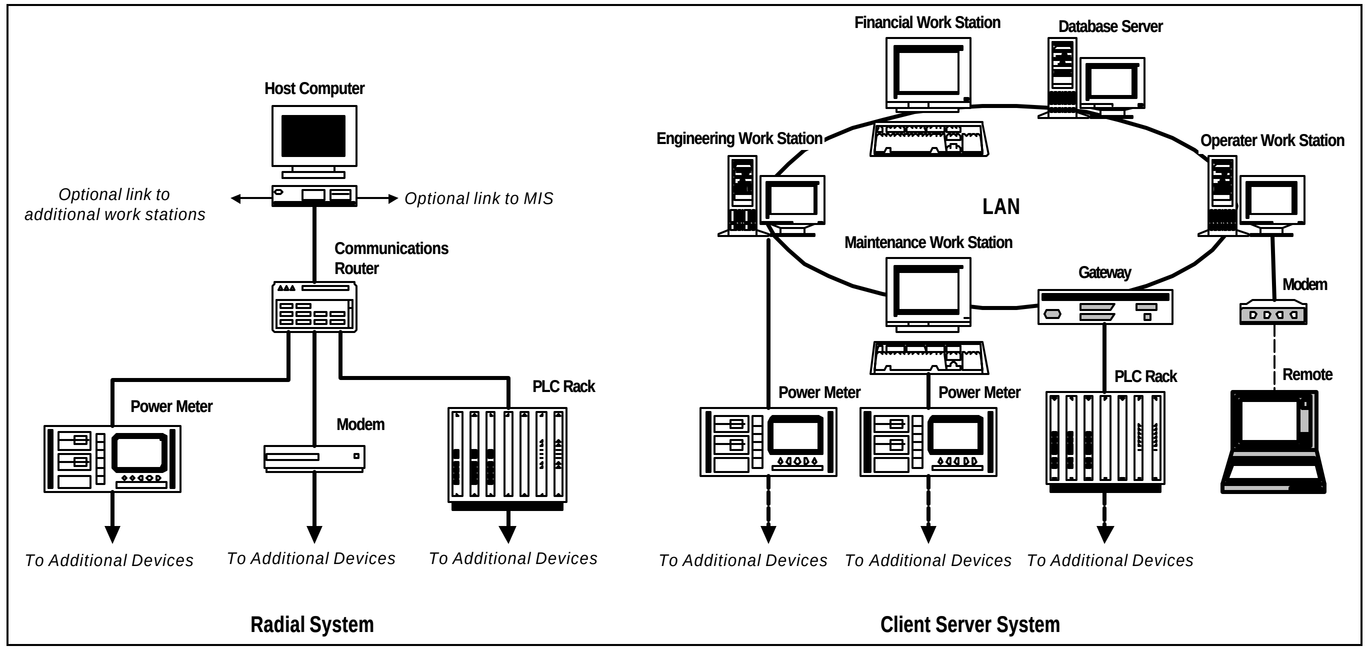


Fig. 3.

The total equipment cost for each segment is then calculated:

1) Site wide system monitor for small plant - $ 17,757
2) Service entrance - $ 4,224
3) Site wide distribution - 4 transformer feeders - 4 x $ 2,910 = $ 11,640
4) Medium voltage substation - main $ 2,490 plus motors 2 x $ 3,030 = $ 8,550
5) LV unit substations - 3 times (incoming $ 2,728 plus feeders 6 x $ 928) = $ 24,888
6) Process utilization MCC - no cost

The total estimated equipment cost for this small petrochemical facility is the total of the cost for each segment or $67,059.

C. Impact of Architecture on System Cost

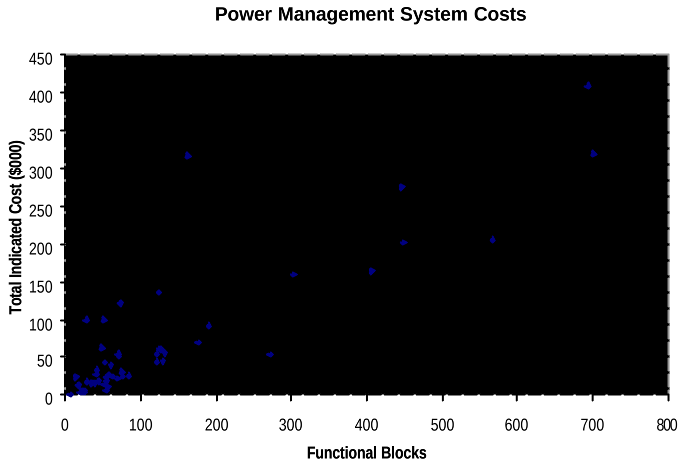
All power management systems use a variation of one of the two basis architectures. The first of these architectures depicted in Fig. 3 is a radial system. Field devices are connected to a central host computer, often by twisted pair cable, but also by fiber optics, telephone modem (both dial-up and dedicated line), radio modem and even microwave or satellite link. The host computer may then be connected to other work stations that can display information from it and/or initiate supervisory control through it. Information may be relayed to many systems including DCS, PLC, and information services including web servers.

The second type of architecture is based on a client/server computer architecture. In this architecture one or more servers are connected in an area network with one or more clients. Any server can communicate with field devices and instruments and both processing and control are distributed throughout the system. Anyone authorized to obtain information or control the system can sign onto the network.

The choice of architectures depends on many factors including the existing communications wiring in the plant and computer network, the desired interface with site control and information systems and other site technology choices. A distributed client/server system has the advantages of simultaneous processing, use of existing networks (and often work stations) and multiple possibilities for redundancy of the upper level network. Radial/host systems, on the other hand, are more available, generally less expensive to install and maintain, and may also be more robust because of their dedicated nature.

D. Total Installed Cost

The Total Installed Cost graph (Fig. 4) shows the total project cost of actual installations graphed against the number of functional blocks as determined from the electrical



Range of Total Installed Cost
Fig. 4

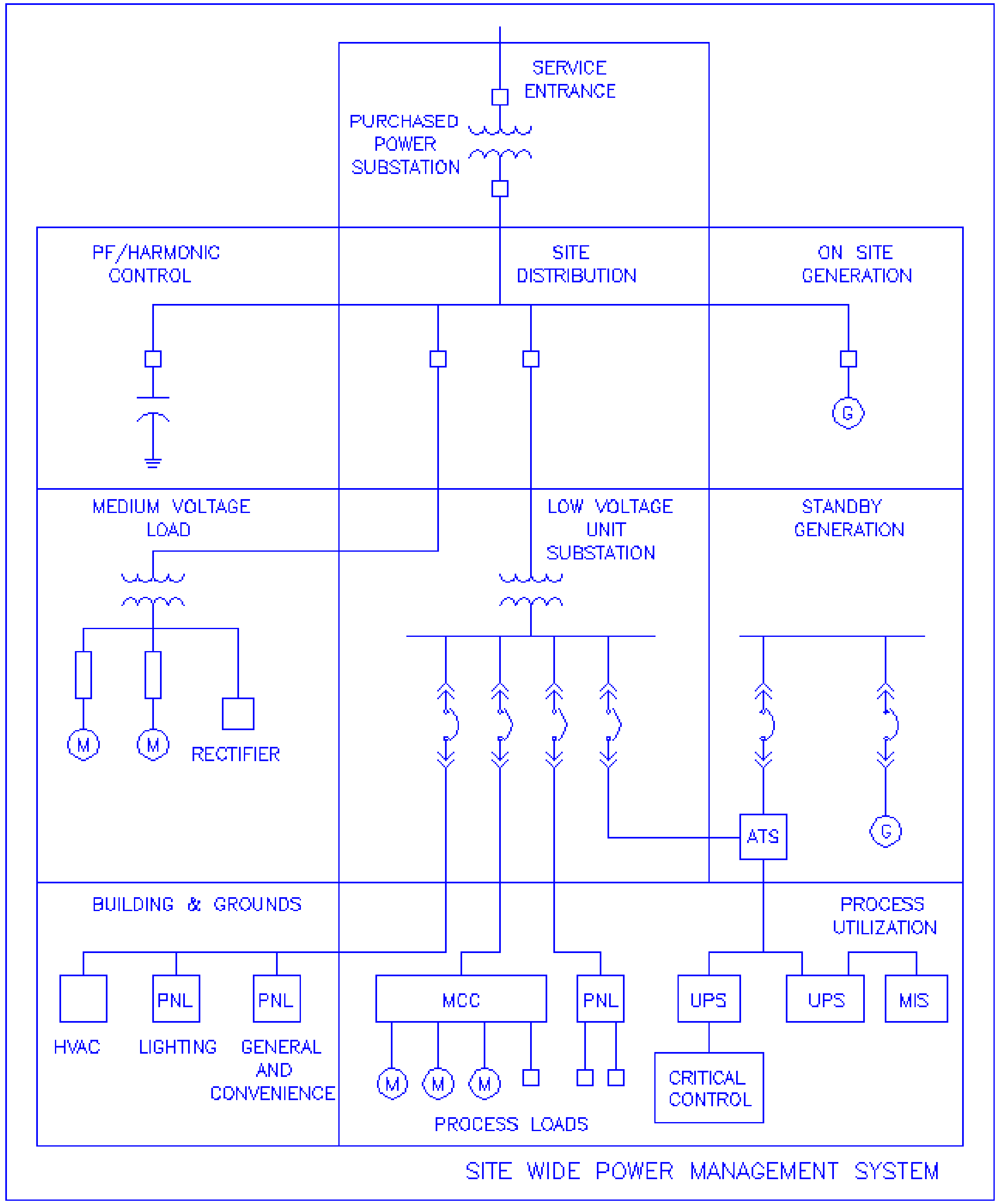


Fig. 1
GENERIC INDUSTRIAL ELECTRICAL POWER SYSTEM
SINGLE LINE DIAGRAM

POWER MANAGEMENT SYSTEM MATRIX										
Functions	**Site Wide System**	**Service Entrance**	**Site Distribution**	**On-site Generation**	**Harmonics / PF Control**	**MV Loads**	**Unit Substation**	**Standby Generator**	**Process Utilization**	**Building & Grounds**
Monitoring										
Voltage (V)		X		X		X	X	X	X	
Current (I)		X	X	X	X	X	X	X	X	X
Frequency (Hz)		X		X				X		
Power (kW,kVA & kVAR)		X	X	X	(kVAR)			X	(kW)	(kW)
Consumption (kWH)		X	X	X		X	X	X	X	X
Demand (kW_D, kVA_D & $kVAR_D$)		X	X			X	X			
Power Factor (PF)		X	X	X		X	X	X		
Harmonic Distortion (%THD)		X	X	X	X	X	X	X	X	
System Operating Status Display	X	X	X	X	X	X	X	X	X	
Analysis										
Utility Pulse Totalizing & Comparison		X								
Sample Waveform Capture		X							X	
Set Point Triggered Waveform Capture		X	X	X		X	X			
Distortion Analysis	X	X		X						
Disturbance Analysis	X	X	X	X		X	X			
Demand Prediction	X		X	X						
Available System Capacity		X	X	X	X	X	X	X	X	
Electrical Availability	X	X	X	X	X	X	X	X	X	
Efficiency of Motors & Transformers		X				X	X		X	
Sequence of Events (time stamped)		X	X	X		X	X	X	X	
Failure & Event Analysis	X									
Cost Allocation	X									
Maintenance										
Device Operation Counting		X	X	X	X	X	X	X	X	
Equipment Run Time		X		X	X	X	X	X	X	
Equipment Run Time over Threshold		X		X		X	X	X	X	
Equipment Loading		X	X		X	X	X	X	X	X
Equipment Life Expectancy		X	X	X	X	X	X	X	X	
Preventive/Predictive Maintenance	X	X		X	X	X	X	X	X	
Operation										
Alarm Initiated Instructions		X	X	X		X	X	X	X	
Transformer Fan & LTC Control		X				X	X			
System Switching Control		X	X	X	X	X	X	X		
Overload Capability Advisement		X	X	X	X	X	X	X	X	
Generation Management				X				X		
Load Shedding	X			X				X		
Electric Rate Based Scheduling	X									
Protection										
Protective Device Function		X	X	X	X	X	X	X	X	X
Protective Device Settings	X									

Fig. 2

existing data displays are optimum, it may be desirable to replace existing displays with the latest technology.

Older style metering and protection devices in existing plants are connected to current and potential transformers. Since the burden of modern metering and protection devices is generally less than for older devices, existing current transformers can generally be reused with new power management devices. In some cases where new metering or protection functions are being added, it may be necessary to install new current and potential transformers to provide the required inputs. If new metering or protection devices with improved accuracy levels are used, it is important to determine if the PTs and CTs are adequately matched. Shutdown of existing electrical facilities may be required and may impact production.

When planning for replacement of existing devices, consider the downtime of process facilities required for device change out and wiring reconnection. Since newer devices may require a modification of panel space, allowance should be made for the patching of panels. If existing panels have inadequate space for required new devices, expansion of existing panels or installation of totally new panels may be required.

Existing low voltage switchgear breakers may be equipped with old style electromechanical or series trips. These devices cannot communicate with a modern power management system. It is recommended that as part of the power management system project, all existing low voltage switchgear breakers be rebuilt using solid state trip devices with communication capability. This retrofit extends the life of the switchgear, provides better site protection and coordination, and provides the benefits of communications. Combining the life extension with the power management retrofit provides additional justification for funding and promotes broader site ownership.

B. Equipment Costs

The approximate equipment cost for a power management system in a new petrochemical plant facility can be quickly estimated using Table II and the electrical single line diagram for the new plant facility. Table II shows the average equipment cost for implementing typical functions in ten segments of the electrical power distribution system based on information from five major suppliers. The table contains a breakdown of each segment type by specific function. Segments are defined based upon the single line diagram model shown in Fig. 1.

The process of estimating the equipment cost is summarized below:

1) Divide the plant electrical single line diagram into segments based upon Fig. 1.
2) Determine the number of each specific function required for each segment.
3) Multiply the number of each specific function required by the average cost per function from Table II.

Note that Table II does not include the cost of current or potential transformers and related wiring, communication cable, or related installation costs. Also note that the costs shown represent the premium for power management system components over those components that would be normally supplied in a power distribution system.

TABLE II
POWER MANAGEMENT SYSTEM EQUIPMENT

Power Distribution System Segment	**Notes**	**List Price Per Unit**	
		Average	**Range**
Site Wide Monitor			
• Small (<50 Points)		$17,757	$7,500 - 30,000
• Medium (>50,<500 Points)		$24,457	$12,285 - 40,000
• Large (>500 Points)		$33,357	$14,285 - 55,000 and above
(Equipment below not			
Service Entrance	1	$4,224	$1,500 - 8,520
Site Distribution System			
• Feeder	1	$3,714	$1,500 - 8,520
	1	$2,910	$1,500 - 3,800
On-Site Generation	1	$4,937	$3,200 - 8,733
Harmonic & PF Control	1	$3,305	$1,375 - 5,000
Medium Voltage Loads			
• Incoming/Main with Transformer	1	$4,300	$2,000 - 8,950
• Incoming/Main	1	$2,490	$1,500 - 3,800
	2	$2,260	$800 - 3,800
• Feeder	2	$3,030	$2,500 - 3,800
LV Unit Substations			
• Incoming/Main	1	$2,728	$800 - 5,440
	2,4	$928	$700 - 1,490
Standby Generator		$2,585	$300 - 5000
Process Utilization			
• Incoming	2	$2,245	$800 - 3,725
	3,4	$750	$500 - 850
Building & Grounds	3,4	$840	$400 - 1,300

Notes to Table II:
1. Assume PTs and CTs already provided, no additional required.
2. Assume CTs/current sensors already provided, no additional required. Also assume no additional space required.
3. Includes necessary CTs and voltage connections.
4. Common display used for multiple devices.
5. All device prices include local device termination and programming labor.
6. Cost for communication cable $0.35/ft. Includes all necessary repeaters, data concentrators, power supplies, etc.
7. Installation labor and conduit/raceways are not included.

An example of the use of Table II will be shown for a small petrochemical facility. Assume that the electrical distribution system of the plant contains the following segments:

1) Site wide system.
2) Service entrance.
3) Site distribution system with four transformer feeders.
4) One medium voltage substation with incoming main and two motors.
5) Three low voltage unit substations, each with incoming and 6 feeders.
6) Each low voltage unit substation feeds six process utilization motor control centers with no power monitoring.