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Load Management System Using Intelligent Monitoring and Control System for Commercial and Industrial Sectors

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1. Introduction

There are vast opportunities to improve energy use efficiency by eliminating waste through process optimization. Applying today's computing and control equipment and techniques is one of the most cost-effective and significant opportunities for larger energy users to reduce their energy costs and improve profits. An Energy Management Information System (EMIS) is an important element of a comprehensive energy management program. It provides relevant information to key individuals and departments that enable them to improve energy performance. Today it is normal for companies, particularly in process sectors, to collect huge amounts of real-time data from automated control systems, including Programmable Logic Controllers (PLCs), Supervisory Control and Data Acquisition (SCADA), etc. The captured data is shared and analysed in an orderly and precise way that identifies problem areas and provides solutions, this mass of data is merely information overload. Advances in information technology (IT), defined here as the use of computers to collect, analyse, control and distribute data, have developed rapidly. It is now common for managers and operators to have access to powerful computers and software. Today there are a number of techniques to analyse the factors that affect efficiency, and models are automatically generated based on "what if" scenarios in order to improve decisions to be taken.

The paper shows a very advanced technology for handling automatically more than 200 digital and analogue (i/p and o/p) parameters via intelligent monitoring and controlling system.

However, load management is the process of scheduling the loads to reduce the electric energy consumption and or the maximum demand. It is basically optimizing the

processes/loads to improve the system load factor. Load-management procedures involve changes to equipment and/or consumption patterns on the customer side. There are many methods of load management which can be followed by an industry or a utility, such as load shedding and restoring, load shifting, installing energy-efficient processes and equipment, energy storage devices, co-generation, non-conventional sources of energy, and reactive power control [1]-[3]. Meeting the peak demand is one of the major problems now facing the electric utilities. With the existing generating capacity being unmanageable, authorities are forced to implement load shedding in various sectors during most of the seasons. Load shifting will be a better option for most industries. Load shifting basically means scheduling the load in such a way that loads are diverted from peak period to off-peak periods, thereby shaving the peak and filling the valley of the load curve, so improving the load factor[4]-[6].

To encourage load shifting in industries, and thereby to reduce peak demand automatically, a new technology such as introduced here will be extended.

Also, power quality is of major concern to all types of industries, especially those operating with critical machinery and equipments. Poor quality of power leads to major problems like break-downs, production interruptions, excess energy consumption etc. Modern industries require automation of their operation enabling them to produce quality products and also for mass production. The conventional systems are being replaced by modern Power Electronic systems, bringing a variety of advantages to the users. Classic examples are DC & AC Drives, UPS, soft starters, etc. Power Quality Alarming and Analysis provides a comprehensive view into a facility's electrical distribution system. Power Quality can be monitored at the electrical mains or at any critical feeder branch in the distribution system such as described here. Devices in this category typically provide all of the parameters found in basic devices, plus advanced analysis capabilities [7]-[8]. These advanced analysis capabilities include using waveform capture to collect and view waveform shape and magnitude, providing harmonic analysis graphs, collection and storage of events and data, and recording single or multiple cycle waveforms based on triggers such as overvoltage or transients. With the ever-increasing use of sophisticated controls and equipment in industrial, commercial, and governmental facilities, the continuity, reliability, and quality of electrical service has become extremely crucial to many power users. Electrical systems are subject to a wide variety of power quality problems which can interrupt production processes, affect sensitive equipment, and cause downtime, scrap, and capacity losses. Momentary voltage fluctuations can disastrously impact production [7]-[8].

The proposed modified intelligent monitoring and controlling system will introduce monitoring, alarming, controlling, and power quality mitigation based on data collected and analyzed from the system. The original system can afford the following features:

- Complete information about the plant (circuit breakers status, source of feeding, and level of the consumed power).
- Information about the operating values of the voltage, operating values of the transformers, operating values of the medium voltage, load feeders, operating values of

the generators. These values will assist in getting any action to return the plant to its normal operation by minimum costs.

- Protective information such as the insulation of cables, temperatures of the generators. These parameters are used as a back up for the main protection.
- Information about the quality of the system (harmonics, current, voltages, power factors, flickers, etc.). These values will be very essential in case of future correction.
- Recorded information such case voltage spikes, reducing the voltage on the medium or current interruption.

2. Original system description

The hardware configuration of the original intelligent monitoring and controlling system is divided into two levels. The first level includes two workstations -1 and -2 with two different software programs are used for data handling and monitoring purpose. The second level includes the PLC for data collected that constituted from 10 digital meters and some smart sensors to cover many points in the system. Some digital meters are fed directly to the workstation-2 using different software for data handling. All other parameters such as breaker status, temperature, controllers, and cable insulators are fed through the PLC. Fig. 1 shows the overall structure of original intelligent monitoring and controlling system achieved at the Eastern Company in Egypt. The intelligent monitoring and controlling system uses the most recent technology of Profibus in data transferring. Workstation-1 used the Wincc flexible software program for data handling received from the MV, Transformers and Generators. Workstation-2 used the Sicaro Q manger software program for data handling from the loads. Both workstations are linked through Ethernet network. One programmable logic controller S7-300 associated with 10 power meters for monitoring the MV, Transformers and Generators, Insulation relays, Temperature transducers for generators, and Circuit Breakers auxiliary points for all loads have been applied to workstation 1 through Profibus network-1. Workstation-2 associated with 12 power quality meters for monitoring all loads (Compressors, Pumps, Motors, Processes, etc.) via Profibus network-2. All system parameters are communicated using the Profibus technology. The output system is limited by given alarming and recommendation to the operator without doing any automatic actions for the system. The system components used in the system are produced from Siemens and can be described as:

PROFIBUS is the powerful, open and rugged bus system for process and field communication in cell networks with few stations and for data communication. Automation devices such as PLCs, PCs, HMI devices, sensors or actuators can communicate via this bus system. PROFIBUS is part of totally integrated automation, the uniform, integrated product and system range from Siemens for efficient automation of the entire production process for all sectors of industry. PROFIBUS can be used, for example, for the following applications: Factory automation, Process automation and Building automation. Different PROFIBUS versions are available for the various fields of application:

- Process or field communication (PROFIBUS DP) (for fast, cyclic data exchange with field devices). PROFIBUS PA (for intrinsic safety applications in process automation)

- Data communication (PROFIBUS FMS) (for data communication between programmable controllers and field devices).

Power Quality devices are installed at various measuring points in order to record a series of measurements of the required values for an analysis of the network quality. The device can be installed on the load. In addition to all relevant measured variables, the meter can also record system disturbances, always when an upward or downward limit value violation has occurred. The recorded values can be called up and evaluated using a PC. Power Quality is available in 3 device versions with the following communication interfaces: RS232, RS485, and PROFIBUS-DP. Furthermore the device version Power Quality with PROFIBUS-DP interface opens up another area of application. Together with programmable control systems (PLCs), it can be used as a “sensor” for electrical measured variables. In the system achieved, the PROFIBUS-DP technology is used.

The Power Quality PAR parameterization software is executable under the Windows 2000/XP operating systems. The software allows you to define the device address, so that each device is uniquely identified and to configure the power quality for the communication protocol to be used (PROFIBUS DP) in order to prepare it for the measurement task. Fig. 2 shows the display of the currently transmitted measured values.

Power Meter is a power meter for panel mounting, with big graphic display and background illumination. The major application area is power monitoring and recording at MV and LV level. The major information types are measured values, alarms and status information. Power monitoring systems with Power Meter, a permanently installed system, enables continuous logging of energy-related data and provides information on operational characteristics of electrical systems. Power Meter helps identify sources of energy consumption and time of peak consumption. This knowledge allows you to allocate and reduce energy costs. Measured values include r.m.s values of voltages (phase-to-phase and/or phase-to-ground), currents, active, reactive and apparent power and energy, frequency, power factor, phase angle per phase, symmetry factor, harmonics of currents and voltages, total harmonic distortion. Ten meters are installed on the system and arranged on the incoming feeders, transformers and also on the generators. PROFIBUS-DP and Power Meter are connected in a master-slave operation mode. The communication parameters are loaded to the master station using the GSD file. The Power Meter supports data transmission rates from 9.6 kbit/s to 12 Mbit/s. The Measured values can be: Voltage, Current, Active power, Reactive power, Apparent power, Power factor, Active power factor, Phase angle, Frequency, Active energy demand, Active energy supply, Active energy total, Active energy total, Reactive energy, inductive, Reactive energy, capacitive, Reactive energy total, Apparent energy, Unbalance voltage, Unbalance current, THD voltage, THD current, Harmonic voltage, and Harmonic current.

SIMATIC S7-300 PLC: S7-300 programmable controller is made up of the following components:

- Power supply (PS)
- CPU
- Signal modules (SM)

- Function modules (FM)
- Communication processor (CP).

Several S7-300s can communicate together and with other SIMATIC S7 PLCs via PROFIBUS bus cables. Fig. 3 shows the components of the PLC. The Runtime application of the WinCC basic software offers all essential functions of a powerful SCADA-System. Using WinCC User Administrator, One can assign and control users access rights for configuration and runtime.

3. Original system operation

The application functions of the data collection and monitoring are all performed via two workstations, PLC and two different software programmes. The program can include data exchange communication protocol between the communication system and PLC, through digital power meters, breakers' status (On/Off), power quality monitoring, threshold for alarming. Figs. 4 and 5 show part of the system operation for monitoring feeder-2 and transformer-2 parameters for the system installed at Eastern Company in Egypt. Fig. 6 shows one of the event messages produced from the system. Fig. 7 shows the block diagram that demonstrates the various function components of IMCS. All of these components are programmed as functions of the system. Some of the system functionality can be described as;

3.1. Sensors, power meters and breakers status

Sensors and power meters communicate measurements and status information from the plant to the monitoring modules of the IMCS.

3.2. Monitoring

IMCS offers a wide range of options for monitoring the plant. Information can be monitored locally and centrally. Access to the IMCS is protected and the users must login to gain access to functionality. Information received from the plant can be monitored in different forms from data or trends mode. The monitoring includes; Alarms, Trends, Recommendations Status, Configuration utilities, Event messages, etc.

3.3. Control

The control of the system is limited while the system is based on monitoring purposes and given recommendation messages for the operator.

3.4. Data logging

The IMCS has the feature of data logging for some selected parameters such as (switching procedure during week; temperature, breaker status, transients, etc.) for further analysis.

3.5. Alarms, recommendation and event reporting

The main feature of the IMCS is producing the alarms, recommendation and event reporting functionality. The alarms, recommendation and event reporting are based on customers basis.

3.6. Predictive maintenance

Predictive maintenance is an essential part of the IMCS. The system gives all information about the power quality of the plant and cable insulation. This can be achieved through reports and alarms message produced from the system.

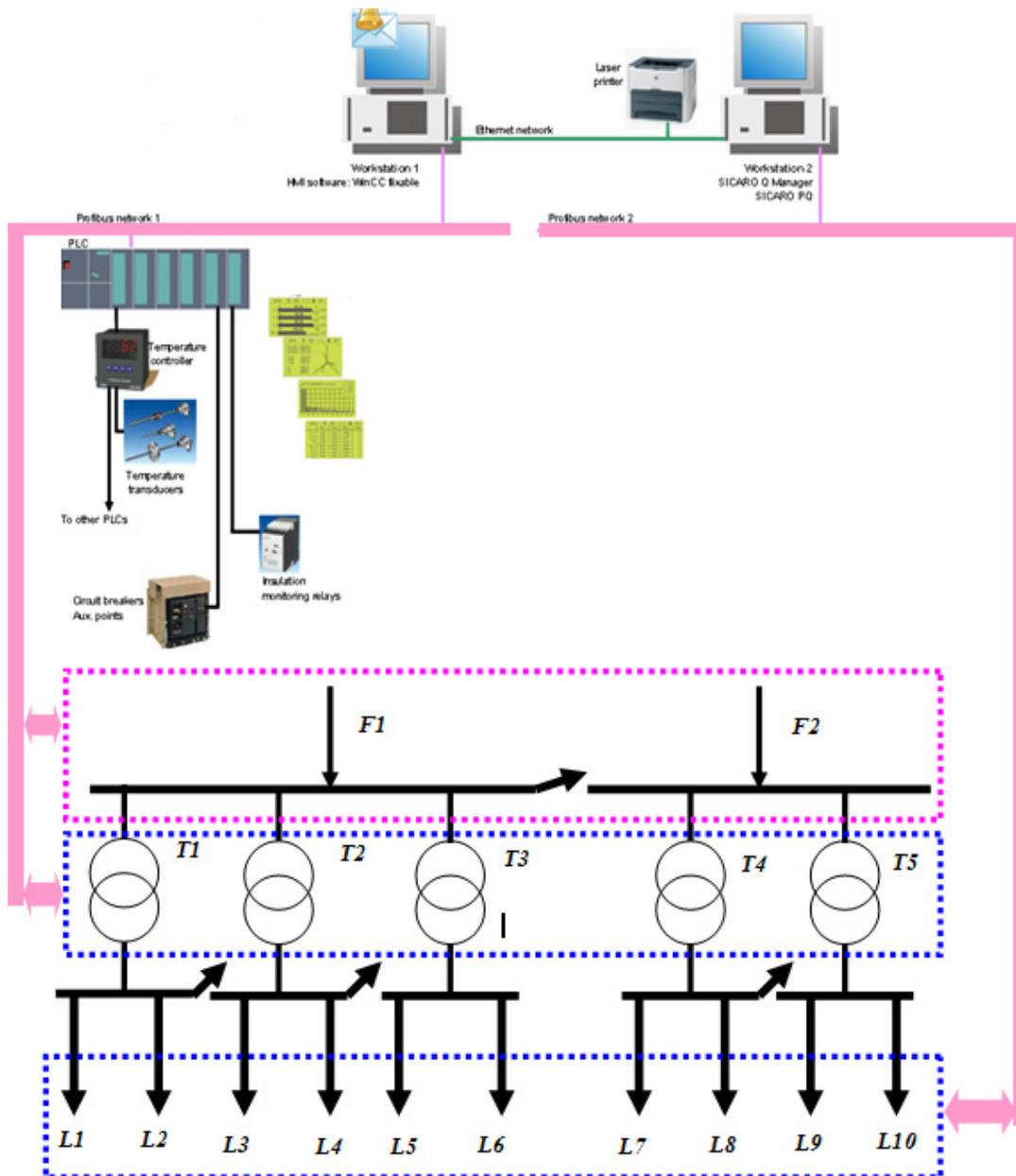


Figure 1. The overall structure of the original intelligent monitoring and controlling system.

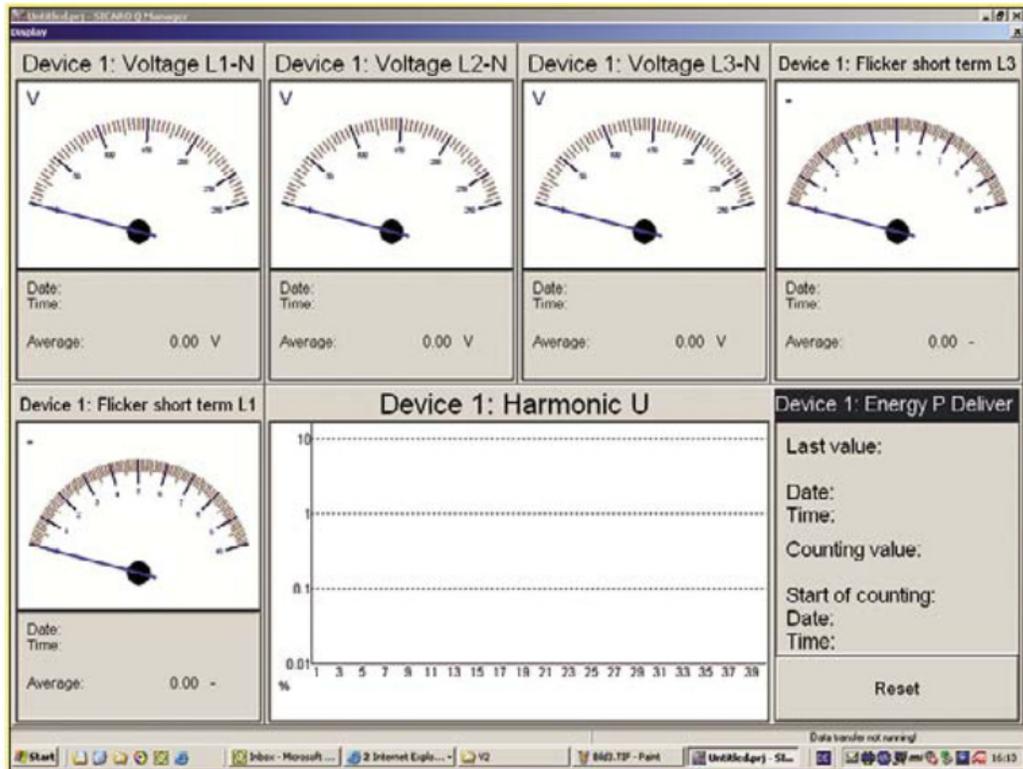
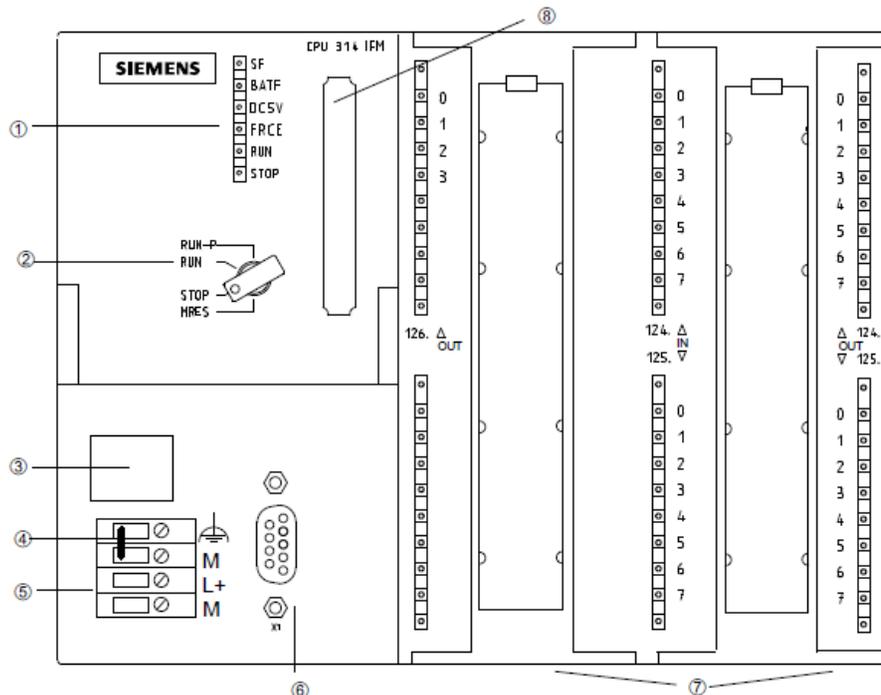


Figure 2. The display of the currently transmitted measured values of Quality Meter used in the system.



- ① Status and fault LEDs
- ② Mode selector
- ③ Compartment for backup battery or accumulator
- ④ Jumper (removable)
- ⑤ Terminals for power supply and functional ground
- ⑥ Multipoint Interface (MPI)
- ⑦ Integrated inputs/outputs
- ⑧ Slot for memory card (-5AE10- only)

Figure 3. The main components of the PLC.

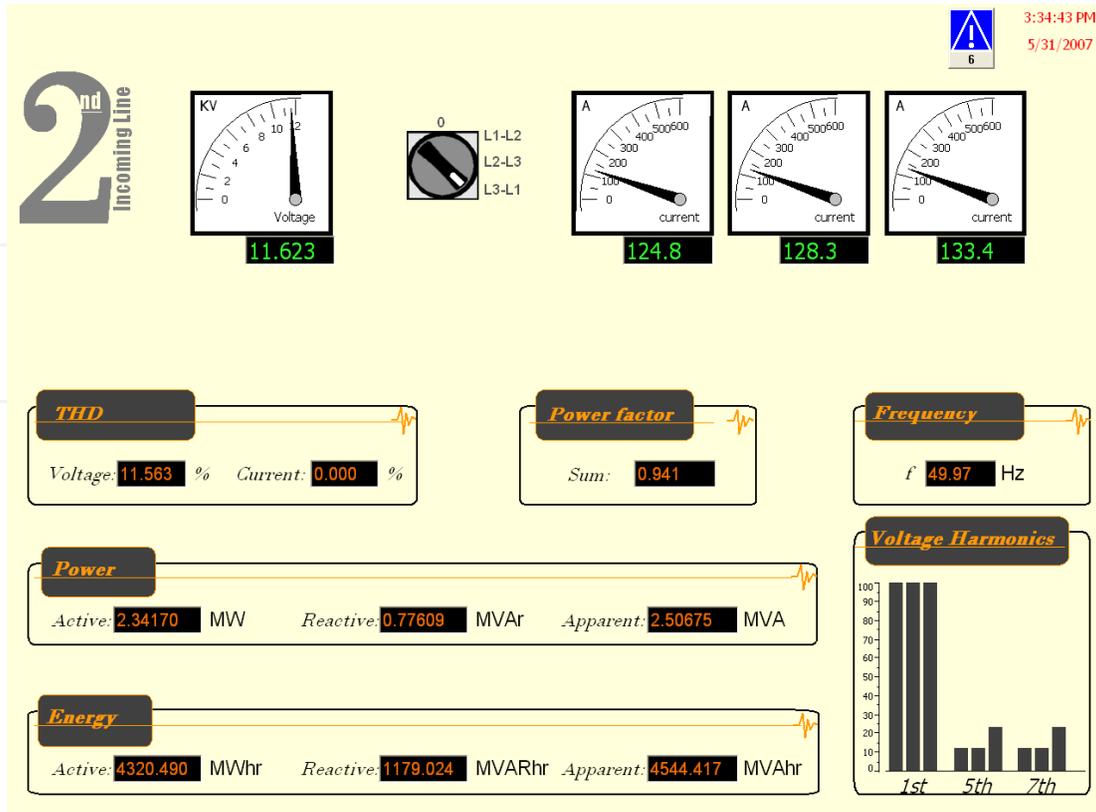


Figure 4. Part of the monitored data on fedder-2 at Eastern Company.

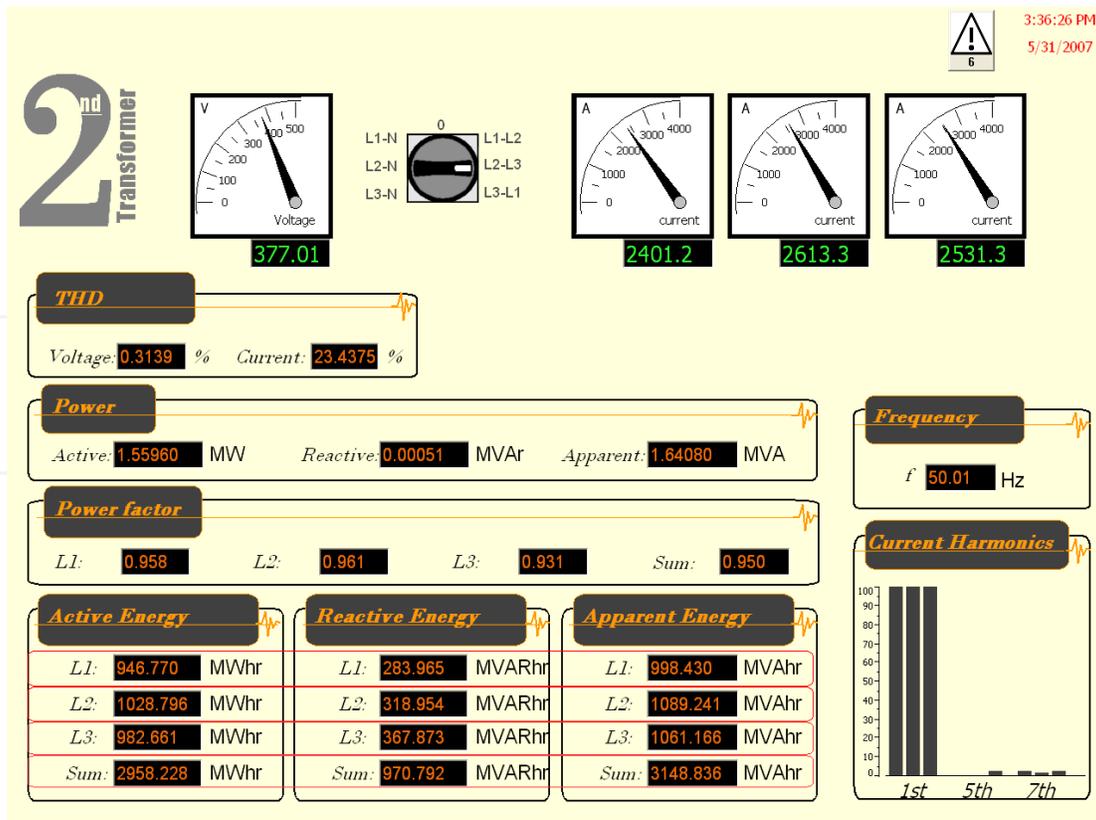


Figure 5. Part of the monitored data on Transfwer-2 at Eastern Company.

Event messages

| No. | Time | Date | Status | Text |
|--------|-------------|-----------|--------|--------------------|
| E..102 | 2:41:58 PM | 5/31/2007 | C | C7 Closed |
| E..103 | 9:06:46 AM | 5/31/2007 | C | C8 Closed |
| E..104 | 5:00:15 PM | 5/30/2007 | C | C9 Closed |
| E..75 | 5:00:15 PM | 5/30/2007 | C | Generator 2 OUT |
| E..169 | 4:59:44 PM | 5/30/2007 | C | K10 OPEN |
| E..105 | 4:59:36 PM | 5/30/2007 | C | C10 Closed |
| E..96 | 4:59:24 PM | 5/30/2007 | C | C1 Closed |
| E..160 | 4:59:16 PM | 5/30/2007 | C | K1 OPEN |
| E..73 | 4:52:52 PM | 5/30/2007 | C | Generator 1 OUT |
| E..97 | 4:47:53 PM | 5/30/2007 | C | C2 Closed |
| E..161 | 4:47:46 PM | 5/30/2007 | C | K2 OPEN |
| E..178 | 11:40:08 AM | 5/30/2007 | C | K4 med OPEN |
| E..95 | 11:40:08 AM | 5/30/2007 | C | K8 med Closed |
| E..94 | 11:40:08 AM | 5/30/2007 | C | K7 med Closed |
| E..93 | 11:40:08 AM | 5/30/2007 | C | K6 med Closed |
| E..91 | 11:40:08 AM | 5/30/2007 | C | K3 med Closed |
| E..90 | 11:40:08 AM | 5/30/2007 | C | K2 med Closed |
| E..89 | 11:40:08 AM | 5/30/2007 | C | K1 med Closed |
| E..88 | 11:40:08 AM | 5/30/2007 | C | Incoming Line 2 In |
| E..86 | 11:40:08 AM | 5/30/2007 | C | Incoming Line 1 In |
| E..111 | 11:40:08 AM | 5/30/2007 | C | C17 Closed |
| E..110 | 11:40:08 AM | 5/30/2007 | C | C16 Closed |
| E..108 | 11:40:08 AM | 5/30/2007 | C | C14 Closed |
| E..107 | 11:40:08 AM | 5/30/2007 | C | C12 Closed |
| E..106 | 11:40:08 AM | 5/30/2007 | C | C11 Closed |
| E..100 | 11:40:08 AM | 5/30/2007 | C | C5 Closed |
| E..99 | 11:40:08 AM | 5/30/2007 | C | C4 Closed |
| E..98 | 11:40:08 AM | 5/30/2007 | C | C3 Closed |
| E..174 | 11:40:08 AM | 5/30/2007 | C | K18 OPEN |
| E..173 | 11:40:08 AM | 5/30/2007 | C | K17 OPEN |
| E..172 | 11:40:08 AM | 5/30/2007 | C | S2 OPEN |
| E..171 | 11:40:08 AM | 5/30/2007 | C | K12 OPEN |
| E..170 | 11:40:08 AM | 5/30/2007 | C | K11 OPEN |
| E..168 | 11:40:08 AM | 5/30/2007 | C | K9 OPEN |
| E..167 | 11:40:08 AM | 5/30/2007 | C | K8 OPEN |
| E..166 | 11:40:08 AM | 5/30/2007 | C | K7 OPEN |
| E..165 | 11:40:08 AM | 5/30/2007 | C | S1 OPEN |
| E..164 | 11:40:08 AM | 5/30/2007 | C | K5 OPEN |

Figure 6. One of the output event messages produced from the system at Eastern Company.

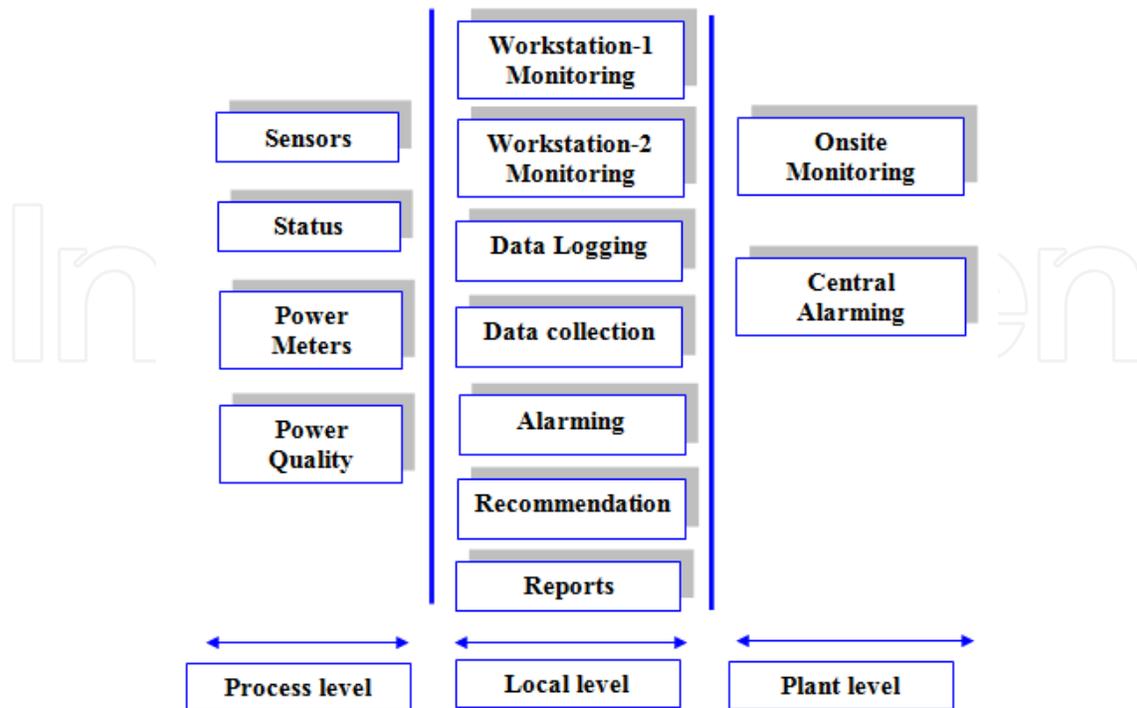


Figure 7. Block diagram of the IMCS components installed at Eastern Company.

4. System Modified for load management and quality mitigation schemes

The original system is used mainly for monitoring purposes with some recommendation messages produced from it. The paper introduces an extension for the system for producing many digital and analogue output signals from the PLC to control loads based on load management programs and power quality mitigation procedure. The proposed modified system can accept load management schemes load shedding during peak period, cycling on/off load control, and direct load control. The modified IMCS associated with load management and power quality schemes gives the customer the possibility of load reduction or control during the peak periods of the day, moreover, gives more information about the power quality of the system.

The modified IMCS with Load management can include:

- Load shedding during peak
- Cycling on/off load control,
- Direct load control.

The modified IMCS with power quality monitoring can include:

- Monitoring overvoltage or transients
- Monitoring harmonic graphs for feeders and loads
- Monitoring power failure
- Monitoring High frequency noise
- Monitoring Spikes
- Monitoring ground faults and deterioration insulation in cables

The IMCS can also monitor all the breakers status and temperatures of the stand-by generators. The following subsections explain some function components embedded in the modified IMCS

4.1. New generation of power quality meter

The new generation of the power monitoring device provides accurate knowledge of the systems characteristics with maximum, minimum and average values for voltage, current, power values, frequency, power factor, symmetry and THD. The SENTRON PAC4200 detects the values for active, reactive and apparent energy – both for high and low tariff. It measures ratings and power values via the four quadrants, i.e. power import and export are measured separately. The SENTRON PAC4200 also facilitates the detection of a measuring period's average values for active and reactive power. These values can be further processed into load curves in a power management system. Typically, 15-minute intervals are used for this purpose. PAC4200 also detects uneven harmonics from the 3rd to the 31st for voltage and current, the distortion current strength (I_d), the phase angle and the asymmetry for voltage and current with reference to the amplitude and phase. For further processing of the measured data, the devices can be very easily integrated in superior automation and power management systems in the proposed system the meters are interfaced with SIMATIC PCS 7

powerrate and SIMATIC WinCC powerrate software packages. The Wincc powerrate software packages can handle very complicated schemes for load management.

4.2. Control

The purpose of the control module in the modified IMCS is to provide the control of the necessary parameters for each point in the plant. It provides the functionality required to control the load in case of peak period or in case of exceeding the threshold boundary. It offers control functionality, e.g. load shedding, on/off load control, direct load control, power quality control. It also provides the functionality required to control devices such as pumps, motors, compressors, on/off breakers, interlocking, power quality mitigation. Operation can be configured to be automatic. The modified system offers the facility for adjusting control parameters (e.g., set points, output quantity, tolerances, time delay) in order to achieve the desired condition for each program. Fig. 8 shows the new added function blocks for the modified intelligent monitoring and controlling system. The figure shows three main components; workstation-2 with control scheme, Control output module, new generation of the power quality meters compatible with Wincc powerrate software program. As given in Fig. 9, the proposed modified system uses one additional PLC interfaced with the new power quality meters located on the loads. The data is shared through Profibus network-2. Workstation-2 uses Wincc powerrate software program for programming and controlling purposes. Workstation-2 manipulates different load management programs through collected data received from the PLC. Many controlled output signals are produce from the PLC o/p modules. The proposed modified system avoids many of original system limitations by replacing the power quality meters interfaced directly with workstation-2. The proposed modified IMCS can manipulate the following programs;

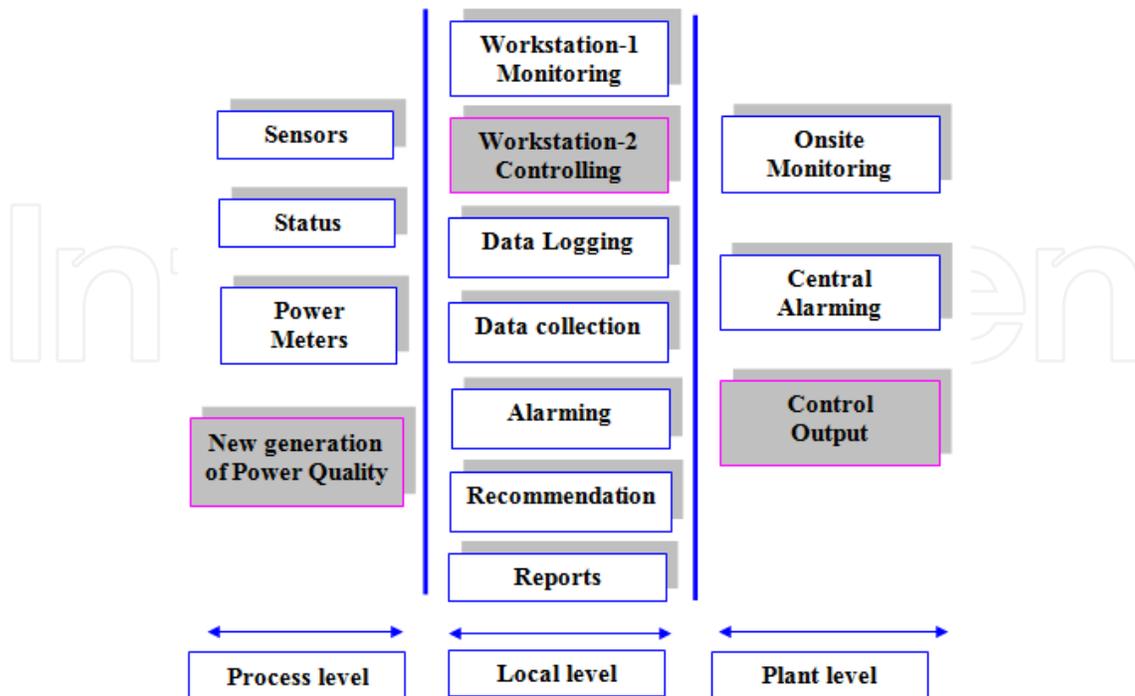


Figure 8. Block diagram of the modified IMCS function components.

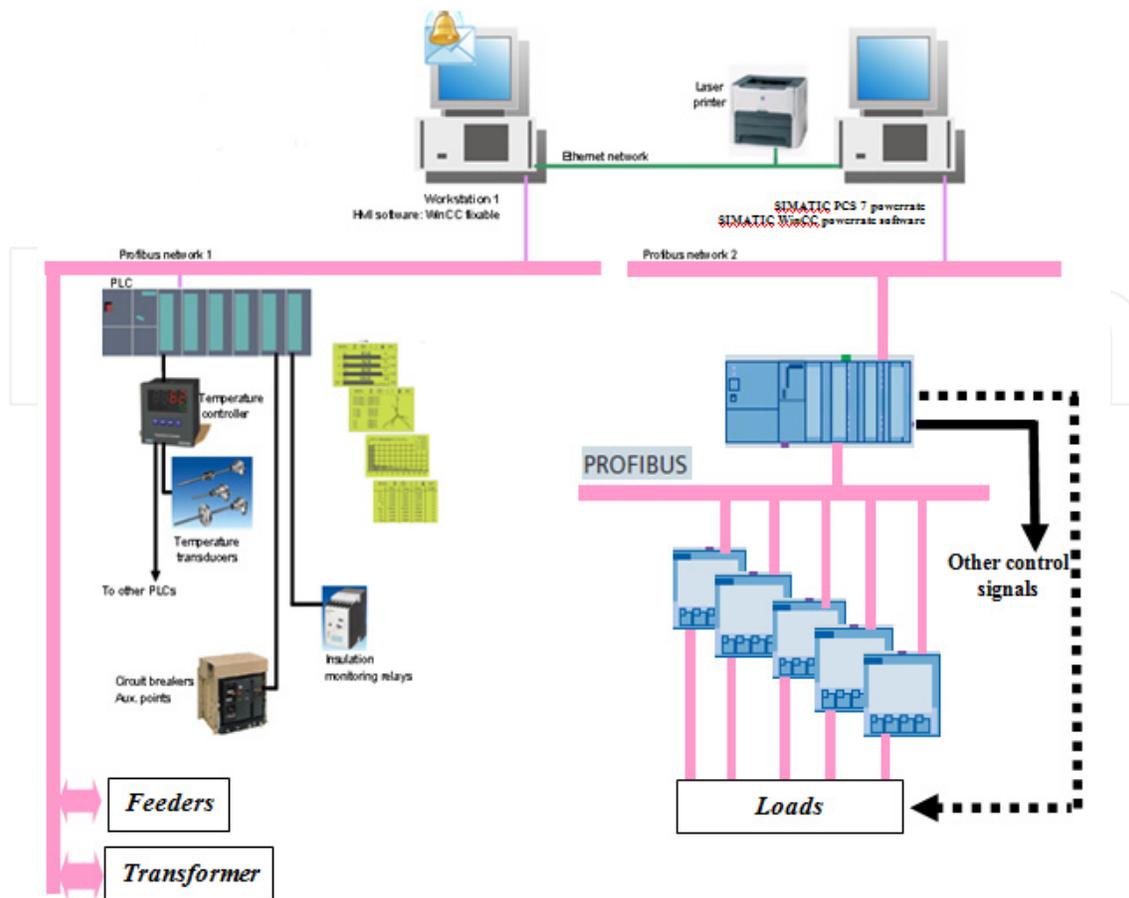


Figure 9. The overall structure of the proposed modified intelligent monitoring and controlling system.

4.2.1. Load management

A company's electric bill, in most countries, consists of two major components: demand charge and energy consumption charge. Demand charges are reset monthly and are based on the highest rate at which electricity is consumed during periods that are peak utility service hours. Demand charges are measured in kilowatts and, depending on the utility service provider, the highest consumption rate is measured in 15- or 30-minute intervals during peak hours or contracted value. Demand charges form a significant portion of a company's monthly electric bill. Peak load management strategies that lower a facility's demand during times when the peak demand is measured can result in significant facility cost savings, especially for commercial, industrial and governmental sectors. Fig. 10 shows the procedure of the load management that can be achieved automatically in the proposed modified IMCS. The scheme of load management can be built and programmed according to previous scenario using energy auditing. In such a case the customer can avoid any penalty from the utility and can save money as well. The procedure of the control can be run through workstation-2 and the readings of the loads received from PLC with power quality meters. The program can be run under Wincc powerrate software program. Firstly, the system will check the required load capacity to be shaved during peak value and then select the minimum diesel power generated that covers the required loads. The system will

produce output signal through the PLC output module to the suitable generator/generators. In case of the load reduction the system disconnects the generator/-s sequentially according to the required load and get back the loads to the normal operation on their feeders.

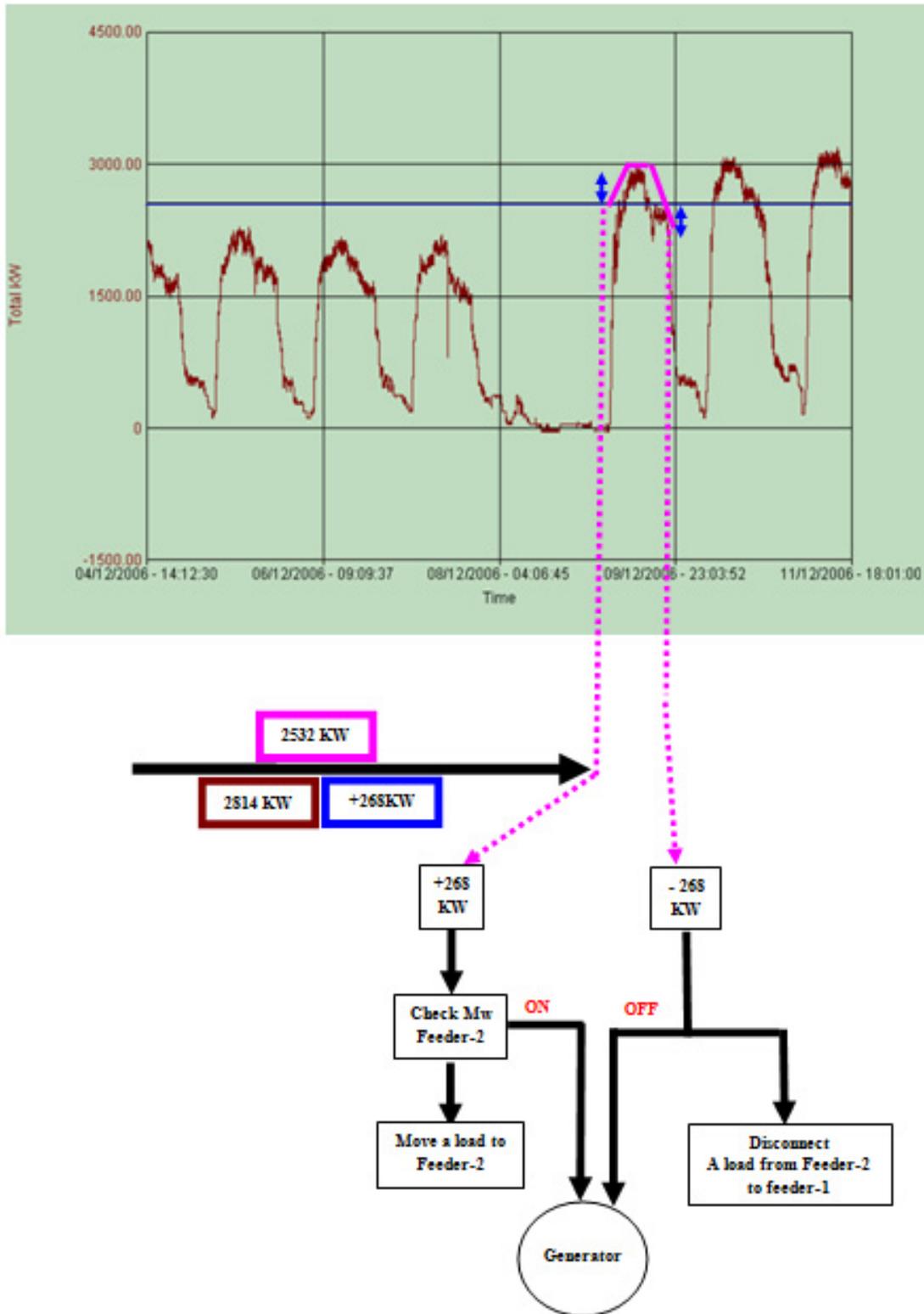


Figure 10. The load management control for avoiding the peak period.

4.2.2. Load reduction and energy saving using VFD for HVAC

Flow generating equipment like fans, pumps and compressors are often used without speed control. In stead, flow is traditionally controlled by throttling or using a valve or damper. When flow is controlled without regulating the motor speed, it runs continuously full speed. Because HVAC systems rarely required maximum flow, a system operating without speed control wastes significant energy over most of its operating time. Using VFD to control the motor speed can save up to 70% of the energy (Central line of Honeywell). HVAC system consumes a large percentage of the total energy utilized by the organization. The original IMCS can not do that. The extended system can include VFD interfaced with the PLC and can run according to the given parameters and atmospheric boundary conditions in the side control module. The devices such as chillers, motors (pumps and fans) and AHU are controlled using VFD through the proposed modified IMCS.

4.2.3. Power quality mitigation through IMCS

The demands to the power reliability and the power quality become stricter due to the popular application of variable-frequency and variable-speed drives, robots, automated production lines, accurate digital-control machines, programmable logic controllers, information manage systems in computers and so on. These devices and computer systems are very sensitive to the power-supply ripple and various disturbances. Any power quality problems may result in the reduction of product quality or confusion of management order which means great economic loss. Power Quality can be measured with power quality meters and analyzed with software in the control module. Power Quality events usually are infrequent, making them hard to detect and store without specialized equipment. Over a certain period, there may only be a few Power Quality events. The system is able to collect and analyze events on the basis for identifying the Power Quality problem. Analyzed data is the starting point for improvement. Data identifies potential sources of problems based on the timing of the events. This information can show the cause of the problem. Once the source is identified, improvement begins based on corrective actions. Corrective actions may include: changing motor starting procedures, replacing faulty switches or relays, filtering harmonic producing loads, or changing switching schedules for power factor correcting capacitors, changing control of the power filter. Once the corrections are in place, further monitoring will verify that the corrective action worked. The applied system such as IMCS can line with this specifications for power quality mitigation.

5. Conclusion

The application of good plant quality and demand control concepts requires an understanding of utility rates, auditing, and metering in addition to a basic knowledge of the process and load being controlled or shed. This process is professionally achieved in Eastern Company with 10MW capacity and 11kV/380V plant before installing the original intelligent monitoring and controlling system. The paper introduced an overview explanation for the original IMCS achieved at the Eastern Company. The paper also

proposed modified intelligent monitoring and controlling system that has the feature of high speed data manipulation through the technology of Profibus and new generation of digital meters. The proposed modified system has the function of demand monitoring/load shedding scheme that operated in automatic mode. Also, Power Quality can be measured with power quality meters and analyzed with software in the control module. Data identifies potential sources of problems based on the timing of the events.

The feature of the energy consumption and power quality mitigation are significantly enhancing the power system operation. The proposed system has the features of

- Accurate load management during peak periods designed based on the plant requirements,
- Real time monitoring of the plant performance,
- Intelligent alarming capabilities for early power quality problems
- Predictive maintenance planning for cables and standby generators
- Energy management
- Power system efficiency
- Save money by avoiding any penalty from the utility
- Keep the voltage tolerance with the allowed limits
- Continuous monitoring for the power quality
- Load control and management with proper methodology
- Keep the consumption with the contracted limit
- Recoding information that can assist for any future development for the electrical network
- Catching any transient vents happened in the system
- Mitigation the plant through continuous monitoring of the power quality
- Fault diagnosis and alarming
- Identify and fix the causes of power disturbances to avoid recurrences
- Improved system efficiency

The authors are going to implement the modified components of the IMCS.

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