Czech Technical University in Prague
Faculty of Electrical Engineering
Department of Control Engineering

DIPLOMA THESIS

Tracking and prediction of energy consumption in a technological process

Prague, 2009

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Prohlášení

Prohlašuji, že jsem svou diplomovou práci vypracoval samostatně a použil jsem pouze podklady (literaturu, projekty, SW atd.) uvedené v přiloženém seznamu.

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podpis

Acknowledgements

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Abstract

This thesis deals with Energy Management systems that are used in industrial process and one system is also realized. The thesis introduction briefly explains the basics of Energy Management. In this place the basic requirements are described on the Energy Management System that is useful in technological process.

Then was made the market survey. Thesis is focused on the Energy Management systems that deal with reporting and prediction of energy data. There are many views on this issue and for purpose of the thesis two main categories were selected. The first one is only database level implementation in Energy Management. This solution type supposes that the data collection will be realized on the customer's side. On the other hand there are solutions that are in both process and database level. These solutions provide services from data acquiring to database processing.

The last part describes the Energy Management solution. This solution is based on the PCS7 Siemens platform and exploits special PCS7 library to retrieving the energy data. The solution consists of two systems. The first one is reporting system that was developed by SIDAT Ltd. Based on this reporting system the prediction system was developed for purposes of this thesis. The user interface of prediction system was selected MS Excel because of it is often used platform for data processing.

Anotace

Tato diplomová práce se zabývá systémy energetického managementu, které jsou používány ve výrobním procesu. Jeden takovýto systém je také realizován pro účely této práce. V úvodu práce jsou stručně vysvětleny základy energetického managementu a také zde nechybí základní pořadavky na takovýto systém, který se používá ve výrobním procesu.

Následně byl vytvořen průzkum trhu, který monitoruje realizovaná řešení různých dodavatelů energetického managementu. Bylo zjištěno, že dodavatelé těchto řešení nahlížejí na problém ze dvou úrovní. V prvním případě jsou dodávány produkty, které předpokládají, že získávání energetických dat je na straně zákazníka. Tato varianta nese v práci označení Databázová implementace. V druhém případě existují na trhu řešení, kde dodavatelská firma zajišťuje jak sběr energetických dat, tak také tzv. databázovou implementaci.

Poslední část této práce popisuje realizované řešení energetického managementu. Toto řešení je založeno na platformě Siemens PCS7 a k získávání energetických dat využívá speciální PCS7 knihovnu, která je určena k těmto účelům. Toto řešení se sestává ze dvou částí. První část tvoří reportovací systém, který byl vyvinut firmou SIDAT. Na základě tohoto reportovacího systému byl realizován systém predikční. Tento predikční systém byl vyvinut pro účely této diplomové práce. Jak pro reportovací, tak pro predikční systém bylo zvoleno rozhraní aplikace MS Excel pro jeho široké uplatnění při zpracovávání dat.

České vysoké učení technické v Praze
Fakulta elektrotechnická

Katedra řídicí techniky

ZADÁNÍ DIPLOMOVÉ PRÁCE

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Název tématu: **Sledování a predikce spotřeby energie v technologickém procesu**

Pokyny pro vypracování:

1. Prostudujte dostupná řešení problematiky sledování a predikce spotřeby energie v technologickém procesu.
2. Navrhněte a realizujte systém umožňující dlouhodobou archivaci dat o spotřebě energie a následné reportování podle uživatelsky definovaných kritérií (období, nákladová centra, regulační stupně apod.). Pro sběr dat použijte přednostně knihovnu IEM v prostředí Simatic PCS7.
3. Navrhněte a implementujte algoritmus pro predikci spotřeby energie na základě znalosti historických dat o spotřebě.
4. Navrhněte rozšíření algoritmu dle bodu 3 o možnost zahrnutí informace o provozním stavu vybraných částí technologického procesu (např. odstavení či chod některého spotřebiče).

Seznam odborné literatury:

Dodá vedoucí práce

Vedoucí: Ing. Pavel Burget, Ph.D.

Platnost zadání: do konce zimního semestru 2009/10

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V Praze dne 27. 2. 2009

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Introduction

This thesis deals with energy management and energy consumption prediction.

The Chapter 1 describes the basic terms that are generally used in Energy Management. The general expressions and goals are explained in the first part. The second part describes the Energy Management from the industrial view. Here are noted the user requirements and needs in industry. In accordance with these requirements is this thesis realized.

In the Chapter 2 are described the Energy Management applications, called Energy Management systems. This description is divided into two parts. The first one consists of applications that are based only on database approach. It assumes that the customer acquires the energy data and the supplier process it in its application. The second part contains the solutions that offer so-called Full-Scaled implementation. It means that the solution consists of two basic layers: the process and the database. The result of this survey is that no solution mentioned here fulfills the specific requirements noted in Sec. 1.3.1.

Finally, the Chapter 3 describes the solution that ensures the requirements noted above for industry field. Here is briefly described the general system that is based on PCS7 platform and how it is possible to extend this system by the reporting and prediction capabilities. In order to develop the reporting and prediction system it was used a commercial project in cooperation with SIDAT Ltd. The reporting system was developed by SIDAT Ltd. and the prediction system was developed for the purposes of this thesis. From this reason the prediction system must conform with several requirements to ensure the system compatibility. The prediction system offers both basic and advanced prediction. The basic prediction computes the forecasting values using the energy data from appropriate database. The advanced prediction uses both the energy data and the substituting data. The substituting parametrization is available through the user interface in prediction system.

Chapter 1

Energy Management

In this chapter the reader will find the explanation of the term *"Energy management"* (EM) and *"Energy management system"* (EMS). It is not easy to strictly define those terms, since it covers a wide range of Energy Management applications and tools. These terms will be described for the purposes of this thesis.

The basics of energy management are explained in the beginning of the chapter. The end of this chapter also contains the industrial approach to the Energy Management, namely the user requirements to the Energy Management System in industry. Further, this chapter describes the different EMS topologies that differ in view of the problem and the customers requirements.

1.1 What is Energy Management

Energy management can be defined as a set of tools and measures for energy management with the use of energy-economic potential in different areas. Energy Management is a management process to ensure energy needs. In a broader perspective, the EM part of the complex activities that deal with management of property (Facility Management). Energy Management puts the accent on analysis, monitoring and prediction of long-term energy consumption.

In this case the keyword "energy consumption" means not only consumption of electric energy but also, for example, consumption of heat or gas.

1.1.1 The Field of Energy Management

The EM is used in many different fields. From this reason the tools of EM differ in these areas. The briefly description of EM mentioned above is general description and it applies to all equally.

One of the main EM areas is EM on state level. In this case the EM tools are legislation. Legislators define laws that should ensure optimal energy production and consumption, eventually they define restrictions that safeguard the environment. Each state in EU must take actions that lead to at least 1% year-on-year energy savings form 2008 to 2016.

Next area in use of EM is EM in cities. Here the main aim is to optimize consumption of fuel, energy and water. To satisfy these goals is necessary to ensure the optimal operation of buildings, operating units and, for example, including new technologies such as renewable resources.

From the previous text implies that it is also needed to ensure optimal operation of buildings - EM in buildings. This issue mainly includes management of heating (air conditioning) and lighting. In this case the sources of wasting are monitoring. The result of this wasting monitoring could be thermal isolating that could save heating energy (Air Conditioning), for example, about 20%. Next way to save energy could be lighting monitoring that could save energy up to 9% of all energy consumption.

The last field where the EM is often used is industry. In this case the EM collects several tools that make a suite that calls Energy Management System. This area is described in the Sec. 1.3 in detail.

1.1.2 Energy Management Cycles

In general we talk about EM and there are some recommendations and methods how to achieve our requirements. Steps of basic activities EM are in general noted below:

- **Monitoring** (data collection, measurement readings, checking bills / responsible staff)
- **Evaluation** (analysis of energy balance , simulation)
- **Planning** (determination of costs, consumption and processing, energy-saving measures, shutdowns, repairs)

- **Implementation** (measures, controls, monitoring frequency, staff update contracts)

Based on these facts it is necessary to ensure the energy data collection. Each sector is responsible for the collection according to their orientation. The collected energy data is then evaluated. Based on this assessment, it is necessary to make a plan. This plan includes measures such as the determination of savings or shutdowns.

These steps of the energy management are a part of each Energy Management System.

1.2 Goals of Energy Management

Some goals of EM are mentioned above in the Sec. 1.1.1, here the general EM goals are listed.

The main aim of EM is to ensure efficient and reliable service for coverage of all energy needs.

One of the other objective is to increase energy efficiency consumption, further optimization of energy consumption in the subject of energy management and also reduce energy losses.

Energy management can be applied or used in these areas (the most common problems):

- Reducing operating energy costs - are directly dependent on the purchase price of energy
- Quantifying the energy use of waste and renewable sources
- Preparation and management of energy-saving projects
- Energy Consultancy
- Monitoring energy prices for energy market
- Exploit the potential of buildings

In all these areas remain the aims very similar. Several targets of Energy Management are noted in the Tab. 1.1.

Area	Acquisition
Energy and water	Reducing energy consumption
	Lower water consumption
	Optimizing the cost of purchasing energy and water
	Reducing the costs of subsequent maintenance of buildings and Technical Equipment of Buildings
	Increased reliability
	The use of local resources and labor
	Providing more efficient and better services
Environmental	Reducing greenhouse gas emissions
	Reduce pollutant emissions

Table 1.1: Energy Management targets

EM is divided into several layers, as it is evident from the text above. It therefore follows that there are several manners (or tools) how to properly use the EM, see Tab. 1.2.

Tool	Examples
Legislative	Law on energy management, energy law, construction law, etc.
Planning	Spatial planning, action plans
Analyst	Energy audit, energy certificate, energy label, energy certificate
Technical	Framework and detailed monitoring of energy consumption
Statistics	Energy statistics

Table 1.2: Energy Management tools

There are several potential sources of energy. This is the possible use of energy reserves with the use of technically viable measures such as thermal insulation of buildings, installation of technical equipment for the use of internal and external heat gains, implementation of isolation systems transmitting thermal energy, installation of efficient lighting sources, justifiable and beneficial applications of renewable and non-traditional sources. Energy Audit majority suggests all available technical measures. In practice we assume, however, only the implementation of cost-effective measures.

In terms of economic potential reflect a reduction in energy consumption after the implementation of technical and organizational measures in the economic parameters such as gross and net return on time spent funds, internal rate of return and net present value at a pre-selected time of economic or technical life of the technical measures. Practice shows from the audit that the economic potential is not fully exploited. The practical usefulness of economic potential is estimated, according to the European experience, the relative amount of about 30 - 60% and includes the implementation of technical measures in the short or medium-long pay back periods.

1.3 Energy Management in Industry

In the field of industry is Energy Management realized using so-called Energy Management Systems.

When we talk about "industry", one can imagine a plant, for example, cement works. The factory has the manufacturing process that is controlled by control system on process level. This control system is usually interconnected with an office system on IT level. The technological process is monitored using SCADA standard. On the IT level the process data is usually archived.

Reducing production costs is one of the permanent requirements for the entire history of industrial production for all production processes. In normal production next to basic materials are the main costs all types of energy that was used during production. The pressure to reduce prices of the products is reflected in particular in the requirements for reducing energy consumption during production. This is why the energy consumption is monitored in the manufacturing process.

The main functions are measuring and storing the data from energetic measurements. Based on this information, the system is able to provide reports and charts of energy consumption over time. Over this data may be carried out analysis of the mapping of the energy flows.

How such a system looks like is shown in the Fig. 1.1. This system consists of two layers: Information and Process. The Process part contains equipments of process automation and is explained in section 1.3.3 and the Information layer includes database components and is described in section 1.3.4 in more detail.

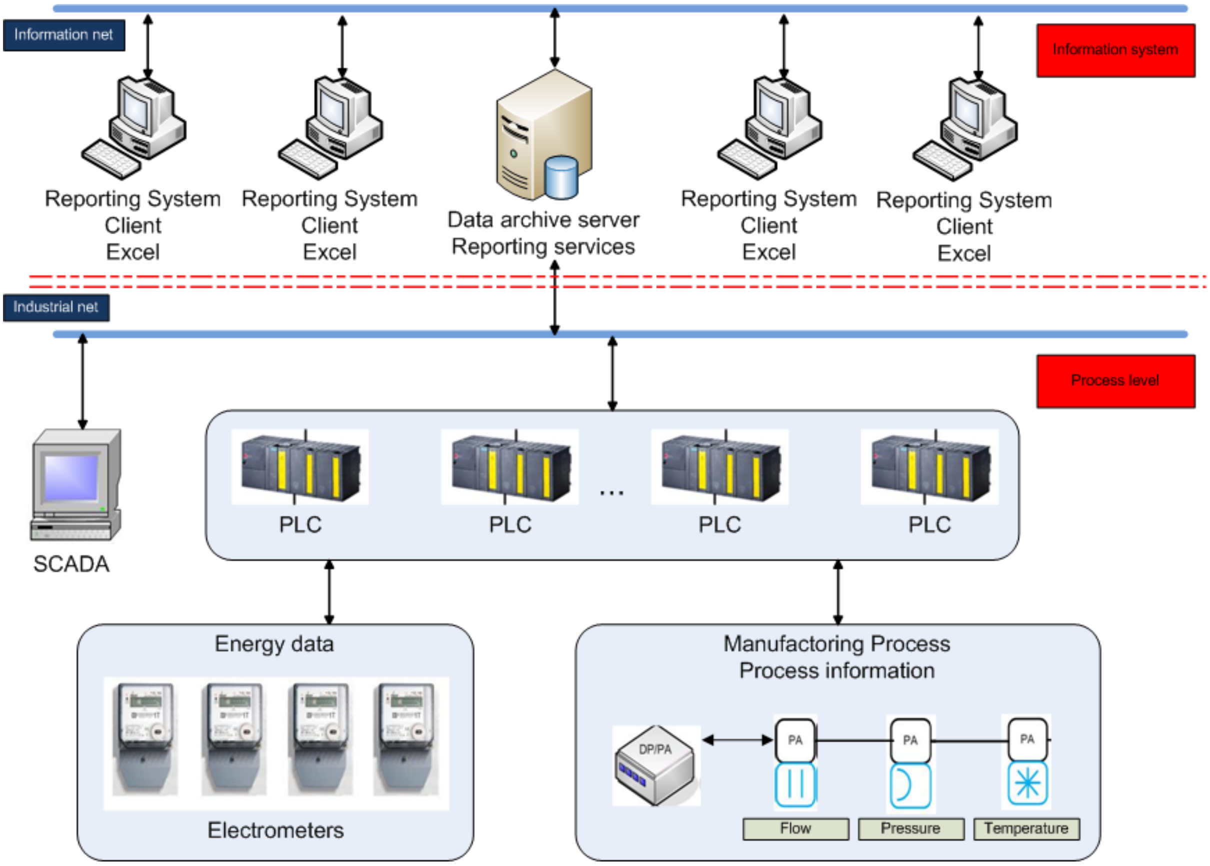

Figure 1.1: Example of Energy Management System

1.3.1 EMS Requirements in Industry

Generally, there are many requirements to the EMS in industry field. The main two requirements on Energy Management System in industry are

- Reporting of consumed energy
- Prediction of energy that will be probably consumed

Both reporting and prediction is described and explained below in text in more details.

Further, the very important aim of EMS is easy implementation into the current manufacturing system that is used to monitor and control the whole manufacturing process in an appropriate plant.

Next, the EMS must be able to offer to the user the possibility of factory dividing into several parts such as crushers, mills, dryers etc. This choice serves to determining the amount of energy consumption in defined parts of the factory that are called Cost Centers.

Each factory part contains measuring units that serve to acquiring energy data. These measuring units are called "Tags". Tag is user defined measured point in manufacturing process that is considered as an energy value and is used in energy management. From this data it is possible to approximately determine production costs in the form of consumed water, heat, gas, electric energy etc. When the user knows the energy consumption in each part of manufacturing process, then it is possible to determine, how much energy was consumed for one concrete batch or product. This information helps to accurately determine the production prices. To determining the energy consumption serve reports that contain energy data.

The reporting (report creating) of energy consumption in the future calls prediction, or prediction reporting. In this case it is not needed the prediction that is based on difficult prediction principles, for example, neural networks or statistical approach. The reason, why it is not needed is based on the manufacturing principle/process. The manufacturing process goes through several phases in accordance with factory technological parts. So, the user approximately knows how much energy will be consumed because he knows how long each process/manufacturing phase takes. The manufacturing process is still repeated with each batch or product. The energy consumption changes during one day. So, the factory removes energy is several energy tariffs (usually three) that are defined by the energy provider. The energy consumption may also vary, for example, in case of scheduled maintenance etc. The EMS must be able to include these cases using user interface. The prediction is typically used when the customer wants to order the electric energy from an energy provider. For example, the customer has ordered, that he will consumed 22MWh on 12.4.2009 from 23:00 to 7:00 in appropriate tariff (see Tab. 1.3). If he will consumed exactly 22MWh, it is all right. But there may be two cases:

- The real consumption was only 2 MWh
- The real consumption was 32 MWh

In the first case the customer has to sell back into the energy system (net) the difference for 0.04 EUR per MWh. In the second case the customer has to buy 10 MWh for price 0.16EUR per MWh. From this reason is needed the prediction on appropriate tariffs/days/hours. It is used the determine the energy consumption based on historical data that is archived in appropriate database.

Relationships between tags and both tariffs and cost centers are defined by the user. It is important to allow users self-management of these two groups. Tags in reporting and prediction reports are assigned to some:

- Cost Centers, with selectable time interval
- Tariffs, with selectable time interval

These expressions are described in detail in next sections.

Another important request is the use of standard program platform, for example, Microsoft Office suite. The user interface needs to be easily used.

1.3.1.1 Cost Centers

Sorting according cost centers helps to accurately determine the production costs. One cost center should contain all tags, that belong to one technology unit. One tag may be in more cost centers. The user defines the cost centers topology.

The selection is expanded by time interval selection.

1.3.1.2 Tariffs

The price of energy is varying in one day. This is caused by different energy tariffs that are changed during one day. That is the reason why it is required tag sorting according the day energy tariffs.

Three tariffs are typically defined by the energy provider on one day, see Tab. 1.3 with tariffs example. Each

Tariff name	Validity	Price of 1MWh [EUR]
Peak	$7:00 - 8:00$	0.2
Day	$8:00 - 23:00$	0.4
Night	$23:00 - 7:00$	0.1

Table 1.3: Example of tariffs in one day

The selection is expanded by time interval selection.

1.3.2 Measuring Devices

To both energy and process measuring serve measuring devices that are based on several different principles. The measuring form depends on the character of the measured values. In general for media flow or energy consumption there are different devices used as the meters providing one of the following output signals:

- **Digital signal**
- **Analog signal**
- **Interface unit**
- **Indirectly measured values**

Digital Signal

These sensor types provide a digital output signal as an pulsing signal representing flow volume or flow mass. The resulting amount of consumed energy is the count of pulses that is multiplied by a sensor constant.

Analog Signal

These sensor types generate a continuous output signal representing flow rate. The continuous signal must be integrated and the resulting energy value is given by 15 minutes integration.

Interface Unit

These units have own internal measuring system. It presents, for example, an electrometer having standardized communication interface. Through this interface it is possible to acquire the actual amount of consumed energy or number of pulses that represent energy consumption. The EMS must know (using storing) the initial value and after the defined time (usually 15 minutes) expires the resulting value is the difference between the initial and the actual values.

Indirectly Measured Values

All measuring methods mentioned above measure all values directly. There is another method that serves to determine the energy flow. It could be in cases when it is not possible to use the direct measuring, for example, to determine how much energy was consumed to heat a tank. This method uses physical laws to determine consumed energy. In this case the flow, pressure and temperature are usual secondary values (see Fig. 1.1 in process level) which server also to determine energy values.

1.3.3 Implementation on Process Level

According to the Fig. 1.1 the Process Level contains measuring units that are connected into programmable controllers (PLCs) and that measured energy consumption. This information is sent through an industrial net from these PLCs to a database server to store. The measured values should be available in real-time from each measuring points. But, usually these energy values (from measuring points) are summarized and the final sums are sent every 15 minutes. The summarizing is achieved through summing functions that are part of the PLCs, see Fig. 1.2.

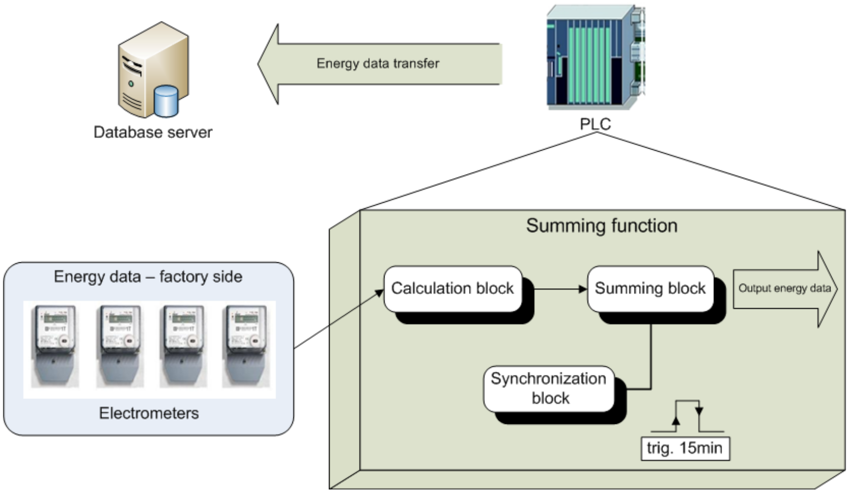

Figure 1.2: Sum function in a control system

There is possible to implement Energy Management System in two ways - inside or outside the control system.

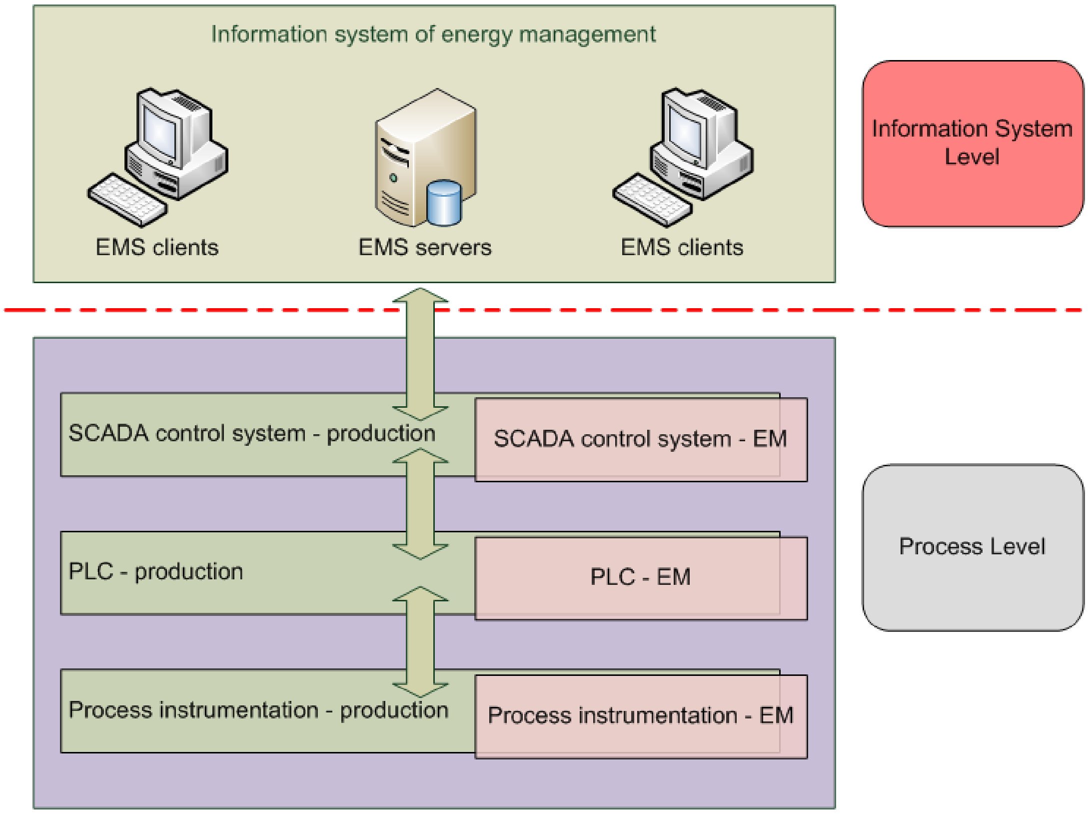

Figure 1.3: EMS is part of a control system

In the first case, the EMS is the part of the control system, as it is shown on the Fig. 1.3. In this case is possible to control the energy consumption using the EMS. If the actual energy consumption is higher then the permitted value, the EMS will seek to restrict the flow of energy, for example, by disabling certain parts of technology.

In the second case, the EMS is outside the control system, see Fig. 1.4. There is no possibility to control the process using the EMS. In this case EMS serves to reporting energy data.

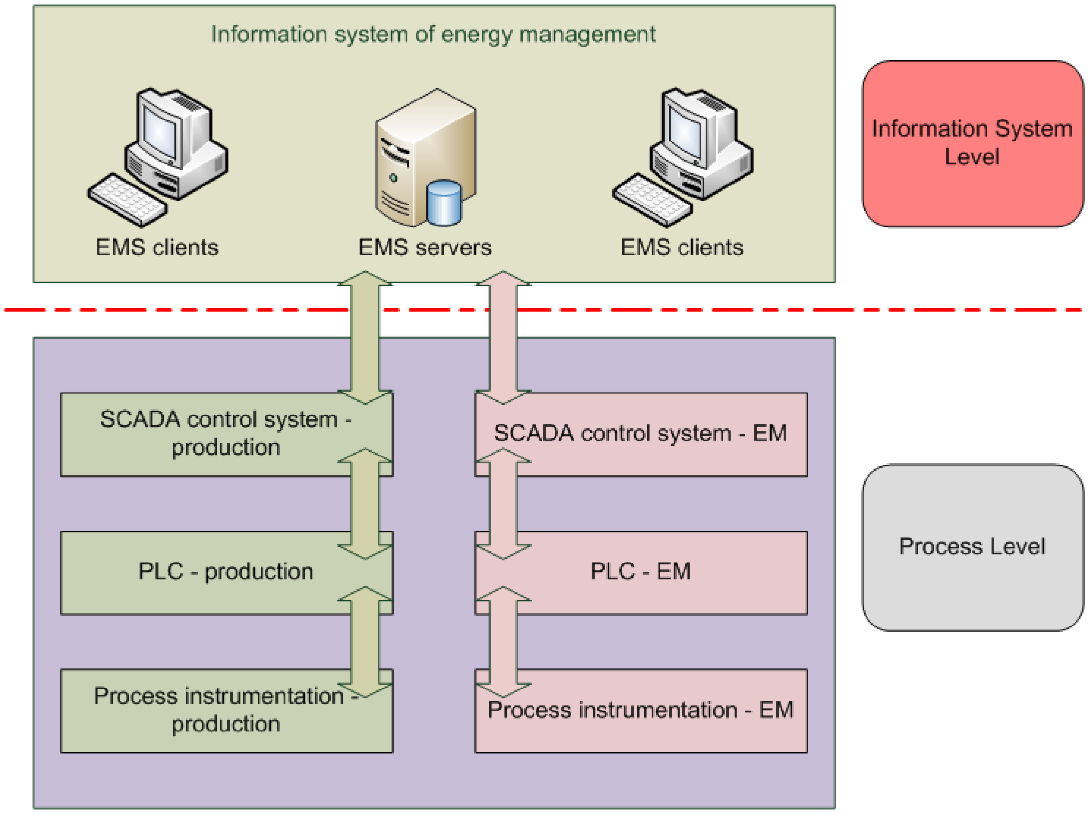

Figure 1.4: EMS is outside a control system

1.3.4 Implementation on Database Level

The Database Level includes one database server or more servers, which have different roles. These servers are interconnected via information network. The database server and the PLCs are interconnected using the standard interfaces, for example, OPC HDA.

The database servers serve to storing appropriate energy values. These values represent values of consumed energy that was used in manufacturing process. It is necessary to have also a reporting server, except the database server. Reporting server offers services that are able to generate reports.

Report generating is based on Client - Server principle. Generally, the user defines his requirements using reporting system client interface. The server executes the user requirements. The result is shown through the client interface. This situation is shown in the Fig. 1.5. In this case the client interface is MS Excel application.

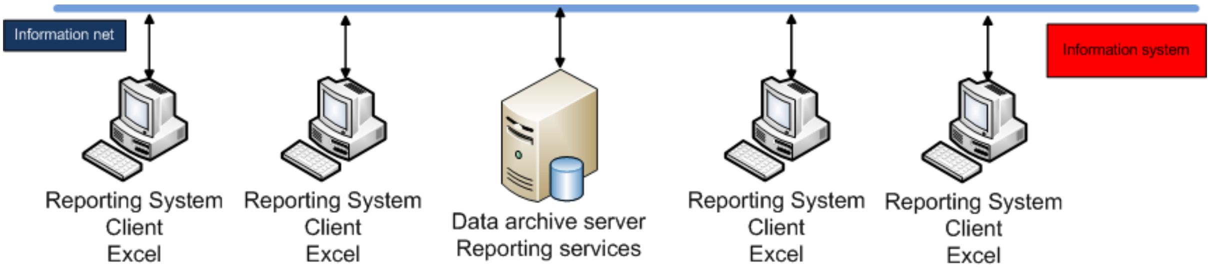

Figure 1.5: Eenergy Management System on information level

Reports and charts are an essential tool to preview the database of measured energy values.

Chapter 2

Market survey

This chapter briefly describes applications of the specialized companies that deal with the prediction of energy consumption and energy management. There are many firms that are specialized in this wide area. This chapter contains companies that deal only with energy management in manufacturing process.

There are two views to these issues. In the first case the Energy Management is only realized on the database level mentioned in the Sec. 2.1. On the other hand there are so-called Full-Scaled solutions that offer both control and database implementations noted in the Sec. 2.2.

The result of market survey is description of several energy management applications. It was selected applications of the most famous companies that offer both Database and Full-Scale implementations. All the terms contained herein are in accordance with the Sec. 1.3.

2.1 Database Implementation

Applications implemented on the database level are described in this section. It exists many companies on the market that deal only with data processing. The data is obtained from databases.

The main aim is to develop or to offer the appropriate customers software according to his requirements. The assumption is that the customer has its own database with process and maintenance data. The basic requirement is that the reporting system is realized on any platform and has the energy consumption prediction functionality.

The next subsections describe several companies that are the most known in this area.

2.1.1 ETAP Energy Management System

ETAP Energy Management System is energy management application delivered by ETAP. ETAP is one of the companies that implements the solution on the IT level.

ETAP Energy Management System is a suite of applications used to monitor, control, and optimize the performance of generation and transmission system. This intelligent energy management system is designed to reduce energy consumption, improve the utilization of the system, increase reliability, and predict electrical system performance as well as optimize energy usage to reduce cost. EMS applications use real-time data such as frequency, actual generation, tie-line load flows, and plant units' controller status to provide system changes.

In next subsections are described the applications that make up the ETAP EMS suite. This suite is represented by the blue box (ETAP EMS) in the Fig. 2.1.

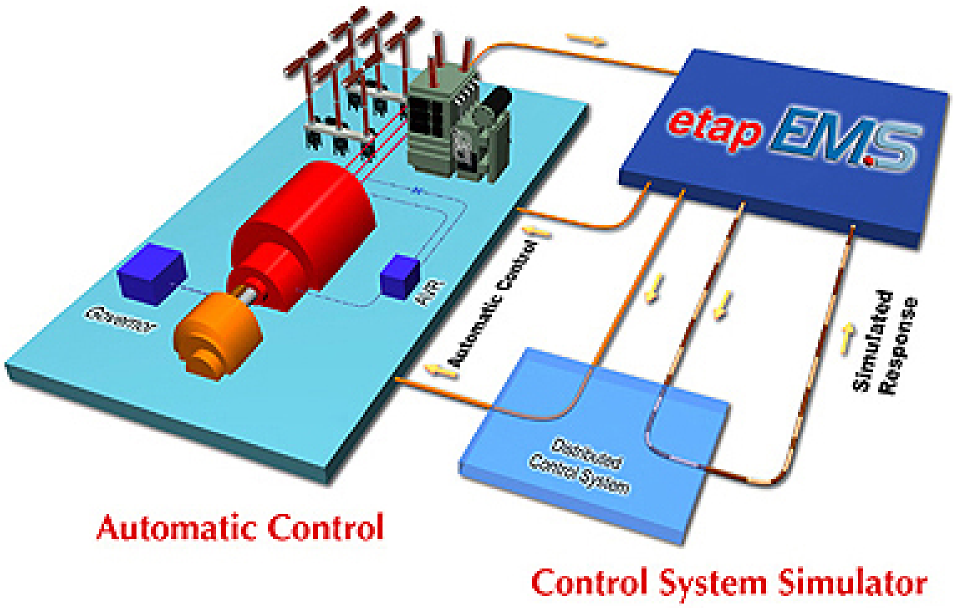

Figure 2.1: EMS plant integration (Etap, 2009)

In the Fig. 2.1 one can see that the ETAP EMS is integrated externally into a plant. The plant distributed control system ensures the industry control. The control signals are distributed into both a plant and the ETAP EMS. ETAP EMS acquires the process and energy data, executes the appropriate operations and sends information to the distributed control system.

2.1.1.1 Automatic Generation Control

Automatic Generation Control (AGC) calculates the required parameters or changes to optimize the operation of generation units and is a part of the ETAP EMS suite. The application uses real-time data such as frequency, actual generation, tie-line load flows, and plant units' controller status to provide generation changes. AGC also calculates the parameters required to control the load frequency and provides the required data on demand to maintain frequency and power interchanges with neighboring systems at scheduled values.

AGC is fully integrated with Economic Dispatch and Interchange Scheduling hence automatically ensuring that generation adjustments are scheduled in the most economical fashion. AGC provides guidelines for optimal electrical system operation to meet power requirements, steam requirements, and minimize fuel cost per generator. This process significantly minimizes the complexities of the decision process.

The whole principle of the AGC is shown in Fig. 2.2. There is shown how the control is generated to ensure the desired process parameters.

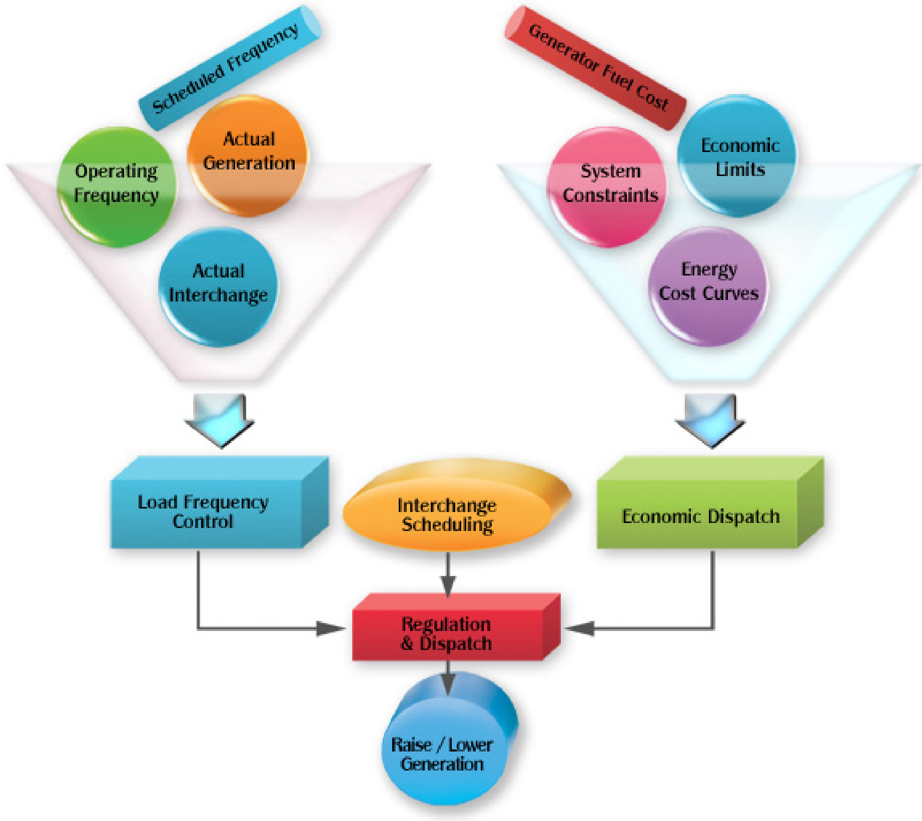

Figure 2.2: ETAP Automatic Generation Control principle, (Etap, 2009)

2.1.1.2 Economic Dispatch

Economic Dispatch (ED) a part of ETAP. It allocates generation changes of a power system among generator units to achieve optimum area economy. Economic Dispatch provides guidelines for optimal electrical system operation in order to meet power requirements, steam requirements, and minimize fuel cost per generator.

ED utilizes advanced optimal power flow algorithms in order to determine the optimal generation pattern while maintaining adequate reserve margins (see Fig. 2.3). Generation levels of individual units are calculated and dispatched in order to meet the load demand at minimal costs. Consideration is given to the fact that the cost of generation is not proportional to the generation level, systems are geographically spread out, and transmission losses are dependent on the generation pattern.

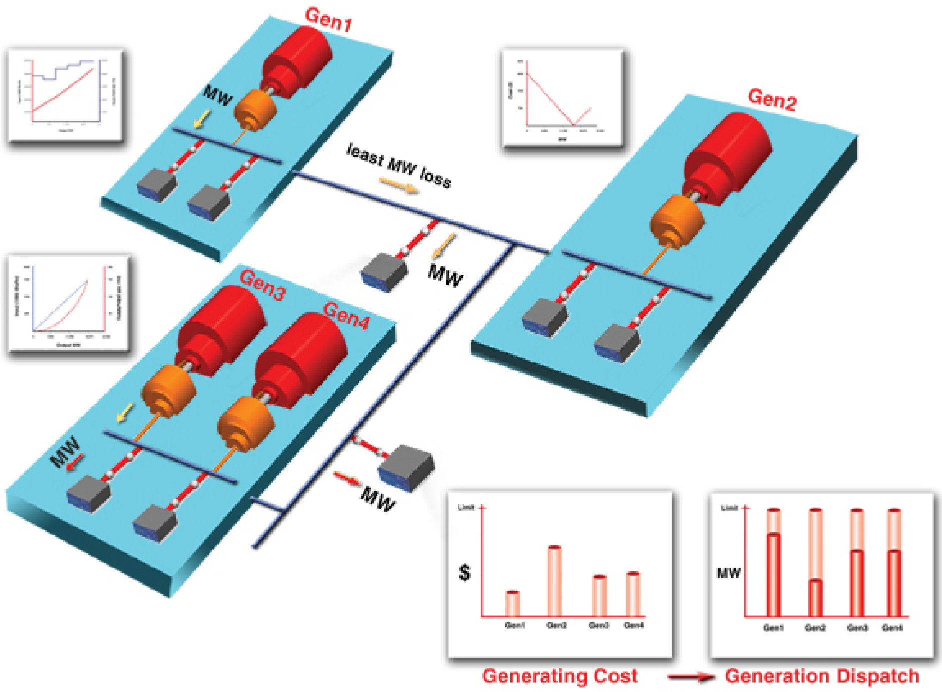

Figure 2.3: ETAP Economic Dispatch example, (ETAP, 2009)

2.1.1.3 Supervisory Control

Supervisory Control belong to the ETAP suite and allows the operator to apply objectives and constraints to achieve an optimal operation of the system. In this mode, recommendations are implemented based on the predefined set of objectives. ETAP utilizes optimal power flow algorithms and user-defined logics to determine the best operating settings for the system.

Optimization can be used to assist energy consumers to automatically operate the system and minimize system losses, reduce peak load consumption, or minimize control adjustment. For energy producers or co-generators, system optimization can be set to minimize generation fuel cost, optimize system operation, and maximize system security.

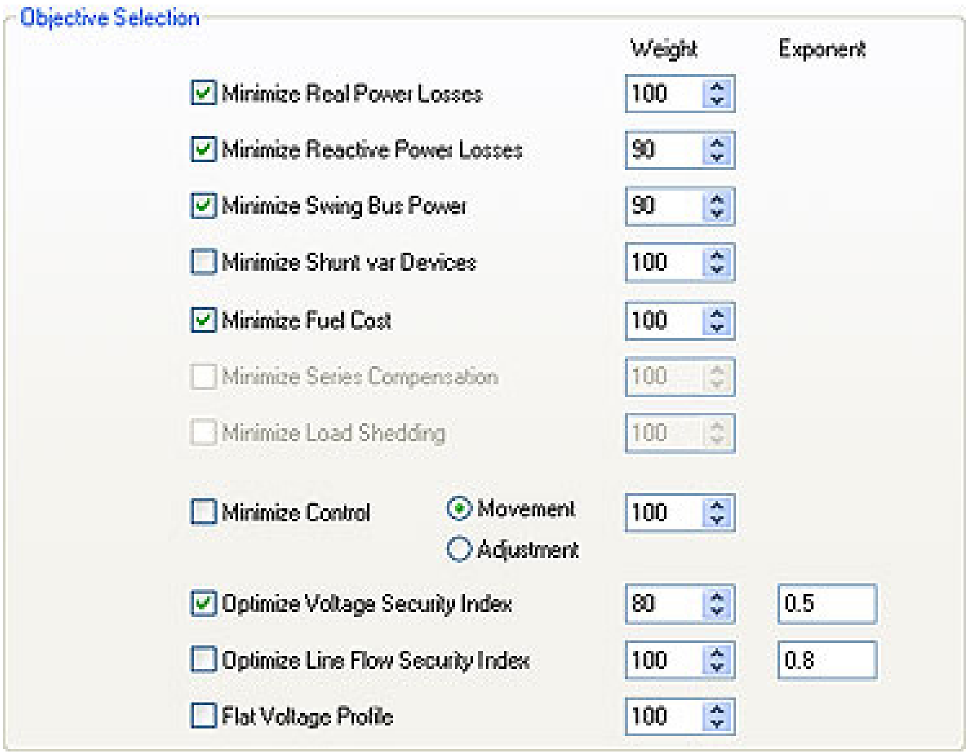

Figure 2.4: ETAP Supervisory Control example, (ETAP, 2009)

Figure 2.4 shows the example of required parameters setting. The appropriate application of system optimization leads to a more reliable and economical operation, while maintaining system voltages and equipment loading within the required range and constraints. System optimization provides intelligent load flow solutions to minimize system operating costs and maximize system performance while maximizing the value of customers energy investment.

2.1.1.4 Interchange Scheduling Software

Interchange Scheduling (IS) inheres in the ETAP suite and provides the capability to schedule energy transfer from one control area to another while considering wheeling, scheduling ancillary services, and financial tracking of energy transactions. Dedicated for electricity power exchange and scheduling, Interchange Scheduling incorporates energy scheduling, transaction management, and energy cost analysis and reporting.

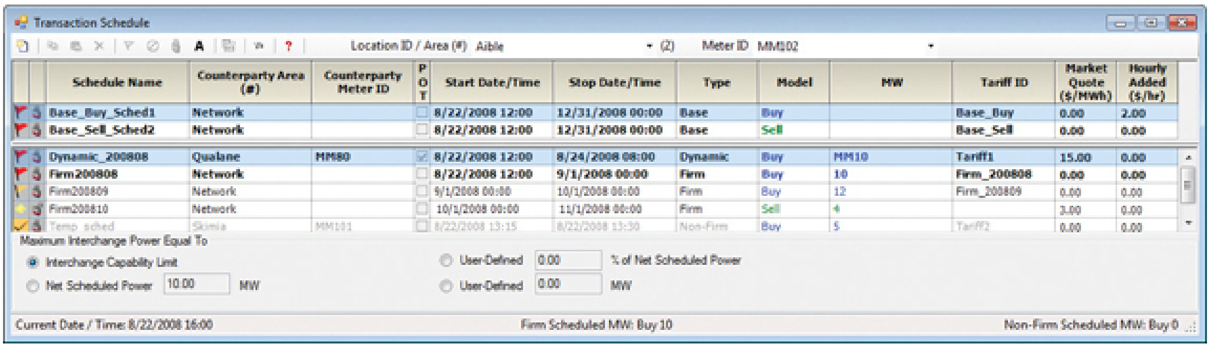

Figure 2.5: ETAP Interchange Scheduling example, (Etap, 2009)

2.1.1.5 Reserve Management Software

Reserve Management is a part of the ETAP suite. It maintains a constant vigil over required system reserves including ”regulating reserve” (spinning reserve immediately responsive to automatic generation control commands), ”contingency reserve” (spinning and non-spinning reserve sufficient to reduce Area Control Error to NERC performance requirements within 10 minutes), ”additional reserve for interruptible imports” (reserve that can be made effective within 10 minutes), and ”additional reserve for on-demand obligations” to other entities or control areas (see Fig. 2.6). Notification is issued whenever the available reserve in a class falls below the corresponding required value.

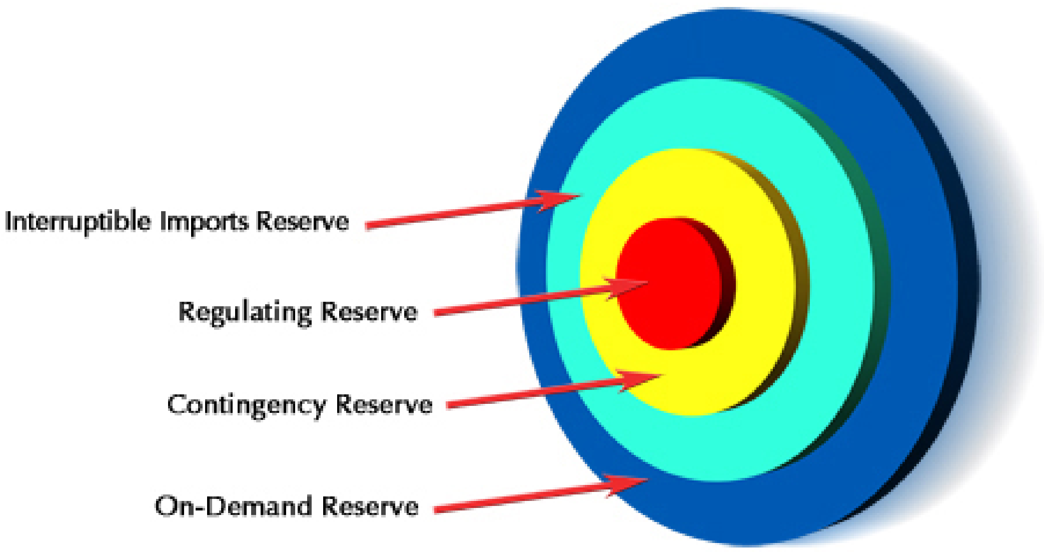

Figure 2.6: ETAP Reserve Management example, (Etap, 2009)

2.1.2 STATISTICA

STATISTICA is a product of international company StatSoft that is concerned with data processing and their forecasting.

StatSoft's flagship product line is the STATISTICA suite of analytics software products. STATISTICA provides comprehensive array of data analysis, data management, data visualization, and data mining procedures. Its techniques include wide selection of predictive modeling, clustering, classification, and exploratory techniques in one software platform.

Generally, STATISTICA takes advantage of user's Data Repositories as it is shown in Fig. 2.7. This stored information is used for next analysis.

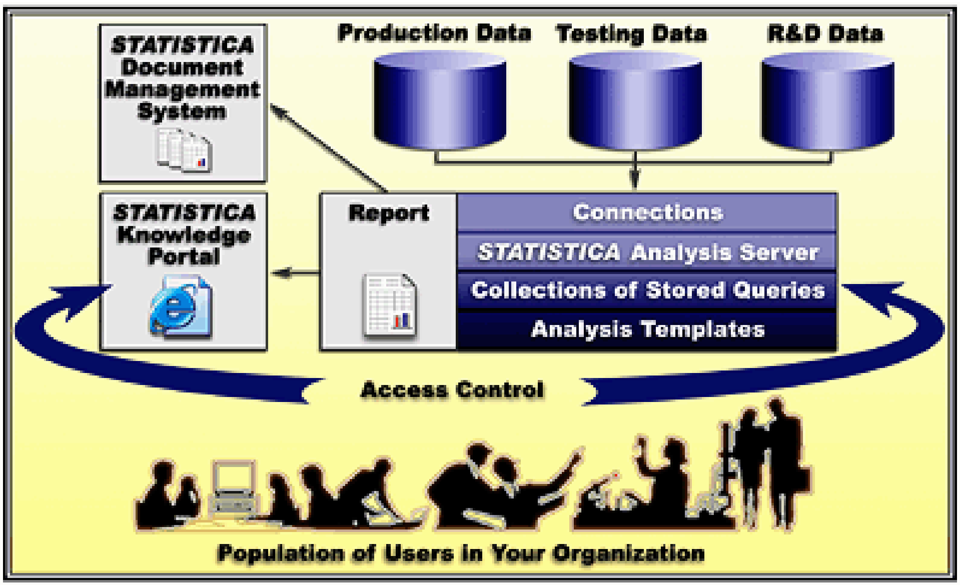

Figure 2.7: StatSoft STATISTICA, (StatSoft, 2008)

StatSoft offers two versions of STATISTICA application suitable for time series analysis and forecasting: STATISTICA Automated Neural Networks (SANN) and STATISTICA Advanced Linear/Non-Linear Models.

2.1.2.1 STATISTICA Automated Neural Networks

STATISTICA Automated Neural Networks (SANN) has the functionality to assist user through the critical design stages, including Neural Network Architectures and Training Algorithms and also approaches to network architecture design by using specific and meaningful error functions that allow the interpretation of the output results. Neural networks analysis can be incorporated in custom applications by using either the STATISTICA library of COM functions that fully expose all functionality of the program or by using the C/C++ code generated by the program to aid in the deployment of fully trained networks.

Like all STATISTICA analysis, the program can be "connected" to remote databases via the tools for in-place-database processing, or it can be linked to active data so that models are retrained or applied (e.g., to compute predicted values or classifications).

In general, data must be specifically prepared for input into neural networks, and also it is important that the network output can be interpreted correctly. SANN includes Automated data scaling for both inputs and outputs. There is also Automated recoding of Nominal valued variables, including one-of-N encoding. SANN also has facilities to handle missing data. There are special data preparation and interpretation facilities for use with Time Series.

The range of neural network models and the number of parameters that must be decided upon (including network size, and training algorithm control parameters) can seem bewildering (the Automated Network Search (ANS) is available to automatically search through numerous network architectures of varying complexities, see below). STATISTICA Automated Neural Networks (SANN) supports the most important classes of neural networks for real world problem solving, including:

- Multilayer Perceptions
- Radial Basis Function networks
- Self-Organizing Feature Maps
- Linear Networks

The above architecture can be used for regression, classification, regression time series, classification time series, and cluster analysis. In addition, ANS supports Ensembles networks formed from arbitrary (when meaningful) combinations of the network types listed above. Combining networks to form Ensemble predictions are suitable to use in SANN, especially for small datasets.

For enhanced performance, STATISTICA Automated Neural Networks supports a number of network customization options. The user can specify a linear output layer for networks used in (but not restricted to) regression problems or soft max activation functions for probability-estimation in classification problems. Cross-entropy error functions, based on information-theory models, are also included, and there is a range of specialized activation functions, including Exponential, Tangent Hyperbolic, Logistic Sigmoid, and Sine functions for both hidden and output neurons.

SANN naturally includes fast, second-order training algorithm: Conjugate Gradient Descent. This algorithm typically converge far more quickly than first order algorithms such as Gradient Descent.

STATISTICA Automated Neural Networks' iterative training procedures are complemented by Automated tracking of both the training error and an independent testing error as training progresses. User can also specify Stopping Conditions when training should be prematurely aborted, for example, when a target error level is reached, or when the selection error deteriorates over a given number of epochs. If over-learning occurs. When training has finished, the user can finally check performance against train, test, and validation samples.

Used training algorithms are:

- Gradient Descent
- Conjugate Gradient Descent
- Kohonen training
- k-Means Center Assignment for Radial Basis networks

User may select multiple models (and ensembles), in which case, wherever possible, SANN will display results generated in a comparative fashion (e.g. by plotting the response curves for several models on a single graph, or presenting the predictions of several models in a single spreadsheet). This feature is particularly useful for comparing various models trained on the same data set.

2.1.2.2 Advanced Linear/Non-Linear Models

This application offers a wide array of advanced linear and nonlinear modeling tools. It contains several modules where the **Time Series** module is suitable for time series forecasting.

The Time Series module contains a wide range of descriptive, modeling, decomposition, and forecasting methods for both time and frequency domain models. These procedures are integrated, that is, the results of one analysis (e.g., ARIMA residuals) can be used directly in subsequent analysis (e.g., to compute the autocorrelation of the residuals). Many options are provided to review and plot single or multiple series. Multiple series can be maintained in the active work area of the program (e.g., multiple raw input data series or series resulting from different stages of the analysis). The series can be reviewed and compared. The program will automatically keep track of successive analysis, and maintain a log of transformations and other results (e.g., ARIMA residuals, seasonal components, etc.). Thus, the user can always return to prior transformations or compare (plot) the original series together with its transformations (see Fig. 2.8). Information about the consecutive transformations is maintained in the form of long variable labels, so if the user save the newly created variables into a dataset, the "history" of each of the series will be permanently preserved.

The specific Time Series procedures are described in the following text.

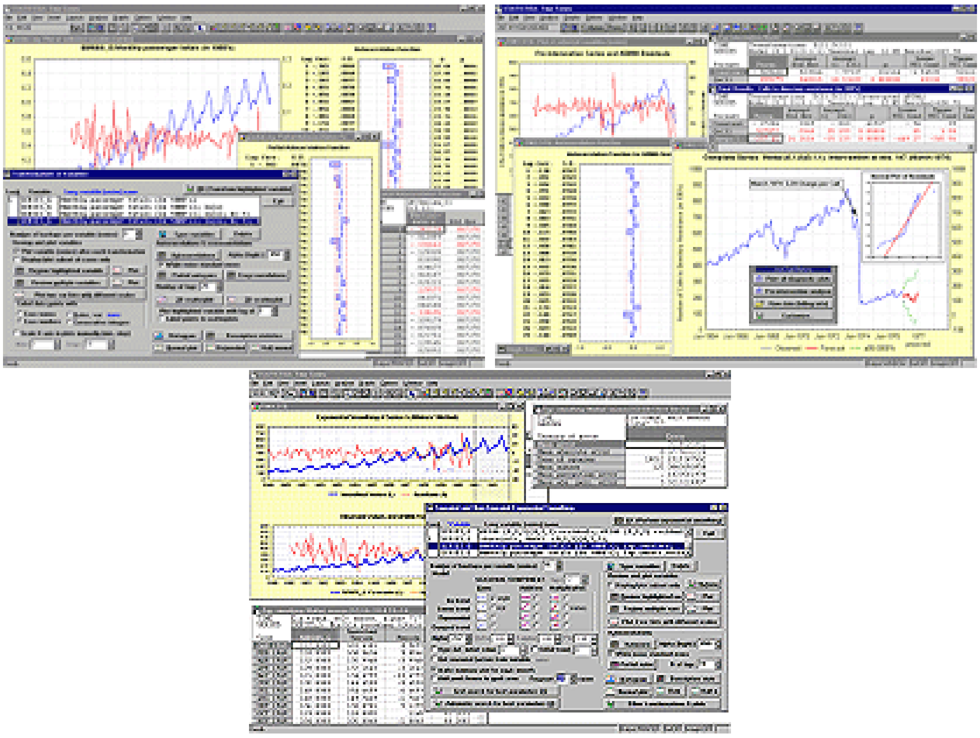

Figure 2.8: Application examples

The available time series transformations allow the user to fully explore patterns in the input series, and to perform all common time series transformations, including: detrending, removal of autocorrelation, moving average smoothing (unweighted and weighted, with user-defined or Daniell, Tukey, Hamming, Parzen, or Bartlett weights), moving median smoothing, simple exponential smoothing, differencing, integrating, residualizing, shifting, 4253H smoothing, tapering, Fourier (and inverse) transformations, and others. Autocorrelation, partial autocorrelation, and cross correlation analysis can also be performed.

The Time Series module offers a complete implementation of ARIMA. Models may include a constant, and the series can be transformed prior to the analysis. These transformations will automatically be "undone" when ARIMA forecasts are computed, so that the forecasts and their standard errors are expressed in terms of the values of the original input series. Approximate and exact maximum-likelihood conditional sums of squares can be computed, and the ARIMA implementation in the Time Series module is suited to fitting models with long seasonal periods (e.g., periods of 30 days). Standard results include the parameter estimates and their standard errors and the parameter correlations. Forecasts and their standard errors can be computed and plotted, and appended to the input series. In addition, numerous options for examining the ARIMA residuals (for model adequacy) are available, including a large selection of graphs. The implementation of ARIMA in the Time Series module also allows the user to perform interrupted time series (intervention) analysis. Several simultaneous interventions may be modeled, which can either be single-parameter abrupt-permanent interventions, or two-parameter gradual or temporary interventions (graphs of different impact patterns can be reviewed). Forecasts can be computed for all intervention models, which can be plotted (together with the input series) as well as appended to the original series.

2.1.3 Prediction Systems Elvira

Elvira is self-learning adapting prediction system. It was developed by Institute of Computer Science on Academy of Sciences of the Czech Republic.

Prediction systems Elvira are large modular systems. These modules are divided into several categories that are described in the following subsections.

2.1.3.1 Short-term Prediction modules

These modules are solving prediction of total daily energy consumption, eventually whole daily charge diagram (24 hour or 48 half-hour values) in desired location with expect outdoor temperature from one to seven days.

2.1.3.2 Mid-term Prediction modules

These modules are solving tasks with daily, weekly and monthly energy consumption prediction. The inputs are expecting weather character (e.g., long therm averages) or calendar phenomena.

2.1.3.3 Meteorological modules

These modules serve to correcting consumption forecasting according to outdoor expecting temperatures. The prediction is specified according to actual weather. Modules enable on-line reading weather information through Internet.

Figure 2.9 shows how the missing data is substituted by Elvira system. It automatically detects losses and improbable values in data set and proposes the completion. In this correction mathematical methods are used based on spatio-temporal statistical data analysis.

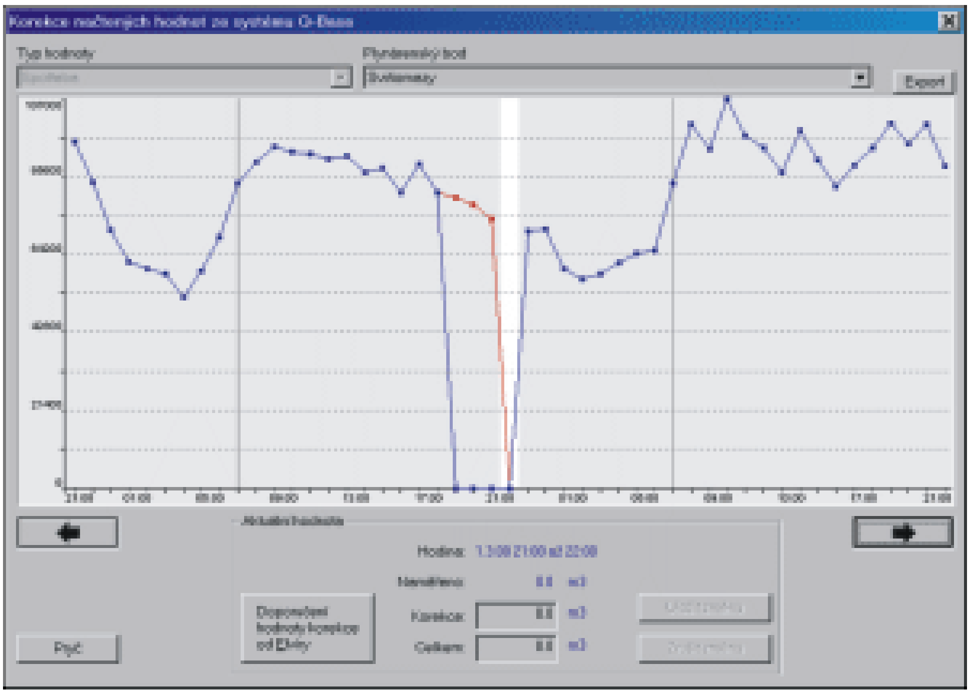

Figure 2.9: Filling missing values, (PELIKAN, E. - EBEN, K. - ŠIMUNEK, M. - KOLMAN, M. - HAIS, J., 2000)

2.1.3.4 Used prediction methods

In prediction systems Elvira are implemented several computing methods. For short-term prediction are used models with Box-Jenkins methodology, Kalman filters and neuron networks in combination with experts and fuzzy approaches. In addition, for longer time horizon are used decomposition adapting models decomposing the whole signal into easily predictable components.

The selection of suitable model depends on appropriate situation. The model suitability is given by e.g. type of prediction that is realized - very short-term, short-term, mid-term or long-term. The next condition to right model choice is location consumption character. If temperature gradient is varying, is not suitable to choose any stationary linear models. In this case is suitable to use an adapting non-linear model that immediately registered temperature change and make appropriate changes.

Figure 2.10 shows the really difficult modeling of consumption dependence (Z-axis) on cloudiness (X-axis) that is varying during one year (Y-axis).

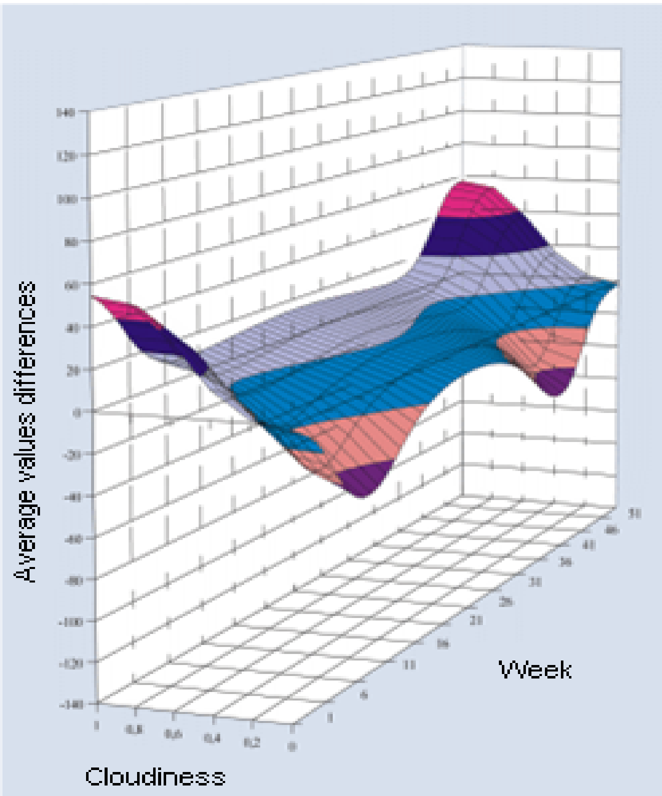

Figure 2.10: Consumption dependence on cloudiness, (Pelikan, E. - Eben, K. - Šimunek, M. - Kolman, M. - Hais, J., 2000)

It is not possible to make one general model and this model to apply everywhere because of different consumption and temperature character in each region. Hence it follows that each region will have different model. Each model consists of one or more algorithms as it shows Fig. 2.11. The right choice is based on prediction efficiency evaluation for appropriate time interval.

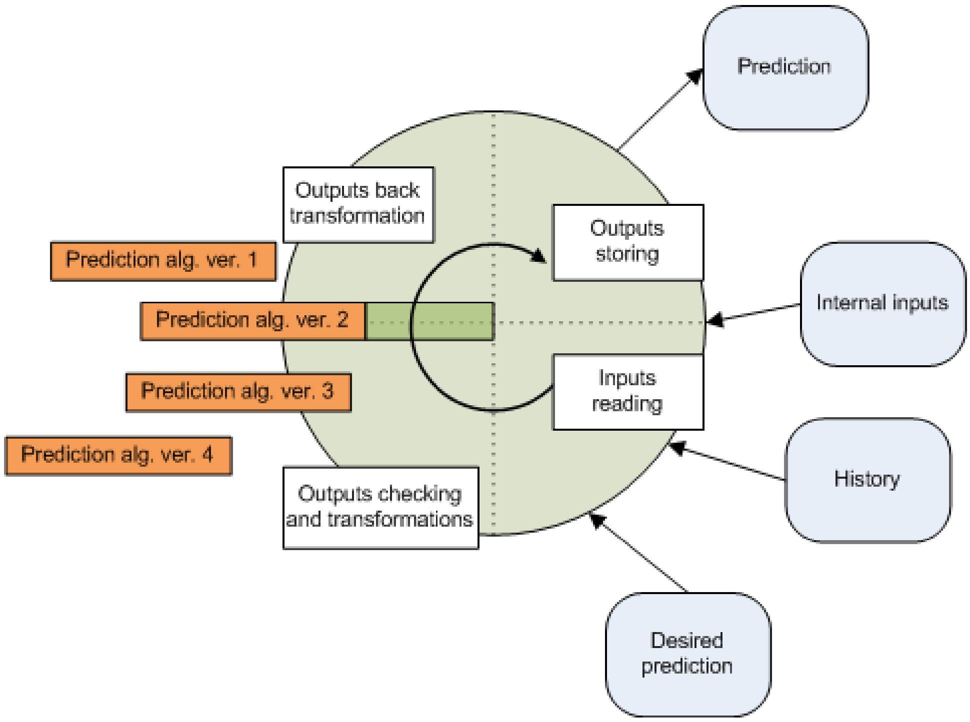

Figure 2.11: Combination of used models

2.1.4 Aspen Energy Management

Aspen Energy Management is an energy management system that is offered by Aspentech company.

Aspen Energy Management is modular application that is able to be integrated into the customers system to ensure his EM requirements. This modular system offers three components:

- Utilities Planner
- Utilities Operations
- Energy Cost Manager

These components of Aspen Energy Management can be deployed separately or together. From this reason it is suitable to use for incremental deployment.

2.1.4.1 Utilities Planner

Utilities Planner is suitable to use in cases when it is needed to know the future scenarios (tomorrow, one week, one year) in:

- Demand Forecasting (integrated with Planning tools)
- Production Planning (Boiler Load Allocation, Choice of Fuels, Choice of Drives, etc.)
- Emissions Prediction
- Budgets

The customer is able to achieve the optimum scheduling of maintenance with Utilities Planner. Next, faster response to problems (and better targeting of problems) is ensured by using this part of Aspen Energy Management.

2.1.4.2 Utilities Operations

This part of Aspentech energy management offers the operational advice. It provides, for example, the track performance.

2.1.4.3 Energy Cost Manager

The Energy Cost Manager is suitable to use, for example, when the user wants to visualize the true energy costs, when the user wants to be inform about contract limits and when the user wants to monitor the actual vs. target costs. The Energy Cost Manager provides active cost management or role specific views - it is able to see the appropriate impact of the each user to costs.

2.2 Full-Scale Implementation

As it was mentioned in the introduction of this chapter, there are solutions that offer Full-Scale implementation. It means that the solution includes both process and information level in comparison with the previous Sec. 2.1. In this case the company delivers both process control and information system (see Fig. 1.1 and compare Fig. 1.3 and 1.4).

In accordance with Sec. 1.3, the process level might include, for example, measuring units or actuators (it depends on the particular situations). Further, the measured values are stored in the process database. From this database the data might be transferred to the information database. The appropriate information system (a part of Energy Management System) is then able to report all the stored process and energy data.

2.2.1 SINAUT Spectrum

Siemens is the larges producer in European industry and also offers energy management system whose name is SINAUT Spectrum EMS. It is a classically representative of so-called Full-scale EMS. The whole general configuration can be seen in the Fig. 2.12.

The architecture of SINAUT Spectrum is scalable. Thus, this system is suitable for the configuration of network control systems of any magnitude, with all possible combinations of application programs.

SINAUT Spectrum provides database management functionality to network applications. Integrated in the data processing environment of customers company, it supports complete business processes.

The system topology in the Fig. 2.12 consists of two networks. The first one is an office network. On this network the management decisions are executed. The second one is generally a LAN (Local Area Network). This network provides the communication functions for all system components.

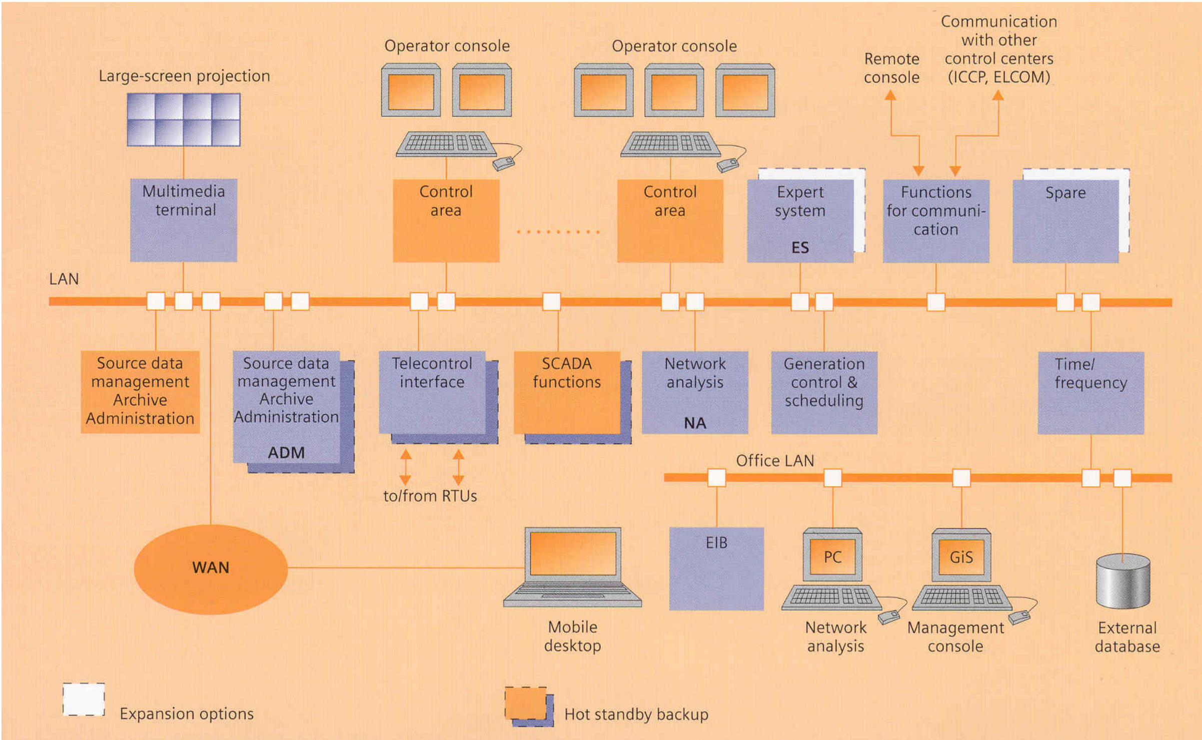

Figure 2.12: SINAUT system configuration, (Siemens AG, 2008)

A core function of network management is the optimal power flow. In the case of SINAUT Spectrum it is fully integrated in the control system, provides a clear, practical interface, and permits largely automated operational sequences and, at the same time, detailed analytical facilities for the specialist. In addition, the optimal power flow of SINAUT Spectrum provides the following advantages:

- Minimized transmission losses
- Reduced reactive power transmission
- Faster correction
- Elimination of transmission overloads in the most cost-effective fashion

SINAUT Spectrum enables full integration of the sub-functions in the SCADA subsystem and the general operation/display interface. Next, continuous optimization of energy utilization over all time ranges of operational planning, extending to annual energy scheduling. System is able to forecasting several processes simultaneously, including use of neural networks. Flexible, convenient facilities are the definition of energy properties and their billing, with interface to energy trading.

There are also integrated monitoring and reporting functions for quantities of energy, fuels and reserve capacity.

2.2.2 Power & Energy Management Solutions

With Power & Energy Management Solutions (PEMS) from Rockwell Automation the customer gains access to a complete portfolio of systems, products, communications and applications from the Complete Automation leader.

In the Fig. 2.13 is shown the structure of the Power & Energy Management Solutions. Each levels contains several optional devices that can be applied to ensure the appropriate requirements.

The lowest level is process layer. There are few programmable controllers that can be used not only to PEMS. Next layer is visualization level, so-called Powermonitors tools, and here is the situation the same as before.

On the higher level is Power Management Software that is the application core, see subsection 2.2.2.1. There are few option applications that differs, for example, in remote (web) vs. local access etc.

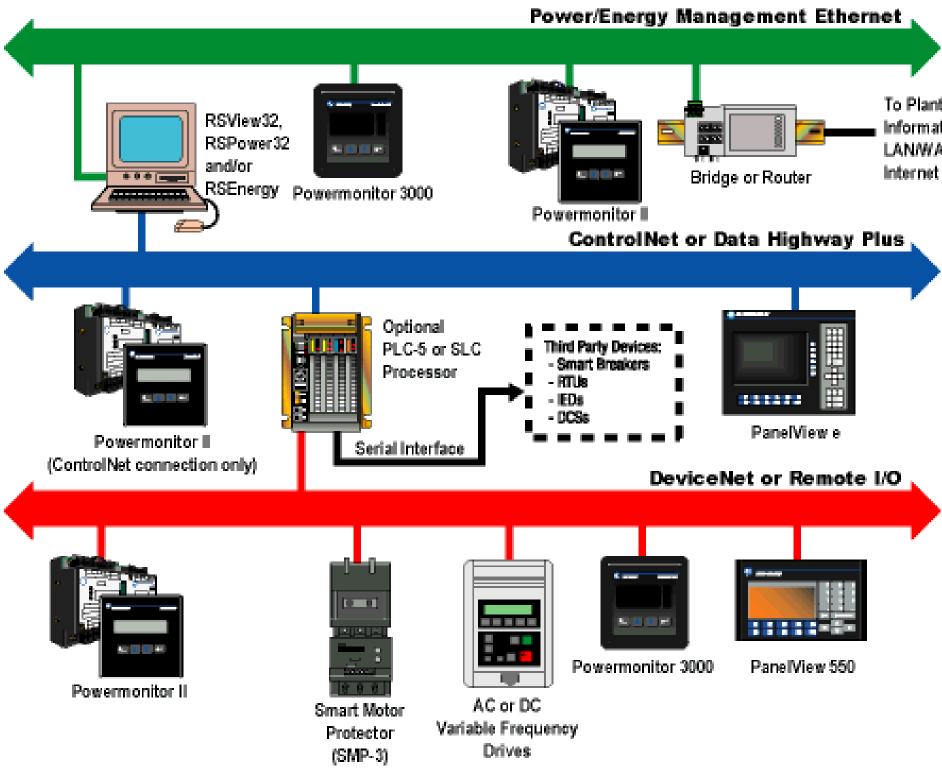

Figure 2.13: Rockwell Automation System Configuration, (Rockwell Automation, Inc., 2009)

2.2.2.1 Power Management Software

The PEMS software helps the user to configure Powermonitors and access energy data in real-time. The software also enables to capture, analyze, and share energy data the customers entire enterprise through standard web browsers. This causes that the data is easily obtainable and distributable.

RSPower32

This application is a stand-alone application as well as containing an ActiveX component for a user to configure and display information from Allen-Bradley power monitoring products. RSPower32 has simple screens for configuring and viewing data from power monitors. When combined with RSView32, RSPower32 adds these features directly to the RSView32 Project Manager interface as well as providing data for tags, alarming, data logging and trending.

RSPowerPlus

RSPowerPlus is a Windows-based application that expands the RSPower32 functionality from configuration and real-time monitoring of Powermonitors to include simple billing and trending via the TOU (Time Of Use) function available in the Powermonitor 3000 products.

RSEnergyMetrix

RSEnergyMetrix is sophisticated web-enabled energy management software that puts critical energy information at users desktop. The RSEnergyMetrix Software Suite combines data communication, client-server applications, and Microsoft's advanced .Net web technology to provide customers with a complete energy management solution, see Fig. 2.14.

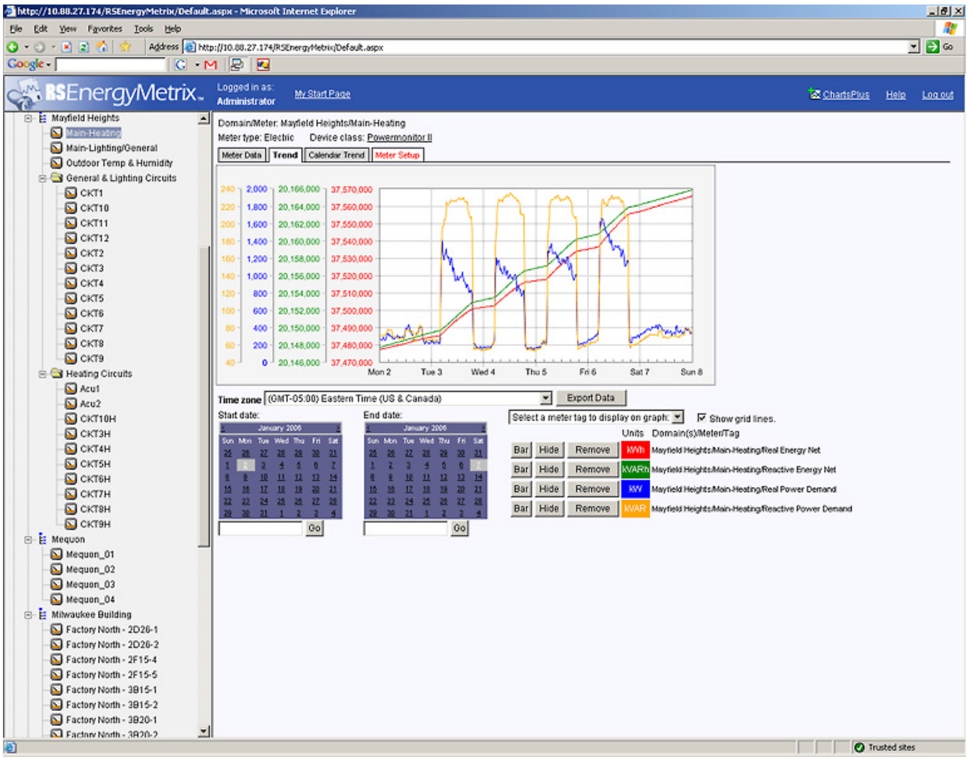

Figure 2.14: RSEnergyMetrix example, (Rockwell Automation, Inc., 2009)

In the Fig. 2.15 is shown one particular case with Rockwell PEMS. There is shown how the RSEnergyMetrix could be used in combination with PLS PM3000.

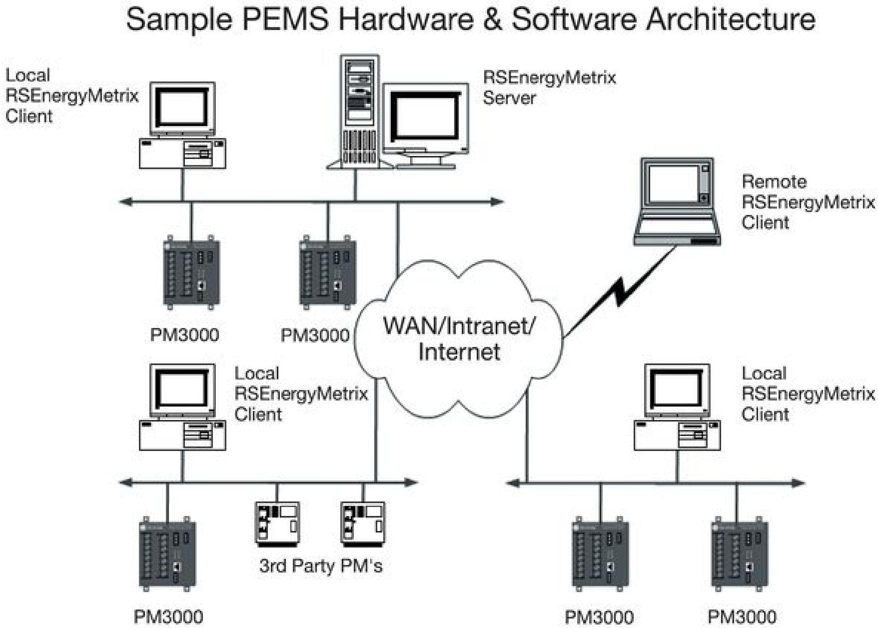

Figure 2.15: Rockwell Automation System Example, (Rockwell Automation, Inc., 2009)

2.2.3 PowerLogic

Schneider Electric offers a wide range applications that deal with energy data processing. These applications are part of PowerLogic software. The particular version useful for energy management calls PowerLogic ION Enterprise Energy Management (EEM).

PowerLogic ION EEM is a unifying application that complements and extends the benefits of existing energy-related data resources. These can include power monitoring and control systems, metering systems, substation automation and SCADA systems, EMS systems, building and process automation systems, utility billing systems, weather services, spot-market energy pricing feeds, and enterprise business applications. Data is automatically acquired, cleansed and warehoused.

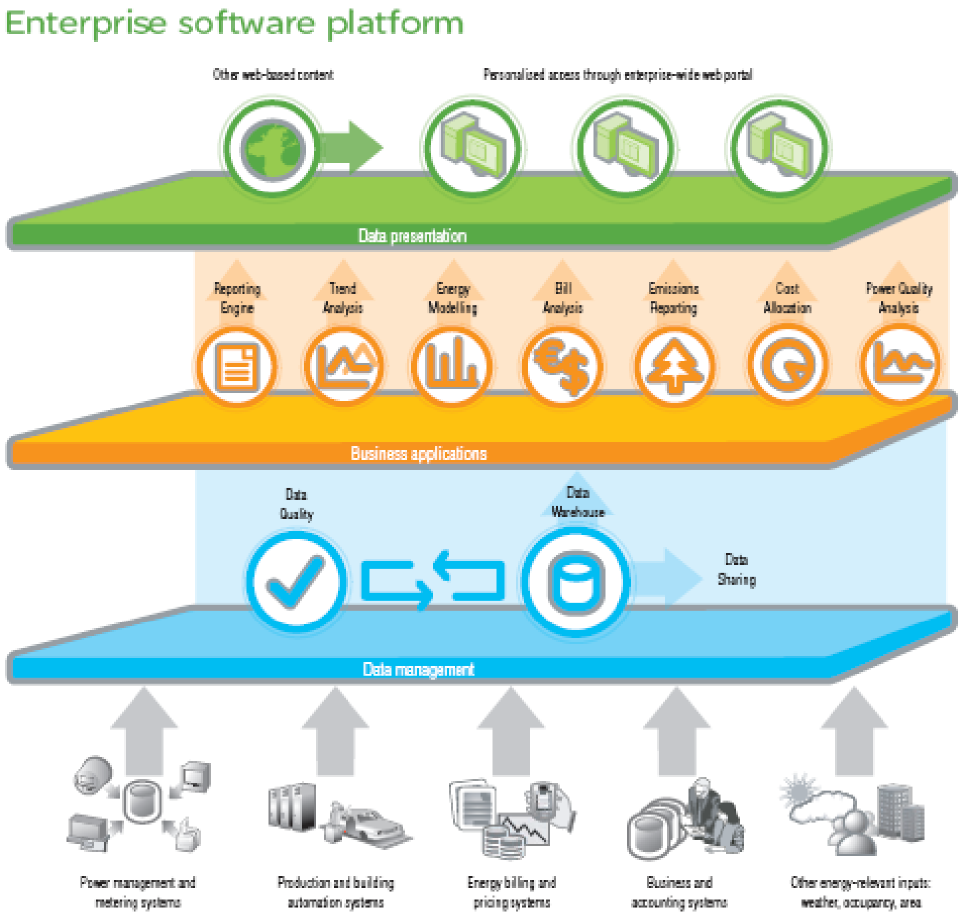

Figure 2.16: PowerLogic ION EEM platform, (Schneider Electric, 2009)

In the Fig. 2.16 is shown the whole application platform. Data presentation tier provides web portal that delivers personalized dashboards, reports, detailed analytics, and integration of other web-based content, see the Fig. 2.17. On the Business applications tier are tool for advanced analytics and reporting on every driver and relationship affecting energy cost and reliability. This level also offers tailors functionality to specific needs with a choice of included and optional modules: reporting, trend analysis, energy modeling, bill analysis, emissions reporting, cost allocation and power quality. Data management tier provides seamless integration of data from a wide range of sources:

- PowerLogic or third-party power management and metering systems: consumption data for all consumed resources, monitoring of all energy assets including power distribution and reliability equipment, generators, loads
- Building and process automation systems: BAS, EMS, DCS, and SCADA

- Energy billing and pricing systems: real-time pricing feeds, manual input of energy bills, and handheld devices

- Other energy-relevant sources: weather, occupancy, area

On this level is data warehouse based on Microsoft SQL Server, efficient data management tools, interoperable with other enterprise systems.

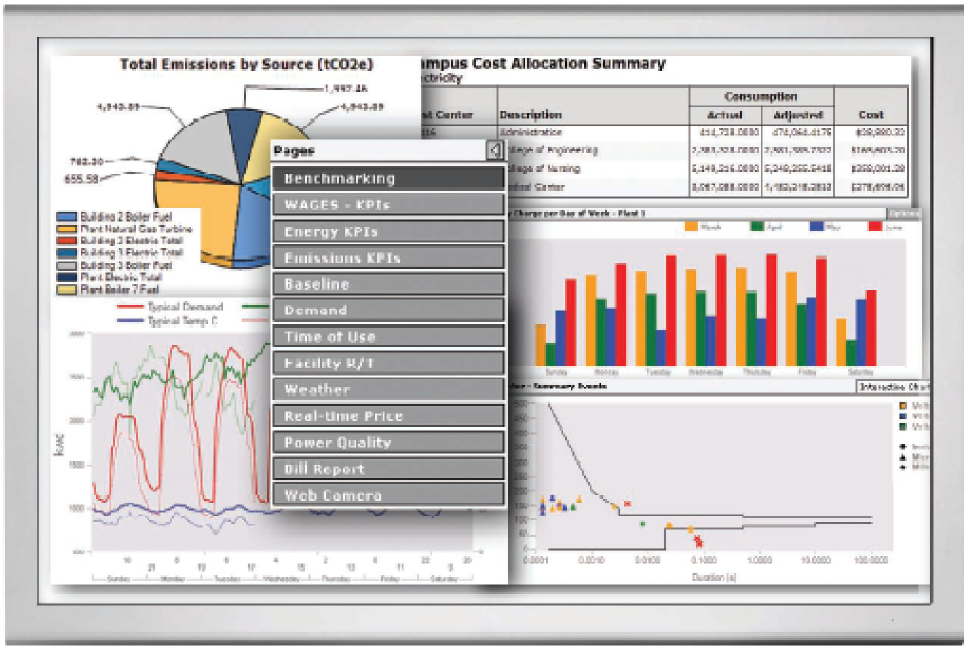

Figure 2.17: PowerLogic ION EEM, (Schneider Electric, 2009)

2.2.3.1 Web Portal

In Web Portal case manages user/group security model access by employees, customers, suppliers, or partners inside or outside a corporate firewall.

Portal also displays disparate information in a variety of formats: numeric, historical trends, charts, tables, reports, facility views, external web pages, and more.

This form also integrates real-time content (e.g. measurements, status and alarm indicators) from PowerLogic ION Enterprise or PowerLogic System Manager software, or third-party web-based automation systems for monitoring and management of loads, generators or other equipment.

Fig. 2.18 shows a Web Portal example.

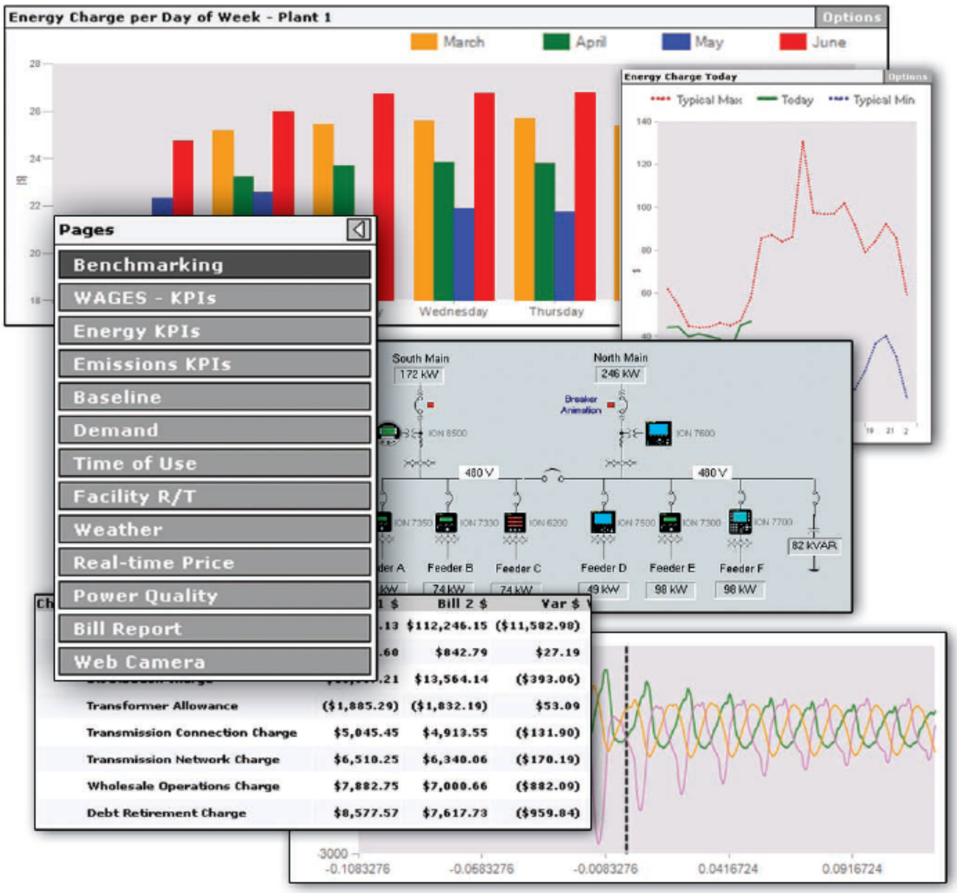

Figure 2.18: Web Portal, (SCHNEIDER ELECTRIC, 2009)

2.2.3.2 Reporting Engine

Reporting Engine enables rich billing, energy and power quality report generation capabilities with multiple pages and composite charts, tables, logos, images, hyperlinks or data from other systems. If is needed, there is possible to develop custom reports to ensure the customers requirements.

There is also schedule-driven delivery via e-mail or HTML format with notification.

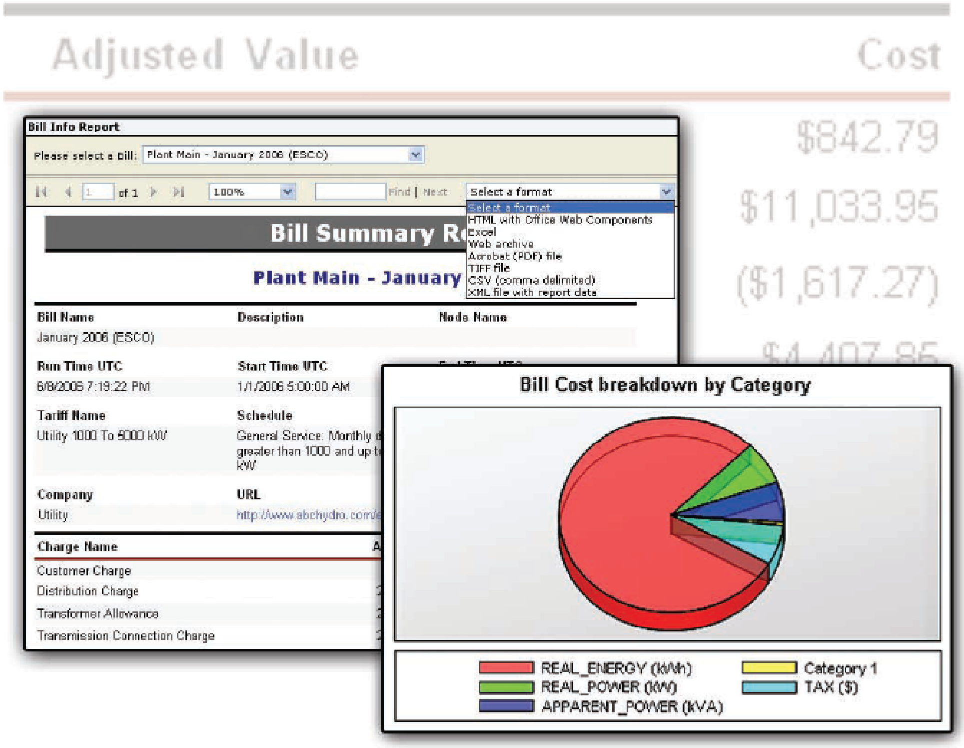

Figure 2.19: Reporting Engine, (Schneider Electric, 2009)

2.3 Summary

This section summarizes all facts that have been found out in the market survey in this chapter above.

There are companies that deal with the data processing in industrial area that don't have equipments to the energy data acquisition but they assume that they will use the data stored databases. The customer ensures the energy data acquisition. This category includes applications from Etap company - ETAP Energy Management System (see Sec. 2.1.1), StatSoft company - STATISTICA (see Sec. 2.1.2), Prediction System Elvira (see Sec. 2.1.3) and Aspentech company - Aspen Energy Management (see Sec. 2.1.4). All these applications offer simple data reporting, moreover Etap's application is able to intervene in the process control (see Sec. 2.1.1.3). On the other hand, StatSoft and Elvira dispose of energy consumption forecasting differing in approach to the problem modeling (neural network vs. linear/non-linear models). Further, Aspen Energy Management provides data monitoring on management level. Finally, one might say that implementation only on database level is suitable for data reporting and data prediction and in special cases also to process control.

If is needed advanced process control to ensure desired optimal process values, there are systems that solve this problem. The world leaders in industry are also interested in this location of industry production. Companies such as Siemens (Sec. 2.2.1), Rockwell Automation (Sec. 2.2.2) or Schneider Electric (Sec. 2.2.3) offer similar applications in energy management spectrum. All support SCADA standards and offer its own industrial equipment such as controlling and measuring units. The solutions differ, for example, in the approach how can the user access to the system in order to make some action. Rockwell Automation and Schneider Electric allow access to Energy Management System not only using local network (LAN) but also through Internet using Web interface (see Fig. 2.15 and Fig. 2.16). Reporting system possibilities of each mentioned companies are very similar, they differ, for example, in graphical processing.

None of these mentioned suppliers offer both prediction and reporting system that is suitable to use in industry field, is accordance with requirements that was noted in Sec. 1.3.1.

Chapter 3

PCS7 Based Energy Management System

In the Sec. 1.3 was defined the specific requirements on Energy Management System that is requested in industry field. The solutions that are noted in Chap. 2 offer either prediction or reporting. These solutions do not cover the customer requirements in industry field, see Sec. 1.3.1. From this reason was extended the existing Siemens PCS7 platform that was developed by SIDAT Ltd. The existing platform is suitable to report and predict the energy data and is able to satisfy the user requirements in industry.

In the Section 3.1 is described the general architecture of the industrial system that is based on PCS7 platform and that was extended for purposes of the energy management system.

This energy management system contains reporting subsystem and prediction subsystem. The prediction system was realized for the purpose of this thesis and represents the possibility of prediction the energy data. This choice is missing in the solutions mentioned in Chap. 2.

The energy management system consists of two basic layers: process and database. The description of process layer is in the Sec. 3.2. Here is explained, for example, the principle how the energy data is measured. The prediction subsystem is implemented on the database level and must meet several requirements. These requirements and the whole prediction system are described in the Sec. 3.3. Here are described the implemented prediction methods, the used prediction algorithm and the extension of the prediction methods in accordance with the thesis submission.

Energy data represents the amount of energy consumption in defined points in a factory. The each measured point is called "Tag" and this expression will be used in text bellow.

3.1 General Architecture

The general architecture complies with the Fig. 1.3. This solution supposes that the control system is based on PCS7 platform on the customer's side. The PCS7 IEM library was incorporated into the customer's system for purposes of energy management. The meaning of EMS servers and clients will be explain in accordance with the Fig. 1.3 bellow in text.

The existing customer's control system was extended with both reporting and prediction. The result of an appropriate system extension is energy management system that allows to report and to forecast values for desired tags. The general architecture of this energy management system is shown in the Fig. 3.1.

Usually, the whole energy management system consists of two basic layers, in accordance with Chapter. 1, section 1.3.

From the Fig. 3.1 one can see that the basic two layers are process layer and information layer. It follows that there are two separate communication networks: industrial and information. The industrial network could be extended by HMI (Human Machine Interface) network, that serves to process monitoring and or to control system parametrization.

The process layer includes PLCs on the lowest level. These PLCs serve to control the process and also to carry over (into the higher level) the energy quantities that was consumed - energy data. The measured energy data are transferred throw the industrial network into an archive that is the part of the WinCC server. Since the WinCC archive is not suitable for long-term data archiving is this problem solved by using the Historian server. Historian server serves to data archiving for years and is supplied by Siemens. The process level could contain several WinCC server redundant pairs, that increase the system safety. Next, there may be engineering and operator stations that serve to parametrization and monitoring the production system. These two stations may be connected to next separate HMI network.

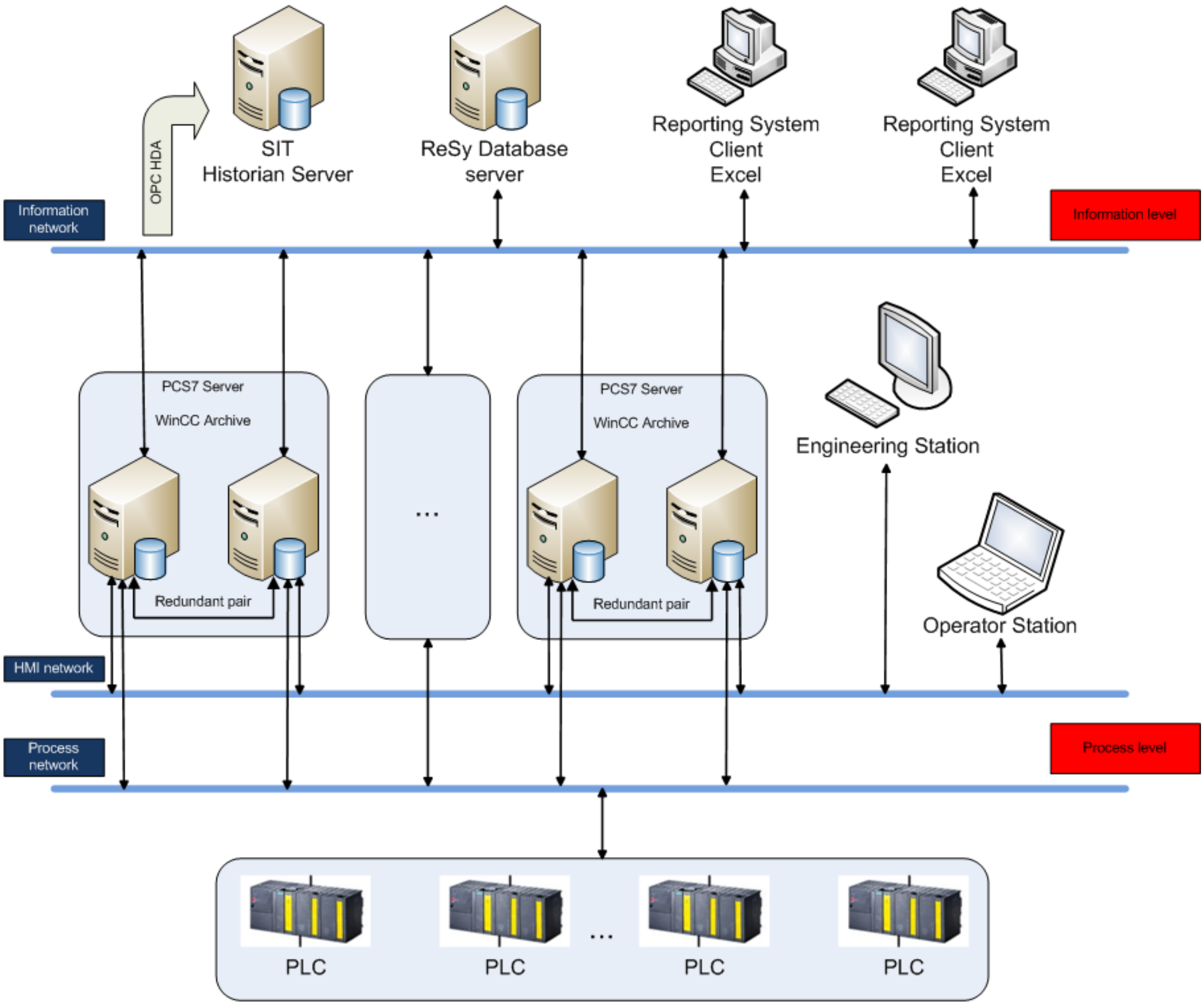

Figure 3.1: The Energy Management System topology

Typically, there are two servers on the information layer. The first one is the Historian Server whose role was explained above. The second one is so-called Reporting System (ReSy) server. Both process and energy data is stored into Historian server. The reporting part of Reporting System was developed by SIDAT Ltd. It is to be noted that the prediction and reporting systems are parts of whole Reporting System. All SQL commands are executed on the Reporting System server because the Historian server is used to data collecting. This causes the Historian Server is not so encumbered.

How does the Reporting System server look inside shows the Fig. 3.2. The Historian server uses standard interface to communication with Reporting System server. Generally, the Reporting System server executes specific requirements from Reporting System clients (see Fig. 3.2). Reporting System server also contains a SQL database.

Reporting System client is an extended Add-in Excel application that enables creation user desired options. In Excel sheet the user specifies his requirement by using an appropriate menu and it is sent to the Reporting System server. ReSy server accepts the request and uses either data in its own SQL database or uses stored SQL procedures to execute appropriate commands. SQL procedures that are stored in MS SQL database serve to data reading from Historian database where are archived not only all energy values of consumed energy for all tags. In the ReSy database is defined the structure of desired both Cost Centers and Tariffs, which was explained in Sec. 1.3.1 and which may be self-management by users.

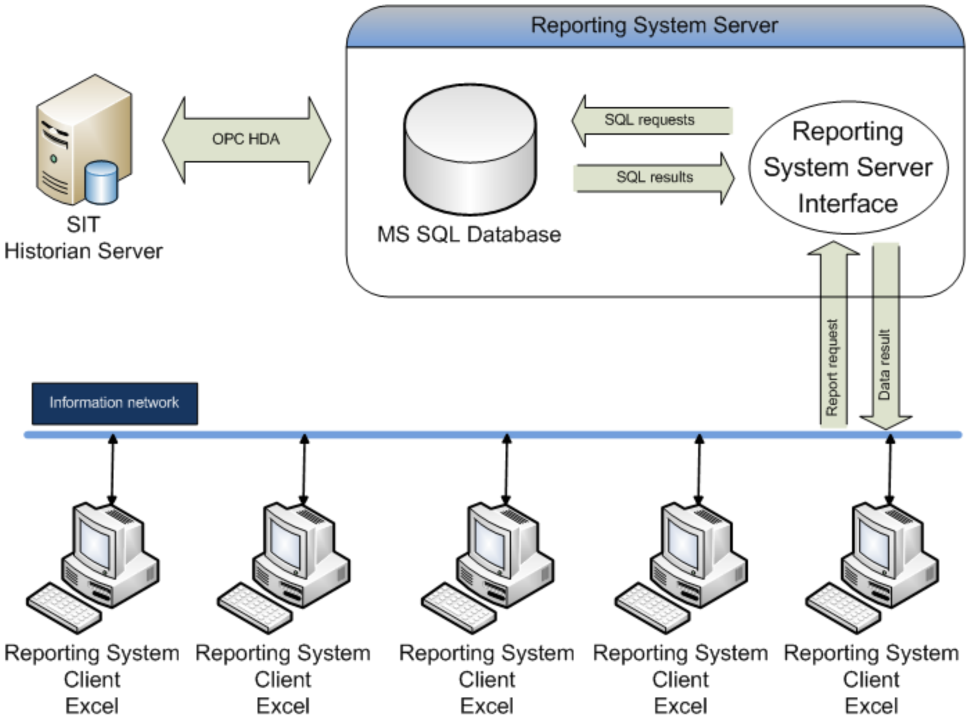

Figure 3.2: Information level topology of realized EMS

3.2 Process Level

This section explains the function of this energy management system on the process level.

What the process level includes was briefly mentioned in previous section. Process level is based on existing PCS7 platform that is deployed in industry.

Generally, the energy management system archive the energy data from appropriate

PLCs through industrial network on process level. This action is carried out after every defined time interval. The energy data are stored in WinCC archive server. WinCC archive server is not used for data archiving. For this purpose serves the Historian server. The energy data is stored in WinCC archive and after some time is transferred into the Historian database to long-term storing.

The energy data are archived form that is shown in Tab. 3.1 and the meaning of all values is described in Tab. 3.2.

Tag name	Time stamp	Value	Description	Quality
1S100_kW	2009-01-01 13:15:00	1342.654	Active power	Good

Table 3.1: Example of one tag in archive database

Value	Meaning
1S100_kW	Tag name_units
2009-01-01 13:15:00	Time stamp
1342.654	The summation result from 13:00:01 to 13:15:00
Active power	Tag description, the meaning
Good	Quality of appropriate Tag

Table 3.2: Example of one tag in archive database - values importance

3.2.1 SIMATIC PCS7 IEM Library

The core of this energy management system on process level is usage of IEM Library functions. This library offers tools that are suitable to measure energy values. The IEM Library was developed by SIDAT Ltd.

In this case are used two main functional blocks.

3.2.1.1 Summing block

This block calculates the current energy consumption for the specified time interval, in this case is the time interval 15 minutes. One summing block is created for each accumulated value - Tag. There are also defined the equality codes on output side.

IEM summing block can be represented by PCS7 standard graphic objects on the operator screen if requested which can give the following information to the operator:

- last logged accumulated energy value
- currently accumulated energy value in present period
- estimated value of accumulated energy at the end of present period

3.2.1.2 Synchronization Block

Synchronization Block serves as a clock generator for all summing blocks so that it is triggered by external synchronization signal or by internal real-time clock. In case of external synchronization the time-stamp for synchronization pulse is rounded to the nearest valid time according to expected period of external synchronization signal and current real-time clock value. Default value for length of the counting interval is 15 minutes.

3.3 Prediction

This section will describe the prediction system, that was developed in order to realize this thesis.

As it was mentioned above, the prediction and reporting systems are an extension of existing control system (PCS7 based solution) and are implemented on information layer.

From the Fig. 3.3 one can see that the Reporting System principle is in accordance with the Fig. 1.5. In this case the server consists of two servers on information level. As it was mentioned, the first one is Historian Server. The second one is server that ensures prediction and reporting services on the server side.

The prediction system was developed for MS Excel platform because of the reporting system that was developed by SIDAT Ltd. was developed for the same platform. This platform was selected because of it is most often used application used for data processing, computing or graph printing.

The application user interface is realized using by MS Excel sheet. It is possible to implement our own program by using the Visual Studio tools for Office runtime for MS Office 2003 into MS Excel. It follows that the MS Visual Studio was selected as the development environment.

From the Fig. 3.3 one can see that the MS Excel application represents a client side in the system topology. It follows that the prediction system imagines a server side that is a part of the Reporting System.

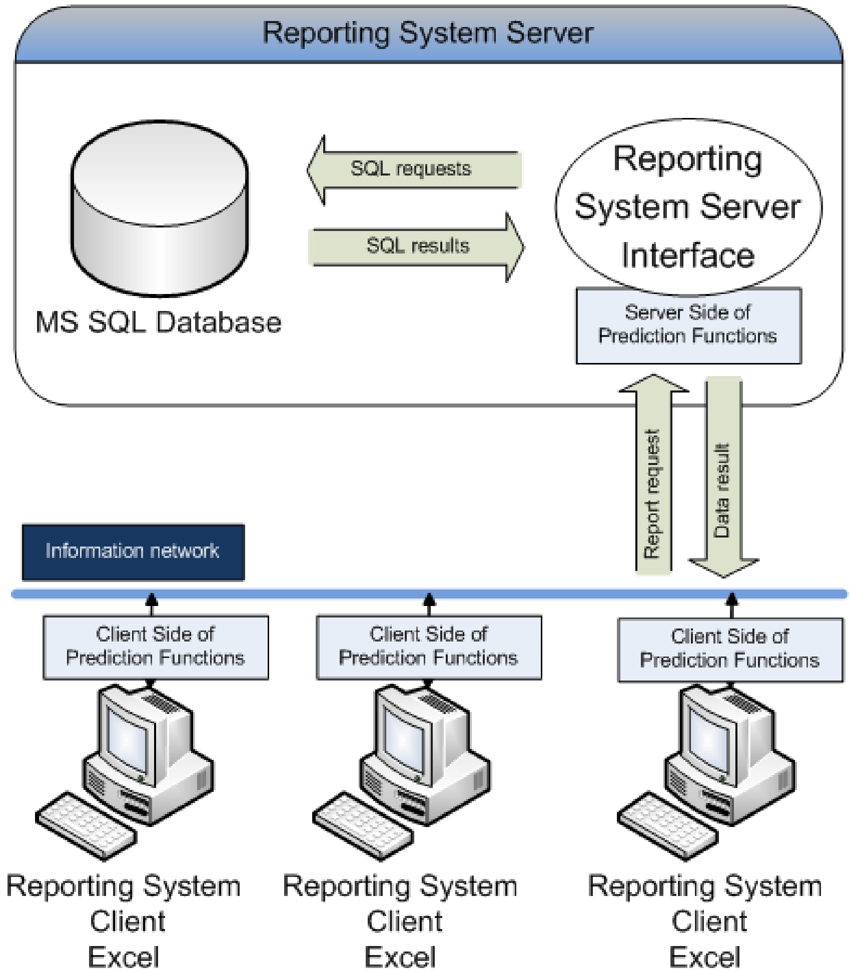

Figure 3.3: Topology and principle of prediction system

Based on the customers requirements mentioned in Sec. 1.3, the prediction system offers options that are included in next prediction methods:

- Predicted time interval
- Basic day prediction
- Basic weekday prediction

These methods use one prediction algorithm, described in the Sec. 3.3.2. The description of these prediction methods is in the Sec. 3.3.1.

The prediction system is extended by tag substitution values that may be used to compute the future values. This extended prediction form is explain in more details in the Sec. 3.3.3. Extended prediction could serve to prediction the energy consumption when the energy data is incorrect, for example, from maintenance reason. The user is able to define the substituting values that will be used to compute the predicted data.

There is also possible to omit the maximal and minimal values in appropriate datasets to determine the future values, see Sec. 3.3.1.1.

The user has to define the Reference Time Interval (RTI) independent on selected prediction method. From this time interval will be computed the prediction.

In the case when the data is missing in process database, for example, because of communication errors between Historian and Reporting System severs there will be used the implemented interpolation method to filling the missing values. The method finds out the missing value and appends it with previous value for each missing tag values. If the first value is missing in database, the method fills in the average value. It is computed based on all values from database that correspond with desired RTI.

If occurs any unusual situation, the user is informed by warning or information dialogs.

The user defines his requirements through the appropriate interface in Excel sheet, see Fig. 3.4. He has two choices to generate the prediction report.

The first one is to create the new clear Excel sheet. There is necessary to select appropriate tags, see Fig. 3.5. In this form is selectable one of the three tabs. Tags are sorted according to user-defined Cost Centers, Tariffs or according to tags that are not assigned neither to any Cost Center nor Tariff. The last case (tags selection) is shown in the Fig. 3.5.

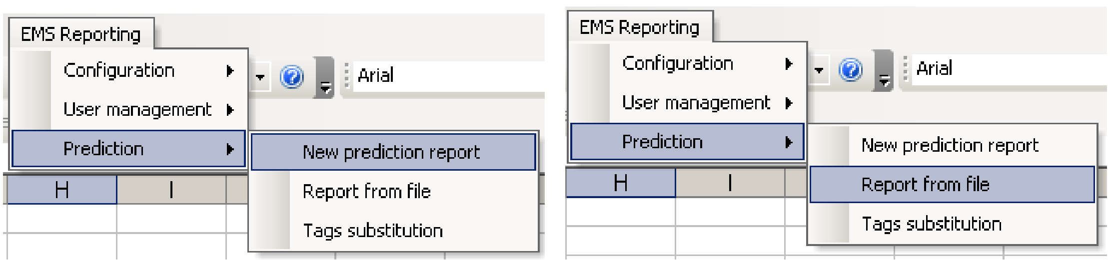

Figure 3.4: Prediction report creation methods

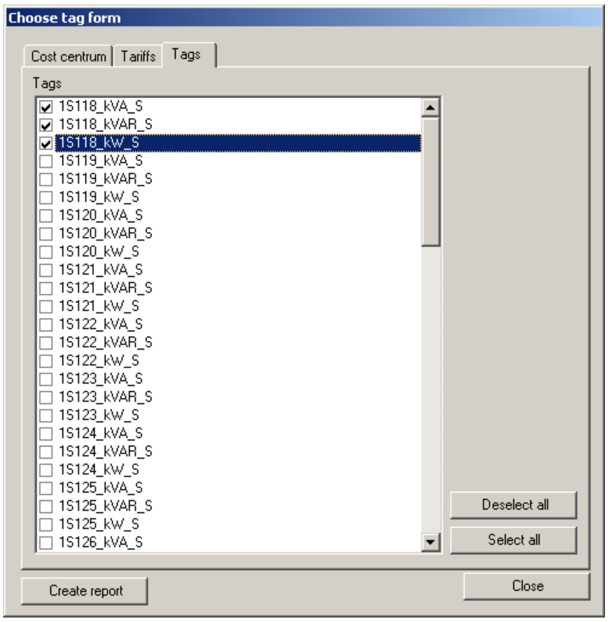

Figure 3.5: Tag selection

The second choice is to generate report with the prepared Excel sheet where the tags are defined. This choice is selected when the user has prepared tags to prediction in MS Excel Sheet. The tags must be defined in cells from "B1" right, see Fig. 3.6. After this step is the reference time interval definition followed in accordance with the selected prediction method.

The system is able to generate the prediction report as is shown in the Fig. 3.6. In this example two tags was selected. The Excel sheet contains several columns where the column "A" is reserved for time stamps and the other columns are determined to selected tags and their predicated values.

	A	B	C	D
1	**Time stamp**	**1S118_kVA_S**	**1S118_kVAR_S**	
2				
3	24.4.2009 0:15:00	1345,057858	389,9542217	
4	24.4.2009 0:30:00	1342,451839	388,9754772	
5	24.4.2009 0:45:00	1338,995461	383,793951	
6	24.4.2009 1:00:00	1346,897373	385,88132	
7	24.4.2009 1:15:00	1335,141975	381,6418858	
8	24.4.2009 1:30:00	1331,6833	375,5181799	
9	24.4.2009 1:45:00	1335,416637	374,8074493	
10	24.4.2009 2:00:00	1335,416637	374,8074493	
11	24.4.2009 2:15:00	1335,416637	374,8074493	
12	24.4.2009 2:30:00	1335,416637	374,8074493	
13	24.4.2009 2:45:00	1365,387619	397,4084091	
14	24.4.2009 3:00:00	1359,785069	393,3537731	
15	24.4.2009 3:15:00	1359,399632	387,8904629	
16	24.4.2009 3:30:00	1357,391243	384,22752	
17	24.4.2009 3:45:00	1362,382057	386,6841564	
18	24.4.2009 4:00:00	1367,001923	387,7904491	
19	24.4.2009 4:15:00	1368,58136	385,2857075	
20	24.4.2009 4:30:00	1369,8102	385,5292397	
21	24.4.2009 4:45:00	1372,710209	389,2971382	
22	24.4.2009 5:00:00	1373,519463	392,414011	
23	24.4.2009 5:15:00	1362,431015	386,1766434	
24	24.4.2009 5:30:00	1365,766315	388,6256676	
25	24.4.2009 5:45:00	1380,211056	400,7896442	
26	24.4.2009 6:00:00	1383,928616	400,5748463	
27	24.4.2009 6:15:00	1374,723801	394,9193802	
28	24.4.2009 6:30:00	1365,907768	390,5415993	
29	24.4.2009 6:45:00	1359,199898	383,6270695	
30	24.4.2009 7:00:00	1356,430916	379,5309849	
31	24.4.2009 7:15:00	1354,86425	376,2886219	
32	24.4.2009 7:30:00	1351,449318	372,6814709	
33	24.4.2009 7:45:00	1355,491951	372,0323353	
34	24.4.2009 8:00:00	1365,665627	379,9046059	
35	24.4.2009 8:15:00	1384,644386	392,3725433	
36	24.4.2009 8:30:00	1392,516151	398,3469639	
37	24.4.2009 8:45:00	1358,440659	390,9552326	
38	24.4.2009 9:00:00	1354,692734	389,2332706	

Figure 3.6: Prediction report example for two tags

3.3.1 Prediction Methods

The prediction system offers three methods how to predict the energy consumption. The selection of prediction methods is realized through the form in the Fig. 3.7. The user have to select one of them.

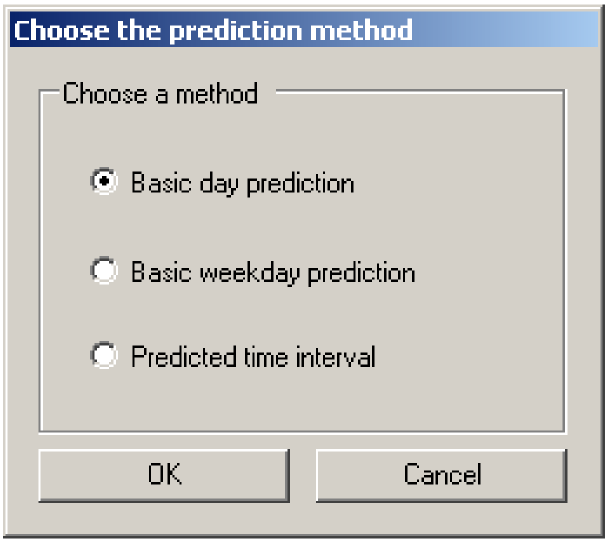

Figure 3.7: Prediction methods

3.3.1.1 Predicted Time Interval

The Predicted Time Interval method is method where the user may create a report by using two main ways. The first one is prediction by days and the second one is prediction by weekdays.

This method is available through the appropriate form, see Fig. 3.8. This form consists of four parts. The first one calls "Reference time interval". The user select the time interval that will be used to data reading from database - Reporting System database in this part. This dataset will be used to create the predicted values. Next part calls "Predicted time interval". The prediction will be executed for this time interval. The third part serves to track the selected tag by using a simple graph. The last part is a method selection called "Prediction method". The user has to select the prediction method, possibly, the method modification in this section.

The first choice of prediction method selection calls "Prediction by days". It takes the whole dataset that was defined by using the RTI. With this whole dataset is executed the prediction algorithm. Prediction algorithm produces predicted values only for one day. In the case where the Predicted time interval is longer then one day, the predicted result will be repeated for all days in this time interval. The prediction result will be saved into the Excel file.

The second prediction method calls "Prediction by weekdays". In this case is also possible to select the omitting the maximal and minimal values. Prediction by weekdays is based on similar principle as previous method. The RTI determinates the dataset. But, in this case are selected the appropriate weekdays in accordance with the Predicted time interval from the dataset. For example, if the Predicted time interval will be only from Monday to Tuesday, from the dataset will be selected only values that correspond to this appropriate weekdays - Monday and Tuesday. The prediction is executed after this selection. In the case when the Predicted time interval is longer then one week, the predicted result will be repeated in accordance with appropriate weekdays. If it is selected the omitting of minimal and maximal values, it will be used a method that omit the maximal and minimal values from the sorted dataset.

The user can track the raw data from database by using the simple graph component in an appropriate form. It may be used, for example, to determine the Reference time interval in order to achieve a higher prediction accuracy. The user can select the desired tag to tracking (by using the "Track to drawing" button) and based on the selected RTI is shown the appropriate curve. There is possible to enlarge the graph by using appropriate button.

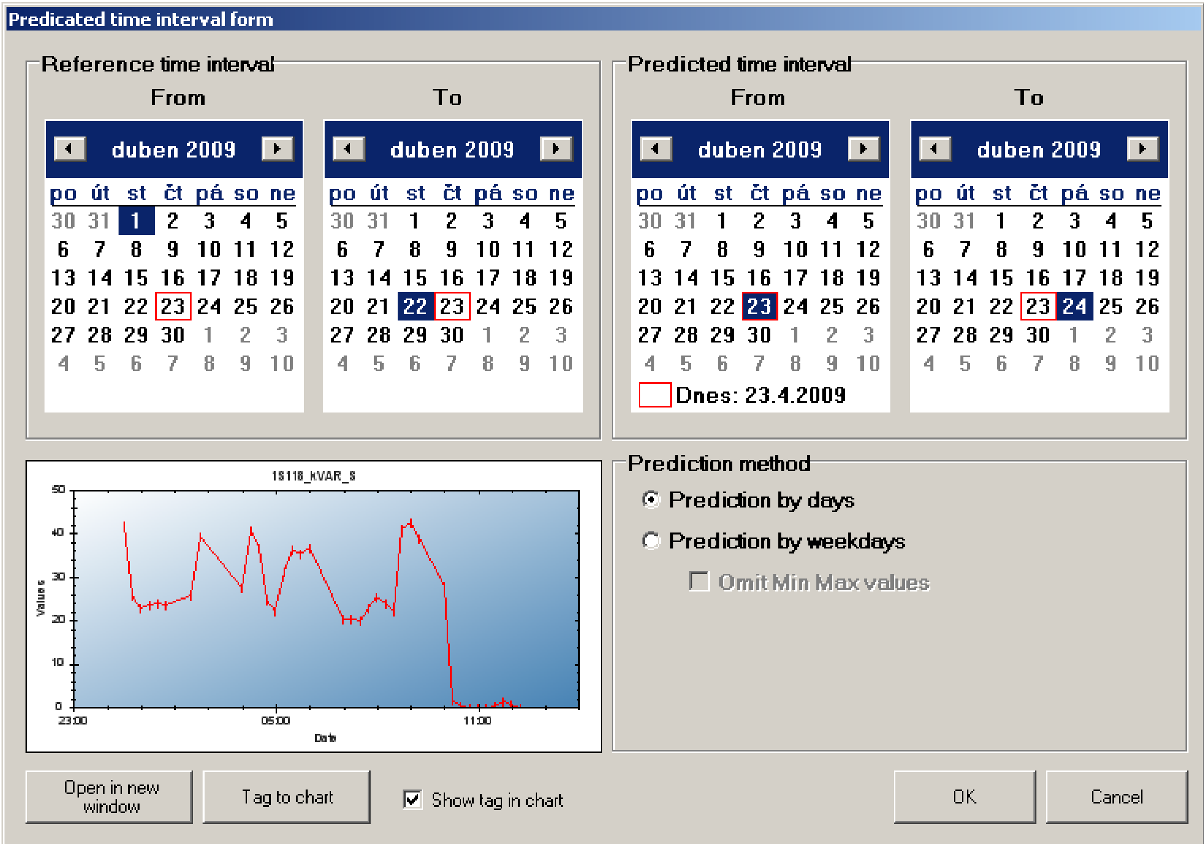

Figure 3.8: Predicated time interval prediction method

3.3.1.2 Basic Day Prediction

This prediction method is based on the same principle as it was mentioned in the Sec. 3.3.1.1. In the Figure 3.9 is shown the appropriate form. In this case the user has to determine only the Reference time interval.

The dataset is given by the selected RTI. The dataset is used for the prediction algorithm and no other operations are executed with it.

As it was mentioned in previous section, there is also possible to track the selected tag. The manipulation is the same as before.

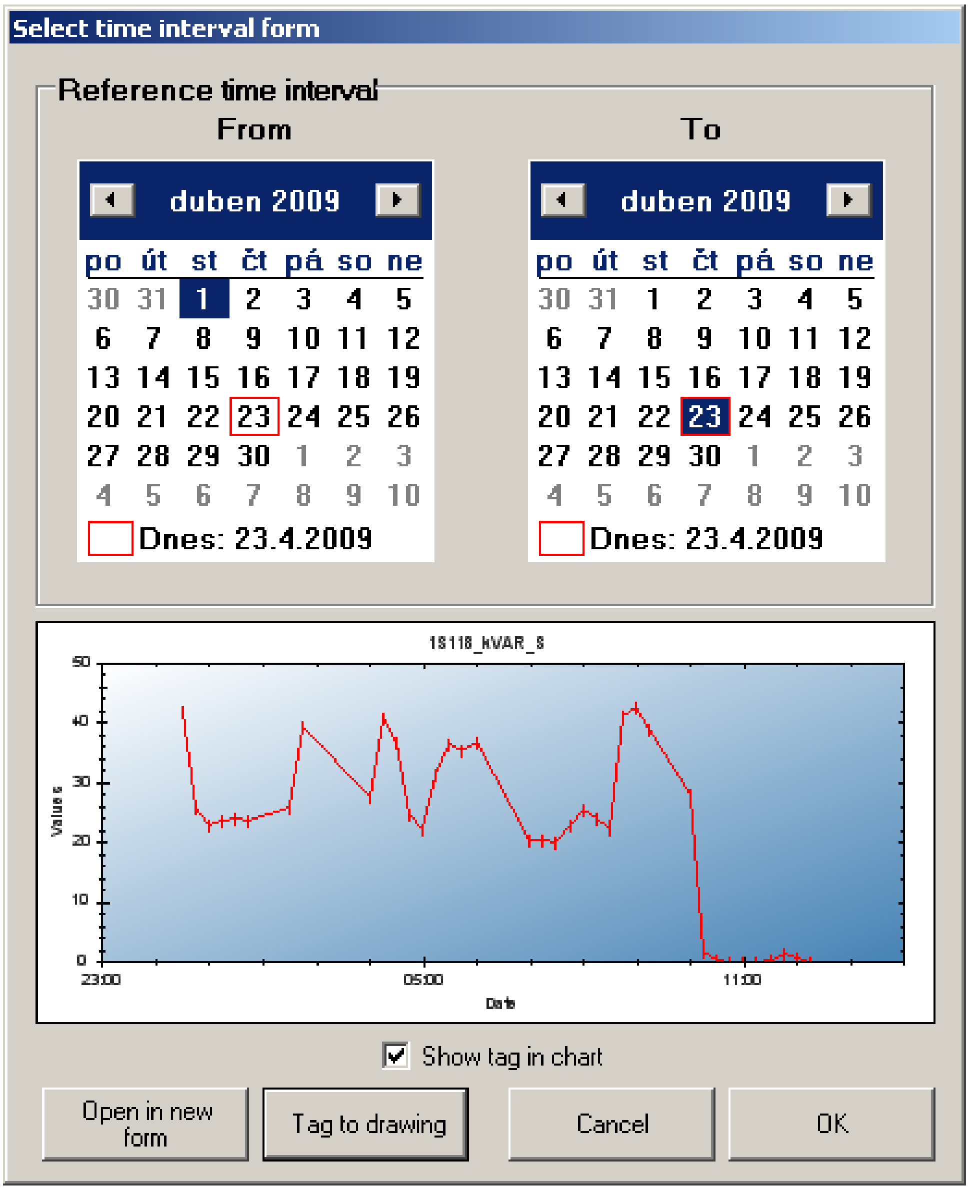

Figure 3.9: Basic day prediction method

3.3.1.3 Basic Weekday Prediction

This prediction method was also mentioned in Sec. 3.3.1.1 and is based on the same principle. The appropriated form looks as is shown in the Fig. 3.10. In this case the form contains both Reference time interval selection and weekday selection.

In comparison with the Basic day prediction method in this case the user has to select not only RTI but also weekday. This method will select all weekdays from the selected dataset and based on this selection is made the prediction on basic weekday.

As it was mentioned in previous section, there is also possible to track the selected tag. The manipulation is the same as in previous section.

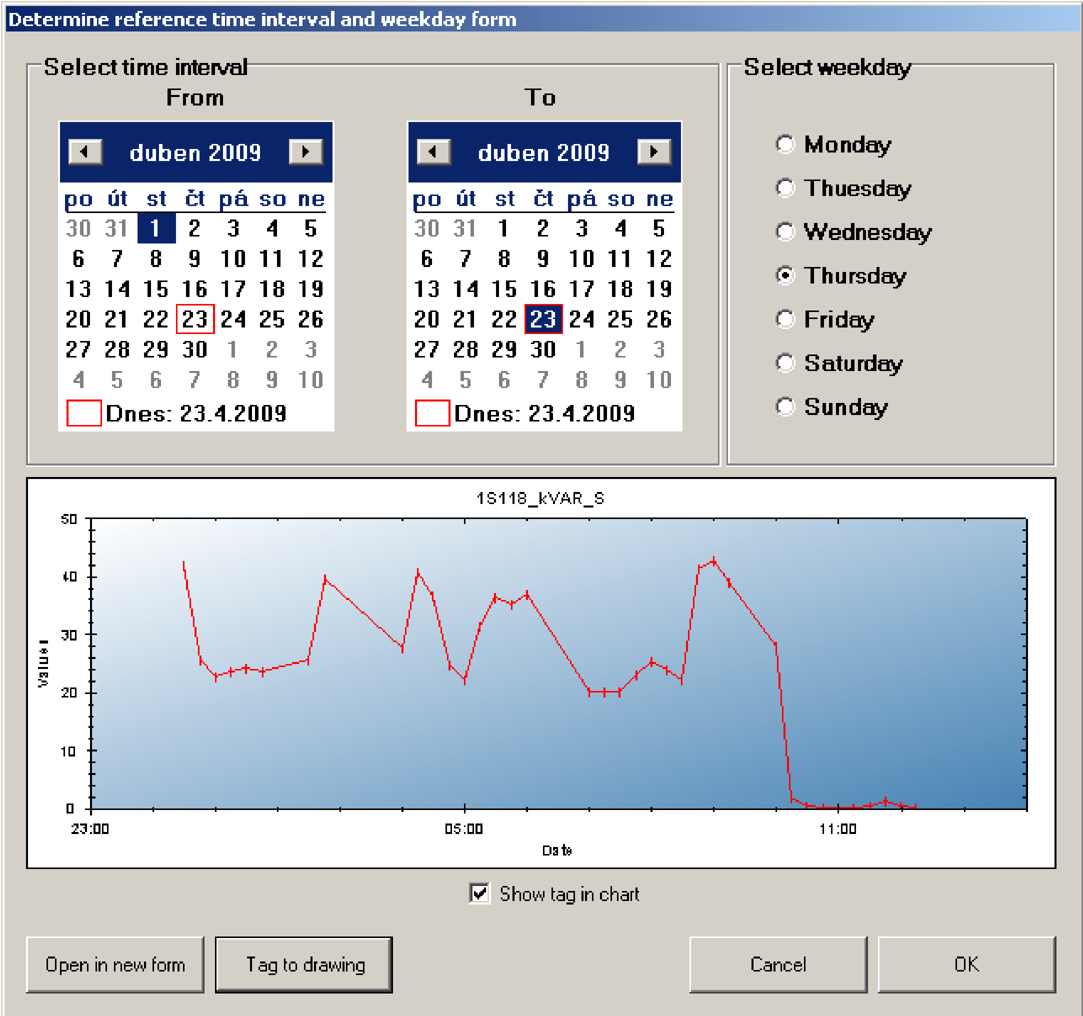

Figure 3.10: Basic weekday prediction method

3.3.2 Prediction Algorithm

There is implemented one prediction algorithm used to forecasting the energy consumption for all prediction methods.

The algorithm uses the dataset from all prediction methods as an input parameter. From this reason it does not matter on the selected prediction method.

The prediction algorithm collects all data records that have the same count of hours and minutes in the input dataset (it does not matter on the day). The collection contains

96 entries (96 times 15 minutes is one whole day). The algorithm computes average values for each collected entry. The result is 96 values that differ in the time stamps.

This prediction algorithm was selected because in this case are well known all parameters that could affect the energy consumption. There are not known any random components that could influence the manufacturing process and his energy consumption except failures.

3.3.3 Extension Prediction

The prediction system enables the tag values substitution and serves as an extension of this prediction system. This functionality could be used, for example, when some manufacturing part is broken. The production was stopped in this part and has no energy consumption. But, the user is able to define the substitution values for appropriate tags from broken manufacturing part. The substitution values are dependent on the user experience.

To define the substitution values servers the choice in Excel menu, see Fig. 3.11.

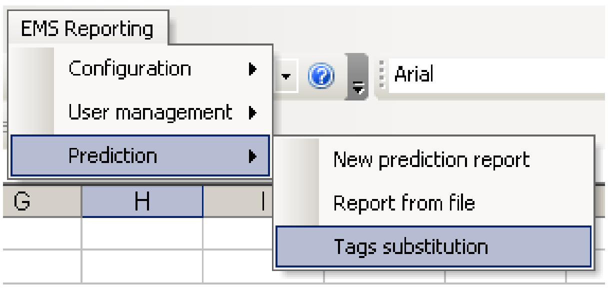

Figure 3.11: Substitution values menu

To overview of the all defined tag substitution values serves the form that is shown in the Fig. 3.12. From this figure one can see that the form enables tag selection. When the tag is selected the substitution values are in the table. If the table is empty, no substitution values were defined. An example of values substitution shows the Fig. 3.13.

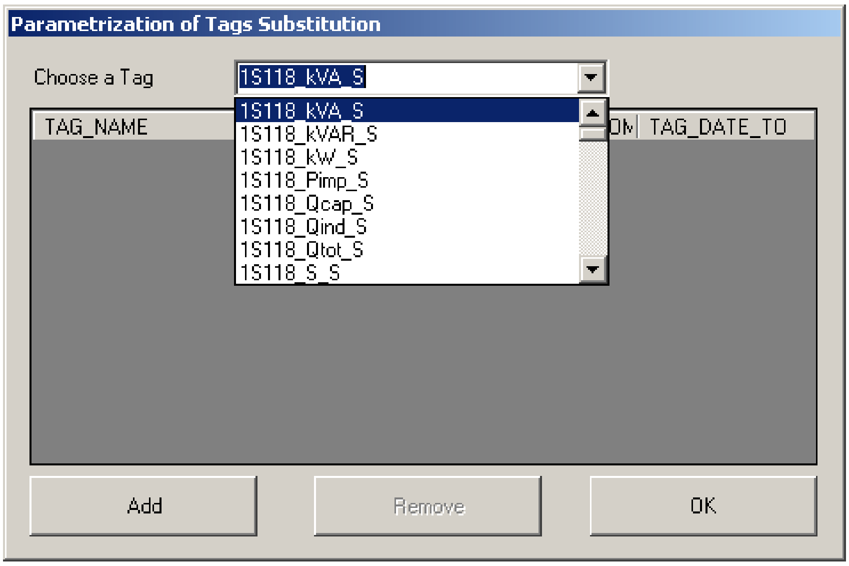

Figure 3.12: Tags Substitution Form

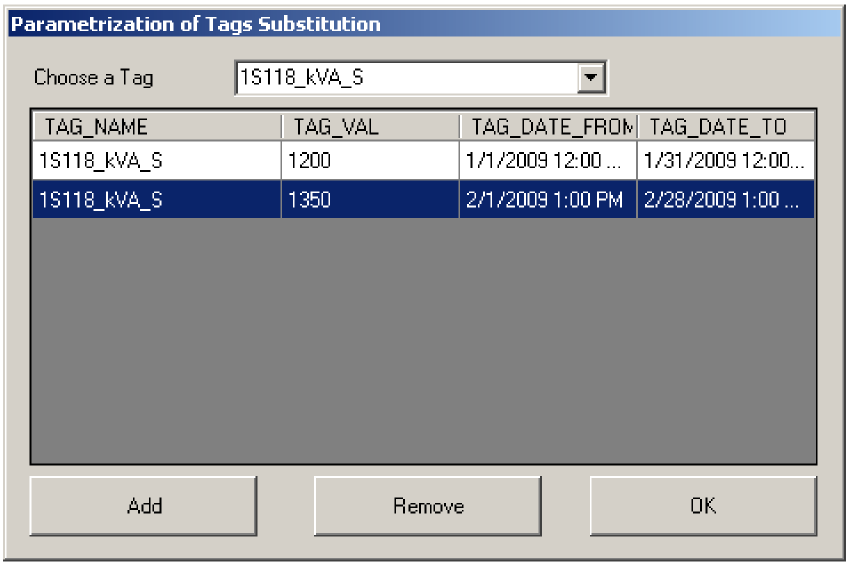

Figure 3.13: Tag substitution values example

The user can manage the tag substitution values for each tags by using the appropriate form. There is possible to add or to remove the defined substitution values. In the case when the user wants to add the substitution value it is necessary to define:

- The substitution values
- The begin of the value validity

- The end of the value validity

Example of tag substitution values is shown in the Fig. 3.14

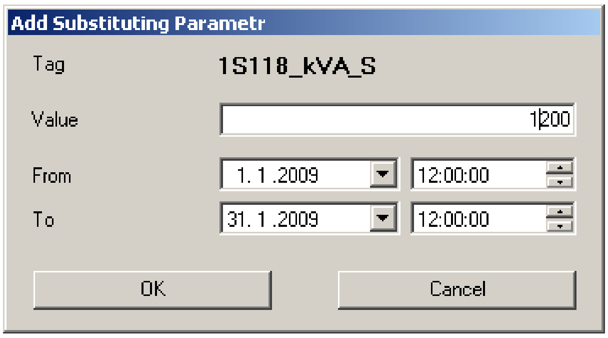

Figure 3.14: Adding a substitution value of a tag

If the tag substitution is defined for any time interval and the user wants to generate prediction report (the Reference time interval matches with the tag substitution time), the substitution value will be used despite of the existing process values to compute the prediction values.

3.3.4 Prediction Result

This section shows the result of prediction. In this case the data was used from 20.3.2009 to 27.3.2009 from a tag that represents a consumed energy (total power) in a technological process.

Figure 3.15 shows the values that was available during creating this thesis. The whole project is still in testing mode. The energy data sometimes are not consistent (data is missing because of communication errors between WinCC Archive server and Historian database) for long time, except data from 20.3 to 27.3. In this figure one can see that the energy consumption in this case (for the appropriate tag) is repeating with one day period.

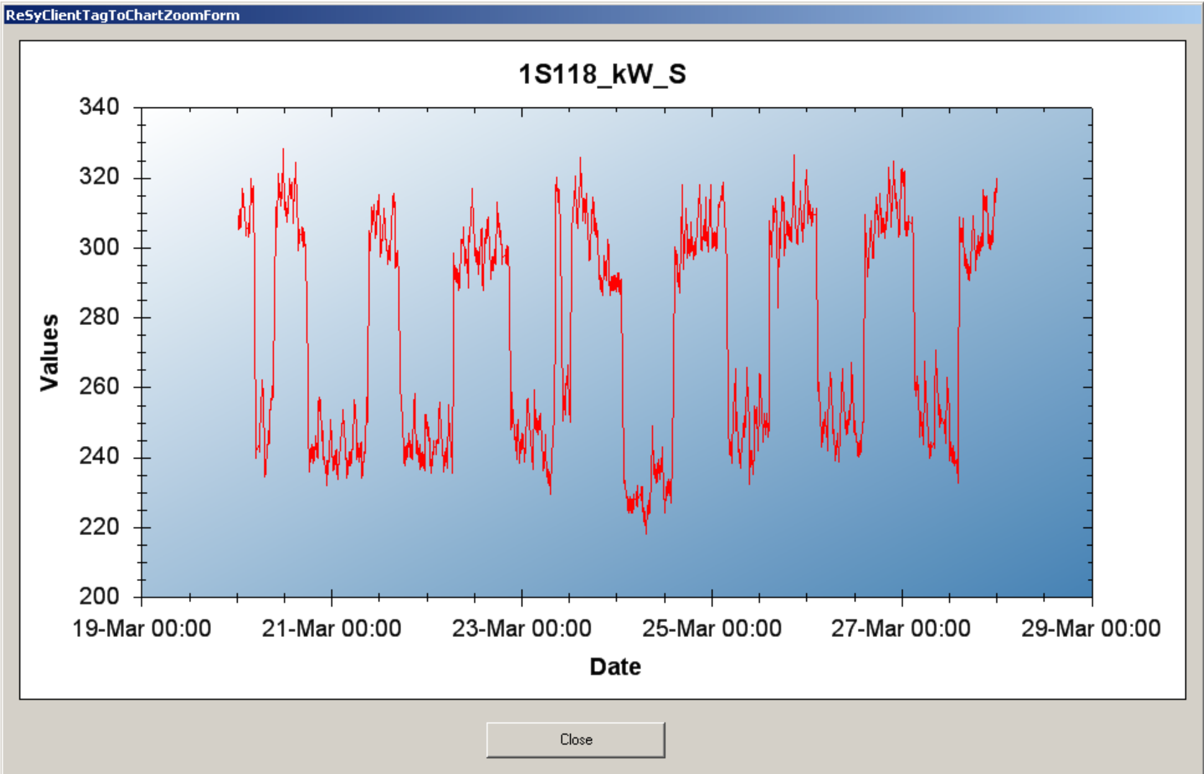

Figure 3.15: Source data used to prediction example

The result of prediction is shown in the Fig. 3.16. The prediction was determined based on the data that was mentioned above. As prediction method in this case was selected Predicted Time Interval, see Sec. 3.3.1.1. The length of predicted time interval was selected on one day as it shows the appropriate figure. The prediction style was selected as Prediction By Days. The resulting Excel sheet contains 96 time stamps (per 15 minutes) for one day. The resulting graph shows that the energy consumption is varying during the day. It is expected that the consumption will decrease from the higher value from 0:00 probably to 5:15. On this value the consumption will be probably by 14:15. Then it will rapidly increase back to the higher value as it was at the beginning.

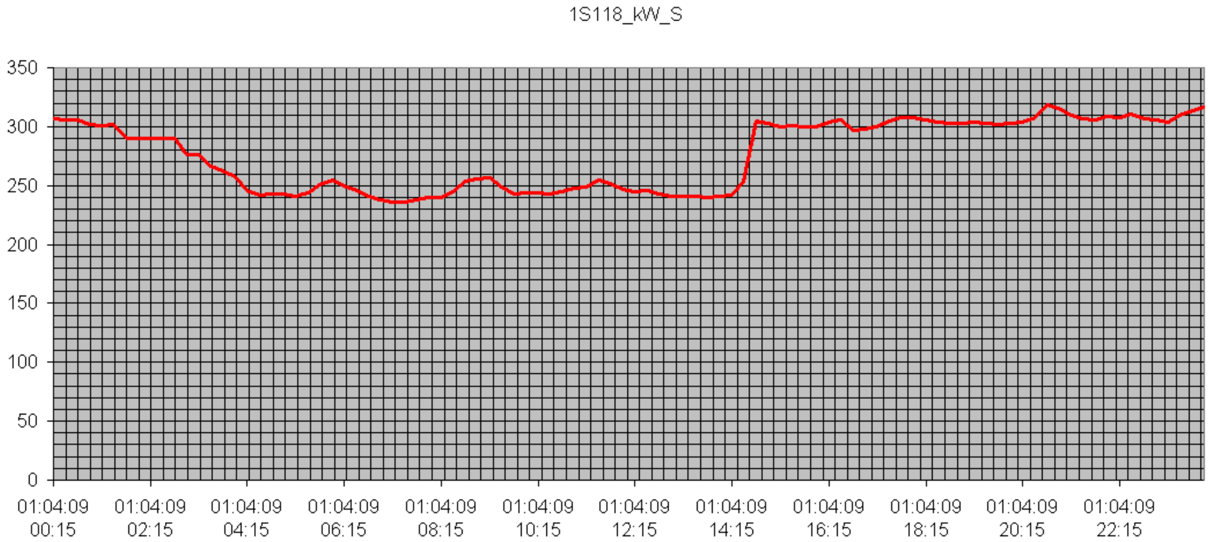

Figure 3.16: Result data prediction example

Chapter 4

Conclusion

In the Chapter 1 this thesis describes the energy management advantages and his requirements. This chapter includes both the general requirements and the requirements for industry applications. In the Section 1.3.1 the requirements are described for the Energy Management System for industrial applications. The topologies that are suitable to the EMS are explained in the same section. This overview served during looking for EM applications on the market. It serves also for the specification of implemented systems functionalities.

Chapter 2 consists of two basic categories in accordance with the term definitions in the Chapter 1. The first category is named Database Implementations, see Sec. 2.1. Here are listed the solutions that are implemented only on database level. It means that they use the stored energy data from customers databases. In one case the EMS is able to control the manufacturing process based on the both energy and process data, see Sec. 2.1.1. Other applications are suitable only for reporting or forecasting the energy consumption. The second category calls Full-Scaled Implementation (see Sec. 2.2) and includes EM systems that are implemented on both process and database levels. These solutions are provided by world automation leaders such as Siemens, Rockwell Automation or Schneider and they offer similar solutions in Energy Management. These solutions differ, for example, in the approach how can the user access to the system in order to make some action. Rockwell Automation and Schneider Electric allow access to their EMS also through Internet by using a web interface.

Chapter 3 is divided into three main parts. The first one describes the general system that is based on PCS7 Siemens platform, see Sec. 3.1. One of many requirements to this thesis was to use the PCS7 platform. The second one contains description of the process level that is used to purposes of the EM and is also based on PCS7 platform, see

Sec. 3.2. Here is mentioned the principle of the process level and the principle of the data acquisition by using the PCS7 IEM Library. The prediction system is described in the last third part, see Sec. 3.3. The solutions/applications described in Chap. 2 do not offer both reporting and prediction. But these two main requirements are required in industry, see Sec 1.3.1. That is the main contribution of this thesis: to extend a reporting system to satisfy customers requirements. This system extends the Reporting System that was developed by SIDAT Ltd. and whose user interface is MS Excel. From this reason the user interface for prediction system is MS Excel too. This prediction system offers options in accordance with the requirements listed in Sec. 1.3.1. Prediction system offers both the basic and the advanced predictions. The basic prediction computes the forecasting energy values from the energy data stored in appropriate database. The advanced prediction computes the prediction values based on the special parameterization. Both predictions results depend on the users experiences. The user must select the time interval in past that will be used to determine the future values. Prediction system takes stored values from database and computes the forecasting values.

The result of this thesis is prediction system that is embedded into the reporting system and the resulting system satisfy the requirements in industry that was defined in Sec. 1.3.1. The reporting system was developed by SIDAT Ltd. and uses MS Excel user interface. The prediction system satisfies the requirements of basic and advanced prediction. All measured energy points (tags) it is possible to sort according to cost centers or tariffs which the user has to define. This solution assumes that the process level will be based on the PCS7 Siemens platform and will used the PCS7 IEM library. It was the basic requirement of this thesis.

The whole system that consists of both prediction and reporting systems is tested in a commercial project as an Intelligent Energy Management System. Now, it is in testing phase and results of testing will be known in several months.

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Appendix A

Abbreviations

Symbol	**Meaning**
EM	Energy Management
EMS	Energy Management System
PEMS	Power & Energy Management Solutions
IEM	Intelligent EM
OLE	Object Linking and Embedding
OPC	OLE for Process Control
DA	Data Access
HDA	Historical Data Access
ReSy	Reporting System
RTI	Reference Time Interval
LAN	Local Area Network
SCADA	Supervisory Control And Data Acquisition
HMI	Human Machine Interface

Appendix B

User's Manual

To create a prediction report it is necessary to have a ReSySimplePrediction.dll library that enables to create a prediction report. The prediction reports are forecasting values of desired tags. Two prediction methods are implemented. These methods are described in more details below. The user must select a time interval from that data will be computed. Then, the user can select the prediction style. The prediction menu is available by clicking on **"EMS Reporting"** → **"Prediction"** (see Fig. B.1).

The user has two choices to create prediction report. The first is **"New prediction report"** and the second one is **"Report from file"**.

The tag substitution is also implemented. Tag values substitution is available by clicking on **"Tags substitution"**, see Fig. B.1. In this case the user is able *to define substituting values for each tag separately.*

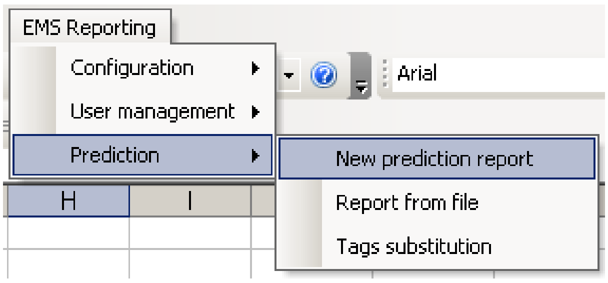

Figure B.1: The prediction method menu

B.1 New Prediction Report

New prediction report will be created into a new Excel file in an Excel sheet named **"RAW DATA"**. This choice is available by clicking on **"EMS Reporting** → **Prediction"** → **"New prediction report"**.

The next step is to define the prediction method (see Fig. B.2) through which the prediction report will be created.

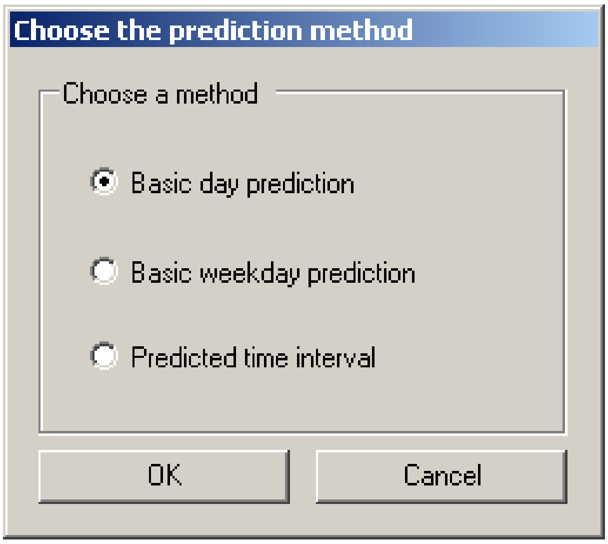

Figure B.2: Prediction method selection

B.1.1 Basic Day Prediction

In this case it is necessary to define for which tags the prediction will be computed. The same form here will be displayed as in Reporting System case and is not subject of this thesis. After all tags were selected, the user must click on button **"Create report"** in tag selection form.

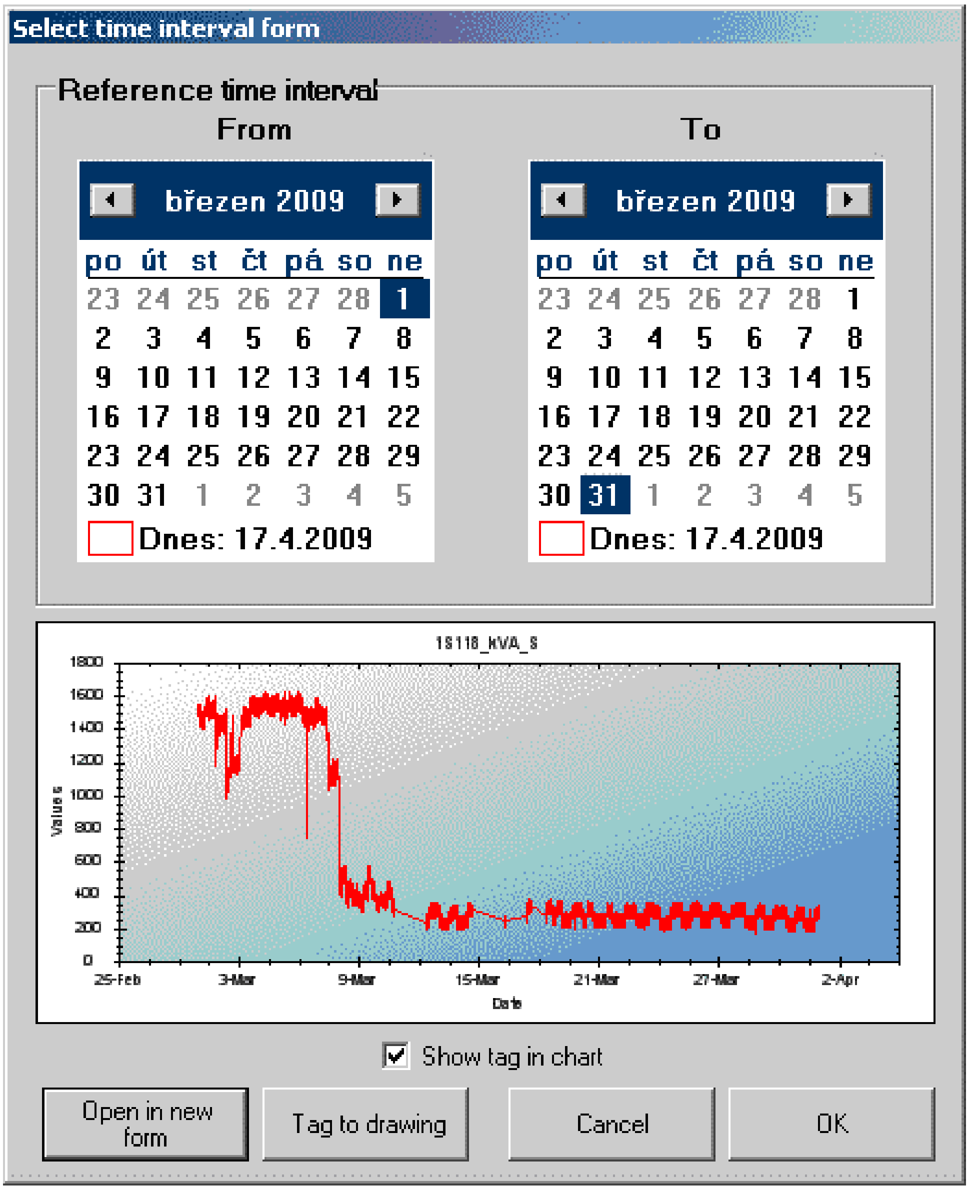

Figure B.3: Basic day prediction form

Figure B.3 shows the basic day prediction form. Here is possible to define the time range in the past that is used to computing the future values. The user selects (click on) both start date and end date in the past. This operation determines so-called reference time interval.

The predicated values are computed as an average values from stored data in database which is given by the reference time interval. If the data is missing (because of communication errors PLC - Historian server) in database, it is interpolated by using the previous values. Moreover, if the so-called tag substitution (see Sec. B.3) is defined for this reference time interval (the substitution value validity matches with the selected reference time interval), the final average values will be determined based on combination of the valid value substitution and the stored data in database.

Using this form it is possible to track the selected tag. The user can select one tracking tag by clicking on **"Tag to drawing"** button, see Fig. B.4.

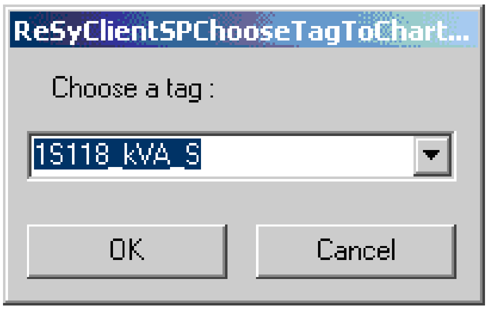

Figure B.4: Selection the tag to tracking in day prediction

To show the appropriate curve it is necessary to define the tag and check the check-box **"Show tag in chart"**. The check-box servers to speed-up the choosing reference time interval. It is recommended to uncheck this check-box, if the tag was selected, and determine the reference time interval. Then the check-box may be checked and the chart will be repainted. Each reference time interval change causes new data generation to display.

It is possible to enlarge the small displayed chart into separate form through clicking on the **"Open in new form"** button, see Fig. B.5. The **"Close"** button serves to close this form.

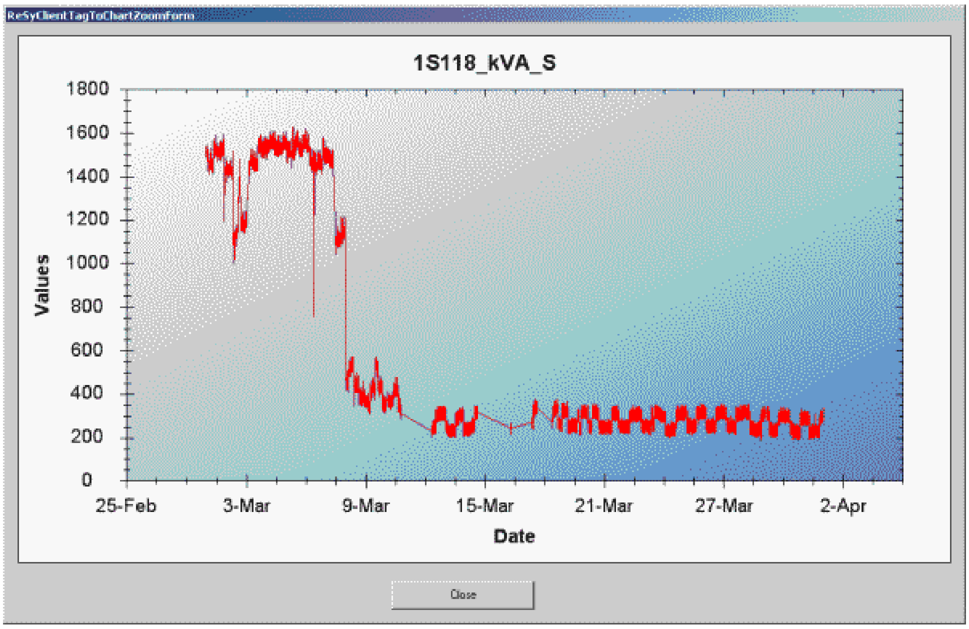

Figure B.5: Enlarged tracking chart in day prediction

To complete the creation of the basic day prediction report the user has to click on **"OK"** button.

The Excel sheet will be filled in with the predicated values. These time stamps are beginning the first day in January 1900.

Note: If the user defines the reference time interval as one day only (the reference time interval length will be one day), the resulting values are the same values as are stored in database for the appropriate day. This result depends on tag value substitutions. If the tag values substitution is defined for the desired day and appropriate tag, it will be used these values in final report. Next, if some data is missing in database for selected day, it will be used their interpolation values.

B.1.2 Basic Weekday Prediction

In this case it is necessary to define for which tags the prediction will be computed. The same form here will be displayed as in Reporting System case and is not subject of this thesis. After all tags were selected, the user must click on button **"Create report"** in the tag selection form.

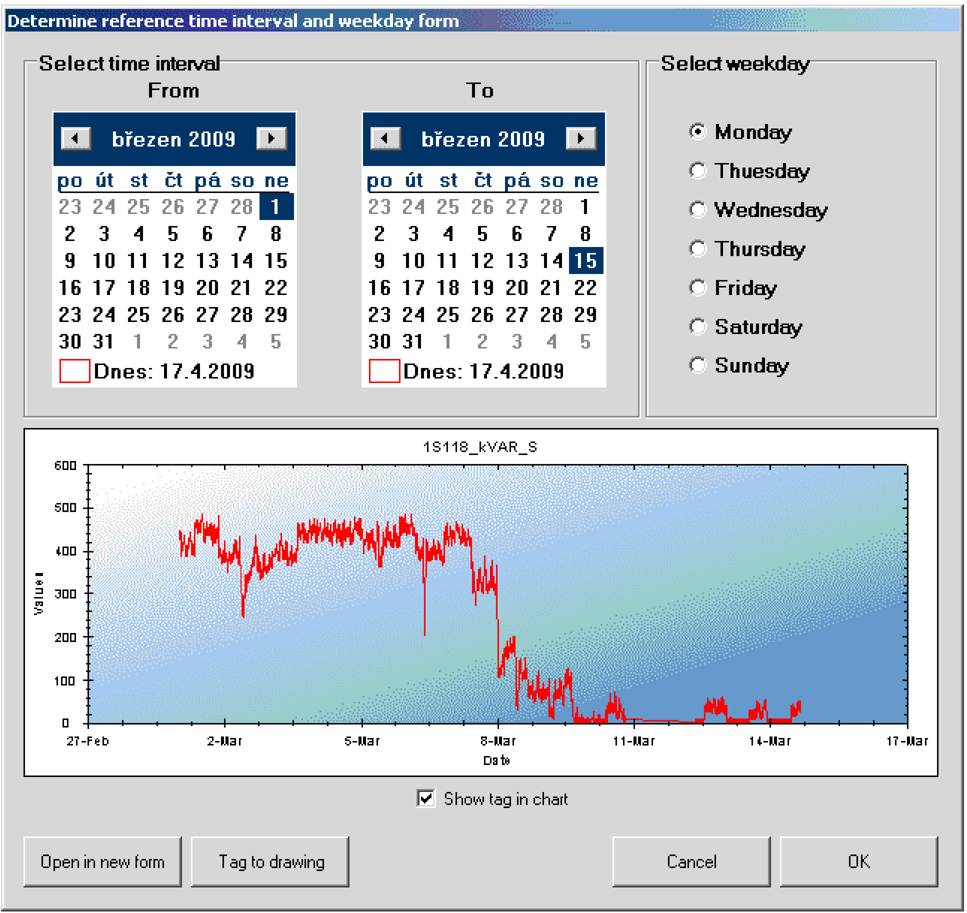

Figure B.6: Basic weekday prediction form

Figure B.6 shows the basic weekday prediction form. In this case it is necessary to define both reference time interval and the weekday for which the prediction will be computed. The user selects (click on) both start date and end date in the past. This operation determines so-called reference time interval.

The predicated values are computed as an average values from stored data in database which is given by the reference time interval but in this case are chosen only all appropriate weekdays. If the data is missing in database (in the past), it is interpolated by using the previous values. Moreover, if the so-called tag substitution (see Sec. B.3) is defined for this reference time interval (the substitution value validity matches with the selected reference time interval), the final average values will be determined based on combination of the valid value substitution and the stored data in database.

Using this form it is possible to track the selected tag. The user can select one tracking tag by clicking on **"Tag to drawing"** button, see Fig. B.7.

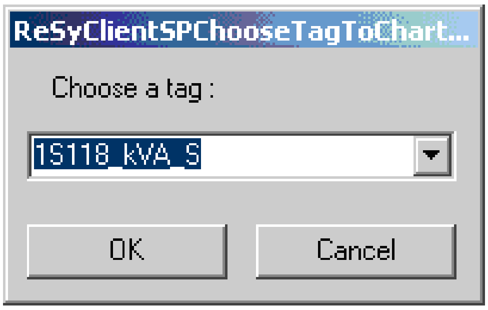

Figure B.7: Selection the tag to tracking in weekday prediction

To show the appropriate curve it is necessary to define the tag and check the check-box **"Show tag in chart"**. The check-box servers to speed-up the choosing reference time interval. It is recommended to uncheck this check-box, if the tag was selected, and determine the reference time interval. Then the check-box may be checked and the chart will be repainted. Each reference time interval change causes new data generation to display.

It is possible to enlarge the small displayed chart into separate form through clicking on the **"Open in new form"** button, see Fig. B.8. To close this form serves **"Close"** button.

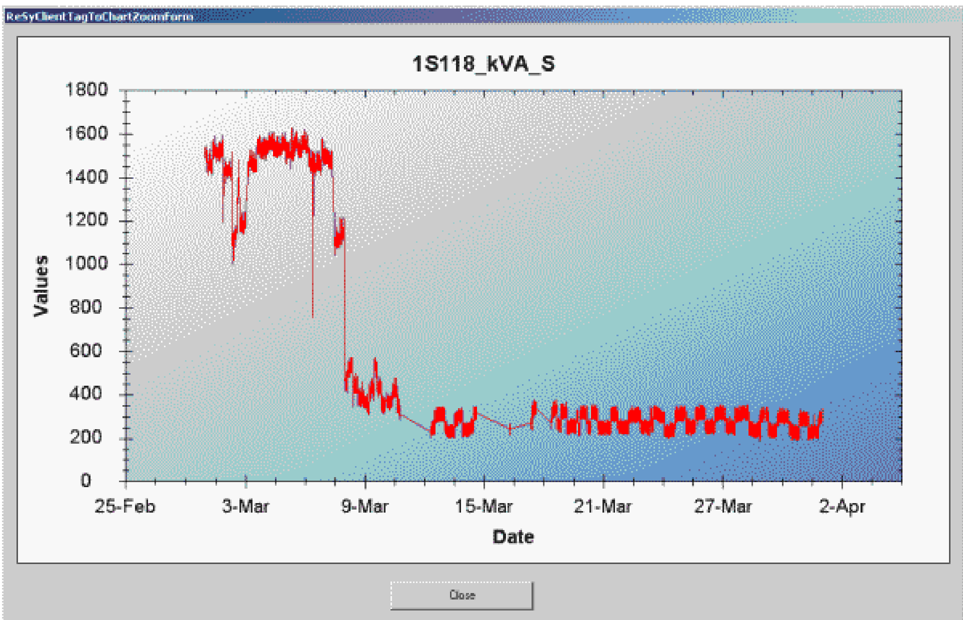

Figure B.8: Enlarged tracking chart in weekday prediction

To complete the creation of the basic weekday prediction report the user has to click on **"OK"** button.

The Excel sheet will be filled in with the predicated values. The time stamps start according to the selected weekday that is related to the first week in January 1900.

B.1.3 Predicted Time Interval

In this case it is necessary to define for which tags the prediction will be computed. The same form here will be displayed as in Reporting System case and is not subject of this thesis. After all tags were selected, the user must click on button "Create report" in tag selection form.

This form combines the previous two prediction methods.

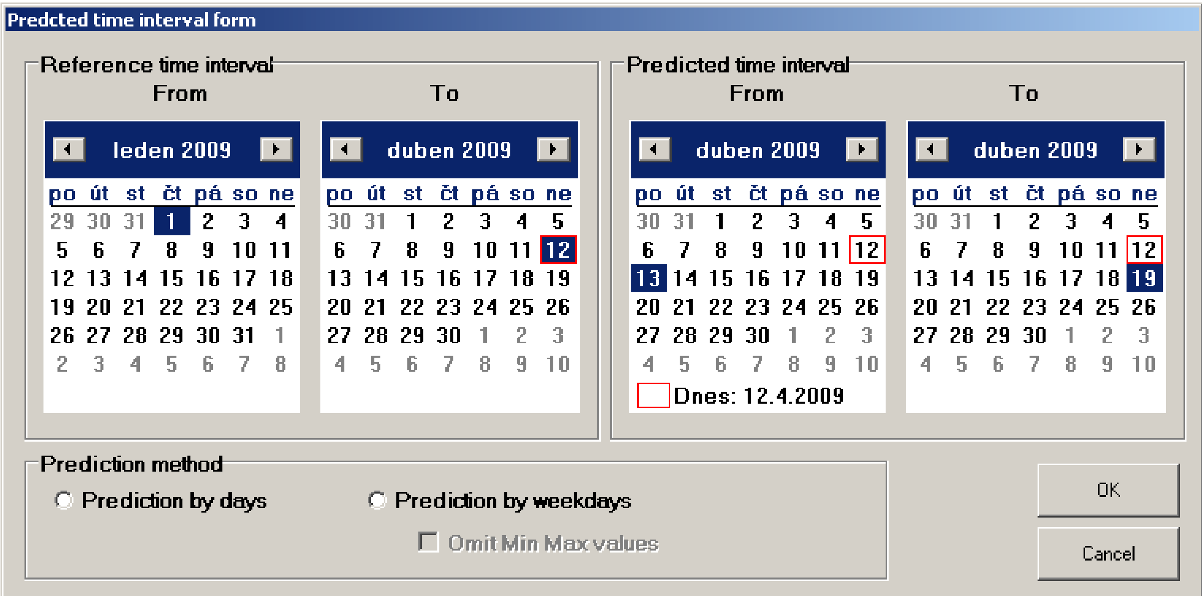

Figure B.9: Predicted time interval form

In the Figure B.9 one can see that this form consists of four parts. The upper half servers for determine the time intervals. As in previous cases there it is necessary to determine the reference time interval. This interval is used to data selection from database (in the past). The predicated time interval is the time interval for which the prediction will be computed. Its length could be from one day to several days.

Next parameter that has to be defined is the prediction method. There is possible to select two methods. The principles of the **"Prediction by days"** and **"Prediction by weekdays"** methods are the same as in previous two appropriate cases. Moreover in the **"Prediction by weekdays"** case is possible to select the option choice **"Omit Min Max values"** using checking the appropriate check-box.

In the **"Prediction by days"** case, if the user selects the predicated time interval that is longer than one day, the result in the Excel sheet will be the repetition of the whole first day. The average values will be the same for each day.

In the **"Prediction by weekdays"** case, if the user selects the predicted time interval that is longer then one day and is not longer then one whole week, the result will be average values on the appropriate weekdays which are determined by the predicated time interval. For example in accordance with the Fig. B.9, the result will be seven predicted days (form Monday to Sunday) that are determined as average values from the data (it was selected the appropriate weekdays only) that is given by reference time interval. If the predicted time interval will be longer then one week, the appropriate weekdays (which are repeated) will be repeated in the result Excel sheet. For example, if the predicted time interval will be 8 days (Monday to Monday), the resulting values will be repeated only for Monday.

Next, in the **"Prediction by weekdays"** case is possible to omit peaks (max and min) using checking the check-box **"Omit Min Max values"**. The appropriate algorithm will find the highest and the lowest value and then these two values will be omitted during determining the resulting prediction.

Using this form it is possible to track the selected tag. The user can select one tracking tag by clicking on **"Tag to chart"** button, see Fig. B.10.

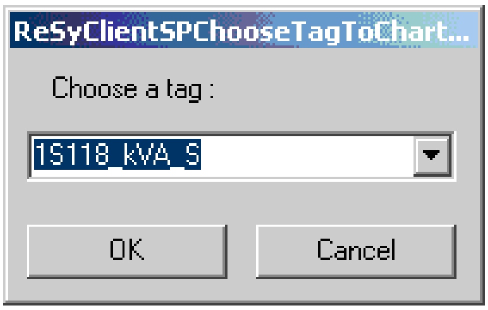

Figure B.10: Selection the tag to tracking in predicted time interval

To show the appropriate curve it is necessary to define the tag and check the check-box **"Show tag in chart"**. The check-box servers to speed-up the choosing reference time interval. It is recommended to uncheck this check-box, if the tag was selected, and determine the reference time interval. Then the check-box may be checked and the chart will be repainted. Each reference time interval change causes new data generation to display.

It is possible to enlarge the small displayed chart into separate form through clicking on the **"Open in new form"** button, see Fig. B.11. To close this form serves **"Close"** button.

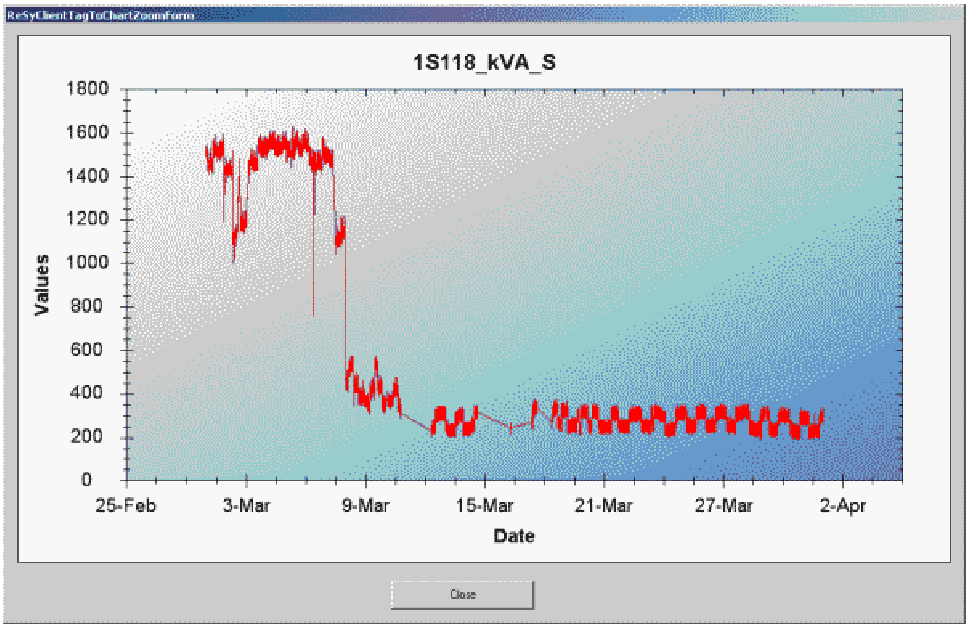

Figure B.11: Enlarged tracking chart in predicted time interval

To complete the creation of the prediction report the user has to click on **"OK"** button.

The Excel sheet will be filled in with appropriate time stamps and values. The time stamps are in accordance with the predicated time interval.

B.2 Report From File

This choice is selected in the case if the user has prepared Excel file that contains sheet named "RAW DATA" and the Excel cells contain the tag names from B1 to left horizontally.

This option differs with the **"New prediction report"** in the tag selection. In this case are tags defines in prepared Excel file.

The application behavior is the same as in the "New prediction report" case, see Sec. B.1.

B.3 Tags Substitution

If is needed to substitute the values for tags, there is appropriate form than can be obtain by clicking **"EMS Reporting"** → **"Prediction"** → **"Tags substitution"**.

When the user clicks on the choice Tags substitution it will be open the appropriate form, see Fig. B.12.

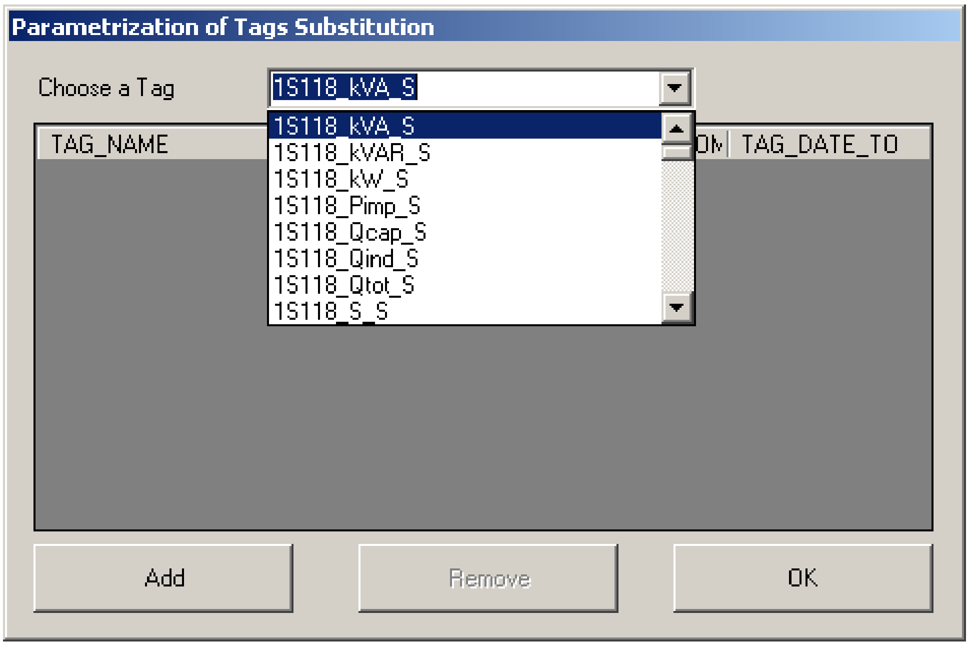

Figure B.12: Tag substitution form

If is defined the tag substitution for any time interval and the user wants to generate predicting report (the reference time interval matches with the tag substitution time), the substituting value will be used despite of existing process values to compute the prediction values.

B.3.1 Editing Substituting Values

To add or remove the substituting values, the user must select the desired tag in appropriate list. After this choice will be shown all values that are parameterized for the appropriate tag, see Fig. B.13.

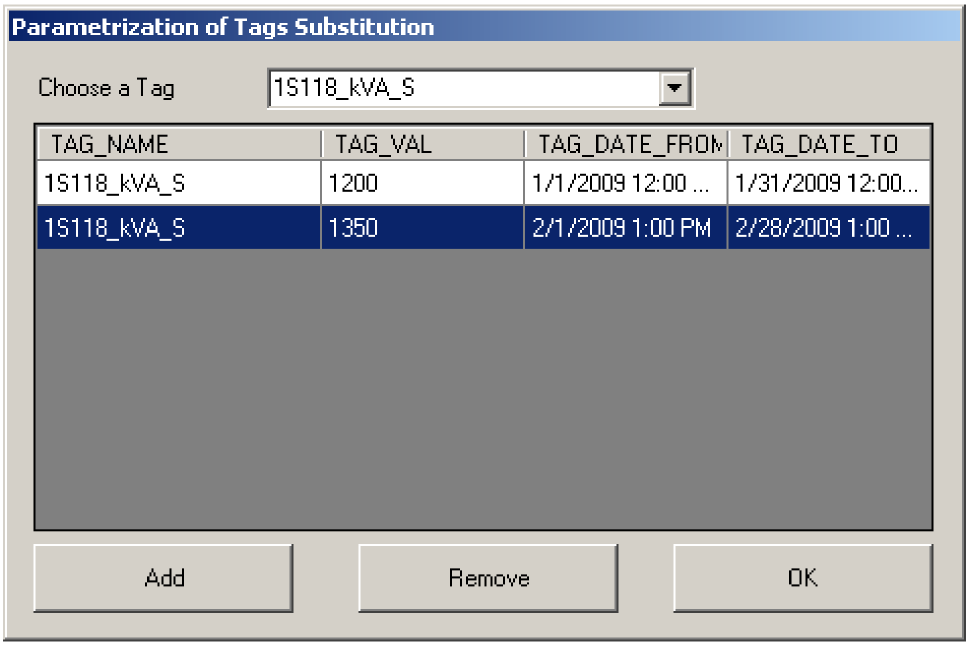

Figure B.13: Tag substitution editing

To add any value the user must click on **"Add"** button, then will be opened the form to add a desired value, see Fig. B.14. It is possible to define the validity range of the values with time resolution per minutes.

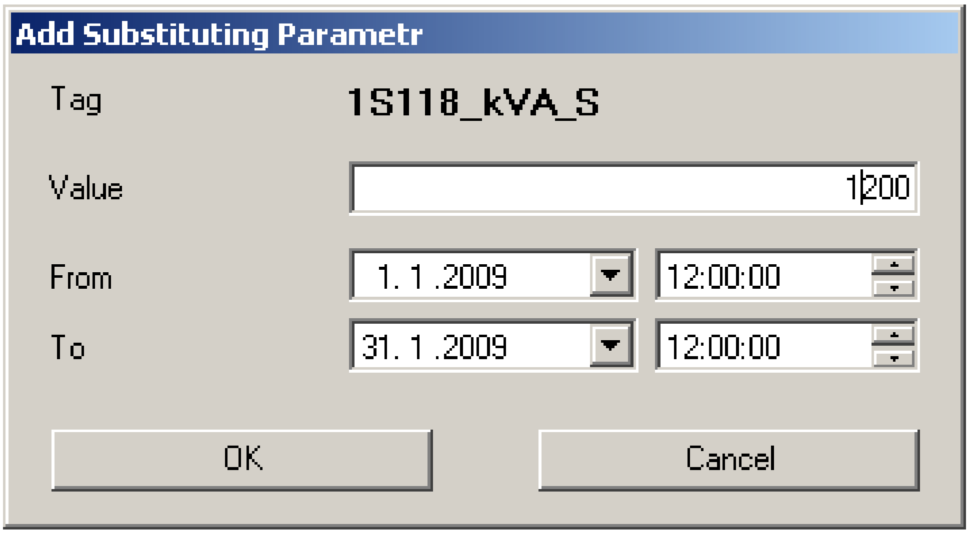

Figure B.14: Adding tags value substitution

To delete the substituting value, the user must click on appropriate row and then click on "Remove" button.

All actions inform the user with the action results, see Fig. B.15.

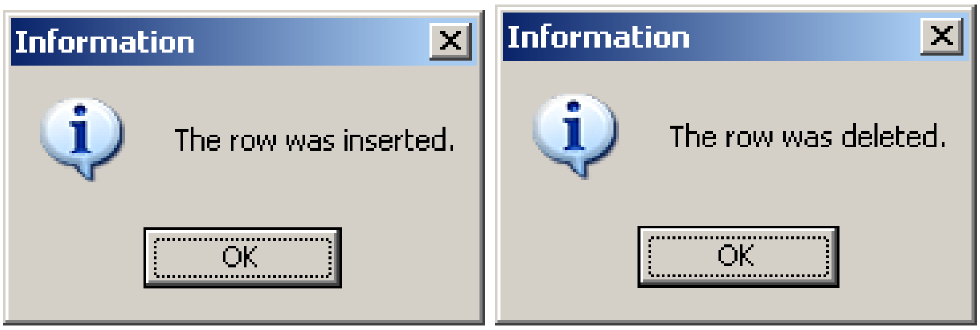

Figure B.15: Action results