Energy monitoring of electricity consumption in tertiary sector building complex

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***Abstract* — Nowadays energy saving is in high importance because of the need of environmental sustainability. However, energy saving can be achieved through a well-defined strategy. The first step of this strategy is the monitoring of energy consumption. In this paper it is described the technology that used for monitoring the electricity energy consumption in the Campus of the National Technical University of Athens (NTUA).**

Keywords— building energy monitoring; electricity consumption; energy efficiency;BEMS.

I. INTRODUCTION

The rising cost of energy, the need for economic viability and environmental protection, pose the need for greater transparency in energy consumption. The main practice of annual energy bills does not help in this matter. By using power meters and integrate them in an “intelligent” system, electricity consumers will be able to view their actual consumption and will be able to have a better control on it. The key to achieving more conscious consumers from energy consumption in buildings is to enable the monitoring of energy consumption as soon as possible by themselves. When consumers are able to see the consumption, electricity in residential buildings, commercial units or in industrial installations, this simple fact can increase their awareness of the excess amount of energy consumed.

The aim of this paper is to describe the accumulation of the energy consumption data and the automatic exportation of reports than will inform the users and the managers of buildings. The buildings, that the above mentioned technique was implemented, are placed inside the Campus of the National Technical University of Athens. The reports are crucial for the design of energy saving strategies.

The proper consumption of electricity in buildings leads to lower operational costs. In other words if the facility manager could predict the electricity demand of a building, actions could be taken to reduce the amount of energy spent and therefore, to reduce the operational cost of the building.

II. NTUA CAMPUS

The National Technical University of Athens is the oldest and largest engineering university in Greece. It covers a total area of almost 100 hectares and its buildings are covering a total of 240,000 m^2.

The campus is energized from the Hellenic distribution network at 20KV. Also, there is a substation inside the campus that feeds 22 main buildings through the medium voltage network. In each of 22 buildings there are also transformers 20/0.4 kV that are feeding the main low voltage panels respectively. There are 36 transformers in these 22 buildings. Usually each building has two transformers except 9 buildings that have one and one building that has three. These main low voltage panels are distributing electricity to different kind of loads in the building such as heat pump panels and lighting and power panels of each floor and laboratory. Additionally, some of these main low voltage panels are energizing adjacent buildings that are in the same faculty. For example, at the Mechanical Engineer faculty there are two main buildings, which are M and O. The main low voltage panel of M feeds adjacent buildings N, L and K and building O feeds Z and E.

Moreover, in each main low voltage field, there is a circuit breaker that isolates the transformer from the field. The nominal current of these circuit breakers varies from 250A to 2,000 A. After circuit breakers there are measurement instruments such as voltage and current meters. Additionally, at the substation, at the side of 20 kV there are voltage, current and energy measurement instruments that are gathering information from an already installed voltage and current converter.

Regarding the communication network, in each main building, there is Ethernet network installed and been operating. On the other hand, the substation doesn’t have Ethernet network installed and the closest point to the network is 500 m away.

Fig. 1. Circuit Breakers and meassurement istruments

III. General Descriprion of the Project

The purpose of the project is to measure electricity, so actual demand can be recorded at strategic locations to perform more detailed load analysis; this is beneficial to both distribution and end-user customers. Smart grid meters, utility meter load profilers, data logging sub-meters and portable data loggers are designed to accomplish this task by recording readings within a set interval. Moreover, these power meters can calculate the actual electricity cost regarding different pricing among day in order pricing of the electricity to be more accurate and fair.

Within the framework of the «NRG4CAST Energy Forecasting» [1], research program the NTUA (Iroon Polytechniou 9, Campus, Zografou) has designed, installed and set up a system to monitor and record the energy consumption inside the campus. Additionally, room conditions are gathered from the Secretary Office of the Faculty of the Mechanical Engineers. These data are referring to inside and outside temperature and humidity and also luminance levels of desks.

The smart grid consists of smart power meters, wiring up the local data centers of the campus, temperature, humidity and luminance sensors, controllers that handle the data from the sensors and meters, and a computer that s supervising the system and accommodates all these data in its databases. Also, the computer exports automatically daily and monthly reports about the energy consumption and acts as server in order to distribute these reports.

Apart from the above, one controller acts as web server and provides another computer with data for projecting the actual consumption at a monitor. The monitor is placed at the reception desk of the central library and informs campus students and staff about the consumption of each building as well as other informative messages.

The philosophy behind the design and the installation of the system is to be fully intergraded by other system and fully expandable in other to have the ability in the future to have more features. More specifically, the use of open communication protocols through Ethernet and Wi-Fi make the system compatible with other third party systems. Moreover, the system has the ability to integrate more controllers, meters, sensors and actuators in order more abilities and information to be available. The topology of the components of the system can be seen at Fig. 2.

IV. Electricity Measuring Devices

The smart meters that are used are divided in three categories; meters that can be installed at the door of the panel and are using Modbus communication protocol, door-panel meters with protocol Modbus TCP/IP and rail meters with Modbus protocol.

In the majority of buildings meters were installed at the door of the main low voltage panels, replacing the old volt-meters (PAC 3100, Fig. 3.). These meters are connected through RS485 network to a Modbus - TCP/IP Gateway (EGX 100). There, Gateway combines Ethernet with RS485 network. In other words, Gateway joins TCP/IP with Modbus protocol.

Additionally, at buildings where only one transformer is placed door panel meters with Modbus TCP/IP protocol are placed (PAC 3200). These meters can be directly connected to Ethernet without the assistance of a Gateway.

Moreover, rail meters with Modbus RS485 protocol were installed where there were technical difficulties with the installation of the door-panel meters (PM3250). These meters also need a Gateway in order to be embodied in the system (Fig. 4.). Furthermore, PM3250 were placed also at the main low voltage panels at the main buildings of Mechanical Engineer faculties for the measurement of specific loads such as adjacent buildings, heat pumps, lighting panels and power panels.

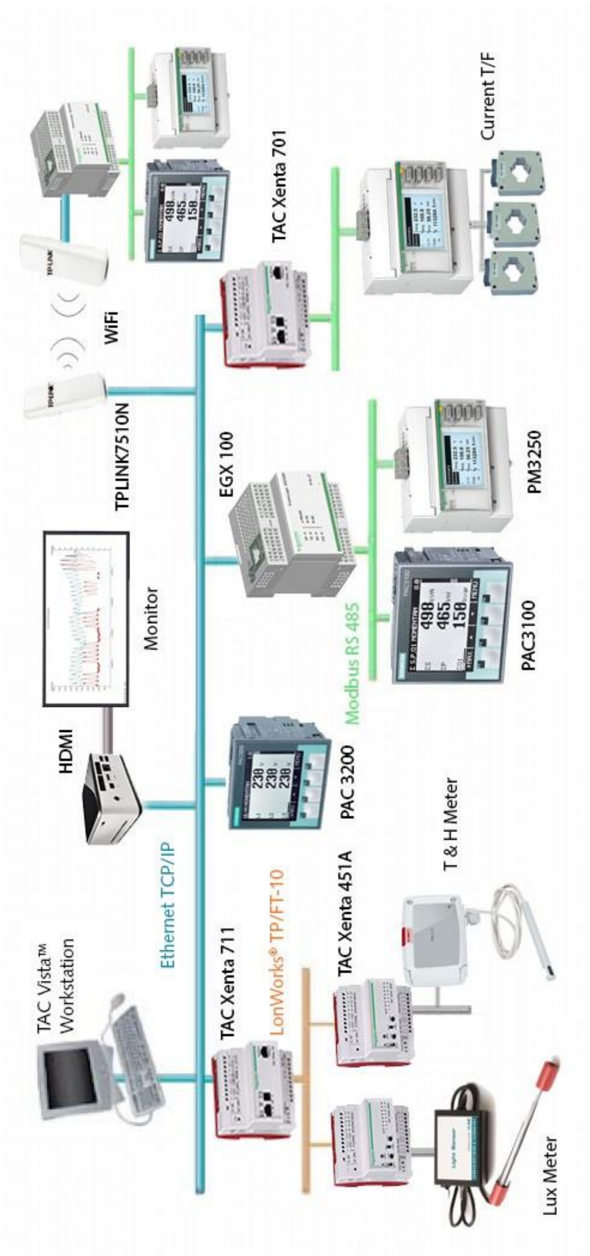

Fig. 2. General Topology of the system

Smart meters can measure phase and polar voltage, line current, total and per phase active. reactive power and apparent power, active, power factor, Total Harmonic Distortion and frequency. For the previous measurements the meter stores the minimum and the maximum value. Additionally, meter calculates the total and per phase energy, the import and export energy, partial energy and energy per tariff.

Fig. 3. Door-Panel Meter PAC3100

Fig. 4. Installation of 10 Meters PM3250 and 1 Gateway EGX100 at building M of Mechanical Engineer faculty

Smart meters need current transformers in order to acquire the current measurement. In most of cases the already installed transformers were used. Also, in medium voltage, the need of a voltage transformer is inevitable for the voltage measurement.

The interconnection of all smart meters is through Ethernet. In most of the buildings there is Ethernet network installed except the substation. There, Wi-Fi transmitters where used in order network to be expanded. The use of 5 GHz transmitters that can operate up to 20 km were used in order to cover the distance range (Fig 5.).

Fig. 5. 5GHz Wi-Fi Transmitter

V. ROOM CONDITION SENSORS

Except of smart meters that are measuring electricity, additional sensors were installed in order to combine power demand with the inside and outside climate conditions. Moreover, luminance sensor were placed in order to find out the relationship between power demand and artificial and natural lighting.

The temperature sensors are PT100 and their range is from -20 to 100 °C. The humidity sensor measures the relative humidity from 0 to 100 %. Both temperature and humidity sensor are placed in the same enclosure with water/dust protection IP65. One temperature sensor is placed outside the secretary office of the Mechanical Engineer faculty, the other one is placed in the main area of the secretary, the other one is placed inside the office of the headmaster of the secretary and the last one in placed in the corridor, in from of the entrance of the secretary.

Fig. 6. Controller Xenta 711 connected with 2 I/O boards Xenta 451A.

On the other hand, luminance sensors can measure from 0 to 15,000 lux, regarding different scales. In the installation, sensor were configured in the range 0 – 1,000 lux. These sensors were placed above the desk of the headmaster of the secretary, above two desks on the main area of the secretary and near a window.

These sensors were interconnected to the system through I/O boards. The I/O boards are receiving 4-20 mA current or 0-10 V voltage and translate the signals to temperature, humidity and luminance. The I/O boards are communicating with the system though a controller. The connection between controller and I/O boards is through LON communication protocol (Fig. 6.).

VI. CONTROLLERS

The main role of controllers in the system is to gather the information from meters, to make some calculations about the consumption and to provide monitor with web pages. More specifically, two controllers were placed in the system; Xenta 701 and Xenta 711. Both of them are handling data from the half meters of the system, so Xenta 711 handles 26 meters and Xenta 701 handles 24 meters.

Both controllers are communicating with their meters and gather information about voltage, current, active and reactive power, power factor and consumed energy whenever the system server needs this information. In other words, controllers are reading data from the registry tables of each meter either directly or through the gateways. Then they translate the data strings and provide the main server with the preferred numbers. Registers are 16 bits long and usually the information is 32 bit Real Float or 64 bit Integer. So, controllers have to combine data from continuous registers in order to have the proper measurement.

Moreover, in every calculation period, controllers accumulate the active power of each transformer and calculate the power demand and the accumulative energy of every main building. Furthermore, they execute a routine that calculates the daily and monthly consumption of each main building.

Another fundamental task for controller Xenta 711 is that operates as a web server. More particularly, Xenta 711 publishes web pages that can be called from each network point. These pages contain data for each main building and the total power demand of the campus. Additionally, there are data about the daily and monthly energy consumption of the above. Additionally, web server also publish trends with outside temperature and total power demand of the campus in a day, week and month basis. This is possible because Xenta 711 also has the ability to log periodically values in its memory. For this reason Xenta 711 and 701 communicate with each other.

Last but not least, Xenta 701 is placed at the Library and communicates with the meter that is installed there directly with Modbus RS485, without the use of a gateway.

VII. DATA PROJECTION

As mentioned above, controller Xenta 711 can act as web server. This ability can be used for informing Campus users about the energy profile of the buildings as well as for the whole Campus. Thus, users are aware of the footprint of their actions and if they are environmental ware, they will try to reduce it. This feature is the most important for energy saving because users of large facilities are not informed about the energy waste that happens because of their attitude. So, informing users is one of the most inexpensive ways to achieve energy saving. This strategy, of course, needs environmental awareness of building users.

Fig. 7. Pojection of the actual active power demand in each building and in the total.

The projection of the web pages is done by a mini PC that is installed behind a 42’’ monitor at the reception desk of Central Library of NTUA Campus. The PC is connected to Ethernet and with the use of internet browser and simple scripts, the pages are been called and shown on a row (Fig. 7.). Also, the monitor in order to be attractive and functional projects also pages with general news or information that are related to the Campus.

Last but not least, the pc and the monitor are configured to start and shut down automatically at working days and hours.

VIII. System Management

The main role of the system can be found on the server that monitors the system. The central server is where one can have full access, and all the features available. More specifically at the server it is installed a program that can monitor the system. This program is called TAC Vista™ Workstation. In other words, Workstation is a Human Machine Interface and through its operation many capabilities are available.

First of all, the configuration of each controller is done through the Workstation. Settings about communication, data acquisition, calculations, logs, trends, graphic pages, web pages, security issues and others that are related to the controllers are done there.

Secondly, through graphic environment, a human can monitor easily the whole system. More particularly, there are pages where someone can have an overview about the power demand, the energy consumption and the room conditions inside the secretary office. Also, a more detailed view of each main low voltage panel is available through the pages where is shown each electrical measurement of the transformers of a building. These measures are referring to the voltage, current, power factor etc. as they were described at paragraph IV.

Another aspect of the Workstation is that an operator can define the values that should be log for further analysis. The log of values in the database of the server is very useful because give to opportunity to someone to have a detailed study of the energy consumption of the Campus. With these data available, someone can define a strategy for energy saving.

The detailed analysis can be more efficient with the automatic export of daily, monthly or annual reports. Thus, at the server, every midnight five reports are generated; two with the active power demand and the energy consumption of every transformer respectively, two with the active power demand and the energy consumption of every load that is measured from the main low voltage panels of buildings M and O of Mechanical Engineer faculty respectively and finally one report with the room conditions of the secretary office of Mechanical Engineer faculty (Fig. 8). Each report has logs from the last day that were logged every 15’ (Fig. 9). Additionally, in the beginning of a month, a monthly report is exported that contains the energy consumption of each day and monthly graphs of the consumption of each building (Fig. 10.).

Last but not least, Workstation informs users about connection or other kind of alarms that the system has.

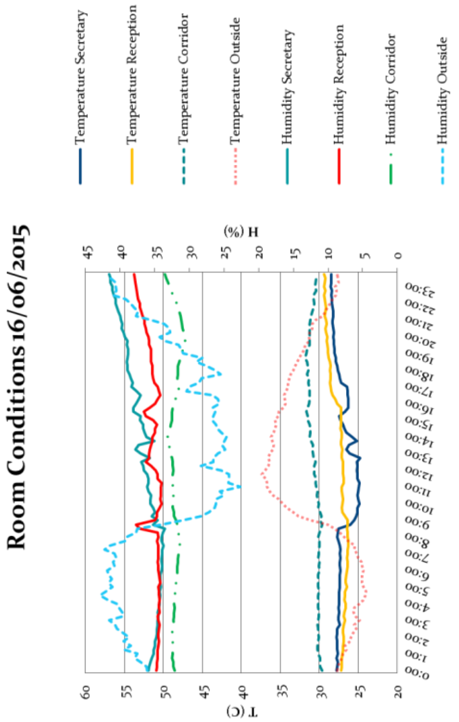

Fig. 9. Daily chart of temperature and humidity of the secretary office from the daily room condition report.

IX. COMMUNICATON

As can be seen at Fig. 2, there are different type of network layers at the system. The most common used kind of network is Ethernet. More specifically, the management workstation is communicating with controllers via Ethernet. Moreover, controllers are communicating with gateways via Ethernet. For the communication with the gateway of the substation Ethernet and Wi-Fi is used. On the other hand, controller Xenta 701 uses RS485 to communicate with the meter that is installed at the Library. Xenta 711, communicates with the I/O boards also through LonWorks™ TP/FT-10.

In terms of security, the IT department of the Campus has realized a virtual network that every component of the system is part of this network. Additionally, only the declared devices with specified settings can be connected to the network physically. Moreover, no other network point at the whole Campus can have access to that virtual network.

X. CONCLUSION

This paper presents the installation of a smart meter system that monitors the energy consumption at the NTUA Campus. The results of the monitoring are used by a new forecasting tool that was developed in parallel with the philosophy of NRG4CAST. This tool takes into account all the latest technologies on the management of large data-sets, use of intelligent energy meters - environmental conditions, use of energy networks, Internet services, operate in real-time, advanced computing technologies so as to provide logging functions energy parameters. Uses appropriate mining techniques and data analysis, information extraction and data processing in order to provide energy information directly and reliably. Gathering and analyzing energy consumption information that is representative for the NTUA Campus is the first step toward the goal of reducing energy use. Moreover, the system informs users about the footprint of their energy attitude.

The aim of all these methods is the recognition of the creation of the observations of the time series in order to obtain the best possible forecast. The logic is based on the assumption that the available observations contain useful information about the way they have been created and how to behave in the future in accordance with the past. Based on our research findings, it is recommended to use the decomposition forecasting method to take the most accurate values for this type of time series. This model can be easily integrated into a Management System or into a real time monitoring system.

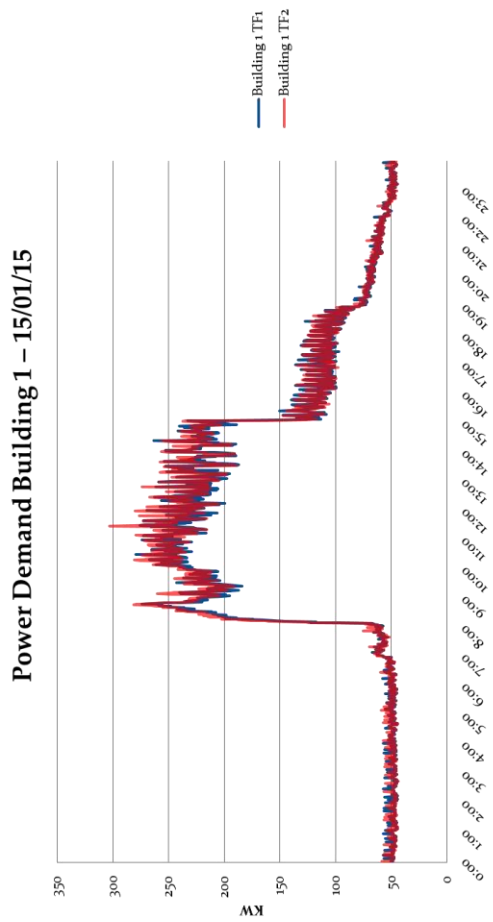

Fig. 10. Daily chart of the consumption of the administration building from the daily report.

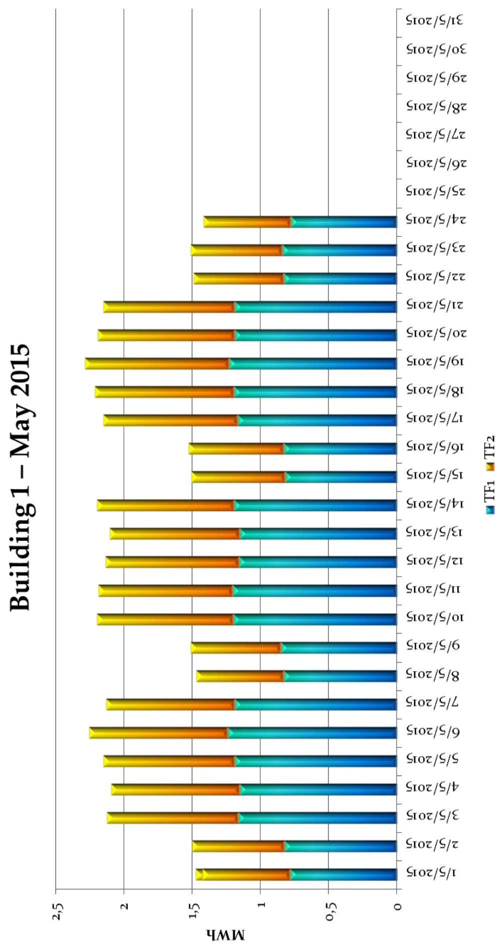

Fig. 10. Montlhy chart of the consumption of the administration building from the monthly report.

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REFERENCES

[1] http://www.nrg4cast.org/