SECTION C

ENERGY AUDIT:

WHAT IS AN ENERGY AUDIT (EA)?

- pool of activities (systematic procedure) focused on analysis of current energy need and consumption going out of valid technical standards,
- analysis of problems (weaknesses and deficiencies),
- EA identifies and in detail quantifies effective possibilities of energy savings tailored to the object being analyzed field-work, economy tool having dynamic character, often basis for grant financing of projects.

WHAT IS THE AIM OF EA?

- to minimize costs for energy
- to minimize operational costs
- to minimize costs for repairs and reconstruction
- increase quality of environment that contributes to increased work productivity

In case of EA as duty (Industrial consumers with annual energy consumption over 5,5 GWh/year) the procedure of EA as well as content of the report is determined by Regulation No. 429/2009.

In case of voluntary EA is the content and focus as well as target given by customers requirement.

MAIN TOPICS/AREAS OF EA

Subject of energy consumption analysis are energy resources consumed in the industrial area, i.e.:

- Electricity
- Natural gas
- Steam
- Coal
- Wood, wood chips/pellets
- Fuels (petrol, oil, propane-butane)

MAIN TOPICS/AREAS OF EA

- thermal-technical protection of buildings,
- heating systems
- hot water preparation,
- ventilation systems and air-conditioning (buildings and technology)
- electric appliances (administrative and technological incl. electrical connection, transformation, distribution network, el. switchboards, el. compensation)
- gas or other energy resources consuming appliances (furnaces, cleaning devices,..)
- Indoor/outdoor lighting,
- measurement and regulation.

WHAT OFFERS EA TO THE CUSTOMER?

✓ identifies highest achievable **potential of energy and costs savings** and its effort,

✓ **points out on often visible** as well as hidden **technical/hygienic/safety** deficiencies of buildings and building and production technology equipment,...

✓ **recommends** technical parameters of measures,

✓ **calculates investment needs** of measures, their asset - economical, technical, environmental,

✓ proposes **procedure for realisation of measures**,

✓ it is very effective technical, economical and **management tool for investment decision** processes going out of economical modelling,

✓ it is solid basement for **effective control of energy consumption** and herewith also operational costs

Power System State Estimation

- Provide an estimate for all metered and unmetered quantities;
- Filter out small errors due to model approximations and measurement inaccuracies;
- Detect and identify discordant measurements, the so-called bad data.

State Estimation

- State Estimation is the process of assigning a value to an unknown system state variable based on measurements from that system according to some criteria.
- The process involves imperfect measurements that are redundant and the process of estimating the system states is based on a statistical criterion that estimates the true value of the state variables to minimize or maximize the selected criterion.
- Most Commonly used criterion for State Estimator in Power System is the **Weighted Least Square Criteria**.

State Estimation

- It originated in the aerospace industry where the basic problem have involved the location of an aerospace vechicle (i.e. missile , airplane, or space vechicle) and the estimation of its trajectory given redundant and imperfect measurements of its position and velocity vector.
- In many applications, these measurements are based on optical observations and/or radar signals that may be contaminated with noise and may contain system measurement errors.
- The state estimators came to be of interest to power engineers in1960s. Since then , state estimators have been installed on a regular basis in a new energy control centers and have proved quite useful.

State Estimation

- In the Power System, The State Variables are the voltage Magnitudes and Relative Phase Angles at the System Nodes.
- The inputs to an estimator are imperfect power system measurements of voltage magnitude and power, VAR, or ampere flow quantities.
- The Estimator is designed to produce the “best estimate” of the system voltage and phase angles, recognizing that there are errors in the measured quantities and that they may be redundant measurements.

SE Problem Development (Cont.)

- Mathematically Speaking…

$$Z = [\ h(\ x\ ) + e\ ]$$

where,

Z = Measurement Vector
h = System Model relating state vector to the measurement set
x = State Vector (voltage magnitudes and angles)
e = Error Vector associated with the measurement set

SE Problem Development (Cont.)

- Linearizing…

$$Z = H \Delta x + e$$

- Classical Approach -> Weighted Least Squares…

Minimize: $J(\mathbf{x}) = [\mathbf{z} - \mathbf{h}(\mathbf{x})]^t . \mathbf{W} . [\mathbf{z} - \mathbf{h}(\mathbf{x})]$
where,
J = Weighted least squares matrix
W = Error covariance matrix

SE Functionality

- Identifies observability of the power system.
- Minimize deviations of measured vs estimated values.
- Status and Parameter estimation.
- Detect and identify bad telemetry.
- Solve unobservable system subject to observable solution.
- Observe inequality constraints (option).

SE Measurement Types

- Bus voltage magnitudes.
- Real, reactive and ampere injections.
- Real, reactive and ampere branch flows.
- Bus voltage magnitude and angle differences.
- Transformer tap/phase settings.
- Sums of real and reactive power flows.
- Real and reactive zone interchanges.
- Unpaired measurements ok

State Estimation Process

- Two Pass Algorithm
  - First pass… observable network.
  - Second pass… total network (subject to first pass solution).
  - High confidence to actual measurements.
  - Lower confidence to schedule values.
  - Option to terminate after first pass.

Load Forecasting

- With supply and demand .fluctuating and the changes of weather conditions and energy prices increasing by a factor often or more during peak situations, load forecasting is vitally important for utilities.

- Short-term load forecasting can help to estimate load flows and to make decisions that can prevent overloading. Timely implementations of such decisions lead to the improvement of network reliability and to the reduced occurrences of equipment failures and blackouts.

- Load forecasting is also important for contract evaluations and evaluations of various sophisticated financial products on energy pricing offered by the market.

- In the deregulated economy, decisions on capital expenditures based on long-term forecasting are also more important than in a non-deregulated economy when rate increases could be justified by capital expenditure on projects.

Load Forecasting

- For example, for a particular region, it is possible to predict the next day load with an accuracy of approximately 1-3%. However, it is impossible to predict the next year peak load with the similar accuracy since accurate long-term weather forecasts are not available. For the next year peak forecast, it is possible to provide the probability distribution of the load based on historical weather observations. It is also possible, according to the industry practice, to predict the so-called weather normalized load, which would take place for average annual peak weather conditions or worse than average peak weather conditions for a given area. Weather normalized load is the load calculated for the so-called normal weather conditions which are the average of the weather characteristics for the peak historical loads over a certain period of time. The duration of this period varies from one utility to another.

Factors for Load Forecasting

Most forecasting methods use statistical techniques or artificial intelligence algorithms such as regression, neural networks, fuzzy logic, and expert systems.

Medium & Long-term forecasting

Historical load
Weather data,
the number of customers in different categories
the appliances in the area and their characteristics including age, the economic and demographic data and their forecasts, the appliance sales data, and other factors.

Short-term forecasting.

time factors,
weather data,
possible customers' classes.

Factors for Load Forecasting

The time factors include the time of the year, the day of the week, and the hour of the day. There are important differences in load between weekdays and weekends. The load on different weekdays also can behave differently. For example, Mondays and Fridays being adjacent to weekends, may have structurally different loads than Tuesday through Thursday. This is particularly true during the summer time. Holidays are more difficult to forecast than non-holidays because of their relative infrequent occurrence.

Factors for Load Forecasting

Weather conditions influence the load. In fact, forecasted weather parameters are the most important factors for load forecasting.

Most commonly used load predictors

Temperature and humidity

Among the weather variables listed above, two composite weather variable functions,

the THI (temperature-humidity index) and

the WCI (wind chill index),

are broadly used by utility companies.

THI is a measure of summer heat discomfort

WCI is cold stress in winter.

Most electric utilities serve customers of different types such as residential, commercial, and industrial. The electric usage pattern is different for customers that belong to different classes but is somewhat alike for customers within each class. Therefore, most utilities distinguish load behavior on a class-by-class basis

Methods of Load Forecasting

Most forecasting methods use statistical techniques or artificial intelligence algorithms such as regression, neural networks, fuzzy logic, and expert systems.

for medium- and long-term forecasting

End-use and econometric approach are broadly used

for short-term forecasting.

Similar day approach,
Various Regression models, Time series, Neural networks,
Statistical learning algorithms, Fuzzy logic, Expert systems

Methods of Load Forecasting

Statistical approaches usually require a mathematical model that represents load as function of different factors such as time, weather, and customer class.

The two important categories of such mathematical models are:

additive models
multiplicative models.

They differ in whether the forecast load is

the sum (additive) of a number of components
the product (multiplicative) of a number of factors.

Methods of Load Forecasting

A multiplicative model may be of the form

$$L = Ln \cdot Fw \cdot Fs \cdot Fr,$$

Ln is the normal (base) load and the correction factors

Fw, *Fs*, and *Fr* are positive numbers that can increase or decrease the overall load.

These corrections are based on current weather (*Fw*), special events (*Fs*),and random fluctuation (*Fr*). Factors such as electricity pricing (*Fp*) and load growth (*Fg*) can also be included.

Methods of Load Forecasting

Methods of Short Term Load forecasting

Similar-day approach

Regression methods

Time series

Neural networks

Expert systems

Fuzzy logic.

Methods of Load Forecasting

Similar-day approach

This approach is based on searching historical data for days within one, two, or three years with similar characteristics to the forecast day.

Similar characteristics include weather, day of the week, and the date. The load of a similar day is considered as a forecast.

Instead of a single similar day load, the forecast can be a linear combination or regression procedure that can include several similar days.

The trend coefficients can be used for similar days in the previous years.

Methods of Load Forecasting

Regression methods

used to model the relationship of load consumption and other factors such as weather, day type, and customer class.

several regression models for the next day peak forecasting. Their models incorporate deterministic influences such as holidays, stochastic influences such as average loads, and exogenous influences such as weather.

Methods of Load Forecasting

Time series

Time series methods are based on the assumption that the data have an internal structure, such as autocorrelation, trend, or seasonal variation. Time series forecasting methods detect and explore such a structure. Time series have been used for decades in such fields as economics, digital signal processing, as well as electric load forecasting.

Methods of Load Forecasting

Time series

ARMA (autoregressive moving average),

ARIMA (autoregressive integrated moving average),

ARMAX (autoregressive moving average with exogenous variables),

ARIMAX (autoregressive integrated moving average with exogenous variables) are the most often used classical time series methods.

ARMA models are usually used for stationary processes while ARIMA is an extension of ARMA to nonstationary

processes.

ARMA and ARIMA use the time and load as the only input parameters. Since load generally depends on the weather and time of the day,

ARIMAX is the most natural tool for load forecasting among the classical time series models.

Methods of Load Forecasting

Neural networks

The use of artificial neural networks (ANN) has been a widely studied electric load forecasting technique since 1990.

Neural networks are essentially non-linear circuits that have the demonstrated capability to do non-linear curve fitting.

The outputs of an artificial neural network are some linear or nonlinear mathematical function of its inputs. The inputs may be the outputs of other network elements as well as actual network inputs.

In practice network elements are arranged in a relatively small number of connected layers of elements between network inputs and outputs. Feedback paths are sometimes used.

Methods of Load Forecasting

Neural networks

In applying a neural network to electric load forecasting, one must select one of a number of architectures (e.g. Hopfield, back propagation, Boltzmann machine), the number and connectivity of layers and elements, use of bi-directional or uni-directional links, and the number format (e.g. binary or continuous) to be used by inputs and outputs,and internally.

The most popular artificial neural network architecture for electric load forecasting is back propagation.

Back propagation neural networks use continuously valued functions and supervised learning.

Methods of Load Forecasting

Expert systems

Rule based forecasting makes use of rules, which are often heuristic in nature, to do accurate forecasting.

Expert systems incorporates rules and procedures used by human experts in the field of interest into software that is then able to automatically make forecasts without human assistance.

This rule base is complemented by a parameter database that varies from site to site.

Methods of Load Forecasting

Fuzzy logic

Fuzzy logic is a generalization of the usual Boolean logic used for digital circuit design. An input under Boolean logic takes on a truth value of “0” or “1”.
Under fuzzy logic an input has associated with it a certain qualitative ranges.

For instance a transformer load may be “low”, “medium” and “high”.

Fuzzy logic allows one to (logically) deduce outputs from fuzzy inputs. In this sense fuzzy logic is one of a number of techniques for mapping inputs to outputs (i.e. curve fitting).

Among the advantages of fuzzy logic are the absence of a need for a mathematical model mapping inputs to outputs and the absence of a need for precise (or even noise free) inputs.

Methods of Load Forecasting

The development and improvements of appropriate mathematical tools will lead to the development of more

accurate load forecasting techniques. The accuracy of load forecasting depends not only on the load forecasting techniques, but also on the accuracy of forecasted weather scenarios.