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DEMAND RESPONSE MODELING UNDER ELECTRICITY MARKET CONDITIONS USING AN OBJECT-ORIENTED APPROACH

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***Abstract* – This paper presents an object oriented approach to the problem of control and optimization of energy cost at industrial and commercial customers based on the control of production chain. This control may be implemented using different Demand Response strategies.**

Keywords: *Demand Response, energy market, object oriented models.*

1. INTRODUCTION

Deregulation in electricity industry and recent evolutions in the electricity markets show that active Demand Response (DR) can play a major role in both system security and market efficiency. The components of various DR programs involved in demand-side participation in the electricity market provide new market opportunities for two important actors: the end user and the supplier.

At present several types of DR programs are implemented all over the world [1, 2, and 3]. National authorities, especially regulatory agencies, or local/regional utilities are involved in projects that focus on the best practices in the field and the adoption of technical assistance for system operators, utilities or consumers during program design, implementation and assessment.

Historically, DR programs, implemented as Demand –Side Management (DSM) programs, were targeted towards reliability objectives, applying strategies like peak load shaving, peak load reduction, interruptible loads or energy analysis. In the last decades of the 20-th century, when DSM programs were initiated, they rather brought advantages to utilities and less to customers, which in fact were the main actors in the implementation schemes. At that moment the DSM actions had a weak echo among customers, and the popularity of this type of programs has diminished. Gradually, the reliability-oriented strategies were compensated by economical-financial ones aiming at developing incentives to encourage customers to consume less energy and power, to change energy usage and to promote energy saving technologies.

Present issues such as congestions in transmission systems, the continuously growing demand for energy, the ever growing trend in the development of electricity markets, the dependency on limited energy resources and the general aim of utilizing more sustainable and environmentally friendly energy sources have determined the revival of DSM concept, new DSM programs and new principles in their application. At the same time the changes that transform electricity into basic commodity, the promotion of financial and commercial instruments in electricity trading and the ever growing competition on the electricity market are critical issues that must be taken into consideration.

Thus, energy efficiency is no more strictly connected with the implementation of new and high technologies, less energy consuming. These technologies are also tied to the usage patterns specific to each customer. On the whole, reductions in kWh consumption can be influenced in a great extent by the cost of the kWh. Customers that act on the electricity market are more and more constrained to assess their energy efficiency based not only on amounts of kWh but also on financial and economical value of these amounts.

In this context, this paper describes a new object-oriented (OO) approach to a DR program that can be implemented to industrial and commercial customers with a view to reduce costs with electricity and enhance energy efficiency through production chain optimization, under trading conditions imposed by the electricity market.

In section 2 the DR strategies and DR programs are discussed. The main differences between DR programs and traditional peak load and efficiency strategies are underlined. Three basic DR programs are also synthetically presented. The main functions that a DR software tool must provide are described in section 3, while the basic aspects concerning OO approaches are presented in section 4. Section 5 contains a short presentation of the OO approach to the software implementation o a DR program for industrial and commercial customers.

2. DEMAND RESPONSE PROGRAMS

DR refers to the modification of customer electricity usage at different moments, but especially during times of peak usage, in order to help address system

Reasons	DSM Strategies		
	Efficiency program	**Peak-load management**	**DR programs**
WHY ?	Utility bill savings Environment protection	Peak demand charges Time of use savings System peak load	Price Reliability Emergency
HOW ?	Integrated system operation	Demand limiting Demand shifting	Demand shedding Demand limiting Demand shifting
WHERE ?	Local	Local	Remote

Table 1: Different types of DSM projects.

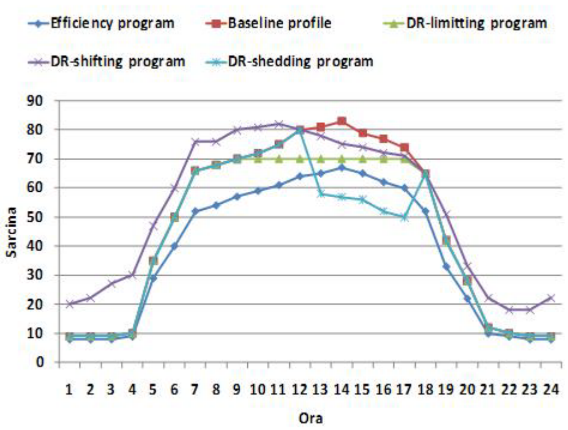

Figure 1: Comparison between baseline profile, efficiency programs, and DR strategies.

reliability, reflect market conditions and pricing, and support infrastructure optimization or deferral. DR programs may include dynamic pricing and tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control or equipment cycling. Different DR strategies are currently in use, such as *demand limiting, demand shifting* and *demand shedding*. Demand limiting and shifting can be implemented when economic and reliability issues can be predicted and curtailment conditions are communicated to each customer in advance. Demand shedding is dynamic temporary reduction or curtailment of peak load when dispatched and refers to strategies that can be possibly implemented within a shorter period of response time. The significance of the three DR strategies, compared to the baseline and simple energy efficiency program is presented in Figure 1.

On the other hand, different characteristics of the above programs and strategies, considered in the framework of a Demand-Side Management (DSM) project are presented in Table 1 [3].

At present several types of DR programs are implemented all over the world. These programs provide financial incentives and other benefits to customers who agree to reduce their energy usage during special events and usually during times of peak demand. Some of these programs are briefly described forward.

2.1. Basic Interruptible Program

The Basic Interruptible Program is a program that pays customers to reduce electricity consumption to a pre-determined amount when the System Operator announces a load curtailment. To participate in the program a customer must accept to curtail a minimum percent of its average load, but not less than a fixed kW amount. This program offers two options for participation:

- The *mandatory option*, which gives to customers a monthly payment for reducing electricity demand to a predetermined level when called upon. For this option the customer receives a notification with 30 minutes or 1 hour prior the mandatory curtailment of load exceeding the pre-determined amount. If the customer fails to reduce load during an event, a fixed charge per kWh must be paid for energy use over the pre-determined service level.

- The *voluntary option*, which pays customers a fixed amount per kilowatt reduced during a curtailment request. For this option the customer receives a curtailment notification few hours prior to the event. The customer will be paid at a fixed rate for each kWh load reduction during the curtailment event. No penalties are charged if the customer fails to reduce load.

2.2. Demand Bidding Program

The Demand Bidding Program pays customers an incentive to reduce electricity consumption based on a voluntary bid made by the customer for a scheduled load reduction on the following day. This program applies only for non-holiday weekday.

For an accepted bid the customer will receive a credit determined as the product of the energy reduction and the appropriate incentive price. Energy reduction is computed as the difference between the customer's

specific energy baseline (determined on an hourly basis using the average energy for the three highest total energy usage days) and the customer's actual energy usage.
This program can be applied using a *day-ahead* or a *day-of* scheme. In the first case customers are asked to present load reduction bids in response to forecasted increases in load for the next day. The day-of scheme is similar with the previous one, but the customer must submit bids in one hour after the request of the System Operator.

2.3. Scheduled Load Reduction Program

Scheduled Load Reduction Program pays customers to reduce electric load during a pre-determined time period that is specified in advance.
The time period is usually of 4 hours length (for instance, 08:00 to 12:00, 12:00 to 16:00 and 16:00 to 20:00) and may be applied for at least one day in the week. The load reduction must comply with minimum restrictions: a minimum curtailment percent from the average load, but not less than a fixed kW amount.
The customer is paid based on a fixed rate per kilowatt-hour for committed energy reductions below a baseline. The baseline is computed as the average of the previous 10-day usage during the selected time period.
Other types of DR programs applied by utilities and/or independent operators are: critical peak pricing, optional binding mandatory curtailment plans, capacity bidding program, technical assistance program or technology incentive program [1].

3. TOOLS FOR DR PROGRAMS

Any tool used to implement a DR program must be designed to enable utilities, suppliers and energy service companies (ESCOs) to work closely with their customers to manage energy demand during certain periods of time, and especially during peak time.
As these modern instruments are applied with new concepts like energy transactions on energy markets, energy management activities frequently need to be applied on-line, requesting specific technologies like e-mails and/or the Internet. Thus, anytime a curtailment event is initiated the customer must be notified, and the control system at the customer premises must act to respond to the curtailment request. At the same time these instruments must contain customized web pages with real-time energy usage information and a collection of DR and other energy conservation programs that can be used by the customer.
Hence, the main functions that a DR software tool must provide are:

- Notify the customer of load curtailment events.
- Offer the customer the possibility to analyze options and respond to calls for participation in load curtailment events
- Offer the customer the possibility to assess its performance for each such event, and for the global activity.
- Provide customers with data like 15-minute, hourly and daily energy usage, hourly local weather conditions and wholesale hourly pricing data to assist him in the decision making process.
- Provide a variety of visualization and analysis tools for statistical or comparative analysis.
- Provide the possibility of importing or exporting data from or to other applications that use these data.
- Collect data from multiple sites/customers and aggregate them for enterprise-wide analysis and reporting (this feature is especially useful for suppliers and ESCOs).

Based on this functions, the following scenario-event can be imagined: anytime a curtailment event is initiated, the customer will receive instant notification (basically by e-mail), allowing him to react quickly and easily to changing market conditions. The available customized web-page can help customers to choose among different energy management incentive programs. Based on this primary information, the customer can quickly respond to the curtailment notice, via the Internet. He can accept or decline the offer and respond with a new bid for committed energy reduction for voluntary programs, or acknowledge the receipt of a mandatory notice, for mandatory programs. On the other hand, for multi-site energy management schemes, the user can respond to multiple curtailment notices through a single communication action. As the curtailment event occurs, the user can compare his current usage profile with the previous load data and load profiles to help adjust operations during the curtailment event.

4. OBEJCT ORIENTED PROGRAMING

Object Oriented (OO) modeling is a fast-growing area of modeling and simulation that provides a structured, computer-supported way of doing mathematical and equation-based modeling.
For a certain type of application OO approach is used to analyze the subjects and elements that populate the universe of the application. From the real world,

class *GenericObject* *LocalObjects* *PropertiesList* *ActionsList* end.	Define an instance of *GenericObject* class: var **MyObject** : *GenericObject*

Figure 2: Definitions for an object or class and an instance of this object.

Step 1	A brief description of the system
	1.1 What kind of system is it ? 1.2 What does it do ?
Step 2	Decompose the system into its most important components
	2.1 Define communications / interactions between components. 2.2 Define interfaces between components. 2.3 Recursively decompose model components of "high complexity".
Step 3	Formulated new model classes when needed
	3.1 Declare new model classes. 3.2 Declare possible base classes for increased reuse and maintainability.

Figure 3: The general approach to the OO model representation of a system.

objects that have the same attributes and the same behavior are grouped in a common class, and the relationships between the classes are also abstracted as connections in the model. Frequently, classes are briefly named objects.
One of the most important properties of the OO approach is that an entity (e.g. a consumer) is considered as an object that has more than one function. This representation of the consumer has more advantage than conventional models which represent it as the minimum indivisible unit in a simulation. Other major advantage is that it will be possible to describe the same consumer acting in different ways. For instance, most electric consumers in a plant would act as primer engines for mechanical drives, while others would act as energy converters for other, different purposes. Besides both type of consumers use electricity that must be purchased from the electricity market, using specific trading methodologies. In short, the OO approach has certain advantages, especially in terms of expansibility, flexibility, reusability and easiness of maintenance of the algorithmic models and the software. Moreover, if parallel / distributed computational architectures

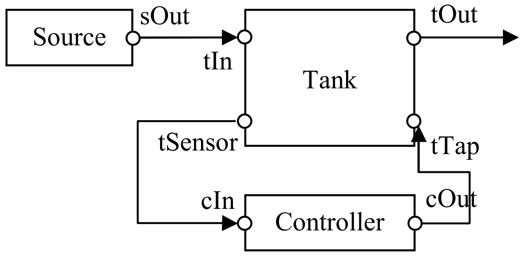

Figure 4: OO description of water level control in a tank.

are available, the OO model can be easily implemented, thus fully exploiting the features of modern computing systems.
A simple structure of an object is described in Figure 2. Here the object or class *GenericObject* is defined as being composed from a set of properties (see *PropertiesList*) and a set of actions (see *ActionsList*) that the object can execute. Moreover the *GenericObject* can contain *LocalObjects* which complete and simplify the definition of the *GenericObject*. An instance of a class or object can be declared by prefixing the *variable name* to the *class name*. For instance, the declaration in Figure 2 states that **MyObject** is a variable containing an object of type *GenericObject*.
A general approach to OO model representation of a system is depicted in Figure 3.
As an example of defining objects, consider the case of modeling the control of a constant level of the water in a tank (see Figure 4). First, consider three predefined classes, namely *TSource*, *TController* and *TTank*, which contains a set of properties, as follows:

TSource	sOut
TController	cIn, cOut
TTank	tIn, tOut, tSensor, tTap

Using this components one can define a complex class *ConstantWaterLevelInATank* with the following structure:

```
class ConstantWaterLevelInATank;
        var Source : TSource;
        var Controller : TController;
        var Tank : TTank;
        procedure ControlFlow (Source.sOut, Tank.tIn);
        procedure ControlTap (Controller.cOut, Tank.tTap);
        procedure ControlSensor (Tank.tSensor, Controller.cIn);
end;
```

In the case of industrial and/or commercial customers with a large number of processes involved in the production chain, the OO modeling and programming techniques prove to be very attractive because they allow, among other:

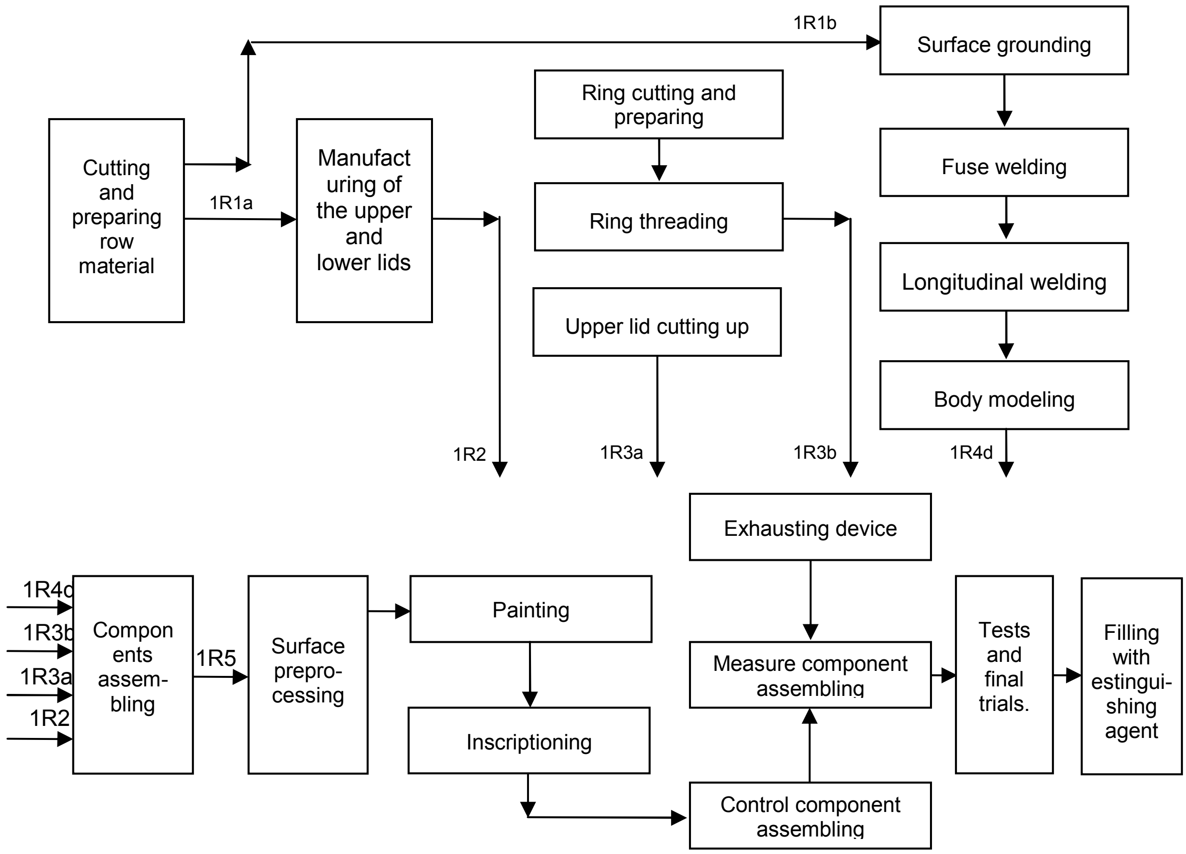

Figure 5: A process from the production chain of the industrial customer.

(i) to build and use a single OO database for all the components and functions of the dedicated Energy Management System;
(ii) easily modeling of the system and the production chain topology changes and
(iii) easily introducing new components.

With respect to the last issue, the OO approach allow to introduce details describing various processes of the production chain, thus accounting with adequate accuracy for different diagrams of the installations, characteristics of devices and apparatuses, specific consumptions, types of energy sources, mutual constraints between components etc (see Figure 5). On the other hand if the OO approach is extended over the electricity market structure and mechanisms, few simplifying assumptions have to be considered during the optimization process.
The next section describes the general structure of an OO database to be used to model the processes in the production chain of an industrial and/or commercial customer. Numerical applications are presented to emphasize the features of the proposed methodology and the flexibility of the OO approach. The analysis of the proposed methodology is in progress using a case study, which involves the activity of an industrial customer whose main activity addresses the production of fire extinguisher equipments.

5. OBEJCT ORIENTED PROGRAMING

The OO approach was applied to model the operation of an industrial consumer based on the description of the production chain. The main activity of the industrial consumer is the production of fire extinguisher equipments. For simplicity and briefness, the analysis has considered that the customer manufactures only two products P1 and P2. Each product is manufactured as part of a specific production chain; there are two production chains denoted by PC1 and PC2 - for products P1 and P2.
As a rule, the manufacturing of products P1 or P2 needs the successive running of the following processes:

1. Cutting and preparing row material.
2. Manufacturing of the upper and lower lids of the equipment.
3. Processing the lower lid.
4. Manufacturing the extinguisher main body.
5. Components assembling.
6. Surface preprocessing.
7. Painting and inscription.
8. Measure and control components assembling.
9. Filling with extinguishing agent.
10. Tests and final trials.

For instance, during the 4-th process of production chain PC1, the following successive operations must be fulfilled:

Step1: Surface grounding – uses one or two pressing machines with rated active power of 11 kW, during a 2 min. cycle.
Step 2: Fuse welding – manual operation during a 2 min./piece cycle.
Step 3: Longitudinal welding – 2 min. operation;
Step 4: Modeling the edges of the extinguisher (component 1R4d of the product P1) is complete. This operation is done on a lathe with rated active power of 7.5 kW, during 5 min..

On the other hand, for the same process but inside production chain PC2 there is a single operation, namely Step 4 from PC1. This operation is executed on the component 2R1 using a specialized lathe with rated active power of 5 kW, during 3 minutes.
Finally, during the fifth process (components assembling), for both production chains PC1 and PC2, welding converters are used. Converters are identical but they are used during different time intervals: 10 minutes for production chain PC1, and 5 minutes for production chain PC2. Figure 5 describes the production chain PC1.
Using the OO approach, each component of the model can be described using objects or classes. For instance, the classes below describe the data type used to represent energy, a process in a production chain and a generic production chain:

```
class TEnergy:
        var EnergyType : TName;
        var EnergyPrice : array of TValue;
        var EnergySched : array of TValue;
        procedure EnergyCost (EnergyPrice, EnergySched, Time);
end;
class TProcess:
        var Name : TName;
        var Duration, Break : TTime;
        var Operations : array of TOperation;
        var InProcess, OutProcess : array of TProcess;
        var RowMaterial : array of TMaterial;
        var SpecificCons : array of TConsumption;
        var EnergyCons : array of TEnergy;
        var DriveActuator : TDrive;
        procedure AssesRowCons (RowMaterial, SpecificCons);
        procedure AssesEnergyCons (DriveActuator, EnergyCons);
        procedure AssesEnergyLoss (DriveActuator);
end;
class TProductionChain:
        var StartTime, EndTime : TTime;
        var ProcessList : TLinkedList of TProcess;
        var RowMaterial : array of TMaterial;
        var EnergyCons : array of TEnergy;
        procedure StartProcess (Process);
        procedure EndProcess (Process);
        procedure ControlChain (ProcessList);
end;
```

The *TEnergy* class has three properties: type of energy (electricity, thermal etc), the energy price or prices represented as an array of values to consider the energy market mechanisms, and the energy consumption schedule (e.g. hourly consumptions). *EnergyCost* is an action or method of the class *TEnergy* which compute the cost with energy incurred by a process or operation.
The *TProcess* class contains ten properties and three actions. The properties are: the name of the process, the duration and breaking time (if any), operations executed during the process, previous and subsequent processes, row materials used, specific consumption of row material, specific consumption of energy, and the drive or actuator used in the process. The three actions define the assessment of row material and energy consumption, and energy loss computation.
Finally the *TProductionChain* class contains five properties and three actions. The properties are: the time for beginning and ending the production activity, the list of processes that form the production chain and the arrays with row materials and energy used. The three actions define the starting, the ending and the control of the production chain.
Using this structure of data, a graphic and computing interface was built to model the operation of industrial and commercial customers. The implementation of this model is in progress. Preliminary computations show that using this model to control and optimize energy consumption at industrial and commercial customers could produce significant energy and financial savings of approximately 10%.

4. CONCLUSIONS

The Object Oriented approach proposed by the authors proves that the implementation of energy management systems based on production chain control and optimization is simple to realize and produce high quality results. The control strategies can use any type of Demand Response methods.

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