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REDUCING ELECTRICITY COSTS BY PRODUCTION CHAIN OPTIMIZATION UNDER ELECTRICITY MARKET CONSTRAINT

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***Abstract* – This paper describes a new methodology dedicated to the analysis and optimization of the production chain with respect to the final electricity customer and the special conditions imposed by the electricity market. The new approach is based on load forecasting and load management.**

Keywords*:* Electricity market, Energy Management Systems, Demand Response, Cost optimization.

1. INTRODUCTION

At present, all industrial and commercial customers are considered eligible. To efficiently take part in the electricity market any customer must find correct answers to two simultaneous constraint types: (i) internal constraints, related to the production chain of the customer and (ii) external constraints derived from special provisions in the electricity contracts. It is in this context that the creation and development of new Energy Management Systems (EMS) become necessary. These systems are dedicated to the real time management of the production chain at electricity consumers, aiming to reduce electricity costs taking into consideration the influence of the electricity market.

At the customer level, the joining of short-term load forecasting with Demand Side Management (DSM) strategies defines the concept of Demand Response (DR) [2,3].The application of this new management strategy, especially to industrial customers, with greater load flexibility, can produce important savings in the customer's electricity bill [1]. The DR strategy has two components, namely the response to the supplier request (RSR) and the response to the electricity price (REP). The profits generated by RSR and REP systems are greater as the load is more flexible and its composition is more varied.

In this context, this paper describes a new methodology dedicated to the analysis and optimization of the production chain with respect to the final electricity customer and the special conditions imposed by the electricity market, with both its components: regulated and unregulated electricity market. The analysis of the proposed methodology is conducted using a case study, which involves the activity of an economic agent whose main activity addresses the production of fire extinguisher equipments.

Section 2 describes the production chain of the economic agent, with its component processes and activities. The main characteristics and constraints related to the production chain are briefly described in Section 3. The procedure of aggregating equipments' load profiles to generate a load forecast for the electricity consumption of the customer is described in Section 4. Finally, the supplier and price constraints applied to the forecasted load profiles, as well as the economic analysis concerning the electricity bill of the customer, are presented in Section 5.

2. DESCRIPTION OF THE PRODUCTION CHAIN

The analysis of internal constraints related to production assignments and the production chain for a specific economic agent is derived based on a case study involving a section in a factory whose main activity consists in producing different fire extinguisher equipments. To simplify the approach, the analysis has considered that the economic agent manufactures only two products P1 and P2, as parts of two production chains denoted by PC1 and PC2.

As a rule, the manufacturing of products P1 or P2 needs the successive running of the following processes: (a) Cutting and preparing row material. (b) Manufacturing of the upper and lower lids of the equipment. (c) Processing the lower lid. (d) Manufacturing the extinguisher main body. (e) Components assembling. (f) Surface preprocessing. (g) Painting and inscription. (h) Measure and control components assembling. (i) Filling with extinguishing agent. (j) Tests and final trials.

For the two different production chains the above processes differ basically by:

- the number of distinct technological operations implied;
- the type and number of equipments / tools used in the process and
- the time and duration of use for every equipment / tool.

For instance, during the fourth process inside production chain P C 1 (manufacturing of the

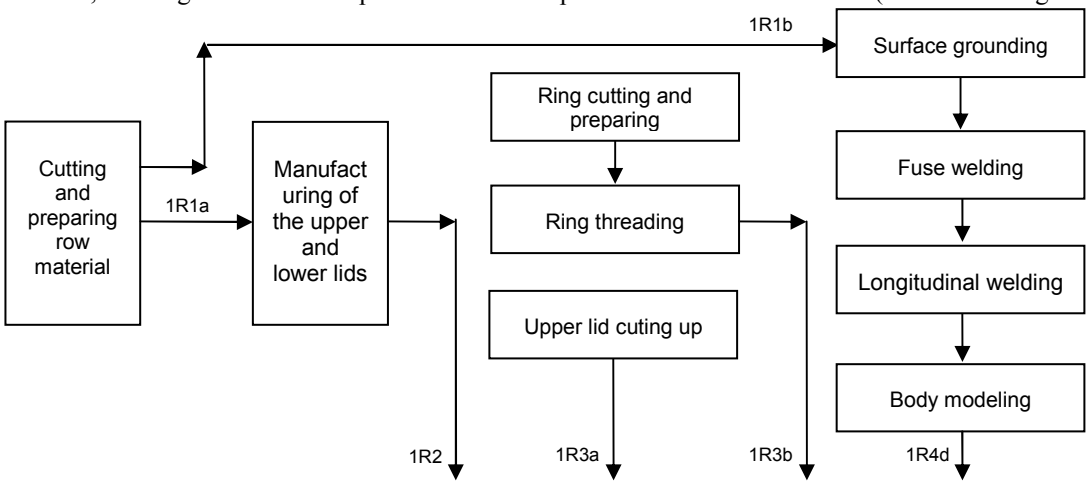

Figure 1: Production chain PC1 (part I).

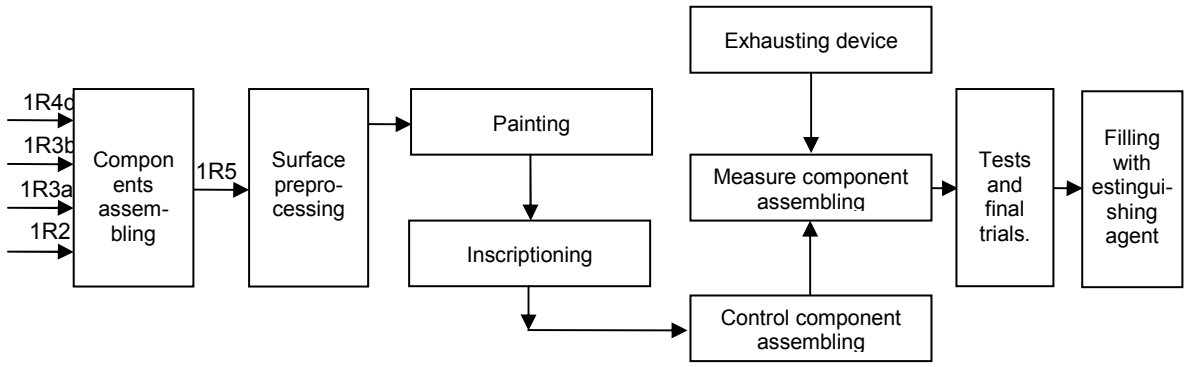

Figure 2: Production chain PC1 (part II).

extinguisher main body), the following successive operation must be fulfilled:

Step1: Surface grounding – uses one or two pressing machines with rated active power of 11 kW, during a 2 minutes cycle.

Step 2: Fuse welding – manual operation during a 2 minutes/piece cycle.

Step 3: Longitudinal welding – a 2 minutes cycle 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 minutes.

As an example, Fig. 1 and 2 show the production chain PC1, while more details concerning these characteristics are briefly presented in Table 1.

3. MAIN CHARACTERISTICS AND CONSTRAINTS OF THE PRODUCTION CHAINS

The detailed analysis of the production chains emphasized the following technological constraints:

- operating conditions over a production cycle (time length associated to each operation, maximum number of successive operations that can be performed before stopping the equipment to refuel, time length of an technological break etc).
- number of production cycles performed over 24 hours.
- the existence of a minimum stock of intermediate products to supply the equipment for at least one complete production cycle, to avoid repeated stopping for refueling.
- working program of the personnel etc

For instance, the operating conditions of the hydraulic press used in process #2 from production chain PC1 has a time length of 2 hours and a quarter, i.e. operation - 2 hours and pause - 15 minutes. The process can start after a stock of 40 pieces is available. The equipment is refueled during the technological breaks.

Painting of items 1R6 for production chain PC1 and items 2R6 for production chain PC2 is performed

during a cycle of 24 / 24 hours, from Monday, at 06:00 in the morning, until Saturday, at the same

Proc. #	Operations	Production cycle				Minimum stock [buc.]	Working program [h/day]
		Time for operation [min.]	#of successive operations [pcs.]	Technological pause [min.]	Rated active power [kW]		
1	Preparing material - lid	1	60	10	7.5	60	16
	Preparing material - body	1	60	10	7.5	60	16
2	Manufacturing the upper lid	3	40	15	15	80	24
	Manufacturing the lower lid	3	40	15	15	80	24
3	Preparing rings	2	30	5	7.5	None	16
	Ring threading	2	90	5	7.5	90	16
	Upper lid cutting	2	60	10	11	60	24
4	Surface grounding	2	45	10	15	90	24
	Fuse welding	2	75	5	5	75	24
	Longitudinal welding	2	45	5	5	45	24
	Body modeling	5	18	10	7.5	36	16
5	Componnets assembling	10	10	5	5	20	24
6	Sanding	10	48	10	15	30	24
7	Painting	180	2	15	8	60	24
	Inscriptioning	10	--	3	1.1	20	16
8	Exhausting devices	25	30	5	7.5	None	16
	Measure component assemb.	3	--	2	0.75	5	16
	Control component assemb.	10	--	3	0.75	5	16
9	Filling	5	90	30	11	100	8
10	Final tests	3	--	2	1.1	20	8

Table 1: Production cycles for production chain PC1.

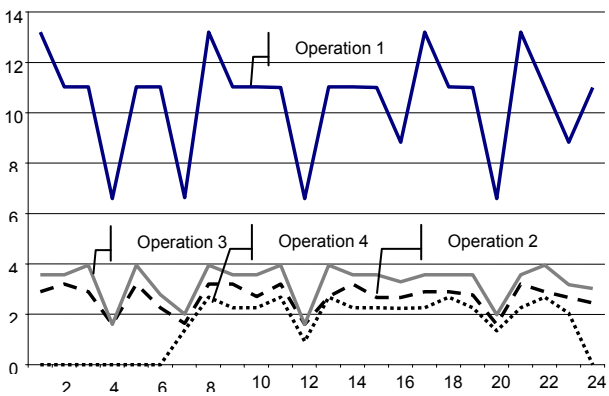

Figure 3: Load profiles for four technological operations.

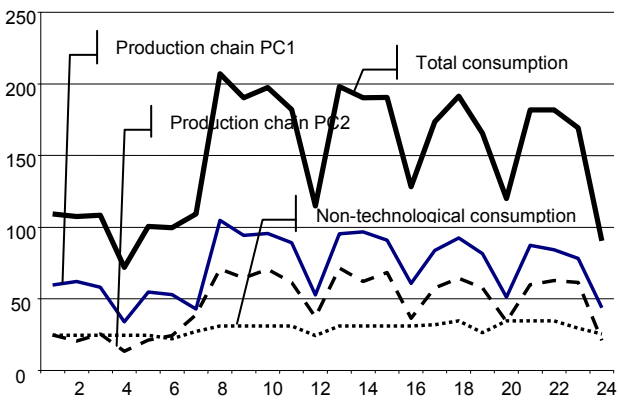

Figure 4: Forecasted LPs for the production section.

hour. During a 24 hours program the painting process is repeated 8 times. The inscription operation of painted items follows the previous painting batches, and is carried out during the working program, between 07:00 and 23:00.

The final tests associated to activity # 10, which uses specialized personnel, are performed separately for each production chain. The working program for this operation is limited to the interval 07:00 to 15:00.

Personnel breaks are scheduled between 11:00-11:30, 19:00-19:30 and 03:00-03:30. With respect to the personnel breaks, non-operating periods of equipments get longer with at most 15 minutes at both ends of the schedule. More details concerning these characteristics are briefly presented in Table 1.

4. FORECASTED LOAD PROFILES

The analysis of the production chains from the previous sections emphasized the existence of the following logical subordination:

- production section, with one or more production chains;

Quantities	Tariff A				Tariff C		Tariff D
	Demand part (ROL/kW/year)		Energy part (ROL/kWh)		Demand part (ROL/kW/ year)	Energy part (ROL/ kWh)	Energy part (ROL/ kWh)
	Evening peak area	Non-peak area	Evening peak area	Non-peak area			
Price	565.0236	237.1068	0.4278	0.1549	353.8272	0.2139	0.2852
Quantity	174.287	25.181	3234.071	25120.478	200.000	32501.264	32501.264
Costs (ROL)	3777.17	229.01	1383.54	3891.16	2714.29	6952.02	9269.36
Total electricity bill (ROL)	9280.88				9666.31		9269.36

Table 2: Comparison of electricity costs with regulated tariffs.

- production chains, with one or more processes
- processes, with one or more technological operations.

However, in practice a technological operation is not executed by itself, in a separate manner, but as a part of a production cycle, defined as a succession of identical operations performed without a technological break. Each production cycle from Table 1 contains such constraints (called "successive operations" and "technological breaks"), which appears at the global level and not at the level of each technological operation.

In this context, for each production cycle described in Tables 1 and 2, specific electricity load profiles were metered. These load profiles were then aggregated according to processes and production chains to generate forecasted load profiles. For instance, Fig. 3 presents the load profiles of the production cycles from process #4 from production chain PC1, during Thursday, 04.05.2006.

At the level of the production section, hourly load forecasts include, besides consumptions associated to the two production chains, other non-technological consumptions, also called indirect consumptions. These include lightning, fan or heating consumptions (Fig. 4).

The Energy Management System (EMS) implemented by the customer is based on the production chains and technological constraints described above.

To promote an efficient response of the customer with respect to the imposed constraints, the proposed EMS must create a response strategy for two of the usual technological problems, namely: (i) congestions in the production chain and (ii) risks of equipment faults.

At the same time, special corrective measures were established for each process if the real value of the electricity consumption in the previous hour outruns the forecasted value with an error greater then admissible value accepted by the supplier. These measures have been established such that the customer still achieves its basic final production objectives (for instance, to produce x pieces during a period of y hours), and may refer to:

- starting the operation of a backup equipment when a similar equipment goes out of order or extra production is required;
- interrupting the operation of equipments that generate great overproduction stocks;
- refueling equipments during the normal personnel breaks, and
- changing the value of no technological consumption.

5. SUPPLIER AND PRICE CONSTRAINTS

Any economic agent aims to reduce its costs with electricity consumption. With this aim in view, someone must consider that in the Romanian electricity market an eligible customer can choose to buy electricity from the regulated market or from the competitive market:

- If the consumer choose to reject eligibility he must choose a regulated electricity tariff proposed by the regulating authority (A.N.R.E.), and he will have no obligations with respect to the hourly load forecasts. In this case the customer or Demand Response (DR) acts rather as a Response to the Electricity Price (REP).
- If the consumer agrees to be eligible he must choose between the best offers of electricity suppliers from the competitive market and he must provide an efficient answer to both components: the Response to the Supplier Request (RSR) and the Response to the Electricity Price (REP).

Table 3: Forecasted load profiles.

Hour	Day 1 Mon	Day 2 Tue	Day 3 Wed	Day 4 Thu	Day 5 Fri	Day 6 Sat	Day 7 Sun
1	2.9	84.5	89.0	89.0	89.0	89.0	30.1
2	3.2	82.7	85.4	85.4	85.4	85.4	26.5
3	2.9	83.7	86.9	86.9	86.9	86.9	29.7
4	1.6	47.3	49.0	49.0	49.0	49.0	17.1
5	3.2	75.9	77.6	77.6	77.6	77.6	26.9
6	2.3	77.5	81.3	81.3	81.3	81.3	25.1
7	76.4	82.0	83.9	83.9	83.9	24.5	24.5
8	176.9	175.8	179.8	179.8	179.8	38.7	38.7
9	156.8	159.1	161.8	161.8	161.8	39.3	39.3
10	168.1	166.3	170.3	170.3	170.3	35.8	35.8
11	152.0	150.8	153.3	153.4	153.4	35.5	35.5
12	89.0	90.3	92.0	92.0	92.0	22.3	22.3
13	168.4	167.0	171.0	171.0	171.0	36.2	36.2
14	159.3	159.1	161.9	161.9	161.9	35.7	35.7
15	156.8	159.4	161.8	161.8	161.8	37.1	37.1
16	98.3	97.1	101.1	101.1	101.1	22.6	22.6
17	142.5	141.6	144.3	144.3	144.3	28.9	28.9
18	157.7	156.9	160.8	160.8	160.8	27.5	27.5
19	137.0	139.2	142.4	142.4	142.4	27.2	27.2
20	89.0	85.4	87.1	87.1	87.1	17.3	17.3
21	143.9	147.4	150.9	150.9	150.9	31.8	31.8
22	148.1	147.2	150.4	150.4	150.4	26.2	26.2
23	140.1	139.8	141.5	141.5	141.5	23.4	23.4
24	65.4	64.8	67.5	67.5	67.5	26.0	26.0
Total	2441.8	2880.8	2951	2951.1	2951.1	1005.2	691.4

Table 4: Real load profiles.

Hour	Day 1 Mon	Day 2 Tue	Day 3 Wed	Day 4 Thu	Day 5 Fri	Day 6 Sat	Day 7 Sun
1	2.9	90.5	91.8	71.7	97.2	94.9	32.6
2	3.5	84.9	96.8	85.8	67.9	86.4	22.3
3	2.4	92.2	64.7	89.0	70.3	91.6	32.2
4	1.8	37.4	38.1	49.3	52.3	37.3	14.1
5	3.2	58.7	82.7	81.6	81.2	78.1	22.3
6	2.3	83.3	90.9	89.2	82.2	86.5	21.5
7	79.0	85.5	91.0	87.2	87.0	19.3	20.1
8	152.8	178.8	196.3	189.3	186.2	28.8	31.6
9	166.8	129.9	174.4	169.0	182.0	41.3	33.9
10	133.3	187.3	186.6	192.5	172.7	38.6	29.6
11	129.6	171.2	172.2	168.7	159.4	38.9	30.2
12	93.5	94.0	106.3	97.7	94.0	25.2	17.8
13	168.9	185.4	188.9	187.7	191.8	37.6	36.5
14	134.5	170.1	171.6	179.2	178.4	40.2	39.3
15	127.6	179.9	177.6	174.7	162.9	40.7	33.0
16	108.9	110.6	107.8	109.0	81.0	17.2	24.3
17	118.2	145.7	107.8	114.1	161.2	22.1	31.0
18	160.2	125.6	163.7	175.7	182.2	27.9	23.6
19	137.7	149.9	110.0	149.3	144.6	30.9	24.0
20	71.1	88.5	91.7	69.4	100.3	13.0	14.4
21	120.5	162.8	169.8	158.1	117.3	33.6	32.9
22	128.2	147.8	115.3	171.7	174.3	20.0	26.2
23	154.4	108.2	143.1	113.5	111.9	23.6	24.0
24	55.4	51.7	72.1	76.5	53.0	28.0	27.1
Total	2256.9	2920.0	3011.2	3050.0	2991.4	1001.7	644.6

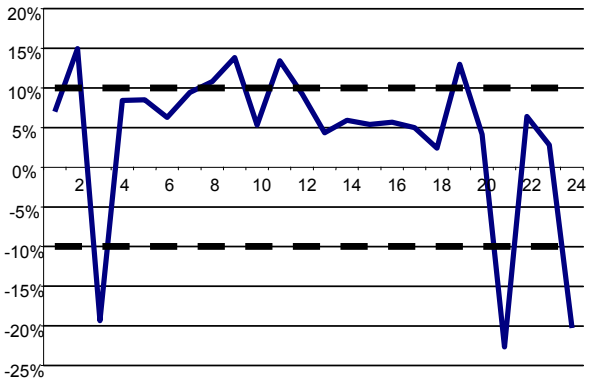

Figure 5: Forecasting errors for May 11-th, 2006

Quantities	Competitive tariffs	
	EMS strategy	Extra costs
Price (ROL/MWh)	0.2567	0.12835
Quantity (MWh)	32501.264	772.947
Costs (ROL)	8,343.07	99.25
Total electricity bill (ROL)		8442.32

Table 5 : Comparison of electricity costs with EMS strategy and competitive tariffs.

For the first case, our analysis determined costs with electricity for 3 types of regulated tariffs, namely:

- Tariff A (demand component and time of use with 2 daily areas);
- Tariff C (demand component without time of use);
- Tariff D (simple tariff, without demand component and time of use)

The values of these costs are those from Table 2.

For the second case, when the customer agrees to be eligible, he must also accept contractual clauses related to short-term (24 – 48 hours ahead) and medium-term load forecasting tasks. With respect to the electricity prices, the authors have considered values widely used on the Romanian electricity market:

- The price from bilateral contract of the eligible customer was considered to be with 10% less the values for Tariff D (the above regulated price);
- If the errors between real and forecasted load profiles are less the ±10% for each hour, the customer will still pay the price from the bilateral contract;
- If the ±10% error is outrun, the settlement process will apply increased prices.

The customer forecasting error ε_i is computed by the supplier for each hour using:

$$\varepsilon_i = (q_{mi} - q_{pi}) / q_{pi} * 100 \qquad [\%] \qquad (1)$$

where: q_{mi} = real electricity consumption at hour i; q_{pi} = forecasted electricity consumption at hour i.

The extra costs paid imposed by the supplier to the customer are computed using equation:

$$PN = \sum_{i=1}^{k} PN_i = \sum_{i=1}^{k} (q_i \cdot f_i \cdot p_i) \quad [ROL] \qquad (2)$$

where: q_i = hourly electricity consumption for which extra cost PNi is applied if $|\varepsilon_i| > \varepsilon_{max}$. Quantity q_i can be computed as :

$$q_i = |q_{pi} - q_{mi}| - \varepsilon_{max} \bullet q_{pi} \quad [\text{MWh}] \qquad (3)$$

where: i = hour when the maximum admissible error was outrun; k = number of hours when errors greater than the maximum admissible value were recorded. ε_{max} = the maximum admissible error = 10%; p_i = the price from the bilateral contract at hour i; f_i = weighting factor for positive or negative errors (in this study the authors considered a balanced weighting factor, equal to 0.5).

Based on data provided by the EMS described above, the customer forecasted and real electricity consumption values for 7 days are those from Tables 3 and 4.

The total daily electricity consumption forecasting errors are less then ± 8.2 %. However, the hourly forecasting errors can reach greater values. For instance, the forecasting hourly errors for May 11-th, 2006 are shown in Fig. 5.

This example shows how the customer can act, using EMSs, to create an efficient response to the constraints imposed by the supplier or the constraints related to the electricity price. Thus, when the forecasting error outrun the prespecified admissible value, corrective measures previously set inside the EMS strategy are immediately applied, to minimize the forecasting error. In practice, this may be achieved by connecting or disconnecting equipments in the production chain. These equipments are similar, in terms of electricity consumption and technological approach, to the ones which were the origin of the forecasting errors. Appling this strategy, the maximum admissible value for the forecasting error cannot be outrun for two consecutive hours.

The velocity and quality of the customer response to the constraints imposed by the supplier (RSR) or the electricity price (REP) are determined in a great extent by the flexibility of the production chain. For the case study considered by the authors, the application of the proposed EMS strategy, for the conditions in the bilateral contract described above, has produced a final electricity bill of 8442.32 ROL (see Table 5), which is 9% cheaper as compared to the case when regulated tariffs are applied.

6. CONCLUSIONS

The methodology proposed by the authors proves that the implementation of EMS strategies by customers is valuable approach to reduce electricity costs. However, demand response quality is distinct for different customers, and is higher for great consumers with greater load flexibility. On the other hand, entering in the electricity market as eligible customers can be a source for electricity savings. These savings depend by the clauses provided in the bilateral contracts (prices, admissible forecasting errors, price penalty values).

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