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Peak Power Optimization Based On Nonlinear Prediction And Fuzzy Logic

Dedicated to Professor Milić Stojić on the occasion of his 65th birthday

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Abstract: A new peak power optimization algorithm of the electric energy consumption with nonlinear prediction is presented in this paper. The system parameters for optimization are adjusted using fuzzy logic.

Keywords: Peak power, nonlinear prediction, fuzzy logic.

1 Introduction

The peak power optimization systems were developing at the same time as computer technique. The first efficient systems were developed in the second half of the last century [1, 2, 3] and with the use of computer technique they are improving today. Most of the existing algorithms use linear prediction [1] for estimating fifteen-minute electric energy consumption. If we use this method of prediction, then we can effectively optimize peak power, but it is impossible to decrease peak power and increase productivity at the same time.

In this paper, new algorithm is developed. Algorithm uses prediction of fifteen-minute electric energy consumption with complex optimization criteria which at the same time involves peak power and plant production and that leads to the use of nonlinear prediction.

Parameters which are used during the adjustment of optimization system are in practice usually adjusted based on experience, with estimation of possible consumption during the next period. In this new algorithm, adjustment is made using two level fuzzy logic [4, 5]. First, universal set for limited energy is scaled based on the following information: raw material level in depot and market of finished

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products. Second level of fuzzy decision is determining concrete value of limit fifteen-minute energy based on consumption and consumption difference in last month. That way of concluding is similar to concluding used in production (food production, tire making...)

2 Peak power optimization problem

It is necessary to form a control algorithm for electric energy consumption in a plant in order to increase production and revenue and to minimize costs for peak fifteen-minute energy during one month. So, we have to maximize next optimization criteria:

$$J = k_1 \int_0^T P(t)dt - k_2 \frac{\max_{t\in T} P(t)}{\frac{1}{T}\int_0^T P(t)dt} \tag{1}$$

where: $P(t)$ - momentary power, T - optimization interval, k_1 i k_2 weight coefficients, J is measured in euros or dinars , coefficient k_1 in (euros or dinars)/kWh and coefficient k_2 also in euros or dinars.

During optimization of criteria J, it is necessary to satisfy the following condition:

$$\frac{dE(t)}{dt} \leq \sum_{j=1}^{n} P_j \tag{2}$$

where $\sum_{j=1}^{n} P_j$ is plant installed power.

This limitation means that a plant cannot use more power than it has installed.

Next condition must also be satisfied:

$$\frac{E(t_k)T - E(T)t_k}{T(T-t_k)^2} < 0 \tag{3}$$

where: $E(t_k)$ - energy until moment t_k, $E(T)$ - maximum energy in period T and t_k - sampling time.

This condition means that the diagram of prediction must be convex.

3 Algorithm for optimization of electric energy consumption

In order to realize optimization algorithm, we must first determine algorithm parameters, i.e. energy limit $E_T = E(T)$. For determining E_T two-step fuzzy logic will be used.

First, basic set for E_T based on information about storehouse amount of raw material (S) and customer demand for finished products (F) should be determined. Second step during fuzzy decision-making is determining limit energy E_T based on production and production difference in last month.

During first step of decision-making, it is necessary to define membership function for S and F.

In membership function names μ_A and μ_B, first letters S, M and L respectively mean small, medium and large.

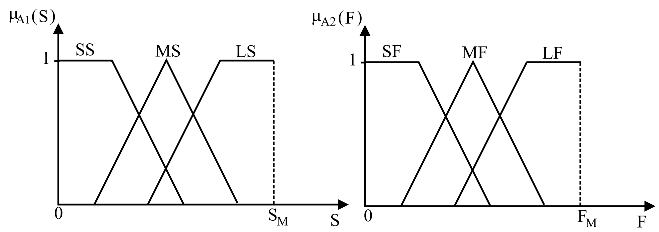

Fig. 1. Membership functions for storehouse raw material condition (S) and finished products market (F)

Basic set for S is in a range from 0 to S_M, and for F from 0 to F_M. Next step is to determine output set K_T for scaling factor of universal set ($K_T \leq 1$). Basic set

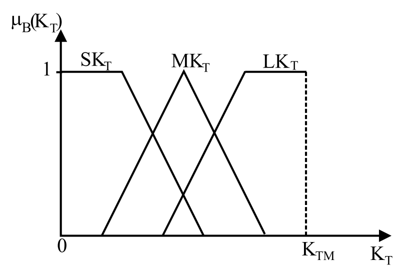

Fig. 2. Membership functions for output set of scalling factor (K_T)

for K_T is in a range from 0 to K_{TM}. Linguistic fuzzy decision rules are:

IF S is small AND F is small THEN K_T is small
IF S is small AND F is medium THEN K_T is small
IF S is small AND F is large THEN K_T is medium
IF S is medium AND F is small THEN K_T is small
IF S is medium AND F is medium THEN K_T is medium
IF S is medium AND F is large THEN K_T is large
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Using the known Mamdany type of fuzzy concluding, we gain adequate output fuzzy set [6, 7]. With defuzzification of that set, we can determine value of the scaling coefficients of universal set K_{Td}. If we multiply maximum value E_T with this coefficient, we gain universal set for maximum fifteen-minute energy.

After that, we define membership functions for the consumption (E_i) and consumption difference ($\Delta E_i = E_i - E_{i-1}$) in last month as follows:

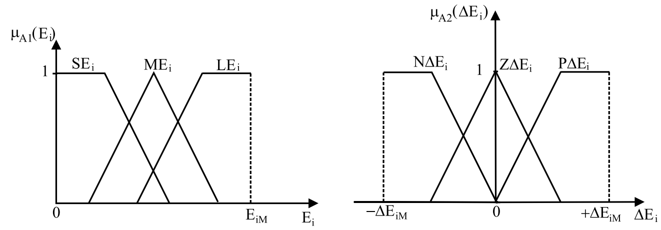

Fig. 3. Membership functions for consumption (E_i) and consumption difference (ΔE_i)

Basic set for E_i is in a range from 0 to E_{iM}, and for ΔE_i from -ΔE_{iM} to +ΔE_{iM}. First letters in names of membership functions N, Z and P respectively mean negative, around zero and positive.

Than, we define membership functions for E_T.

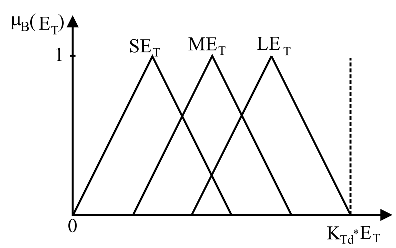

Fig. 4. Membership functions for output set of maximum fifteen-minute energy (E_T)

Set of fuzzy decision rules with proportional differential law, can be written in a form of linguistic statements:

IF E_i is small AND ΔE_i is negative THEN E_T is small
IF E_i is small AND ΔE_i is around zero THEN E_T is small
IF E_i is small AND ΔE_i is positive THEN E_T is medium
IF E_i is medium AND ΔE_i is negative THEN E_T is small
IF E_i is medium AND ΔE_i around zero THEN E_T is medium

IF E_i is medium AND ΔE_i is positive THEN E_T is large
IF E_i is large AND ΔE_i is negative THEN E_T is medium
IF E_i is large AND ΔE_i around zero THEN E_T is large
IF E_i is large AND ΔE_i is positive THEN E_T is large

or, in logical form:

$$\begin{aligned}
&\mu_{A1S}(E_i) \wedge \mu_{A2N}(\Delta E_i) \Rightarrow \mu_{BS}(E_T)\\
&\mu_{A1S}(E_i) \wedge \mu_{A2Z}(\Delta E_i) \Rightarrow \mu_{BS}(E_T)\\
&\mu_{A1S}(E_i) \wedge \mu_{A2P}(\Delta E_i) \Rightarrow \mu_{BM}(E_T)\\
&\mu_{A1M}(E_i) \wedge \mu_{A2N}(\Delta E_i) \Rightarrow \mu_{BS}(E_T)\\
&\mu_{A1M}(E_i) \wedge \mu_{A2Z}(\Delta E_i) \Rightarrow \mu_{BM}(E_T)\\
&\mu_{A1M}(E_i) \wedge \mu_{A2P}(\Delta E_i) \Rightarrow \mu_{BL}(E_T)\\
&\mu_{A1L}(E_i) \wedge \mu_{A2N}(\Delta E_i) \Rightarrow \mu_{BM}(E_T)\\
&\mu_{A1L}(E_i) \wedge \mu_{A2Z}(\Delta E_i) \Rightarrow \mu_{BL}(E_T)\\
&\mu_{A1L}(E_i) \wedge \mu_{A2P}(\Delta E_i) \Rightarrow \mu_{BL}(E_T)
\end{aligned} \tag{4}$$

For concrete input values E_i^* i ΔE_i^*

$$\begin{aligned}
&\mu'_{A1} = \min[\mu_{A1S}(E_i^*), \mu_{A2N}(\Delta E_i^*)] \Rightarrow \mu_{B1}(E_T) = \min[\mu'_{A1}, \mu_{BS}(E_T)\\
&\mu'_{A2} = \min[\mu_{A1S}(E_i^*), \mu_{A2Z}(\Delta E_i^*)] \Rightarrow \mu_{B2}(E_T) = \min[\mu'_{A2}, \mu_{BS}(E_T)]\\
&\mu'_{A3} = \min[\mu_{A1S}(E_i^*), \mu_{A2P}(\Delta E_i^*)] \Rightarrow \mu_{B3}(E_T) = \min[\mu'_{A3}, \mu_{BM}(E_T)]\\
&\mu'_{A4} = \min[\mu_{A1M}(E_i^*), \mu_{A2N}(\Delta E_i^*)] \Rightarrow \mu_{B4}(E_T) = \min[\mu'_{A4}, \mu_{BS}(E_T)]\\
&\mu'_{A5} = \min[\mu_{A1M}(E_i^*), \mu_{A2Z}(\Delta E_i^*)] \Rightarrow \mu_{B5}(E_T) = \min[\mu'_{A5}, \mu_{BM}(E_T)]\\
&\mu'_{A6} = \min[\mu_{A1M}(E_i^*), \mu_{A2P}(\Delta E_i^*)] \Rightarrow \mu_{B6}(E_T) = \min[\mu'_{A6}, \mu_{BL}(E_T)]\\
&\mu'_{A7} = \min[\mu_{A1L}(E_i^*), \mu_{A2N}(\Delta E_i^*)] \Rightarrow \mu_{B7}(E_T) = \min[\mu'_{A7}, \mu_{BM}(E_T)]\\
&\mu'_{A8} = \min[\mu_{A1L}(E_i^*), \mu_{A2Z}(\Delta E_i^*)] \Rightarrow \mu_{B8}(E_T) = \min[\mu'_{A8}, \mu_{BL}(E_T)]\\
&\mu'_{A9} = \min[\mu_{A1L}(E_i^*), \mu_{A2P}(\Delta E_i^*)] \Rightarrow \mu_{B9}(E_T) = \min[\mu'_{A9}, \mu_{BL}(E_T)]
\end{aligned} \tag{5}$$

membership function of output fuzzy set takes a form:

$$\begin{aligned}
\mu_B(E_T) = \max\big[&\mu'_{B1}(E_T), \mu'_{B2}(E_T), \mu'_{B3}(E_T), \mu'_{B4}(E_T), \mu'_{B5}(E_T),\\
&\mu'_{B6}(E_T), \mu'_{B7}(E_T), \mu'_{B8}(E_T), \mu'_{B9}(E_T)\big]
\end{aligned} \tag{6}$$

Finally, using defuzzification, we gain limit value of fifteen-minute energy E_Tg:

$$E_{Tg} = \frac{\int_0^{K_{Td}E_T} \mu_B(E_T)\, E_T\, dE_T}{\int_0^{K_{Td}E_T} \mu_B(E_T)\, dE_T} \tag{7}$$

This offered algorithm resolves a problem of determining fifteen-minute energy $E_T g$. In order to optimize electric energy consumption, with respect to criteria (1), next algorithm is formed. Basic input value for this algorithm is output value $E_T g$, gained from fuzzy algorithm.

/*program*/
define $E_T g$ **real**; "peak plant energy"
define N **integer**; "priority group"
define K **integer**; "machine number"
signal S **boolean**; "maxigraph synchronization"
read $E_T g$
read $matrixM(i,j), i = 1,...,N, j = 1,...,K$
while $(TRUE)$
begin
  read S
  if $(S = 1)$ **then**
  begin
    repeat
      read E_{tk}

$$E_t = \frac{E_{t_k} T - E_{Tg} t_k}{T(T-t_k)^2} t^2 + \frac{E_{Tg} T^2 - 2E_{t_k} T^2 + E_{Tg} t_k^2}{T(T-t_k)^2} t + \frac{T(E_{t_k} T - E_{Tg} t_k)}{(T-t_k)^2}$$

      write E_t, E_{Tg}
    until ($E_t > E_{Tg}$)

$$P_d = \frac{E_t - E_{tk}}{t - t_k} - \frac{E_{Tg} - E_{tk}}{T - t_k}$$

    repeat
      looking up $P_d \cong M(i,j)$

    until (switching off without signaling OR switch

      off confirmation)
    machine M(i,j) turning off
  end
end

4 Conclusion

The main result of this paper is control algorithm for optimization of electric energy consumption based on nonlinear prediction using fuzzy logic for calculation of input data. Algorithm takes into consideration conditions on the market of finished products, amount of raw material in factory storehouse and electric energy consumption and consumption difference last month. Final goal of fuzzy algorithm and optimization algorithm is the increase of plant production and decrease of peak power. For realization of this algorithm it is necessary to use nonlinear prediction of fifteen-minute energy consumption with minimization of adequate optimization criteria.

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