DECODING AND PREDICTION OF ENERGY STATE IN CONSUMPTION CONTROL

DJURDJE PERIŠIĆ[1], ALEKSANDAR ŽORIĆ, DJORDJE BABIĆ, DJORDJE PERIŠIĆ

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A new approach to consumption peak load control is shortly presented. The realized system is dedicated to those electricity customers, who use device "maxigraph" for the measurement of the maximum average consumption power during 15 minutes. Particular significance in this description was given to the decoding and to the prediction of energy state. The decoding and prediction are used for optimal control of the consumption peak load. The described principles are demonstrated on the graphics, recorded on the realized system.

1. INTRODUCTION

The development of a general peak load solution for large electricity customers was complex in theoretical and practical sense, because of the very wide variety of large customers, the number of parameters that might have influence and the indefinite number of cases, which may happen during the consumption.

This article is mainly devoted to decoding and predicting of the energy state of the large consumers. These solutions are involved into the developed Peak Load Control (PLC) system, but they can be widely used, as well.

The general approach to PLC system, based on frequency locked loop (FLL) is described in [1]. This approach offers the natural and optimal way of peak load control for all kind of large consumers, regardless of the consumption in a factory, the technological process, organization of production, the variability of the used electricity consumers, the size, the space and position of the factory, and the other parameters that might have influence on the peak load control.

The approach is applied in the project "Expert system for peak load control", within the national projects of the Ministry of Science and Technology. The described algorithm was created through years of experience and contributions in

[1] Faculty of Information Technologies, Slobomir P University, Str. Pavlovića put bb, 76300 Slobomir, Republic of Srpska, Bosnia and Herzegovina, e-mail: djurdje@beotel.rs.

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the field of rational energy consumption and in the field of electronics and control. Refs. [2–3] are FLL, used as the basic concept of PLC. Ref. [4–7] are closely related to the previous FLL. Refs. [8–14] are used in the realization of PLC concept, in electronics implementation and software support.

2. **DESCRIPTION OF PLC SYSTEM ORGANIZATION**

The PLC system is shown in Fig. 1. The device maxi-graph (MAX) registers total electricity consumed by consumers from C1 to CN and at the same time shows the average electric power of total consumption during 15 minutes. Photo sensors, which are incorporated into MAX, generate pulse rate Sp whose frequency corresponds to the current consumption power of all consumers C1 to CN. Installation of photo sensor in MAX is under control of the laboratory of Electrical Distribution. Checking the functions and verifications of extended MAX makes Republican Bureau for Measures. The programmable generator generates pulse rate Spmin, whose frequency corresponds to the minimum consumption power of all consumers C1 to CN. This minimal power consumption is achieved when all consumers, whose short exclusion will not disrupt the process of technological work, are switched off. The consumption, which corresponds to frequency of Smin, will appear as the main criterion curve of the factory on the graphics, later on, in Fig. 2, Fig. 3 and Fig. 8. Signal S_{15}, whose period is 15 minutes, synchronizes devices MAX and all PLC system parts. In addition to the accumulator, the central part of PLC contains binary decoder, sound coder and the other electronic modules.

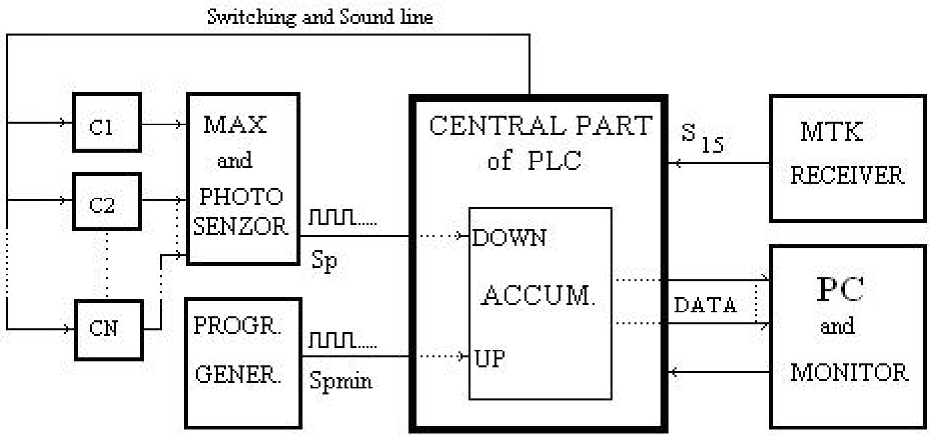


Fig. 1 – The PLC system organization.

The PLC system acts as the frequency locked loop, ref. [1].

3. PARAMETERS FOR REALIZATION OF BINARY DECODER

The accumulator (ACC) in the central part of PLC is 16-bit Up-Down counter. Initial value E_0 is preset into ACC at the beginning of each 15-minute interval. E_0 represents the initial energy. The integrated difference between the frequencies of *S*p and *S*pmin in ACC during 15 minutes is added to E_0. The changes of the accumulator content, during 15 minutes interval is shown in Fig. 2. The value E_{max} corresponds to the energy, which is not to be exceeded during 15 minutes interval. Since the pulses of Spmin increases the content of ACC, E_{max}

$$E_{max} = E_0 + q \cdot 15\ \mathrm{min} \tag{1}$$

is defined by (1), where "*q*" is the coefficient direction of the main criterion curve. Since the pulses of *S*p, representing the total consumption of all consumers, decrease the content of ACC, the shaded part in Fig. 2 represents the current content of ACC during time interval of 15 minutes. It is expected that the coefficient direction of the total consumption curve is greater than the coefficient direction of the main criterion curve. Because of that, the current content of ACC

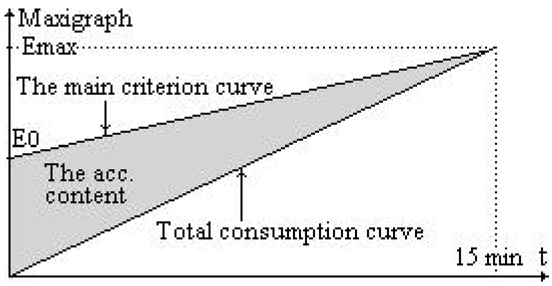


Fig. 2 – The physical meaning of the accumulator content.

tends to zero in practice. If the content of ACC is prevented to reach and become less than zero during interval of 15 minutes, the total consumption curve will never overcome E_{max}. In order to monitor and timely prevent the content of ACC to become less than zero, eight additional criterion curves are introduced in Fig. 3a. The additional criterion curves are separated by the same step. The field of detection consists of eight steps. Since the step is programmable, the field of detection is changeable and adaptable to the users. The main and additional criterion curves, E_{max}, the initial energy E_0, step and the field of detection are the main parameters, which define the different approaches to functioning of PLC system. They are chosen in a way to enable the optimal control of the peak load, according to the user needs. The function of software predictor "Eprogres" is illustrated in Fig. 3b. "Eprogres" shows that the total consumption curve 1 will not reach E_{max} at the end of 15-minutes time. Although it entered the field of detection, it is not necessary to switch of the consumers. On the other hand, the total consumption

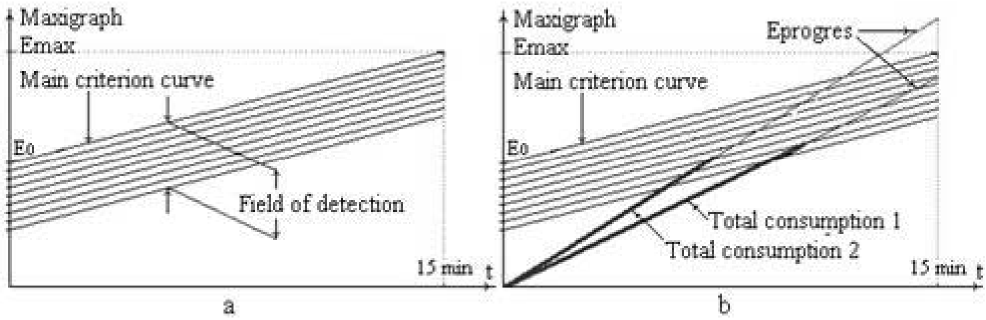


Fig. 3 – a) The additional criterion curves and field of detection; b) software predictor "Eprogres".

curve 2 also entered the field of detection, but it would overcome E_{max}, providing that total consumption power stays on the same level. Because of that, as soon as the total consumption curve crosses the first additional criterion curve, the switching will start. If after the first switching "Eprogres" still shows excess of E_{max}, the additional switching of consumers will be performed at the next crossing. After last crossing with the main criterion curve, the total consumption will be reduced to the minimum consumption of the factory. The total consumption curve will automatically follow the main criterion curve, according to the previously given explanations. Due to that, the total consumption curve will reach E_{max}, exactly at the end of 15-minutes time, what will be demonstrated on the graphics, recorded on the realized system.

4. **REALIZATION OF THE SOUND DECODER**

To realize the approach described it is necessary, among the other requirements, to identify electronically nine crossing points, *i.e.* eight bands between the nine criterion curves. For this purpose, one sound decoder is used, which consists of one binary decoder of bands, one sound coder, one detector of excess of the main criterion curve and modulator. The detail scheme of decoder with binary outputs C, B and A, is shown in Fig. 4. Every band corresponds to the step of $2^4 = 16$. Four least significant bits 2^0 to 2^3, shown in Fig. 4, define the step. The next three outputs C, B and A represent the natural binary counter of the occurred steps. Since, according to the given description, decoder is to register the bands of the 16-bits counter contents, which are closely to zero, it is necessary to disable the counting of steps for all the other values of counter content. To do that the zero decoder is used, whose output $Yz = 1$ only if all inputs to decoder are equal to logic zero. If $Yz = 1$, the real counter outputs will appear as C, B and A.

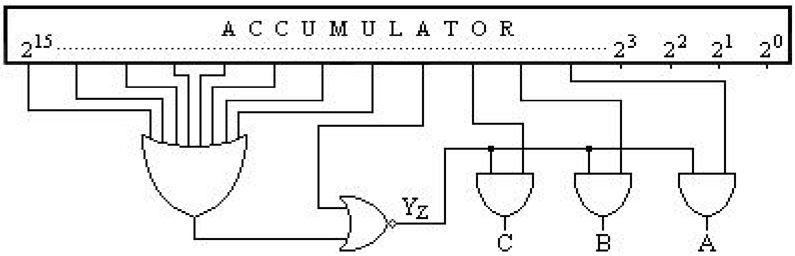


Fig. 4 – Binary decoder of eight bands with steps of 2^4.

The sound coder of eight bands is shown in Fig. 5. The clock is realized by IC CD 4060 which works as quartz oscillator and counter at the same time. The used quartz frequency is 32768 Hz, so that the frequencies of the output pulse rates Q_5 and Q_{14} are respectively 1024 Hz and 2 Hz. The pulse width of Q_{14} is 0.25 s.

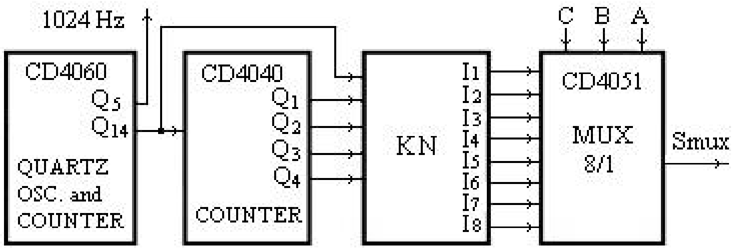


Fig. 5 – Sound coder of eight bands.

The binary counter CD 4040 generates on the outputs Q_1, Q_2, Q_3, and Q_4 pulse rates with frequencies respectively 1 Hz, 0.5 Hz, 0.25 Hz and 0.0125 Hz. Using Q_{14}, Q_1, Q_2, Q_3 and Q_4, combinational network KN generates eight different Morse codes with points for 0.25 s and lines for 2 s. The outputs of KN I_1 to I_8 are Morse codes respectively: one point, two points, three points, four points, one point and line, two points and line, three points and line and four points and line. These eight pulse codes, I_1 to I_8 are entered to the inputs of multiplexer CD 4051. The decoder outputs C, B and A are entered to control inputs of multiplexer, enabling in that way appearance of only one of eight pulse codes at the multiplexer output Smux. If, for instance, the counter content is between 0 and 15, Smux would be pulse code I_1. Providing the counter content is between 16 and 31, Smux would be pulse code I_2 and so on. So, all of eight bands are coded by the corresponding pulse code I_1 to I_8. All points and lines of Smux are modulated by 1024 Hz. Such signal is suitable for sending through factory either by switching line or wirelessly.

The decoding described represents, actually, the electrical registration of crossing points, when the total consumption curve crosses the additional criterion curves. If the 16-bit Up-down counter changes from zero to negative content, it generates negative pulse on its output “Borrow”. This pulse is used for detection of the state when the total consumption curve crosses the main criterion curve. In this case, the signal with continuous frequency of 1024 Hz is send trough factory.

5. PREDICTION OF ENERGY STATE

Software predictor “Eprogres”, which will be demonstrated on the graphics later on, is developed to continuously predict and show every second what would be the value of E_{max} at the end of 15-minutes time, providing that the current consumption be maintained all the time. On the first sight, it seems that one linear predictor would be the corresponding solution. However, the linear predictor, following exactly the changes of the consumption power, makes chaotic motion of the pointer on the monitor and an impression of unrealistic process. On the other hand, an averaging of the mathematical coefficient direction of the pointer, during a few seconds, makes also an impression of unrealistic system, which does not work continuously. This is why it was necessary to develop an adaptive predictor, which would overcome the defects described.

For this purpose, a recursive predictor of the second order is developed. This predictor is described by two equations:

$$C(k+1) = C(k) + ad(k) + bd(k+1), \tag{2}$$

$$d(k+1) = C(k) - R(k). \tag{3}$$

Variable $R(k)$ is the real mathematical coefficient direction (MCD) of the total consumption, which is measured at discrete time t_k. Variable $C(k+1)$ or $C(k)$ is the calculated MCD of the total consumption at discrete times respectively t_{k+1} and t_k. Variable $d(k+1)$ or $d(k)$ is the difference between the calculated and real MCD at discrete times respectively t_{k+1} and t_k. At last, a and b are the predictor parameters.

The basic idea is to calculate MCD of total consumption curve $C(k+1)$ so that $C(k+1)$, if $k \to \infty$, reaches $R(k)$ after some discrete steps. The usual discrete step of measurements of MCD was 1 sec in the realized PLC system, although the step may be changed accordingly. That means the pointer of MCD will reach the real position $R(k)$ in 3 s, 4 s, 5 s or in any number of seconds, depending on the chosen parameters a and b. It is now necessary to analyse, using the Z transform, under which conditions the predictor would have the properties described. The Z transform of equations (2) and (3) are respectively:

$$zC(z) - zC_0 = C(z) + ad(z) + bzd(z) - bzd_0\,, \tag{4}$$

$$zd(z) - zd_0 = C(z) - R(z)\,, \tag{5}$$

where C_0 and d_0 are the initial values of respectively $C(k)$ and $d(k)$ at discrete time $t_k = 0$. It may be found out from (4) and (5):

$$C(z) = \frac{-R(z)(a + bz)}{z^2 - z(1+b) - a} - \frac{azd_0 + z^2 C_0}{z^2 - z(1+b) - a}\,. \tag{6}$$

In practice $R(k)$ is always a step function and it may occur at any discrete time t_k. Providing $R(k) = R$ = constant, the Z transform of R is:

$$R(z) = \frac{Rz}{z-1}. \tag{7}$$

To prove that $C(k)$ may reach R, if $k \to \infty$, *i.e.* $C(\infty) = R$, let us use the final value theorem. Instead to make the inverse Z transform of equation (6) to find $C(\infty)$, usage of the final value theorem is shorter procedure to check if $C(\infty) = R$. If we change $R(z)$ from (7) into (6) and apply the final value theorem to that expression, we would get:

$$C(\infty) = \lim C(k)_{k\to\infty} = \lim (z-1)C(z)_{z\to 1} = R\,. \tag{8}$$

The equation (8) confirms that the predictor described by equations (2) and (3) may meet the required task. One additional condition is that the predictor must be stable system. The predictor is stable if $|z_1| < 1$ and $|z_2| < 1$, where z_1 and z_2 are the poles of the system. The poles z_1 and z_2 are the zeros of $z^2 - z(1+b) - a = 0$, *i.e.*

$$z_{1/2} = \frac{1 + b \pm \sqrt{(1+b)^2 + 4a}}{2}\,. \tag{9}$$

After analyses of the conditions $|z_1| < 1$ and $|z_2| < 1$, using equation (9), one may found out the region of parameters "a" and "b", for which the predictor is the stable system, Fig. 6. The region is limited by mathematical straight lines $a = -b$, $a = b-2$ and $a = -1$. Using equations (2) and (3), two simulations of predictor outputs $C(k)$ are shown in Fig. 7. The case when R changes from 0.8 to 1 (positive step) is shown in Fig. 7a and the case when R changes from 1.2 to 1 (negative step) is shown in Fig. 7b. It may be seen that the predictor functions in the same way in both cases. Choosing the corresponding values of "a" and "b", the calculated $C(k)$, may reach R in 3, 4, 5 or any number of steps, as it is shown in Fig. 7. For all curves in Figs. 7a and 7b, a = 0.01. Parameter b is –0.8, –0.65 and –0.5 for, respectively Curve 1, Curve 2 and Curve 3.

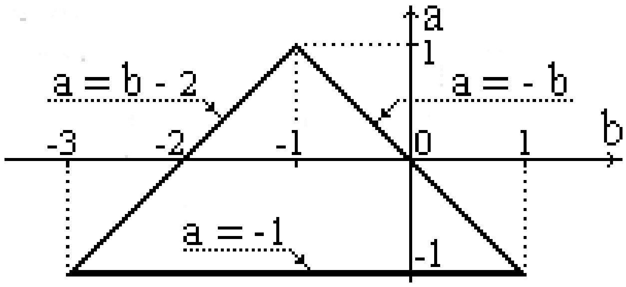


Fig. 6 – The region of parameters
a and *b* for the stable system.

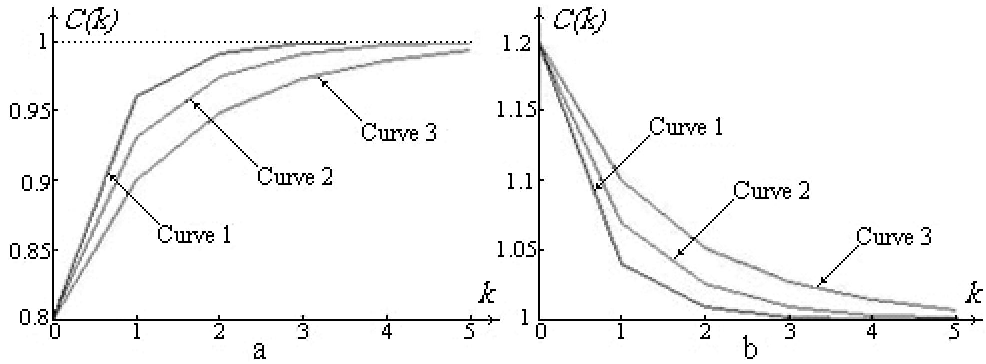
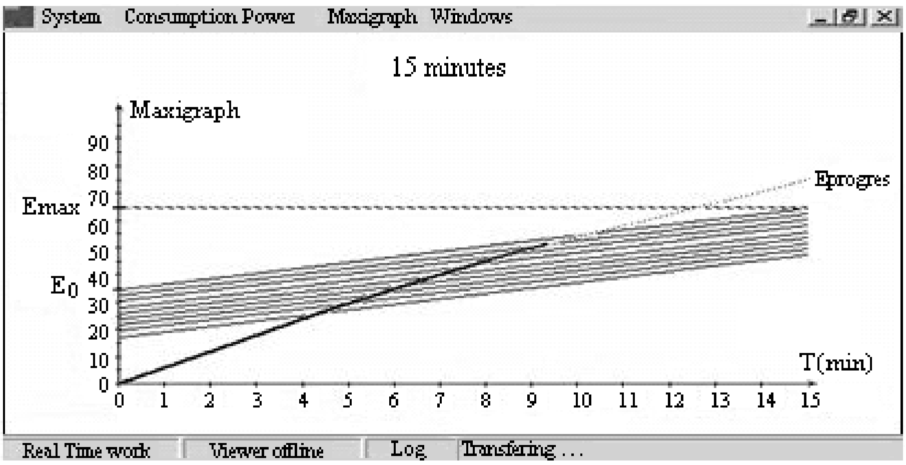


Fig. 7 – $C(k)$ reaches the real MCD in 3, 4 and 5 steps:
a) R with positive step;
b) R with negative step.



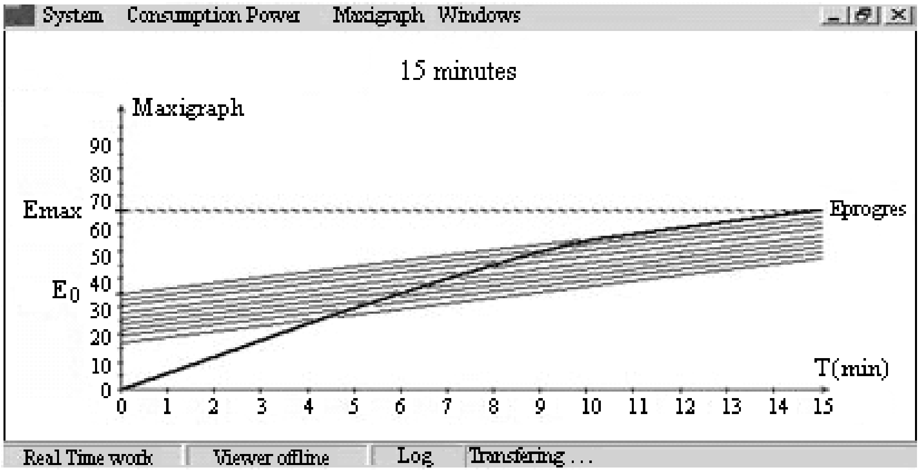


Fig. 8 – The total consumption curve reaches E_{max} at the end of 15-minutes period.

To illustrate the pointer of "Eprogres", the graphics of the same 15 minutes process, which are recorded in the real time on the applied system, are shown in Fig. 8. The graphics illustrate at the same time the total consumption curve, the criterion curves, the steps between the criterion curves, the initial energy E_0, E_{max}, and the detection field. The first graphic is recorded during the tenth minute and the other one at the end of 15 minutes period. It may be noticed that the slope of the total consumption curve gradually decreases in the detection field, but when it reaches the main criterion curve, the total consumption curve precisely follows it, reaching E_{max}, at the end of 15 minutes period.

5. **CONCLUSIONS**

The decoding described for the need of PLL system, represents band decoder of the binary content, which is close to zero. The binary band consists of steps. Every step is defined by 2^n (n is the number of the least significant bits chosen). The number of steps is 2^m (m is the number of the next least significant bits). The same approach to decoder may be used to cover a band, which is not close to zero. In this case, it is necessary to shift the number of m-bits to the corresponding place of the binary outputs. These m-bits may be separated between themselves, offering decoding of more bands with the same steps. At last, using simple additional combinational networks, more steps that are different, can be used instantaneously. This makes this approach suitable for wide range of applications.

Choosing the parameters a and b, the oscillations during the transition state of the predictor, are avoided. The predictor can be adapted, using the combinations of *a* and *b*, for different applications. It is especially suitable for software realizations, although it can be realized as an electronic circuit, as well.

At last, the PLC system described represents the natural way for solution of the peak load control of energy consumption, which may be adapted to any kind of customers. It offers many benefits and advantages, which are pointed out in [1].

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