



POWER OPTIMIZATION SYSTEM

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Abstract: This paper is intended to describe system for power optimization. Power optimization system has an ability to measure power consumption (usually considering large electrical energy consumers, but could also be used for other consumers) and according to established thresholds, performs power optimization. Power optimization is performed through automated control of switches and relays. System also features graphical display of controlling process.

Key Words: Power measurement, power optimization, control algorithm, controlling process monitoring.

1. INTRODUCTION

Production and distribution of electrical energy, one of the most precious resources nowadays, becomes one of the most important issues. During recent years, power consumption has grown constantly, and now we have a situation where stable and uninterruptible delivery of electrical energy to numerous consumers is required and has no alternative. On the other hand, large consumers of electrical energy, like factories, are constant threat to power system. Instantaneous power overload could completely damage entire infrastructure, so large electrical energy consumers have to be limited in their consumption in order to provide stable, reliable and robust system for power distribution. Thus, large energy consumers are allowed to consume electrical energy as long as the amount of consumed power (energy) is being kept inside predefined boundaries. So, a large consumer (for example factory) is allowed to define energy amount it will be able to import every 15 minutes. As long as the consumer imports quantities of electrical energy that do not exceed defined limits during 15 minute intervals, the price of the imported energy is regular. If the consumer imports more energy during 15 minute intervals, certain penalties are going to be applied. This mechanism forces electrical energy consumer to be aware of a possible overload of an electrical energy system.

2. SYSTEM DESCRIPTION

Power optimization system consists of a measuring unit and control unit.

Measuring unit

Measuring unit is implemented as an embedded system based on AVR microcontroller. Block diagram of a measuring unit is presented in Figure 1.

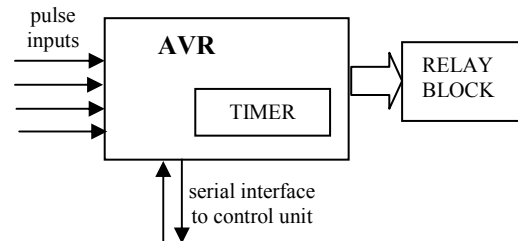


Figure 1: Measuring unit

Measuring unit has pulse inputs, serial interface to the control unit (RS232), and a relay block which is intended to be an actuator in a process of power optimization. AVR CPU measures time intervals that elapse between two consecutive pulses on pulse inputs. Measured time interval is sent to control unit which processes data received. Complete logic for control is located on a control unit. After determining that consumed energy exceeded limitations, control unit sends signal to measuring unit in order to reduce amount of energy consumed. After receiving of control signal from control unit, measurement unit performs action on a relay block. Action could be switching off particular line within system when energy exceeds limits, or switching on a line if there is enough energy reserve comparing to maximum energy that could be imported during that particular 15 minute time interval.

Control unit

Control unit is implemented on a PC. Complete logic for control of a relay block residing at the measuring unit is implemented on a control unit. It also implements graphical overview of a process and allows user to set parameters (Fig. 2) such as:

- *maximum power* - in relation with that parameter maximum quantity of energy could be calculated as:

$$E_{max} = P_{max} \times 1/4hour [wh] \quad (1)$$

If we have some energy E_{tot} consumed during some 15 minute interval, *average 15 - minute power* or *average quarter hour power* (AQHP) is a power consumed during that 15 minute interval resulting in energy consumption E_{tot} . Obviously AQHP corresponding to E_{max} is P_{max} .

- *time of toleration* - defines period of time during which exceeding over energy limitation won't cause any control action;

- *delay time* - defines time interval between two successive operations of switching off/on;
- *energy meter constant* - important parameter for calculation of energy consumed.

Figure 2 also shows two fluid tanks used for graphical presentation of energy consumed and time elapsed. More details about interpreting of fluid tank level will be presented later when concept of relative energy level will be presented later when concept of relative energy consumption is introduced.

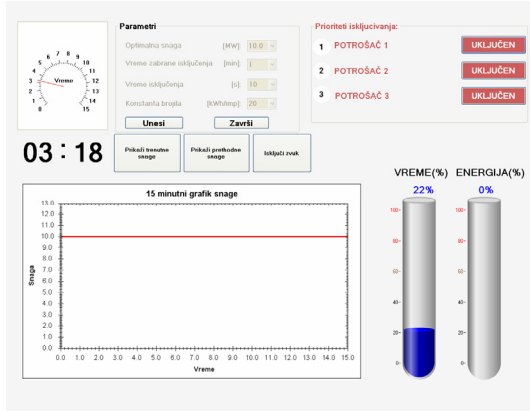


Figure 2: Setting parameters

3. SYSTEM OPERATION

Control unit receives messages from measuring unit. From that message control unit can read information about time interval elapsed between last two pulses received from a meter. According to that interval control unit can calculate average power during interval, because meter constant is known. For example, if constant is 10000 Wh/imp, and time elapsed between last two impulses is 2 seconds, average power during these two impulses is:

$$P_{avg} = \text{EnergyQuantum} / \text{TimeElapsed}$$

$$P_{avg} = 10kWh * 3600 / 2 = 18MW \quad (2)$$

Calculated power is shown on a graph and energy amount that corresponds to one pulse of a meter is added to energy accumulator. The easiest observation of energy consumption is performed through parallel monitoring of time elapsed and energy consumed. Lets assume that time is 0 at the beginning of a 15-minute interval, and the accumulated energy by the moment t_0 is E_1 . Maximum energy quantity reserved for whole 15-minute interval is denoted as E_{max} , and normalized energy (E_{norm}) according to moment t_0 is then calculated as:

$$E_{norm} = E_{max} * t_0[min] / 15[min] \quad (3)$$

Controlling unit takes into account E_1 and compares it with E_{norm} . If E_1 is greater than E_{norm} at moment t_0 either alarm is fired or switching off sequence is started, depending on *time of toleration* (TOT) defined by the user. The purpose of TOT is to provide user with programmable period of time during which greater power than allowed could be consumed. If energy overload is present before TOT has elapsed, only alarm

is fired to alert user. When TOT elapses and energy overload is still present, switching off sequence starts. Before we present TOT influence on the controlling algorithm, we have to make a note about energy consumption overload monitoring. Although comparing E_1 to E_{norm} , explained above provides reliable monitoring of energy consumed, even better approach is to observe relative energy consumption along with relative time elapsing. Relative energy consumed (comparing to E_{max}) is calculated as:

$$E\% = E_1 / E_{max} * 100 [\%] \quad (4)$$

Similarly, relative time is calculated as:

$$t\% = t_0[min] / 15 * 100 [\%] \quad (5)$$

Defining $E\%$ and $t\%$ allows user to easily observe measure of energy overload. Figure 3 shows fluid tanks indicating that no power restricting measures have been taken so far, since consumed energy is below threshold allowed (9% relative energy and 24% relative time). 9% of relative energy shows that only 9% of a maximum energy has been consumed so far, while 24% of relative time elapsed shows that 24% of a 15 minute interval has elapsed so far. As long as percentage of relative energy is below percentage of relative time elapsed, there is no need for actions to be taken. That situation could also be noticed from a power graph since power bars (cyan bars) are at much lower level comparing to maximum power line (red line) during interval of 3 minutes and 36 seconds.

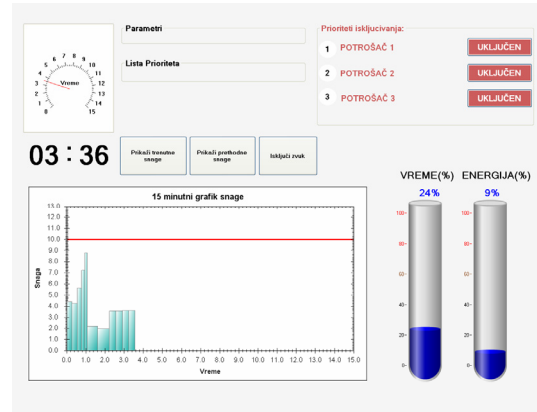


Figure 3: Energy consumption monitoring

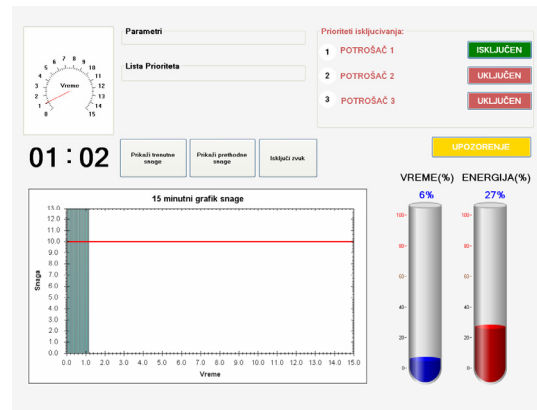


Figure 4: Line 1 switched off

If we define **line** as a set of electrical consumers connected with a single wire, which could be controlled through a single relay from a measuring unit, figure 4 shows action of switching off line 1. Switching off is performed because energy consumed exceeded allowed quantity of energy and TOT has elapsed. One should note that switching off line 1 hasn't started before only because *time of toleration* has been set to 1 min by the user. Before than TOT elapsed only alert was activated (yellow sign UPOZORENJE) and fluid presenting relative energy consumption has changed color to red in order to visualize energy consumption overload. When *Delay time* interval after switching off line 1 has elapsed, line 2 is going to be switched off too, but only if energy consumption at that moment is still higher than allowed. System supports up to three lines. Final action would, thus, be switching off line 3 (figure 5). That action should completely stop energy consumption. If all lines are switched off, energy consumption is stopped and from that moment only time elapses, so percentage of relative time elapsed will, eventually, reach consumed energy level. Thus, system prevents higher energy consumption than the one that is allowed by the user.

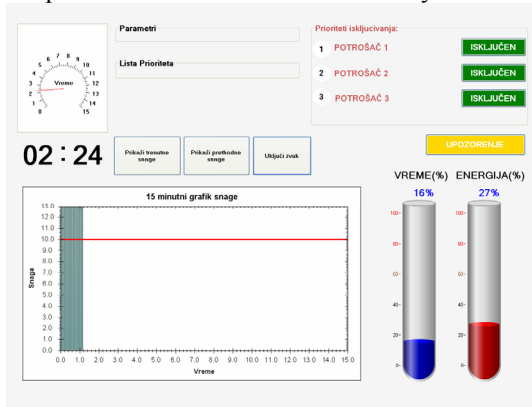


Figure 5: Alert when energy consumption overload occurs

Reverse actions of switching on line 3, than line 2 and finally line 1 are going to happen when 10% reserve is achieved (time percentage comparing to energy percentage). 10% reserve has proved to be the optimal one providing, on the one hand, consumption as close to optimal as possible, and, on the other hand, optimal switching rate for relays (Fig. 6).

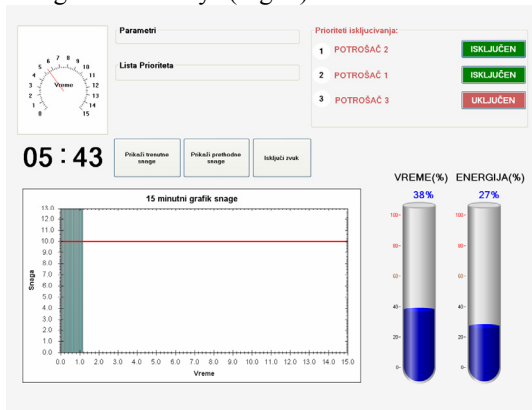


Figure 6: Switching on sequence start

User is allowed to set priority level of up to three power consumers (lines). The consumer assigned to the highest priority level (highest number – 3) is going to be switched off last during switching off sequence. During action of switching on, similarly, consumer with the highest priority is going to be switched on first. Window for priority adjustment is shown in figure 7.

User is able to pick consumer (line) and to drag it to a different place on a list. As a priority list changes, list in the upper right corner of the screen also changes so it reflects new priority list. Figure 8 shows situation where priority list has been changed by the user. Consumer 2 (Potrosac 2) has been moved to the first location on a priority list so it is going to be switched off first during switching off sequence and switched on last during switching on sequence.

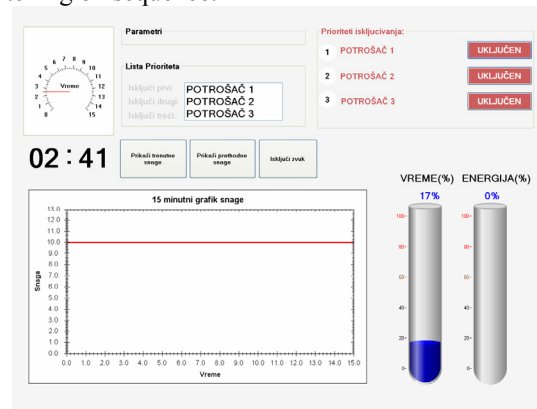


Figure 7: Priority adjustment

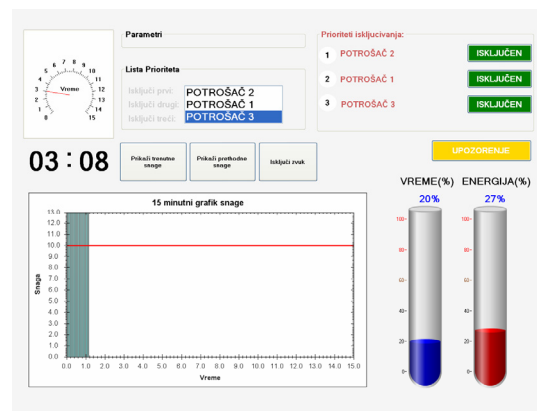


Figure 8: Changing priority

4. DATA OVERVIEW

After 15 minutes have elapsed, previously recorded AQHP is being stored and shown on a graph which could be seen after pressing button called **Prikazi prethodne snage**. Figure 9 shows graph for presenting previous AQHP (PAQHP window). Beside the graph itself new window emerges right below windows for parameters and priority adjustment (which are becoming shaded and cannot be used until PAQHP window is closed). Overview of previous AQHP is performed by moving mouse over bars presented on a graph. Figure 10 shows graph when mouse is located over second bar. That particular bar becomes black and window above shows numerical value of AQHP during 15 minutes chosen.

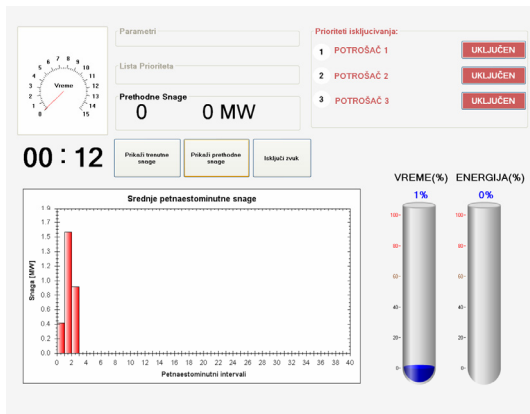


Figure 9: Previous average power window

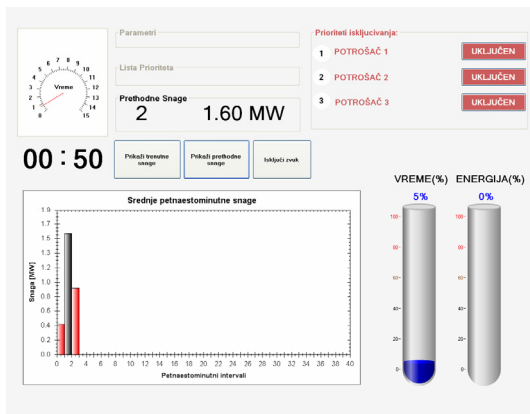


Figure 10: Selecting bar with 1.60MW

In front of the numerical value (1.60MW), there is an index of a chosen bar (2). The leftmost bar on a graph always presents previous AQHP (power averaged during previous 15 minutes interval). When current 15 minutes

interval elapses all bars are moved one position to the right and new bar is added to the leftmost position with assigned index 1. Maximum index number on a graph is 96 meaning that PAQHP window always presents AQHP recorded during previous day (24 hour x 4 bars per hour = 96 bars).

5. CONCLUSION

System for power optimization is well designed system that allows consumer to import energy quantity as close to its maximum as it is allowed. At the same time, system prevents consumer to import more energy than maximum allowed. Therefore, power optimization system serves electrical energy system by preventing power overload, but also preserves electrical energy consumer from being charged for electrical energy overload. Further development of control unit and more sophisticated control logic might present even better power optimization and that fact should be taken into consideration. Also, since AQHP values are recorded, these values might be stored in a database for later analysis (on a month or annual level). However, such a system would require real-time clock in order to store correct data. Present system doesn't have real-time clock, since it's only supposed to observe power and energy consumption during 15 minute intervals.

6. REFERENCES

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