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Adaptive Load Shedding of Energy Unit under Meaning Active and Reactive Power Shortages

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KEYWORDS

Emergency control, collapse of frequency, collapse of voltage, automatic restriction of frequency drop, automatic restriction of voltage drop, complex control of load shedding.

1 BACKGROUND

In Russia and abroad, the most massive automation, the process of carrying out load shedding with deficit of active power, is the under frequency load shedding (UFLS), a part of the automatic restriction of frequency drop (ARFD). In Russia, the UFLS is connected to 60% of the load [1].

As a measure against accidents in the distribution channel, it can be effective in cases of emergency, or maintenance of the regime selection of electric power system (EPS) at an isolated job. However, in these circumstances, when separation of the network of EPS is alert and sudden need to be considered not only with the possibility of relatively slow and gradual reduction in the incidence of what is intended UFLS, but with the possibility of more complex and hazardous processes :

- large power deficit and the corresponding rapid and profound reduction in the incidence (and consequently the development of the avalanche frequency), when the speed of UFLS may not be enough;
- a large deficit is not only active but also reactive power and the corresponding deep voltage sags (and as a consequence of the development of the collapse of voltage).

In such cases, the process can be developed as a collapse of voltage appearing before a significantly lowered frequency. Collapse of voltage can create such a deep load shedding, which decrease in frequency without affecting UFLS quickly change its rise against the background of violations of all consumers energy system [2]. In these cases the need automation with a very high speed, reacting to the fact the emergency break electrical connections, resulting in the area allocated to autonomous operation and control of the previous regime, which determines the magnitude of disturbance of balance of both active and reactive power [3].

2 IMPROVING THE EFFICIENCY OF FREQUENCY LOAD SHEDDING

Using presented at the electrical market in our country UFLS device, it is difficult to construct an effective discharge. This is due, firstly, the low accuracy of the measurement unit of frequency, and secondly, discharge frequency and voltage are performed separately, and thirdly, do not take into account the previous mode of the system and the current value of the interruptible power load. The presence of UFLS I, UFLS II and additional load shedding leads to great complexity in the construction of unloading. In this case, the need for auxiliary load shedding (ALS), performing a fast power off the set when the local power shortage with a large reduction in the incidence rate is explained only a small speed and low accuracy of measuring frequency.

The first attempts to improve the operating principles of under frequency load shedding have been made in the 70's and 80's. the last century. Until now, known to some previous studies, where available:

- mixed UFLS, which uses already existing in the power discharge and is complemented by a number of rounds from the initial rate of change of frequency. Appointment of queues for speed - speed up unloading due to faster off of the consumers and thereby reduce the amount of disconnects from the UFLS I and UFLS II loading. To turn on the speed to have the property to local self-tuning, and system deficiencies, setting the speed adopt a one for all interconnection, regardless of the conditions for their best performance. Investigation of the effectiveness of the proposed UFLS in different variants of combining volumes of unloading on the speed and frequency deviation showed that to eliminate cascading failures and reduce the frequency deviation preferably combine the queue to speed with the first stage of the deviation;
- under frequency load shedding, which reacts remains as to the absolute value of the frequency and the rate of decline. As opposed to mixed UFLS this unloading provides switching-off of consumers by separate turns with different set value on frequency, and set value the first stage has the fixed value, and frequency set value by the second and the subsequent turns are reconstructed depending on speed of decrease in frequency: the above speed, the increases by the big step frequency set value and switching-off of consumers will faster occur that.

At the end of 1980 A.H. Kalyuzhny, A. A. Grebe, J. M. Shlemenzon and N. A. Darkov (Siberian Research Institute of Electric Power – SRIEP) first proposed a fundamentally new way of combination UFLS (KUFLS). Consumers are supposed to turn off while reducing the frequency in the power and voltage in the energy system. On the basis of a new principle was made a theoretical assessment of the effectiveness of UFLS-based software system analysis of the "vitality", developed in SibNIE. In the course of these studies have identified significant shortcomings of the proposed control method unloading. Found that the effective application of KUFLS possible only in isolated working power systems or any other, where you may experience deficits in excess of 40% of the total power load. Thus, KUFLS in these energy systems must complement the work of staff automation (UFLS I, UFLS II), rather than replace it. In step KUFLS not taken into account prior treatment of the energy system – an important factor for efficient load shedding. Another drawback of the proposed method – still the main parameter, which provides job KUFLS and the formation of the overall impact is still lower rates. Information about the rate of change of voltage and frequency, and voltage value is used only in emergencies with a large deficit of power. As a result, the algorithm of formation of the overall impact on consumers KUFLS was never developed, and the proportionality of various parameters of the equity in the sum signal had not been conclusively substantiated.

The effectiveness of the under frequency load shedding can be increased, if the input parameter is used not only reduce the frequency, but also its speed. The latter allows you to instantly assess the relative importance of a sudden power deficit and promptly disconnect the required volume of customers. The result is a theoretical possibility to exclude excessive load shedding and significantly reduce the depth of the frequency.

In severe accidents, leading to a large deficit of active power, there is an additional risk-local deficits of reactive power when there is a profound reduction in tension, the possibility of violation of stability in the post-accident conditions and the further development of the accident - the collapse of voltage. If the under frequency load shedding will turn off consumers primarily in the areas with the lowest voltage, then the violation of stability in post-emergency conditions can be prevented.

In addition, it allows to combine in one device at once two functions: UFLS and ARVD (automatic restriction of voltage drop). Especially in the current energy system to the existing ARVD have insufficient "survival", since it is not able to resist the systematic development of accidents that can cause an avalanche to reduce stress and thereby lead to a breakdown of the entire power district, including the consumers of the first category [4].

3 COMPLEX APPROACH TO LOAD SHEDDING THE SIGNIFICANT SHORTAGE OF ACTIVE AND REACTIVE POWER

It is well known that the speed category UFLS I bounded the depth of the frequency, preventing unacceptable reduction in frequencies below 45 Hz. To this end, ACHR I disconnected from consumers with low time delay 0,1-0,5 s at different set values of frequency. Prolonged operation at frequencies of 49 Hz and below prevented by category UFLS II, which disables users with different time delay at a frequency of about 48,8 Hz. UFLS I and UFLS II deal well with their tasks at a relatively small deficits, not to exceed 30% of the total power load. For large power deficit UFLS I, as a rule, turns off unnecessary amounts of stress. This is due to retardation of the UFLS I, which is called from time delay UFLS I, time relay frequency, time off switches and is $\Delta t_{\Sigma} = 0,45-0,85$ sec. At even larger deficit of more than 50% of total power, because of the delay Δt_{Σ} queues, which are also run not once, but with decreasing frequency, the work of UFLS I cannot prevent a reduction in frequencies below 45 Hz. To prevent deep reduction in the incidence of these cases, apart from UFLS I apply additional load shedding, breaking consumer in fact disable the generators and/or feeders. The use of such emergency control complicates the operation and is not always effective.

For more efficient load control (not just disable, but also included) are invited to use the generic parameter having dimension of frequency, the following form

$$A_{\Sigma} = k_1 \Delta f_1 + k_2 \frac{d\Delta f_1}{dt} + k_3 \Delta f_2 + k_4 \frac{d\Delta f_2}{dt} + k_5 \int \Delta f_1 dt + k_6 \int \Delta f_2 dt + k_7 \Delta U_1 + k_8 \frac{d\Delta U_1}{dt} + k_9 \Delta U_2 + k_{10} \frac{d\Delta U_2}{dt}, \quad (1)$$

where $k_1..k_{10}$ – weighting coefficients that allow to give different weight components of a generalized parameter for each case; $\Delta f_1 = f_{уст.откл} - f$ – reduce the current frequency (f) below the specified setting to disable ($f_{уст.откл}$); $\Delta f_2 = f_{уст.вкл} - f$ – reduce the current frequency (f) below the selected setpoint for inclusion ($f_{уст.вкл}$); $\Delta U_1 = U_{уст.откл} - U$ – voltage drop (U) below the specified setting to disable ($U_{уст.откл}$); $\Delta U_2 = U_{уст.вкл} - U$ – voltage drop (U) below the selected setpoint for inclusion ($U_{уст.вкл}$). And it can be argued that the importance of setting to disable the setting is less than the inclusion (the inclusion of disabled customers is carried out only after the recovery rate and (or) the voltage in the power system to a certain level): $f_{уст.откл} < f_{уст.вкл}$, $U_{уст.откл} < U_{уст.вкл}$.

In accordance with a given dimension of the total signal (A_{Σ}) weighting factors in (1) have dimensions: $k_1 - [\text{Fr. e.}]$; $k_2 - [\text{sec}]$; $k_3 - [\text{Fr. e.}]$; $k_4 - [\text{sec}]$; $k_5 - [\frac{1}{\text{sec}}]$; $k_6 - [\frac{1}{\text{sec}}]$; $k_7 - [\frac{\text{Hz}}{\text{V}}]$; $k_8 - [\frac{\text{Hz} \cdot \text{sec}}{\text{V}}]$; $k_9 - [\frac{\text{Hz}}{\text{V}}]$; $k_{10} - [\frac{\text{Hz} \cdot \text{sec}}{\text{V}}]$.

Using such an complex signal to generate the control action can also get a number of advantages over traditional under frequency load shedding. Firstly, the use of velocity factor of change in frequency makes it possible to instantly assess the shortage of power and thereby accelerate the discharge power (to act as an additional load shedding). Secondly, the integration frequency in time to prevent it "hangs" at unacceptable level (execution of functions UFLS II). Thirdly, participation in shaping the impact of the total signal voltage deviation and its rate of change accelerates unloading at the sites with the lowest levels of stress.

Block diagram of the proposed method is executed in accordance with expression (1), shown in Fig. 1. The unit 1 calculates the frequency deviation from the set value run reclosing. At frequencies $f \leq f_{уст.вкл}$ signal at the output of this block is $\Delta f_2=0$, in the case $f > f_{уст.вкл}$ output signal appears $\Delta f_2 = f_{уст.вкл} - f$. Block 2 generates the frequency deviation from the set value to start the trip. At frequencies $f < f_{уст.откл}$ (emergency power shortage) output unit 2 a signal $\Delta f_1 = f_{уст.откл} - f$, in the case $f \geq f_{уст.откл}$ (normal) no signal $\Delta f_1=0$.

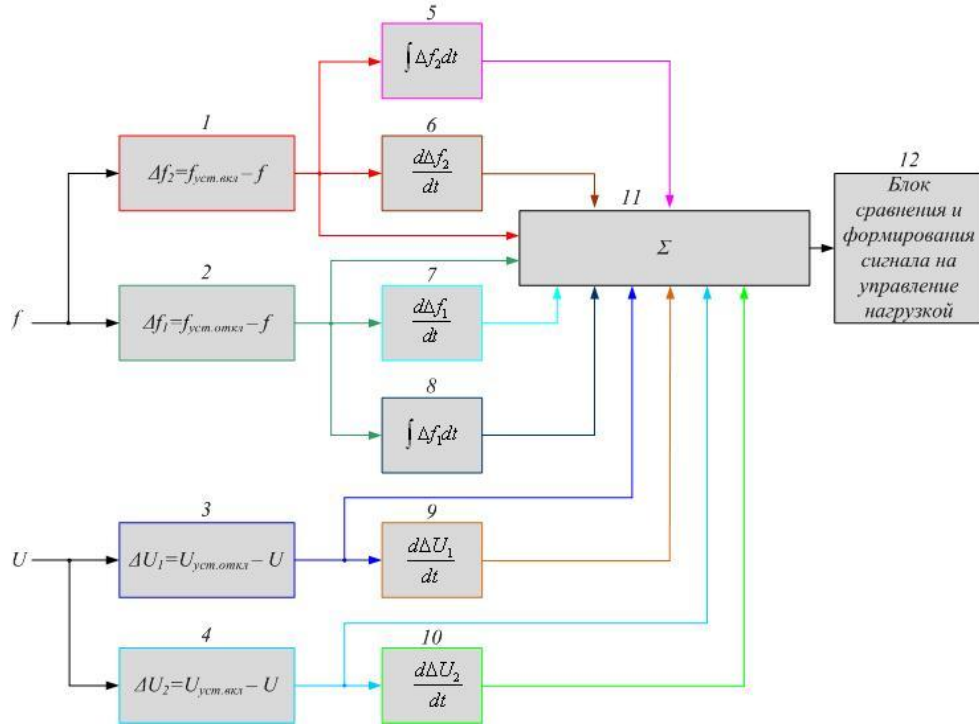


Fig. 1: Functional - block diagram of a generalized parameter of load control

The output of block 3 is formed voltage deviation from the setpoint to start the trip. At voltages $U < U_{уст.откл}$ the output of this block a signal $\Delta U_1 = U_{уст.откл} - U$, and when $U \geq U_{уст.откл}$ (normal) signal at the output of unit 3 is missing ($\Delta U_1 = 0$). In block 4 is calculated voltage deviation from the set value run reclosing. At voltages $U \leq U_{уст.вкл}$, signal ΔU_2 the output unit 4 is missing ($\Delta U_2 = 0$), at $U > U_{уст.вкл}$ 4 appears at the output signal $\Delta U_2 = U_{уст.вкл} - U$.

Blocks 6, 7, 9 and 10 are designed to measure the speed of recovery rate, the rate of decline of frequency, speed, voltage rise and the rate of voltage reduction, respectively (blocks differentiation). And the elements 5 and 8 - to integrate the frequency deviation from the set point run-out and frequency deviation from the set value to start the trip.

Block 11 forms the calculations the total discharge control signal, combining elements from Units 1 - 10 according to expression (1) with their weights. Assignment of these weights is carried out to set the device for each specific case of installation to ensure the desired quality of transient processes with decreasing frequency and (or) the voltage in the power system.

Total signal from unit 11 to the input block 12, which is how it compares with set values, as well as the formation of signals on opening and closing the queue load.

In the event conditions $A_\Sigma \geq A_{i\text{откл}}$ from the output of element 12 in the executive body is given a signal to disable the i -th queue load ($i = 1 \dots n$). At $A_\Sigma < A_{i\text{откл}}$ signal output unit 12 is absent. In the same block of the congruence of the total signal with a given set point for the inclusion of disabled before the load $A_{i\text{вкл}}$. At $A_\Sigma < A_{i\text{вкл}}$ from the output of element 12 signal in the executive body of the inclusion of the load. At $A_\Sigma \geq A_{i\text{вкл}}$ the output signal of the body 12 is absent.

Everything is connected to the consumers are distributed in order of increasing responsibility. It is necessary to ensure the conditions

$$\begin{aligned} A_{1\text{откл}} &< A_{2\text{откл}} < A_{3\text{откл}} < \dots < A_{n\text{откл}}; \\ A_{1\text{вкл}} &< A_{2\text{вкл}} < A_{3\text{вкл}} < \dots < A_{n\text{вкл}}, \end{aligned} \quad (2)$$

and

$$A_{1\text{вкл}} \leq A_{1\text{откл}}, A_{2\text{вкл}} \leq A_{2\text{откл}}, A_{3\text{вкл}} \leq A_{3\text{откл}} \dots A_{n\text{вкл}} \leq A_{n\text{откл}} \quad (3)$$

With such an arrangement sequence of the device disable and enable consumers are not violated under any circumstances and will strictly comply with their degree of responsibility. The order of inclusion of consumers - the reverse order of their trip.

Shape parameter of the total impact on consumers and the principle of an complex approach is shown in Figure 2.

Upon reaching the total signal setpoint $A_{1 \text{ откл}}$ off the first load at the moment $t_{1 \text{ откл}}$ signal for disabling it ($\Delta P_{\text{откл}1}$). With increasing A_{Σ} and the conditions $A_{\Sigma} \geq A_{2 \text{ откл}}$, $A_{\Sigma} \geq A_{3 \text{ откл}}$ etc. going off the next load, respectively ($\Delta P_{\text{откл}2}$, $\Delta P_{\text{откл}3}$, ..., $\Delta P_{\text{откл}n}$) at times $t_{2 \text{ откл}}$, $t_{3 \text{ откл}}$, ..., $t_{n \text{ откл}}$, and the sequence off loads strictly corresponds to the order of their increasing responsibilities. In this strict sequence off of consumers satisfied with any character of the emergency process in the power system (rapid or slow decrease in the frequency, the simultaneous reduction of voltage cascaded lower rates). If the operation of these queues would raise the frequency, the derivative changes sign, frequency deviation and, consequently, the total signal, it starts to fall. However, while the frequency deviation from the setpoint to trip a positive (frequency below the minimum allowed), the integral of the deviation increases. This leads to a further increase of the total signal and triggering bursts of discharge until the recovery rate is higher than set inclusion.

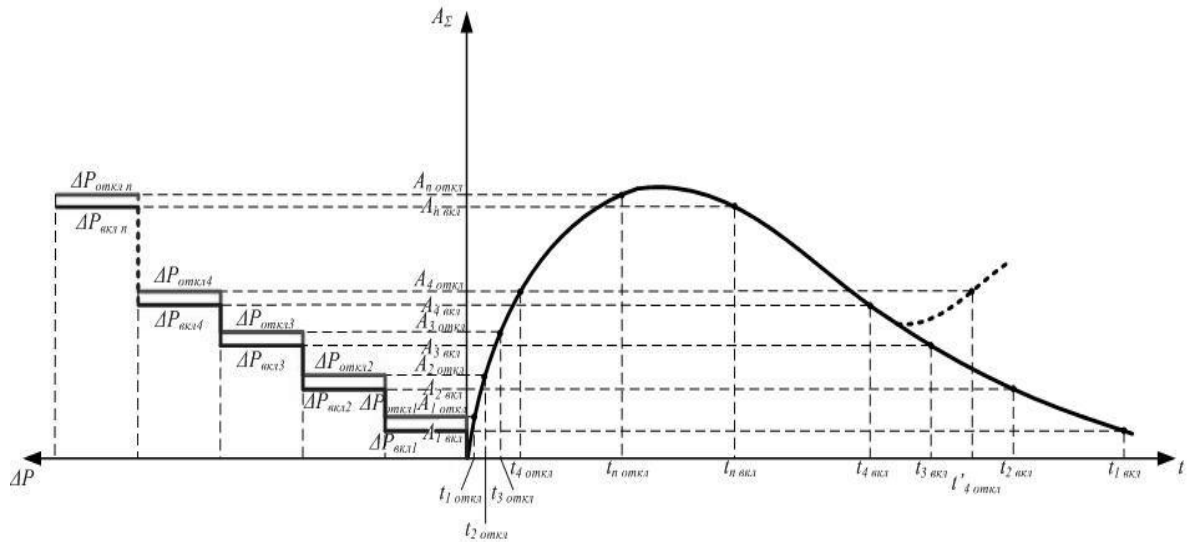


Fig. 2: The operating principle of the complex control of discharge

With the rise of frequency response to the setpoint $f_{уст.вкл}$ total signal begins to decrease in proportion to the integral of frequency deviation from this setting. When the condition $A_{\Sigma} < A_{n \text{ вкл}}$ at moment $t_{n \text{ вкл}}$ in the unit of comparison and the signal on load management team formed by the inclusion of disabled before the n -th load ($\Delta P_{\text{вкл}n}$). With decreasing A_{Σ} and the conditions $A_{\Sigma} < A_{n \text{ вкл}}$ is the inclusion of consumers in a strict sequence according to their degree of responsibility, the reverse order of their trip.

4 PROGRAMME AND TECHNICAL IMPLEMENTATION OF LOAD SHEDDING BY FREQUENCY AND VOLTAGE. EFFECTIVENESS OF APPLICATION

Implement all the desired properties of the device integrated unloading at the present level of technology and electronics, in particular, can only be based on microprocessor.

Develop devices running on the base of the Complex emergency control - CPS-M (development and production company «PSAI») for performing the functions of various emergency control devices fitted to electric power facilities [5]. The main unit, allowing input of analog and discrete information about the state of the controlled object, processing and forming the output digital signals, is a functional unit (BF). Main technical characteristics of the input/output devices integrated circuits based on the discharge of BF in the CPS-M are summarized in Table 1.

<i>Parameter name</i>	<i>Value parameter</i>
Inputs analog signals:	
– rated voltage controlled network $U_{НОМ}$, V	100/220
– operating voltage range $U_{НОМ}$, %	0-130
– permissible relative basic error in measuring the voltage operating range, %	$\pm 2,0$
– nominal frequency of the monitored network, Hz	50
– operating frequency range, Hz	30-65
– operating range of the rate of change of frequency, Hz/sec	от -20 до +20
– number of voltage inputs	2
– absolute error of frequency measurement, Hz, no more	$\pm 0,0003$
Inputs of discrete signals:	
– number of inputs	to 32
– rated voltage AC (DC current), V	100 (110) 220 (220)
– voltage stable operation, V, at least	$0,6U_{НОМ}$
– input current, mA, no more	5,5
– minimum signal duration, msec	30
The outputs of discrete signals:	
– number of inputs	to 32
– band switching voltage AC (DC current), V	5-264
– fault current and retention, A, no more	8
– current opening for an active DC - inductive load with a time constant $\tau = \frac{L}{R}$ no more 20 msec, A, no more	0,15

Table 1: Specifications automatic load shedding

To justify the effectiveness of an complex approach to managing stress were studied long transients in the characteristic patterns in accidents of varying severity. Simulation of reducing the frequency of the light trigger bursts of discharge is difficult, because in the process of the device varies deficit, and hence changing the initial conditions at each step of the calculation. Thus, construct curve reducing the frequency is time-consuming task. It was therefore decided to use differential equations of motion energy with a deficit of active power, which has the form

$$\frac{df_*}{dt} = \frac{1}{T_j} P_{HEB*} = \frac{1}{T_j} (P_{HEB0*} - k_H \Delta f_*), \quad (4)$$

where T_j – time constant of the grid; P_{HEB*} – relative imbalance of power when the current frequency; P_{HEB0*} – relative imbalance of power at rated frequency; k_H – regulating effect of load (REL); f_* – the current value of frequency, relative to the nominal value; Δf_* – change in frequency, relative to the nominal value.

In contrast, the frequency of the voltage is a local parameter node power system, therefore, speaking about the law changing the voltage, you must have the dynamic characteristic of the load. Dynamic load characteristics determine its behavior during sudden changes in voltage at node load caused by accidental disturbances.

The simulation frequency power system with a deficit of active power and voltage in some of the node where you installed the integrated management of discharge were obtained waveforms shown in Figure 3. With the shortage of active power value 50% («deficit») due to the frequency of the devices did not fall below 46 Hz and was restored to the nominal value of 12 sec («Frequency»). The shape of the total parameter («Asum») and its character changes coincide with the alleged curves obtained in the course of theoretical studies (Fig. 2). For the simulation was laid five steps actuation for control of five loads with the "1" - enabled and "0" - disabled (Figure 3 schedule «Load», steps are

spaced along the vertical axis on the unit). Voltage drop (Figure «Voltage») also had an impact on the total signal.

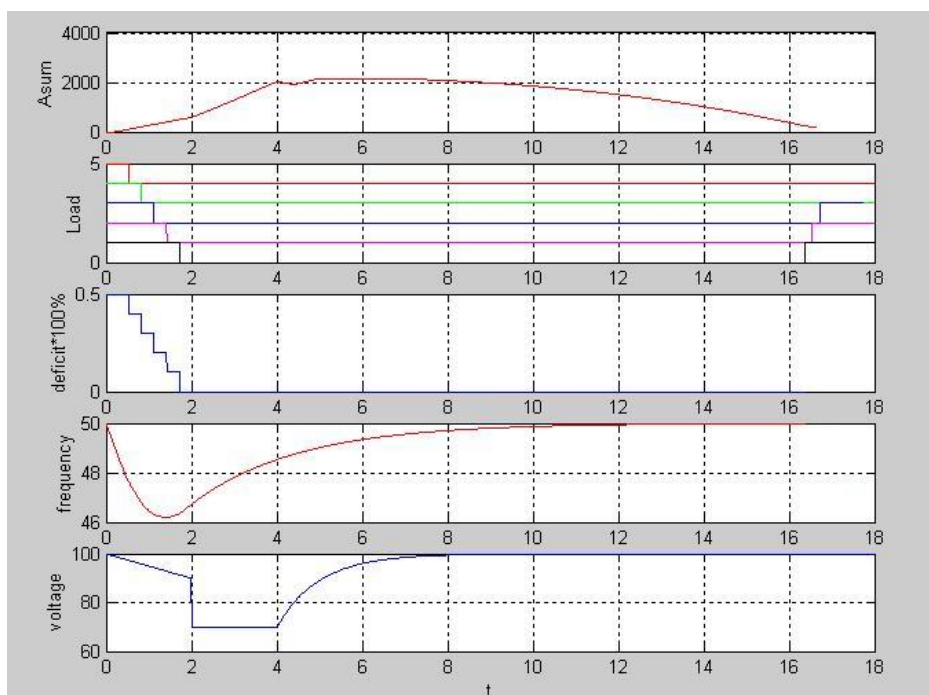


Fig. 3: Functioning of the complex control of load shedding device

After disconnecting the load was made to switch in reverse order after the restoration of the parameters being monitored.

5 CONCLUSION

An complex approach to the control of discharge frequency, voltage and speed of change allows you to:

- 1) improving overall system stability in post-emergency mode, i.e. improve the survivability of the entire power system;
- 2) reduce the total number of devices the EC, whose actions are aimed at the elimination of power shortages, and thus eliminate the inconsistency in their work, leading to unnecessary disconnection of customers;
- 3) reduce the supply interruption of consumers after discharge of the complex and, consequently, reduce the damage from load shedding under the influence of automation.

During the simulation of the automation of integrated discharge separately while reducing the frequency or voltage or both frequency and voltage in all cases was fixed to work correctly functioning algorithm. Therefore, developed the principle of control discharge has been recommended for implementation in microprocessor-based device for testing in response, a pilot, and later industrial exploitation.

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