The Guaranteed Power Supply System on the Base of Alternative and Renewable Energy Sources

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Summary: **The necessity of developing and implementation of the guaranteed power supply system using distributed generation on the base of alternative and renewable energy sources is proved in conditions of responsible technological processes. The theoretical and experimental researches were made in raw mineral enterprises, which have a great amount of responsible technological consumers. The permitted duration of power supply interruption for responsible consumers of continuous technological processes of raw mineral industry is determined. The effectiveness of distributed generation using for guaranteed power supply mode is shown. The reasonability of solar, wind and followed oil gas energy applying in role of power sources for distributed generation is also proved in the paper. The basic variants of guaranteed power supply system structure are described and offered in the paper for all kind of industry and technique, especially for responsible digital control systems and telecommunications.**

Key Words*:*
Alternative, Renewable, Power Supply, Voltage Sag, Power Supply Interruption, Distributed Generation, Guaranteed, Uninterrupted

INTRODUCTION

The problem of an uninterruptable power supply in conditions of Russian Federation raw mineral industry, caused by remote allocation of the main perspective mineral deposits from centralized power systems, also due to geographically distributed responsible power consumers and continuity of important technological processes, is quite topical. The mentioned problem is also topical in case of every country, where the perspective mineral deposits are also allocated from centralized power systems. In the case of centralized power system presence there are a number of vital power quality problems related to the power transmission such as voltage drops, deviations and harmonic distortion. The reasons of mentioned problems could be different, but their influence on responsible consumers of mineral industry is always negative. Thus, considering that the most perspective mineral deposits are not covered by centralized power supply systems with probably poor power quality, the development and implementation of an uninterruptable power systems using distributed generation on the base of alternative and renewable energy sources becomes a topical problem.

2. PERMISSIBLE DURATION OF POWER SUPPLY INTERRUPTION

According to the results of theoretical researches and mathematic modeling, provided by authors, it was determined that for mineral industry consumers the maximum value of permitted duration of interruption of power supply is 0.15 s. [9]. This permitted duration allows consumers not to stop technological process, saving its continuity. The determined permitted duration depends of consumer's parameters, technological process mode, power quality level, and ensure continuity of the raw mineral industry production. Therefore, it is clean that interruption more than permitted duration in the power supply of important technological processes of the raw mineral industry production leads to significant economic and technical damage and in some cases to human sacrifices. For example on the base of research work [8] it is possible to identify the following relationship for determination of the permitted interruption time in a power supply for the electric centrifugal pumps with submersible motors in oil production:

$$\Delta t = 0.06 + 0.03T_j - 0.01\Delta U \tag{1}$$

In equation (1):
T_j — the time constant of the motor inertia, [s],
ΔU — volume of the voltage dip [percentage of rated voltage],
Δt — permitted interruption time, [s].

The similar relationships with different coefficients were obtained by authors for other technological consumers of raw mineral industry and other industrial sectors for evaluation of permitted interruption time value [3].

3. NECESSITY OF GUARANTEED POWER SUPPLY SYSTEM CREATION

Also it must be considered that power demand diagram for every kind of installation is characterized by constancy during twenty-four hours. For electrical equipment stability ensuring it is necessary to held power quality and electromagnetic compatibility level in compliance with requirements of the Russian standard GOST 32144-2013, and main International normative documents in this area. This condition must be provided in the case of short time power supply interruption and also during the automatic load transfer or starting of reserve power supply generator for feeding responsible consumers in the case of long-term interruptions.

The example of electric centrifugal pumps with submersible motors in oil production is chosen because of its most sensitivity to power supply interruption and heaviness of problems, which can occur in the case of oil production failure. That's why a large part of theoretical and experimental researches for creation of proposed guaranteed power supply system are provided in the power supply systems of oil-production enterprises with electric centrifugal installations based on submersible induction motors, which are used to extract oil to the surface, and also complexes with synchronous motors, which are used to maintain reservoir pressure. The short-time interruption in a power supply of mentioned installations can lead to breakdown of electrical motors and, as a consequence, to the technological process failure. Revival and leading to the nominal rating of the technological process require time from some minutes to several hours. This circumstance leads to significant economic damage due to losses at oil extraction [3]. That's why it's very important in economic point of view to create the guaranteed power supply system on base of distributed generation using alternative and renewable power sources for responsible technological processes not only for raw mineral complex, but for every kind of industry and technique, especially automated digital systems for responsible process control and monitoring [7, 10].

Thus, the necessity of proposed system is defined by following two key factors: remote allocation from centralized power systems and availability of continuity technological processes. The development of proposed guaranteed power supply system using distributed generation with alternative and renewable energy sources is provided on the base of numerous theoretical and experimental researches, made by authors in different raw mineral enterprises of Russia.

4. THE STRUCTURE AND BASE FUNCTIONING MODES OF PROPOSED GUARANTEED POWER SUPPLY SYSTEM

In the development of the structure of proposed guaranteed power supply system it has to be taken into account following work modes of industrial power supply systems [6]:

- Normal.
- Post accident.
- Transient.
- Maintenance.

The normal is the mode related to steady-state condition of power supply system. In this mode all elements and subsystems, which were provided in design stage, are functioning normally without any failures and malfunctions, also in this mode all consumers are supplied in standard conditions without any limitations.

The post accident is the mode related to steady-state condition after emergency shutdown of damaged element of power supply system. This mode lasts until recovery of the proper power supply system scheme, which is designed for normal work mode.

The transient is the mode when the speed of power supply system parameters and conditions changing is very fast. Therefore it must be considered when designing of proposed guaranteed power supply system.

The maintenance mode is the mode when all repairing measures can be provided. Also during this mode it is possible to maintain and adjust all units and devices, which

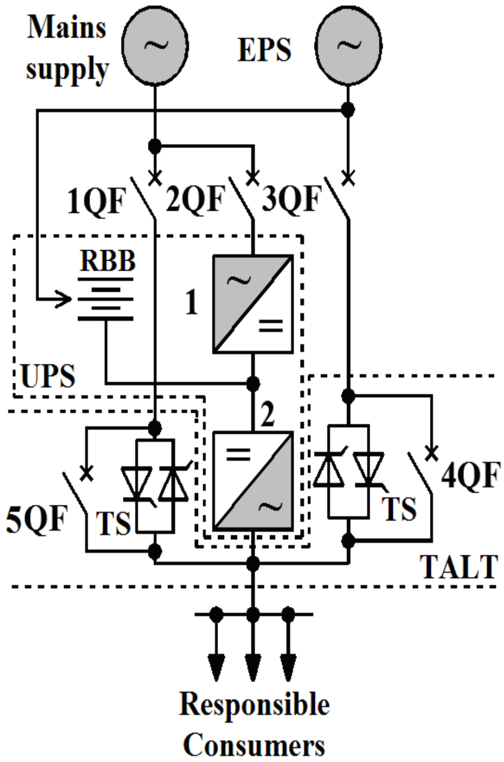

Fig. 1. The base variant of proposed guaranteed power supply system

are compiled proposed guaranteed power supply system, without any interruptions in consumer's power supply [6].

On the base of numerous theoretical and experimental researches the following structure base variant of proposed guaranteed power supply system has been defined and realized in accordance with requirements under consideration. This base variant is represented in Figure 1.

The base structure in the Figure 1 shows that consumers are powered from the uninterruptible power supply (UPS), which consist of the rectifier 1, inverter 2 and rechargeable battery bank (RBB). Feeding from the battery is implemented in case of fault on the mains power supply or continuously declined voltage level below 0.8 of U_n (where U_n is nominal power supply voltage). The value of energy stored in the batteries should be enough for the starting period and for the time to lead the emergency power source (EPS) in normal mode. The value of battery energy is depends on the following key factors:

- Maximum value of permitted duration of interruption of power supply for consumers.
- Rated power of connected consumers.
- Degree of technological responsibility of connected consumers.

EPS can be implemented by wind generator, solar power station, hybrid wind-diesel power installation or power micro turbine, which works on the following oil gas. Thyristor switch (TS) prevents the flow of energy from the inverter 2 to the mains power supply and is activated in post accident period. Simultaneously the signal for starting EPS is sending. Then the switch 3QF is turning on, and the switches 1QF and 2QF are turning off. The switch 4QF is used for backup TS in EPS connection [6].

During theoretical and experimental researches it was detected that there is a risk of increasing of phase mismatch angle between the voltages of UPS and EPS in the period of EPS starting and its connection to the load, feeding from the UPS. Possibility of EPS connection to the alternative current busbar without occurrence of an overcurrent exists if the phase mismatch angle isn't over then 30 electrical degrees [6].

Thyristor automatic load transfer (TALT) is used for connection of EPS without the phases mismatch in the UPS output. Also TALT is faster that common automatic load transfer.

The TALT is intended for supporting responsible electrical consumers at work in case of emergency mode. When the power supply voltage declines at one of the inputs, the TALT is switching on the serviceable input with maximal speed without the overcurrent occurrence. The transient processes optimization is provided by synchronization of the moment of switching TALT with the angle of voltage phase mismatch between the EPS cleats and UPS outputs. This angle of phase mismatch is situated in the range between 0 and 30 electrical degrees. The logic of TALT work lets implement synchronous switching of the connected consumers to EPS with the angle of phase mismatch not over then 30 electrical degrees. It also lets control recovery of the mains power supply voltage level with automatically switching to the normal scheme after recovery of the inadmissible input voltage [6].

In most hard cases RBB also can charge from EPS.

The particular case of base structure is shown on Figure 2. This is the more simple case for small power load when responsible consumers in normal mode are supplied from mains supply only through the UPS. In case of the structure which is shown on Figure 2, the consumer's feeding is continuously implemented through the rectifier 1 and inverter 2 which are implemented the double conversion of energy. In case of fault or continuously declined voltage level below 0.8 of U_n at mains power supply input, uninterruptible supplying of the consumers is implemented by the RBB. At the moment of power supply failure the control system is sending the signal for EPS starting. When the EPS is ready to consumers supplying, the switch 2QF is turning on. The switch 3QF provides inverter's protection from overloading, failures, peaks load and battery's discharging. Besides according to the Russian state standards GOST 13109-97 and GOST R 54149-2010 in power quality area, permitted harmonic distortion level of the voltage form can be controlled by the parallel active filter (PAF) as option [1].

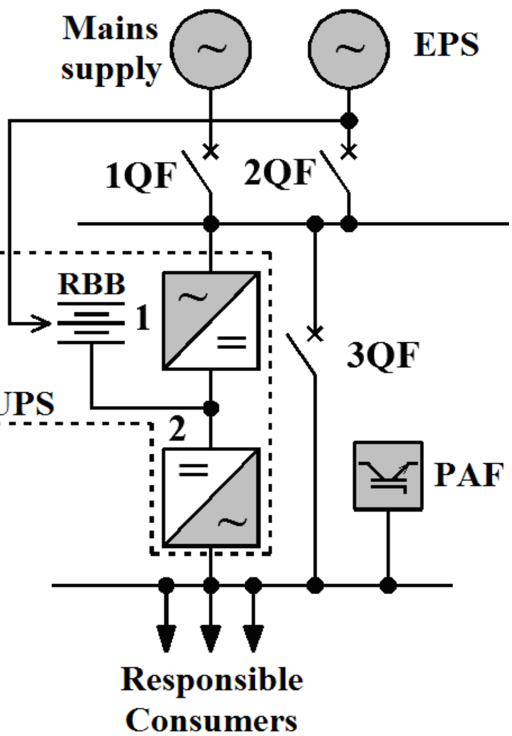

Fig. 2. The particular case of base structure of proposed guaranteed power supply system.

5. THE BASE METHOLOGY OF STRUCTURE, MAIN PARAMETERS, FUNCTIONING MODES AND CONTENT CHOOSING FOR PROPOSED GUARANTEED POWER SUPPLY SYSTEM

The methodology of proper choosing main parameters, components content and functioning modes of proposed guaranteed power supply system is based on two main moments. The first is the proper determination of UPS main parameters. The second is the studying UPS and EPS interference and according to it's results detecting main technical decisions for damping possible problems. Also it is necessary to provide effective storage elements and methods of its charging and discharging.

For proper choosing of UPS, which can ensure protection of responsible technological consumers from short time power supply interruptions, during EPS starting, the following key parameters and factors should be determined [5]:

— UPS rated power.
— The duration of off-line work.
— The type of applied power storage devices.
— Power storage devices capacity.

Also the UPS choosing should be provided according to limitations, specified by value of permitted duration of interruption of power supply and necessity of dynamic stability ensuring of responsible consumers.

The total power of consumers S_{cons}, connected to UPS, is defined by means of the following equation:

$$S_{cons} = \sqrt{\left(\sum_{1}^{n} P_{cons.i}\right)^2 + \left(\sum_{1}^{n} Q_{cons.i}\right)^2} \qquad (2)$$

In the equation (2) $P_{cons.i}$ and $Q_{cons.i}$ — correspondingly active and reactive power of some i consumer from group of n consumers, connected to AC busbars of UPS. The equation (2) is valid in case of linear load, connected to AC busbars of UPS. In conditions of voltage and current harmonics presence the equation (2) may be complemented with distortion power. But nowadays there is not any universal, strict and unequivocal theory and methodology for distortion power definition, that's why, when considering UPS parameters, it's quite enough to define S_{cons} according to the equation (2) for preliminary evaluation.

In the case of necessity of technological process normal finishing, the value of is defined on the base of analysis of electrotechnical installations and load diagram, which determines power consumption level during final stage of process [8].

The rated UPS power SUPS is defined by means of the following equation:

$$S_{UPS} \geq \frac{k_r \cdot (1-\Delta U) \cdot S_{cons} \cdot \cos \varphi_{cons}}{\cos \varphi_{UPS}} \quad (3)$$

In the equation (3):

k_r — coefficient of UPS power reserve, which has a value 1.1-1.2;

ΔU — calculated value of permissible voltage decrease in conditions of dynamic stability ensuring of responsible consumers [percentage of rated voltage];

$\cos\varphi_{cons}$, $\cos\varphi_{UPS}$ — correspondingly equivalent power factor of consumers and UPS output.

The value of power accumulated by storage elements should be enough for ensuring of normal functioning of responsible consumers during automatic load transfer working. In the case of proposed guaranteed power supply system application, which includes UPS and emergency power supply generator or installation of different type, the value of power accumulated by storage elements also should be enough during emergency power supply generator starting and accepting of consumers.

The duration of UPS off-line functioning is defined by value of power accumulated by storage elements and consumers rated power consumption.

For each certain type of UPS it is possible to calculate the capacity of storage elements and batteries, which can ensure required time for proper power supply reservation.

The capacity of storage battery Cbat can be defined according to following equation:

$$C_{bat} = \frac{I_d t_f}{K_g \cdot K_p} \quad (4)$$

In the equation (4):

C_{bat} —is the required capacity [Ah];

I_d — discharge rated current [A];

t_f — required functioning time [s];

K_g — coefficient of available capacity, for 0.5 hour discharge mode $K_g = 0.4$, for 1 hour discharge mode $K_g = 0.5$, for 2 hour discharge mode $K_g = 0.65$, for 10 hour discharge mode $K_g = 1$;

K_P — recommended coefficient of storage battery discharge depth equal 0.5–0.7. The value of K_P is selected according to technical documentation of storage capacitors.

Discharge rated current I_d is the current, demanded by consumer from storage battery, and can be defined by means of the following equation:

$$I_d = \frac{P_{cons}}{\eta_e \cdot U_{bat}} \quad (5)$$

In the equation (5):

I_d — discharge rated current [A];

P_{cons} — average consumers power [W];

η_e — inverter efficiency during AC/DC conversion;

U_{bat} — storage battery voltage [V].

The following main problems connected with storage batteries operation organization, which must be decided for increasing of functioning effectiveness and operating life, should be provided:

— Charging process effectiveness ensuring.
— Ensuring of resource-saving operation and keeping.
— Performance of required prevention measures.

Also for effective functioning of proposed guaranteed power supply system, the following storage batteries types should be applied in UPS:

— Hermitic lead-acid batteries.
— Lead-acid batteries with ventilation.
— Nickel-Cadmium batteries with ventilation.

Batteries charging must be realized in mode, which provides significant current decrease to the end of charging process. There are the set of charging methods, which demands some equipment of different modification and cost.

The results of theoretical and experimental researches proved that the charging should be performed on direct current which value numerically is equal to 0,1 of rated value of storage battery capacity, according to equation (4). Most of applicable storage batteries are recommended to charge at direct voltage of value 2.4-2.45 V.

The acceleration of charging process can be reached by means of value charging current rising up to 0.3 of rated value of storage battery capacity.

It's necessary to notice that the main perspective technology for optimization charging and discharging process of storage batteries is the applying of super-capacitor elements with double electrical layer. Besides the using of alternative and renewable energy sources in distributed generation demands high-capacity storage elements, such as super-capacitor elements.

The traditional methods of EPS rated power choosing are based on assumption of linear character of connected consumers. That's why the problem of considering influence of UPS as non-linear load by means of harmonic components on functioning mode of EPS is quite topical.

The most part of produced generators on the base of different type of diesel and gas turbine engines are designed for working on active-inductive load with small value of total harmonic distortion factor.

According to Russian GOST 23377 the total harmonic distortion factor for voltage of three phase generator must have values 5, 10 and 16% for different operation cases. One of the basic criteria of functioning ability in case of synchronous generator is the heating temperature of winding isolation i.e. working temperature less than permissible value. In normal functioning mode the permissible maximum winding isolation heating temperature is defined by special class of isolation heat resistance and calculated in considering of linear character of load. In proposed guaranteed power supply system the role of load for EPS plays UPS, which is the classical type of non-linear load through the rectifier presence in the UPS input.

In the UPS rectifiers based on thyristors the load rectified voltage has pulsations and contains direct and alternative components. The Furrier conversion of current curve form shows the presence of harmonic components, which order n is defined by following equation:

$$n = k_p \pm 1 \quad (6)$$

In the equation (6) n is the harmonic order:
k — constant value is equal 1, 2, 3,… and so on;
p — the pulsations or conversions number of rectifier.

For example 6-pulse rectifier generates following harmonics: 5, 7, 11, 13, 17, 19, 23, 25 and so on. In the case of 12-pulse rectifier we have following harmonics: 11, 13, 23, 25 and so on.

Harmonic currents from UPS rectifier are closed in generator windings and cause the following number of negative effects:
- Additional power looses in generator windings and cores.
- Potentially dangerous overheat of windings and cores.
- Insufficient power supply to load.

Mentioned negative effects causes the necessity of power redundancy of proposed guaranteed power supply system in comparison with UPS power.

The redundancy coefficient value can be determined by following way. There is the consideration that the redundancy coefficient is the ratio of two components. First is the additional power looses in generator stator and rotor core in real mode, produced by harmonics, which are usually well-known and can be simply determined. Second is the power looses in normal functional mode of proposed guaranteed power supply system with linear load.

That's why the structure of proposed guaranteed power supply system, showed on Figure 2, includes PAF as the most effective and universal device for current and voltage harmonics compensation. The functioning principle of PAF is based on phase conversion theory [1, 2, 4].

The structure on the Figure 1 has following advantages:
- Absence of the significant harmonic distortion due to short time of rectifier and inverter work.
- Synchronization of the phase mismatch angle between UPS and EPS voltages.

Also the structure in the Fig. 1 has following disadvantages [6]:
- The RBB are resided in constant booster charge mode, that reduces their lifetime.
- The double conversion of energy reduces the total performance factor of the system.
- The switching time from the maintenance to the UPS is conditioned by poor performance of the TS.

The structure on the Figure 2 has following advantages:
- Absence of power supplying interruption during the switching time from the major maintenance to RBB feeding.
- Protection from the short-time mains failure.
- High level of power quality due to the PAF working.

The structure in the Figure 2 has following disadvantages [6]:
- The double conversion of energy reduces the total performance factor of the system.
- Absence of synchronization of the phase angle mismatch between UPS and EPS voltages.
- The RBB are resided in constant booster charge mode, that reduces their lifetime.
- Additional losses in EPS generator due to its parallel working with UPS.

In case of short-time mains power supply failure with duration less then EPS starting time, the EPS unit can be excluded from the guaranteed power supply system structure. Both structures are applicable for raw mineral complexes. Thus the choosing one or another type of proposed guaranteed power supply system structure is defined by nominal parameters of responsible consumers.

The proposed guaranteed power supply system in comparison with existing developments has several advantages: the opportunity of combined using of solar, wind and followed oil gas energy, the opportunity of guaranteed power supply of geographically distributed responsible consumers, which have different rated power, functioning mode and immunity to short time power supply interruptions, the opportunity to store significant power.

Thus, developing guaranteed power supply system with complex using alternative and renewable energy sources in distributed generation and fast-acting devices of TALT provide continuity of the responsible technological processes and stability of power supply mode not only for raw mineral but for every kind of industry.

6. DISCUSSION

The proposed structure of guaranteed power supply system is firstly intended for power supply of most responsible consumers in conditions of raw mineral enterprises. Such consumers are able to save the continuity and stability of technological process in case of power supply interruption, which duration is no more than 0.15 s. In terms of this all transfer switches of proposed system must be implemented on the basis of fast thyristor switchboards.

The type and implementation method of EPS is defined by rated power of responsible consumers. According to research results when rated power of responsible consumers is more than 200 kW, it is reasonable to use micro turbine, which works on the following oil gas. For responsible consumers, which rated power is situated in the range of 3–200 kW, it is reasonable to use wind installation. For responsible consumers, which rated power is less than 3 kW, e.g. technological automation systems, digital control systems, it is reasonable to use solar panels.

The minimal capacity of storage batteries of UPS is also defined by rated power of the most responsible consumers, e.g. technological automation systems and digital control systems of oil and gas production, which shutdown is prohibitive. Also for efficiency improvement of proposed system it is reasonable to use the fast chargeable capacitors.

According to research results for proposed system the short-circuit level at the mains must be no more than 20 kA for stability ensuring.

The existing well-known PV-fuel cell installations may be considered as the special case of proposed system in conditions of raw mineral enterprises.

7. CONCLUSION

The necessity of proposed guaranteed power supply system creation for responsible consumers is proved. In this case under responsible consumers is considered the electrical installations, which define the robustness and continuity of different technological processes.

During researches, the structure and methodology of key parameters choosing of proposed guaranteed power supply system of responsible consumers with use of emergency power supply sources and uninterruptable power supply is developed. The emergency power supply functions on the base of the alternative and renewed energy sources, such as wind generator, solar power station, hybrid wind-diesel power installation or power micro turbine, which works on the following oil gas. Each of these sources allows avoiding occurrence of emergencies and infringement of technological process continuity.

The main stages of choosing structure, main parameters and content of proposed guaranteed power supply system are presented.

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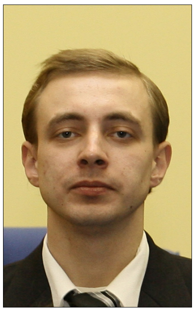

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