DOI 10.18454/PMI.2016.6.845

UDC 658.382

ENGINEERING AND TECHNICAL MEASURES TO IMPROVE RELIABILITY OF POWER SUPPLY TO CONSTRUCTION FACILITIES

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The paper examines an issue of ensuring reliable power supply to construction facilities, proposes ways to reduce losses in distribution networks and improve power supply reliability.

The primary focus is on increasing the transmission capability of power distribution networks and improving power supply reliability and safety of single-phase electricity consumers.

Engineering and technical proposal belongs to the field of electrical engineering and in particular concerns power supply to single-phase consumers from three-phase networks, including construction industry consumers, and can be used in three-phase three-, four- and five-wives alternating current power distribution networks.

Key words: power supply; power supply reliability; construction operations; construction engineering; symmetric distribution of single-phase load; balancing unit.

***How to cite this article*:** Orlov P.S. Engineering and technical measures to improve reliability of power supply to construction facilities. Zapiski Gornogo Instituta. 2016. Vol. 222, p. 845-851. DOI 10.18454/PMI.2016.6.845

Relevance of Efforts on Ensuring Reliable Power Supply to Construction Site. It's hard to imagine the present-day society without the use of electric power. It is used in all sectors of national economy, including the construction industry.

In order to secure proper power supply to the consumers the combined electric power systems have been created with high standards set for their power supply reliability and the quality of generated electric energy.

Failures of electric power system entail a chain of negative developments, which lead to social and economic consequences. Interrupted power supply or unserved energy experienced by the consumers of the construction site may cause considerable losses: underuse or inefficient use of resources, underproduction or degraded quality of the product, damage to equipment, additional costs for the means of production, fires, explosions, etc.

Such losses are commonly known as damage from interruption of power supply. The damage is a complex economical indicator of how reliable the power supply to the consumers is and one of the most important criteria, describing the notions of reliability and quality in the energy sector.

It is known, that in some power supply systems in the present-day Russian conditions the accidents may reach a number of several dozens per year, and annual undersupply of electric power due to the accidents is measured in millions of kilowatt-hours. With accident rate as high as that, assessment of reliability of separate elements of power supply networks, equipment and units and search for ways to improve their reliability both in the process of operation and at design stage become a primary concern [11].

Any degradations in reliability and quality of operation of power supply systems, even instantaneous and rare, may lead to long-lasting disruptions in construction processes, suspension in production of construction structures and materials or aftermath of any other kind.

Low reliability of power supply to the consumers is first of all explained by outdated requirements of the electric installation rules as concerns the length of allowed power supply interruptions for electricity consumers of the second and the third categories. In addition the equipment is not updated, construction of new power transmission lines to replace the damaged and the inoperable one has come to standstill, network construction rates and technical re-equipment of networks decreased, accompanied by growing depreciation of fixed assets of the power supply companies, a need to use overhead transmission lines and transformation substa-

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tions beyond their standard service life. This has resulted in higher risk of accidents with equipment and lower reliability of power supply [4, 11].

Most works carried out during construction and maintenance of transmission lines are classified as highly hazardous, that's why the risk of staff injuries in the companies installing and maintaining overhead transmission lines (OTL) is rather high. In the process of construction of OTL and substations with voltage below 35 kV 23.2% of all injuries account for construction and installation works, 26.8% of injuries result from the operation of hoisting and carrying machinery, while repairing and auxillary works lead to 35.7% of injuries [9].

Most electric injuries occur in power networks – 84% of all cases, 56% of which are fatal, that is why the electric injuries are most dangerous as result in fatalities more often than other causes. According to statistics from different countries electric injuries account for less than 1% of total number of accidents, but cause death and severe injuries to 50% of people affected by electric accident.

The analysis of reasons behind electric accidents in Russia shows that 40-45% of electrical injuries are caused by violation of the rules for working with the electrical equipment, which reduces the insulation resistance, induces voltage in electrically-dead conductive parts of equipment; 25-30% of electrical accidents occur due to workstation equipment not meeting the safety requirements and violation of job instructions; 30-35% of accidents result from violation of design requirements during installation (no safety fencing, alarms or locking, open current-carrying parts) [9].

All this points to the high relevance of efforts on ensuring reliable power supply, inter alia in the construction industry.

Power Supply to Construction Facilities. The task of power supply to the construction facilities implies uninterrupted electricity feed to electrical receivers, optimization of parameters of power supply systems through the proper selection of the rated voltage, conditions of accession to the grid, appropriate electrical equipment based on electrical load calculations, compensation of reactive loads, rational distribution of power, ensuring protection of electric plants, and the task of power consumption is to organize safe and efficient modes of operation with minimal financial costs and to reduce power losses.

Electricity consumers in construction industry are construction sites, which can be broadly divided into large (construction of large industrial facilities and complexes), medium (construction of medium by volume industrial facilities) and small (construction of residential buildings and social and cultural facilities) [12].

In general the construction sites in accordance with the requirements to the construction master plan shall include: temporary electricity supply network, pre-assembly site, temporary industrial buildings, warehouses and other facilities as needed and used during construction and installation works, lighting and utility units, construction cranes, machines in repair workshops, construction equipment, machinery, tools and other consumers of electricity.

The main consumers of electricity used at the construction facilities include such equipment as electric motors of hoisting and auxiliary machines; welders; heating devices; lighting devices, etc.

The share of electricity expenses within total cost of construction and installation works vary from 0.5% to 1.5%. Most electricity (70%) is spent to power electric motors of construction equipment and machinery, about 20% is spent to cover industrial needs (electric welding, and electric heating of concrete and erection joints in winter season, electric calorific drying of premises for finishing works, etc.) and 10% is spent on external and internal lighting of the construction site, working sites where works are performed during hours of darkness, buildings and structures under construction, administrative, cultural and social, utility and storage space [5].

Besides construction site reliable power supply shall be secured for the plants of the construction industry (delivering reinforced concrete, metal and wooden structures and goods), enterprises producing bricks, concrete, mortar and paint coatings and for the repair shops.

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Power networks used at the construction facilities can be powered from either underground or overhead power transmission lines (PTL). With regard of the specifics of construction works, implying frequently changing location of the main consumers, it's recommended to arrange facility power supply via PTL. The underground PTL shall be installed to feed the construction site only in cases when the overhead PTL constitute hazard for the construction workers.

In cases where there are no regional high-voltage grids or it is impossible to get electricity from the power plants of industrial enterprises located in the vicinity of the construction site, the constructors resort to temporary fixed or mobile power generating stations. These include locomobile and diesel power stations rated from 28 to 258 kW and power trains being a powerful mobile thermal power plants mounted in 8-12 cars.

Electrical receivers include electric motors of construction equipment and machinery drives, industrial plants for electric curing of concrete, heaters, welding machines, rectifiers, high-frequency plants, electric lamps in lighting systems and radio-electronic equipment.

All receivers can be connected to a single-voltage distribution network or electrical networks of different voltages.

Power supply networks of construction sites and plants producing construction materials can be intended for constant or temporal use. They shall ensure: reliable power supply; high quality of transmitted power; safety of electrical engineers and other staff during operation of the networks and electrical installations; efficiency, i.e. cost reduction due to construction and operation of networks and installations; changes in network configuration in response to change in construction technology; reduction of energy losses in the networks; eco-friendliness, i.e. no harmful impact on the environment.

It is known, that the electric installation rules define three categories of electrical receivers by their degree of power supply reliability [8, 10, 12].

The first category includes power consuming equipment and systems, any interruption in power supply of which can result in considerable losses, damage to major equipment, product defects on mass scale or disruption of production process. Such consumers shall be powered from at least two autonomous power supply sources. Their power supply can be interrupted only for the length of automatic switching to the second power supply source.

At the construction site the power consumers of the first category include pumps and sprinkler-based fire suppression systems and fire hydrants; fire alarm system; security alarm system; warning and evacuation systems in case of fire; evacuation and emergency lighting; general-purpose industrial plants, including those used for construction operations, as well as pumps, compressors, etc.

The second category includes power consuming equipment and systems, any interruption in power supply of which results in underproduction on mass scale, staff and machinery dead time. Such consumers shall be powered from two autonomous power supply sources. Interruption in power supply is allowed only for the time required for the staff on-duty to promptly switch to the second source.

The power consumers of the second category used in the process of construction or production of construction materials and structures include construction equipment and machinery; electrotechnological units, including electric heating devices, units for spark and ultrasonic metal processing, electric welding equipment, electrical plants, including for power transmission and distribution, consisting of transformer substations and distribution devices interconnected by electric lines used for power supply to consumers, for electrical lighting of the construction site, on-site warehouses, roads, driveways; some ventilation and compressor stations, as well as the electric engines of pumps and fans, not belonging to the first category, workplace lighting, electrical appliances.

Interruption in power supply of the consumers included in the second category may entail staff, machinery and transport dead time, production defects.

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The third category includes power consuming equipment and systems not meeting the definitions of the first and the second categories. Such consumers can be powered from a single source. Interruption in power supply is allowed for the duration of restoration works, not exceeding 24 hours.

For instance, the consumers of the third category, used to support the construction process include individual external lighting points, electrified tools, etc.

Problems Affecting Reliability of Power Supply to Construction Facilities and Possible Solutions. As was mentioned above the construction equipment and machinery, without which erection of buildings and structures is impossible belong to the second category of electrical receivers. Most construction machines have asynchronous motors: hoisting machines with electric drive are equipped with three-phase asynchronous alternating current electric motors; the high-rated hoisting machines have asynchronous motors with phase rotor allowing to adjust the rate of rotations and ensure cargo soft landing; conveyors run for a long time with constant load in highly variable atmospheric conditions at different seasons and in conditions of high dust content and humidity are equipped with asynchronous motors appropriate for such operating conditions (the asynchronous motors with short-circuited high-slip rotor with single engine drive and motors with phase rotor if soft start or rate adjustment is necessary);the low rated concrete- and mortar-mixing machines have asynchronous short-circuited AC motors, and high-rated machines are equipped with electric motors with phase rotor; concrete and mortar piston pumps are equipped with asynchronous electric motors with phase rotor, where speed is regulated by a resistor included in the circuit and a controller-based resistance changing; the auxiliary mechanisms of concrete and mortar pumps employ short-circuited asynchronous motors; the low-rated compressors are driven by asynchronous short-circuited motors, the high-rated compressors use asynchronous motors with a phase rotor and synchronous motors; the power tools and finishing machines use three-phase asynchronous electric motors with a current frequency of 50 Hz and 200 Hz and universal collector single-phase AC or DC electric motors [1]; fans in exhaust ventilation system, elevators, pumps, supplying water for production needs or heating and other machinery and equipment use asynchronous motors.

The modern state of the asynchronous electric drives pool gives rise to a number of technical, economic and scientific problems, related to moral outdating and physical wear of the fleet of electrical equipment serving as electric drives in the construction industry, its structure being inappropriate for operating conditions, high level of power losses in construction across the Russian Federation, low quality of electric motors troubleshooting and repairs. The consequence is high electricity bills for enterprises and organizations, unscheduled repairs and replacement of asynchronous machines, compensation of costs incurred due to downtime of production equipment.

The main reasons behind power losses and premature failure of asynchronous motors are unbalanced modes of their operation, first of all unbalanced load on electrical networks and physical wear of electric motors, the wide spread of open-phase modes of three-phase motors and wide use of electric motors powered by a single-phase network.

With permissible value (GOST 13109-97) of constant voltage of reverse sequence symmetric components equal to 4% the period of motors' accident-free operation is reduced by half. Meanwhile it's not unusual when reverse sequence symmetric components reach 15-20%. Taking into account that annually around 20% of all asynchronous machines get out of order, the damage caused by asymmetrical modes on a Russia-wide scale comprises RUB 15 bln per year [2].

The physical wear accelerates in case of exposure to aggressive environment (gases, sharp fluctuations in daily and seasonal temperature and air humidity), poor quality of electricity generated by long and low-power networks, wide spread of single-phase and non-linear loads, frequent transition processes, low quality of electric engines' repairs and maintenance, repair shops lacking modern diagnostic and testing equipment.

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All this leads to high electric energy losses, intensive wear and failures of electric machines [7].

A special balancing unit has been developed by the Belarusian Technical University (Minsk), which is applied on an increasingly wider scale in Belarus power supply system for balancing distribution of load between phases of a three-phase network (Fig.1) and which represents an additional coil wound on top of all three-phase windings of $Y/Y_н$ transformer, included in a break of a neutral wire. The winding of a balancing device is designed for long-continued flow of the nominal transformer current (for full single-phase load) and is included in such a way that zero sequence magnetic fluxes it creates in the transformer magnetic circuit $F_{0к}$ fully compensate oppositely directed zero sequence magnetic fluxes $F_{0р}$ in the transformer's working windings, preventing imbalance of phase voltages [7].

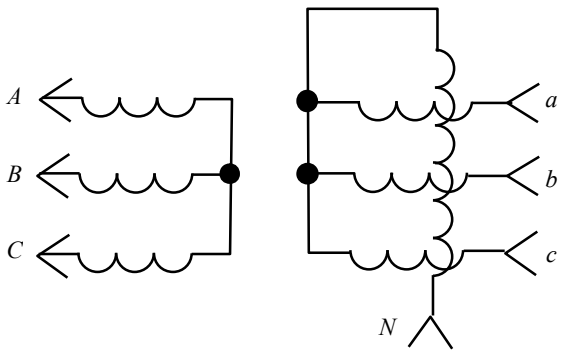


Fig. 1. Balancing Unit

A, B, C – are terminals of primary winding of a special balancing unit; *a, b, c* – are terminals of secondary winding; N is a neutral terminal, the break of which includes an additional winding (magnetic circuit of a unit is omitted for clarity)

But such balancing unit, the same as transformer with a zigzag winding connection, only reduces generation of zero sequence magnetic fluxes, reducing imbalance in phase voltages but is not able to eliminate the load asymmetry between phases.

The author of this paper has developed and protected with a patent of the Russian Federation a device helping to increase the transmission capability of power distribution networks, the power supply reliability and the safety of single-phase electric power consumers [6].

The device for balanced distribution of single-phase load across phases of three-phase network is a consumer's three-phase single- or multiple-winding (in the secondary circuit) isolating transformer, the secondary winding of which has additional turns, independent from the main winding, intended to offset voltage drop on the line. Each consumer of the multiple-winding isolating transformer is powered from its own or shared (for single-winding transformers) secondary winding, in which the lines connected to consumers are powered from transformer's series-connected three-phase coils, two of which are connected accordantly and the third one in opposition (Fig.2).

Series connection of the transformer's three-phase coils of each secondary winding, any two which are connected accordantly and the third one in opposition, helps to get a single-phase alternating voltage with load uniformly distributed across phases of a three-phase network and ensures absolute balance of load on the lines and the transformer substations, irrespective of whether single-phase load is generated by one or several consumers, or all consumers simultaneously consume different power.

Symmetric load on the line and the substation transformer allows to increase the transmission capability of power distribution network at peak load, exclude overloading of one of the phases and prevent current flow through the neutral wire.

The unit has a number of significant new features:

• each secondary winding has additional turns independent from the main winding, providing a three-step upwards voltage control and if necessary three-step downwards control, thus improving the quality of power supply;

• when each consumer is powered from its own winding of multiple-winding transformer, the galvanic connection with other power consumers is completely excluded and the quality and safety of power supply is improved;

• when each consumer is powered via isolating transformer, its galvanic separation from the extremal high-rated network is ensured, thus increasing power supply safety;

DOI *10.18454/PMI.2016.6.845*

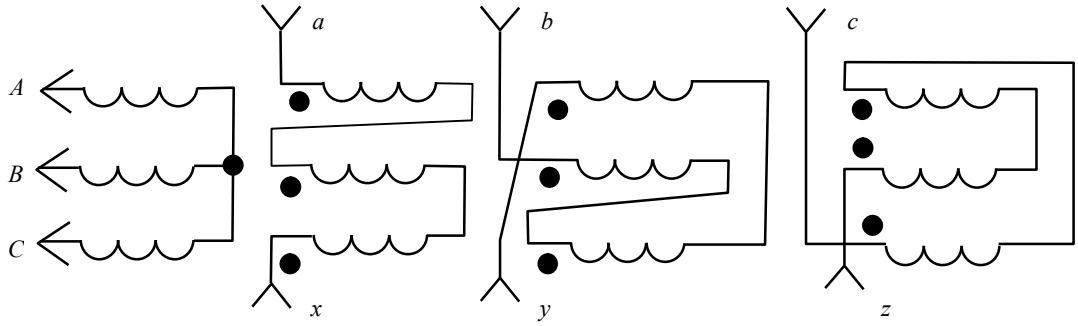


Fig. 2. Unit for symmetric distribution of single-phase load

A, B, C –are terminals of primary winding of the unit for symmetric distribution of voltage across phases of three-phase network; *a, b, c, x, y, z* – are terminals of secondary winding; (magnetic circuit of a unit is omitted for clarity)

• symmetric load across phases excludes imbalance of phases and emergence of reverse sequence symmetric components and reverse torque in asynchronous machines;

• when each single-phase winding is powered simultaneously from three phases, it helps to get the same current phase angle for all phases, reduce costs for power meters and improve accuracy of accounting for consumed electric power;

• if voltage is lost on any of the phases, the power feed to single-phase winding simultaneously from three phases will secure power supply from the other two phases, connected in opposition to each other under voltage equal to 0.95 of the network rated voltage with the number of additional turns comprising 10% of total number of winding turns, thus enhancing the quality and reliability of the power supply.

This device will help to increase reliability of all protective measures, since it ensures the network protection from neutral wire «burning-off».

Conclusions

Based on the studies performed, the following conclusions can be made:

1. The urgency of the explored problem stems from the scale of power losses in energy sector and high electric accident rate in manufacturing sectors of Russia, including the construction industry.

2. Replacement of outdated equipment with energy-efficient equipment will help to reduce material losses.

3. The task of improving the power supply efficiency shall be addressed at the legislative level, in particular, the electric installation rules shall be supplemented with the requirement of ensuring the single-phase load conversion to balanced three-phase load for each newly constructed facility.

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The paper was accepted for publication on 03 November, *2016.*