**Distributed generation in small-scale power generation. Search for energy-efficient solutions by automation of complex power systems**

T V Golubchik, A S Kulikov, D Y Taratutin

1 Moscow Automobile And Road Construction State Technical University, Leningradsky Ave, 64, Moscow, 125319

E-mail: tvgolubchik@mail.ru

**Abstract.** The Paper presents data on the control of a generating set from an external source in parallel operation with the network. An experimental study was carried out on the example of a real generator set that provides a production facility with electricity. The economic feasibility of the simultaneous use of several sources of electricity is considered. The advantages and disadvantages of usage a generator set for parallel operation with the mains are considered. Considered solutions for the automation of complex systems in the small power industry.

1. **Introduction**

Scientific and technological progress, centralization of industry facilities, increase of population density in cities driven by an increase of development density are the factors responsible for an increased demand for electric and thermal power. Over the past 30 to 40 years, electricity consumption in developed areas has increased tenfold while the main burden can be attributed to the already densely populated areas and technology parks. The method of modern separate economic management prioritizes the infrastructure and transport accessibility of the facilities, which inevitably leads to centralization of loads, and increased energy consumption.

Given other positive aspects of load centralization, there is a number of negative factors, including the duration of the design of the power supply system and the construction of network infrastructure facilities. The reconstruction of electric mains takes place over the decades, not to mention the limitation of output due to the insufficient capacity of generating, nuclear, hydro and thermal power plants. In the old areas, we have to work with networks designed and constructed 40-50 years ago, and ultimately not designed for the increased loads. Therefore, we have a serious shortage of electricity both in industrial and residential areas. This factor severely constrains manufacture, economic and technological growth of economic facilities in the modern world. The cost of connection to electricity mains is growing exponentially. The denser the area is developed, the more complex and costly are the measures to connect a facility to a power source located on its territory, and the more electricity is needed.

2. **Isolated power supply and network management**

The From the economic point of view, the self-contained power supply consists of three fundamental components: the cost of initial capital investments, the cost of fuel, and the cost of maintenance and operation. Summing up the three values, comparing them to the cost of connection to the external mains,
and the cost of kW/h of electricity we get an answer to the question of the expediency of construction of an entire power center. Often, the cost of self-contained power supply is higher, so the issue changes to the plane of off-line operation and reduction of energy consumption, or relocation of production to a more resource-friendly area.

Fortunately, the experience of using hybrid sources, branched self-contained power systems, automation systems in power centers make it possible for us to approach the solution of the issue comprehensively: combine heterogeneous power systems with a network, use diesel and gas power plants to remove peak loads, use solar panels, energy storage devices, etc.

It stands to reason that such approach requires a complex systematic approach, the energy map of a facility has to be developed first considering the availability of certain resources (limit of connection to the power supply network, gas pipeline, wind potential, prospect of installation of solar panels, etc.). When creating facilities’ energy map, allowance is made for daily, weekly, monthly, and seasonal maximum and minimum loads, nature of loads, stability and continuity of consumers. Based on the above, the required amount of electricity, maximum and average load values, as well as the category of electrical receivers have to be calculated.

3. Issues in operation of a network of different sources
Power quality parameters directly depend on the stability of the generating sources. No such problem occurs during operation from such network. When using the equipment of self-contained power centers, the designer often tries to use the same-type equipment that is a part of the power complex, with the same-type device of the control gear, comparable to the values of internal resistance of sources. This is due to the fact that when the load changes, especially its reactive component, each source reacts differently and compensates for changes in the network. As a negative factor, self-induced oscillations and, in general, instability of the system are possible.

The next issue is the need to develop a complex process automation system to divide the load between the generating sources. Such system should centrally distribute the load between the generating systems, considering their load, the required level of redundancy and the correction factors (e.g., the daily coefficient for a grid source or solar panels, etc.). Such system is quite an expensive and elaborate automated complex, but its use can provide the economic effect of the entire combined system.

Another obstacle in network operations – the demands of regional network companies of strict control over electricity export to the network (some internal network companies allow export, but under strict control and according to the agreed specifications). Once again, this factor makes it necessary to apply a centralized power center control system with a load control for each of its elements and a protection system against export, considering a number of factors (unloading of consumers, emergency shut-off, reactive power of asynchronous motors, etc.).

In summary, the combination of self-contained power centers and network sources is an effective complex solution for the delivery of electricity to the consumer in conditions of an increased demand, which is a feasible task these days, yet requiring an integrated approach to automation of the process and administration of power generation.

4. Implementation of a parallel network management solution and power distribution
As an example, let us examine a small power system implementing the principle of power distribution and control between a stand-alone source and a network.

Technical specifications of the power system:
- Power supply of consumers by 1 and 2 categories of reliability,
- Input 1, transformer 10/0.4 kV, 1000 kVA, model TMG-21.
- Input 2, transformer 10/0.4 kV, 1000 kVA, model TMG-21,
• Combined bus section (2 sections), islanding is not carried out, parallel operation of transformers is not provided,
• Input 3 from the gas-reciprocating power plant (hereinafter referred to as the GRPP) designed through the circuit breaker for consumers of the 1st bus section, parallel to input 1,
• TN-C-S five-wire system.

The electrical diagram is shown in Fig. 1

![Electrical Diagram](image_url)

**Figure 1.** Electrical diagram.

In this project, the Customer is not limited by the capacity of the network connection, but due to the individual tariff and the high cost of 1 kW/h, the calculation was based on the choice of a gas power plant for parallel operation with Input No. 1 for its maximum unloading. By means of a calculation, the maximum power value of the GRPP was obtained based on the limits of gas connection, i.e. 400 kW of active power in the maximum mode, as well as the schedule of average daily loads in summer and winter seasons, which is shown in Fig. 2.

![Average Daily Load Graph](image_url)

**Figure 2.** Average daily graph load.
For this system to operate in parallel with the existing network, it was necessary to arrange an automation system performing the following functions:

- Control of power consumption from the network.
- Automatic start and stoppage of the GRPP when the set load is reached. This is necessary for efficient use of the power plant’s life and operation in an effective power range.
- Control over the distribution of load between the GRPP and the GRPP load priority network in an effective range of 60-80%.
- Protection against export to the network by adjusting the load capacity of the GRPP with its unloading while reducing the load of the consumer.
- System dispatch for monitoring of running processes and protection of equipment in the event of malfunctions.

In the arrangement of parallel work with the network, organizational measures are taken, in particular, the development of technical specifications for the distribution of power and the amount of exports to the network (including for transitional processes), the design of the power supply system, the design of the automation system and the development of a set-up and testing program.

The automation block diagram is shown in Fig. 2. The PRAMAC model GGW400G was used in the implementation of this GRPP system. The GENERAC GRPP controller, PowerZone model was used as automation equipment. To monitor the controller of power system (network and power distribution, as well as the logic of operation of the whole automation system) ComAp, model IM-NT-BB IV5 was used. In addition, the KLEA 320P power quality analyzer, manufactured by KlemSan, was used. This device made it possible to obtain parameters of active, reactive and full power with high accuracy and speed, which was a necessary prerequisite for reducing the duration of transition processes in operation of the GRPP.

To control the algorithm of system operation, a discrete and analogue PLC logic was applied, cascade PID (proportional-integral differential) control of a controller secondary to GRPP was also used for power distribution, as well as for the engine speed control (fast governor) and alternator excitation control (slow governor).

The Main Control Unit was written using the original IM-NT-BB controller tools (ComAp) in the PLC Free Programming Unit, which was a non-trivial task and required long-term testing, debugging and correction of the installation’s operational remarks.

The protection against export to the network is carried out through the discharge of the load by reducing the engine speed and at high unloading – disconnection of the network switch and switching to island mode – operation from the GRPP. 120 kW power reserve setting to enable starting of heavy starting motors according to the load chart and technical specifications.

The percentage of exports to the network is insignificant and is due only to technological transitions at load discharge, and is approx. 0.01% for active and 0.2% for reactive power, the power factor in the range from 0.77 to 0.97 is stable with the control accuracy of 0.1 subject to constant load.

This automated system has the 3rd degree of automation according to GOST 50783-95 and is also integrated into SCADA (Supervisor Control and Data Acquisition) system for monitoring operational parameters. Technical record-keeping of electric energy and gas consumption was arranged. Later, integration into the High Level Control System for monitoring and diagnostics is carried out by installing the APM (operator’s automated working station) and developing the remote monitoring site based on the Wonderware software.

The automation block diagram is shown in Fig. 3.
From a technical point of view, the following activities were carried out:
Initially, the active/reactive power distribution has to be stabilized between the generating units and the network.

In this case, all load changes (active and reactive) compensate the gas power plant, being the main source of power, see Fig 4.
Fig. 4 shows the reset and ascention of active power received by the GRPP, which are caused by a change in the consumer’s load while the network is maintained at a minimum stable level. In this case, condition is also met to maintain the generating capacity power reserve at the gas-reciprocating power plant. Otherwise, it would be possible to switch the network switch off. Here, we can also see some fluctuations in reactive power, they are related to the operation of the asynchronous motors in the network, as well as their launch.

The second important point in setting the power distribution is to provide acceptable power-ascension/drop properties when the equipment is introduced into the network. This is to avoid any loss of electricity quality, emergency shut-down of the equipment, and to ensure that the system is operating smoothly in general.

Fig. 5 shows a graph of a power ascension with a high overshooting value.
This graph shows that the regulator needs additional setting. Also, the relationship between the network and the generator in transition processes is clearly visible, as well as the need for accurate adjustment of the PID settings of the GRPP controller – the harmonization of the controller factors and the feedback parameters of the adjustable value. Fig. 5 shows continuous fluctuations in the active power, which means that the governor of the GRPP engine has to be adjusted.

System settings during debugging were adjusted to acceptable values, overshooting in the process of ascension/dropping of load of approx. 5-7%, without auto-oscillations and static controller error.

The third important point is to maintain stable and even operation of the power system under varying and constant loads.

This factor is implied by the previous one and is an indicator of the stability of the system as a whole in a continuous-duty mode. To do this, the system is tested for 10-16 hours and point corrections are made to the factors of PID controller.

The fourth point of adjustment is the arrangement and logic of on/off switching on the mains switch. In this case, this entirely depends on the need to maintain the power reserve and is controlled by the power distribution controller. In our case, the impact on the power switch has been completely reduced to the functions of protection against export of electricity to the network. As may be required, a system is created with the switch disconnected and connected with reverse synchronization on command from the managing controller in case of a lack of power in the system.

The fifth point is to protect against export of electricity to the network. This factor is the result of arrangement of the energy system as a whole and the comprehensive sustainable work of the previous four points. In particular, it depends on the duration of transient processes at unloading/loading of the GRPP by the consumer, the accuracy of setting of the cascade of power distribution controllers and GRPP management taken together, the stability of maintaining the set parameters by the speed controller and the generator’s excitation controller.

5. Analysis, solutions, and conclusions

It is possible to use the example of this system to analyze the technical solution as a whole, as well as for a follow-up revision of the concept of distributed generation.

Advantages:

• Possibility of partial replacement of electricity consumption from the network with electricity produced by self-contained sources.
• Quality of electricity produced in accordance with GOST 33105-2014.
• Provision of 3rd degree of automation according to GOST 50783-95.
• Automatic power distribution between generating units based on current load, and rapid power change as network load changes.
• Flexibility of the system in terms of equipment redundancy, repair, provision of high category for electrical receivers by using a stand-alone generating unit.

Disadvantages:

• Complexity of setting and debugging of the system.
• Cost of the solution, even though the system is simple (3 sources, of which 2 are mains supply sources), it requires significant development and implementation costs, testing on a case-by-case basis.
• Duration of operation in the test mode as a consequence of the previous item.
• The power distribution principle is not implemented, considering the operation of the equipment in the energy-efficient range. This solution is discrete and oriented on generation from the main source (in our case - GRPP), and unloading of the latter.
• No feedback for consumers – unloading/loading takes place without feedback to the system, which complicates management and imposes high requirements to the system’s responsiveness to changing loads.

From all of the above it follows that for the complex automation of such energy solutions, and especially in case of operation from several generating sources, new technical solutions for power distribution are needed, and, if possible, the departure from complex customized software systems to
reliable and proven industrial solutions, in particular, due to the inability to perform long-term testing of the power system at the implementation site. In particular, an effective solution would be to use a controller taking lead in arrangement of power distribution according to a given and pre-configured algorithm, having I/O for feedback with equipment, a terminal block for frequency/reactive unloading of the network, with a built-in function of controlling the loading of generating units in a given range and switching it on/off if necessary, with a set power reserve.

This device would improve the energy efficiency of distributed generation solutions, reduce the cost of implementation for such projects, move from experimental systems to industrial ones and sustainable solutions, and would provide a pronounced economic effect.

References
[1] Andreev E B, Popadko V E 2005 Software tools for process control systems in the oil and gas industry (Moscow: “Oil and Gas”)
[2] Denisenko V S 2006 PID Regulators: Principles of Building and Modification Modern Automation Technologies 4
[3] Golubchik T V, Yutt V E, Taratutin D Y 2019 Automated Control System for Parallel Operation of Five Generator Sets in the Electric Power System Institute of Electrical and Electronics Engineers 2019 International Science and Technology Conference "EastConf".
[4] Korkov S A 2011 Calculations of electrical consumption in the energy survey of an industrial enterprise: A training and methodical manual (Izhevsk: “Udmurt University” publishing house)
[5] Serdtseeva A V 2016 Development of automated systems of control of technological processes The Herald of UIGTU
[6] Trutnev S Y, Marchenko A A 2014 Analysis and investigation of parallel operation of the synchronous generator and static converter Bulletin of the Kamchatka State Technical University (Petropavlovsk-Kamchatsky)