# Optimizations of Structure the Generators in Isolated Microgrids in Russia

K. V. Suslov
*Irkutsk State Technical University, 83, Lermontov str., Irkutsk, Russia*

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Abstract: Many parts of Russia is not connected to centralized electricity supply by virtue of their geographical position. A large number of distributed consumers which can be supplied with electricity only from the autonomous energy sources and problems in the existing decentralized electricity supply system require that the issues of development and optimization of electricity supply be urgently solved. Taking into account a nonstationary character of electricity generation, presence of electricity storage devices, as well as stricter requirements of consumers to power quality and reliability of electricity supply, we can say that operating conditions of such systems and their control represent a difficult problem that needs to be studied. In the paper the specific features of microgrid operation in different seasons of a year and different time of a day are analysed, a set of problems related to control of operation are formulated and specific features of their solving are discussed. The main principles of building the isolated power systems and control of operating conditions are suggested. A case study is introduced and calculation results are discussed.

## 1 INTRODUCTION

In Russia there are many small isolated settlements. They are supplied with electricity from diesel power plants using expensive fuel delivered at large distances. However, in many cases it is possible to supply electricity to consumers on the basis of renewable energy sources, such as wind turbines, small hydropower plants, power plants based on biomass, in particular by converting it into gaseous or liquid fuel. The studies show that in the majority of cases the use of renewable energy sources is economically sound. Besides, for this purpose it is also advisable to consider energy storage systems. The power supply system to be formed in such a way is a microgrid of specific structure. Because of unsteady character of power generation, availability of energy storage systems, electricity demand management and also stricter requirements of consumers to power quality and power supply reliability development optimization of such power, is not an easy problem that calls for further research.

## 2 ISOLATED POWER SUPPLY SYSTEMS

About 60% of Russia's territories, mostly in the North, are not connected to centralized electricity supply due to their geographical position.

Many studies are devoted to technical and economic assessment of electricity supply to isolated consumers. The feasibility of connecting them to centralized power source or using local small power sources has been shown (Ivanova, 2010). Also the areas of efficient centralized and decentralized power supply are presented depending on electricity tariffs and diesel fuel cost.

This approach makes it possible to identify at the regional level the zones which require further detailed estimation of applicability of one power supply option or another in terms of their technological feasibility and cost efficiency. Results of the studies for different regions allow one to make recommendations concerning prospective directions of technological progress in the area of small-scale energy, estimate feasible scales of implementation and market of equipment for economically attractive projects.

A large number of scattered consumers which

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can be supplied with electricity only from autonomous power sources and the problems in the existing decentralized power supply system require urgent development and optimization of power supply to isolated consumers. An obvious way to enhance energy efficiency of such areas is maximal use of alternative and local energy resources.

The problems of power supply to isolated territories are actively studied in different countries. The models created for isolated microgrid also include those intended to optimize the systems for control of distributed generation, including, in particular renewable energy sources (Arai, 2009; Hugo Morais et al., 2010; Darvishi et al., 2010; Martinez-Cid and O'Neill-Carrillo, 2010; Hatziargyriou et al., 2009). Models of the kind make it possible to optimize network operation by different parameters.

# 3 PROBLEMS OF ISOLATED POWER SUPPLY SYSTEMS

The above characteristics of isolated territories in Russia make the systems of power supply to these territories specific in terms of load flows and their control in different seasons of the year and different time of the day. Because of variable renewable generation, presence of energy storage devices, control of electricity consumption and ever growing role of consumers in this process as well as higher requirements of consumers to power quality and reliability of power supply operation of such power supply systems and their control represent a problem that requires research.

Trends towards change in power supply - from both sources and consumers are presented in Table. 1. These changes impose new requirements on power quality, reliability and, hence, on problem formalization.

Analysis of data presented in Table 1 allows the conclusion that it is necessary to thoroughly consider load and generation curves, and parameters of power flows in the electricity supply system.

Analysis and control of isolated power supply systems should solve the following problems:

- study of the nonstationary character of power supply system operation which is determined by varying operating conditions of wind turbines and small hydropower plants in different seasons of the year and different time of the day;
- optimization of long-term and short-term operation of power plants with variable operating conditions;
- monitoring and control of voltage levels in distribution network;
- joint optimization of power supply system and load-controlled consumers' operation;
- study of the emergency control problems to provide system stability and survivability;
- study and provision of reliability of power supply to isolated territories.

Table 1: New factors in power supply in Russia.

| Sources | Consumers |
|---|---|
| New generation technologies (wind turbines, photovoltaic panels, etc.) | New domestic appliances with higher requirements to power quality and reliability of power supply |
| Energy storage devices | Specific requirements imposed by industrial consumers |

Currently the studies on many of the foregoing problems are under way (N.I.Voropai and co-authors 2010, 2012), etc.

# 4 MICROGRID EXPANSION PLANNING AND CONTROL

The main objectives to be accomplished when expanding the isolated electricity supply systems are:

- choice of the type and structure of generation sources;
- choice of configuration and parameters of electrical network;
- estimation of electricity supply reliability;
- analysis of operating conditions.

Conditionally the problem of isolated microgrid expansion planning and optimization can be represented by the following structure (Tabl.2).

The main generating capacities to be included in the structure of isolated electricity supply system are: diesel generators, mini-CHP, energy storage devices, wind turbines, solar panels ect.

The generation mix is chosen on the basis of specific requirements of industrial and domestic consumers, availability of energy resources. Stochastic character of generation when using renewable energy sources also has a great impact on the choice of generation sources.

Table 3 presents the problems of operation control in isolated electricity supply systems.

Table 2: Isolated supply system expansion planning.

| Problems | Requirements |
|---|---|
| Choice of type and mix of generation sources | • Requirements imposed by consumers<br>• Availability of fuel<br>• Capabilities of continuous fuel supply<br>• Climatic conditions |
| Choice of network configuration and parameters | • Economic feasibility<br>• Geographical features of the territory<br>• Choice of place for installation of generation |
| Estimation of electricity supply reliability | • SAIFI: System Average Interruption Frequency Index<br>• SAIDI: System Average Interruption Duration Index<br>• ASAI: Average Service Availability Index |

Since the isolated electricity supply system includes active consumers, energy storage devices, it operates like a virtual power plant. In this case the virtual power plant has first of all technical purpose.

Table 3: Problems of operation planning and control.

| Operation | Problems |
|---|---|
| Long-term planning of operating conditions | • Adjustment of protection and automatic systems<br>• Maintenance planning<br>• Consideration of seasonal consumption and generation of electricity<br>• Reliability analysis |
| Daily control of operating conditions | • Optimization of daily operating conditions<br>• Reliability analysis |
| On-line control of operating conditions | • State estimation<br>• Calculation of operating conditions<br>• Reliability analysis |
| Automatic control of operating conditions | • Automatic control of system frequency, voltage levels and loading of tie lines |

# 5 PROBLEMS OF GENERATION MIX OPTIMIZATION

According to the characteristic of isolated electricity supply systems in Russia optimization of their expansion requires consideration of generation units that use fuel resources for electricity and heat production and renewable energy sources (Voropai and Styczynski, 2010). Due to variability of consumer load curves and uneven electricity generation from renewable energy resources account is taken of energy storage devices of different types.

The representation of an isolated electricity supply system relies on balances between generation and load that are specified with certain discretization of the week. Taking into account a relatively small number of some types of generation units, their mix is considered to be discrete.

Thus, the optimization problem of the isolated electricity supply system expansion is represented as the following mixed-integer linear programming problem for each time instant of the day, taking into account the level of discretization of power generation and consumption curves:

$$\min \sum_{i=1}^{n} C_i\left(u_i P_{gi}\right) \tag{1}$$

subject to constraints

$$\sum_{i=1}^{n} P_{gi} = P_{e\Sigma}\ ; \tag{2}$$

$$u_i P_{gi}^{\min} \le P_{gi} \le u_i P_{gi}^{\max}\ ; \tag{3}$$

$$i = \overline{1,n} \tag{4}$$

where $u$ - binary variable that takes a value of 0 or 1 to take into account the presence (1) or absence (0) of power generation from the unit of a certain type $i$;

n - the number of time instants during the period at discretization of power generation and consumption curves;

$K$ – the number of intervals in which the cost characteristic of power generation by the units of power plants is linearized;

$P_{e\Sigma}$ - total load of a system;

$P_{gi}$ - power generated by the unit of type $i$.

By solving the formulated problem we:

1. Minimize the costs of electricity production during the considered day by following procedure:
   - for a given daily or weekly load curve,
   - for the given wind and radiation conditions,
   - calculate the wind and PV load using generic models of wind and PV generators,
   - substrates the energy generated by renewable from the daily (or weekly) load profile,
   - use the traditional generation to fully balance

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the needed power (energy).

2. If the generation form renewable energy will be higher for some period of time then a given daily (weekly) load profiles an electric energy storage can be used for save the produced green energy. This saved energy can be in-feed into the system replacing the traditional generation and in this case save the fuel resources.

## 6 CASE STUDY

The test system consists of:

- Load - by 25 MW given by a load curve (in this calculation for one week).
- Wind generation - 10 MW
- PV generation – 2,5 MW.
- CHP generation - 25 MW.

The calculation will be done in 4 scenarios:

A. Basic mix of generation given below.
B. High PV generation – PV – 5 MW.
C. High wind generation – 25 MW.
D. High RES – PV-5MW, Wind -25 MW

Using wind and radiation profiles the wind and PV generation can be computing in to account the generic models of wind and PV systems.

The necessary generation mix for each hour is finding by using of mentioned mixed-integer linear programming solved. The priority of renewable injection has been set.

For optimization parameters are investigated: fuel cost, emission $CO_2$, emission $NO_x$.

The emission is calculated taking in to account the equivalent emission for different technologies (Ackermann et al., 2001).

The results of investigation for 4 scenarios are given in the table 4. All data are presented in relative units. For the basic scenario A the computations show the maximum value of each of the indicators.

Table 4: Different variants of mix generations.

| Scenario | Fuel cost* | Emission | | Energy per week | |
|---|---|---|---|---|---|
| | | $CO_2$ | $NO_x$ | CHP, MWh | RES, MWh |
| A | 1 | 1 | 1 | 1526 | 794 |
| B | 0,78 | 0,95 | 0,95 | 1460 | 860 |
| C | 0,61 | 0,76 | 0,76 | 1143 | 1177 |
| D | 0,59 | 0,73 | 0,73 | 1085 | 1235 |

*fuel cost taking in to account transport cost

Figures 1-4 shows the share of the participation of different generation in the covering of the load profile for one selected week.

In general the investigation results strongly depend on the local wind and radiation conditions. This dependency also changes seasonally, and therefore it is recommended to conduct a one year simulation.

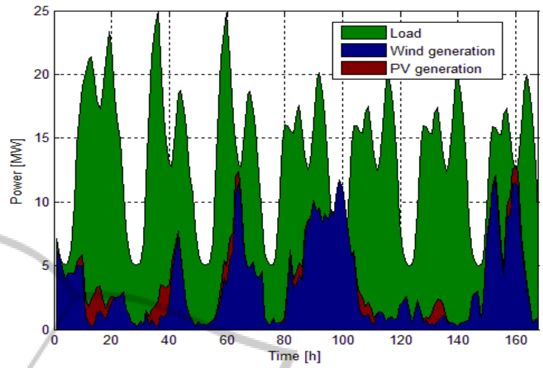


Figure 1: Unit commitment for one week (Scenario A).

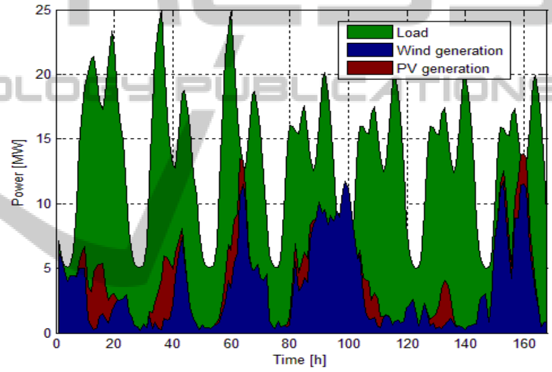


Figure 2: Unit commitment for one week (Scenario B).

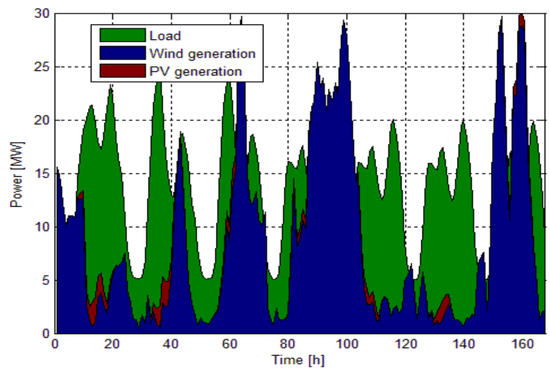


Figure 3: Unit commitment for one week (Scenario C).

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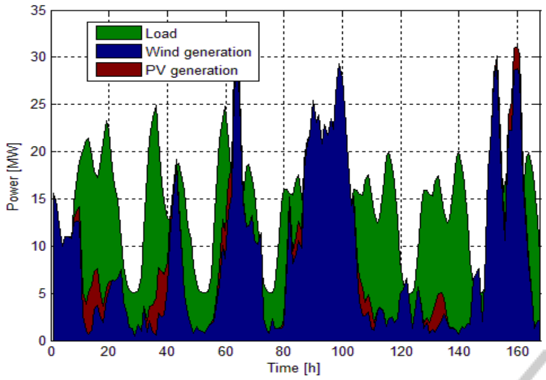


Figure 4: Unit commitment for one week (Scenario D).

The input date for this simulation should come either from local measurements or from global weather data, e.g. RENO- Database, so that it reflects the local conditions well. Also, the load curve should correspond as closely as possible with the local conditions.

The Figure 5 graphically presents the results for the test cases A, B, C and D.

We can see that the best option in this case is a scenario D, i.e, high increases of RES generation. Anyway two observations can be done:

- The emission factor does not change very much with the increasing of RES generation; doubling the RES decreases the emissions by only about 25%
- The $SO_2$ and $NO_x$ emissions are quite the same, so it is enough to use one of this indexes

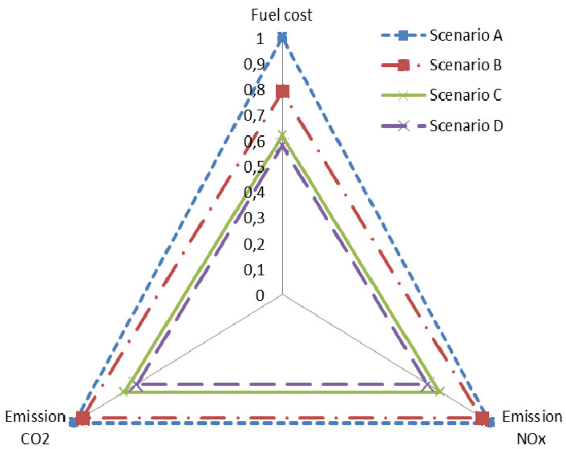


Figure 5: Diagram for different scenarios.

It is clear that a further increase in PV-generation will not reduce the fuel cost of this test system, as evident (Fig. 1-4) that the contribution - is small. And it will not bring significant increase in results. This is due to the climatic conditions and the length of daylight. For the final decision the limiting factor is the cost and the climatic conditions.

## 7 CONCLUSIONS

The systems of electricity supply to isolated areas and populated settlements in Russia are rather specific which affects the structure of microgrids. The renewable can provide a crucial amount of energy locally without very high cost of fuel. Also the emission can be limited using renewable generation. The problems of stabile and control of operation of such isolated electricity supply systems should be solved taking into account their specific features. This will be done more specific in other studies also taking into account the use of electric energy storage.

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