A Review of Smart Off-Grid Power Systems Optimization Models for the Oil and Gas Industry

V V Fedorenko¹, V V Samoylenko¹, I V Samoylenko², Yu K Dimitriadi¹

¹ North-Caucasus Federal University, Department of Oil and Gas Wells Construction, 1 Pushkin str., Stavropol, 355000, Russian Federation

² Stavropol State Agrarian University, Department of Information Systems, 12 Zootekhnicheskiy Ln, Stavropol, Russian Federation

E-mail vvsamoylenko@ncfu.ru

Abstract. The article discusses current issues of using alternative energy sources for electricity supply of consumers in the oil and gas industry. Examples of off-grid power systems used for the electrification of different facilities of oil and gas production are shown. This paper introduces a review of mathematical optimization models of modes in micro-energy systems with different distributed generation resources. Optimization methods based on mathematical programming in game theory are studied in details. It is concluded that the use of adaptive-game modelling is perspective in solving optimization problems.

Keywords: Off-Grid Power Systems, Mathematical Programming, Game Theory, Micro-Energy System, Oil and Gas Industry, SCADA

1. Introduction

Intense development of informational systems, power electronics led to wide use of new technologies of generation and energy distribution. Important structure element of such technologies is Smart grid and micro-grid [1]. Smart grid conception is government policy in technological development of energy future in such countries as USA, Canada, China. This concept is considered as “intelligent power system with active-adaptive net”.

The implementation of power supply of remote objects based on renewable energy sources, including Smart Grid technology, is widely used in various areas of industry. The oil and gas industry is targeted to achieve maximum efficiency in oil and gas production in numerous fields. This industrial sector is considered as one of the dirtiest and most energy-consuming. In particular, in the USA mining and processing companies consume about 26% of all electricity used in industry [2]. Technological operations cover exploring, mining and transportation of these natural resources, using a wide range of equipment that requires a reliable electricity supply. The territorial remoteness of oil and gas industry facilities from centralized power supply systems make the use of alternative energy sources attractive. Renewable sources replace traditional methods of generating electricity for the needs of oil and gas wells, such as diesel generators, pneumatic systems, and the use of natural resources, such as natural gas from a well. The disadvantage of these methods is a low economic efficiency and a number of...
environmental problems that force oil companies to more active application of renewable energy sources, such as solar energy and wind energy with backup storage.

2. Examples of renewable energy sources application in oil and gas industry
Reliable operation of remote wells, gas and oil pipelines implies wireless telemetry elements of the technical condition of the objects. The supply issues of this equipment are a complex technological problem. In particular, data acquisition is realized for pipelines monitoring, regulatory equipment and emergency response. Alternative power supplies are also used for dispatching of these objects, including SCADA and RTU. In addition, system integrators often offer projects for the complex use of solar or wind energy [3,4] for the following energy-consuming processes:
- Well Site Monitoring & Control;
- Multi-well Pad Sites;
- Emergency Shutdown Valves;
- Wireless Monitoring;
- Chemical Injection;
- Natural Gas Processing;
- Tank Level Monitoring & Control;
- Remote & Process Automation;
- Cathodic Protection;
- Valve Automation & Control;
- Burner Management;
- Fixed Flame & Gas Detection;
- Flow Computers.

Figure 1. Hybrid power system on the offshore oil platform in Brazil
A wide range of the represented operations has the main task: replacement of brown energy in mining and oil and gas processing with renewable power plants installed near industrial sites. Therefore, the green energy provides the main power for pumps, heaters and compressors.

The scientific literature presents implementation examples of this concept. In the mining industry a wind power plant is used to feed the cement plant [5], in the oil and gas industry the wind power plant is also used at surface oil production field.

The first offshore oil pumping unit operating at the onshore wind farm was registered in the UNFCCC as the Clean Development Mechanism (CDM). Other specific applications in the oil and gas industry can be used as solar heating to supply thick oil and produce steam for injecting oil wells [6]. Another possible application is the use of solar radiation for photovoltaic panels that supply critical electrical loads.

One of the most effective options for the use of renewable energy sources is a hybrid system, which includes both wind and solar stations. In the Brazilian Northeast, there is an application of green technology at the offshore oil platform [7].

One of the main initial problems is argued choice of primary power sources and optimal ratio of rated power of all generating sources, included in created micro-grid structure. The correct solution to this problem is possible by optimization function choice based on adequate modeling of micro-grid control processes.

3. Optimization models of the Off-Grid Power systems

Nowadays a lot of scientists suggest different methods of mathematical modeling of micro-grids with several sources of distributed generation. Optimized micro-grid indices are output power parameters, such as: the load curve of consumers; the quality of electric energy; the reliability of the power system and its operational conditions. Optimization models and methods of mathematical programming, mostly used in studies of micro-grids are:

1. Linear programming (LP) methods are simple optimization methods in which objective function and the constraints are defined by linearity. These methods are used for searching the parameters of economic power distribution, designing and power systems operation, the consistency of its protection, insurance of the load curve, estimation of the system state [8–10]. A special case of the PL is a method of integer programming in which some or all variables are defined as discrete integer values. This method is used for security assessment of energy systems, transmission lines optimization and design, reliability analysis, design of distributed systems and load management [11,12].

2. Methods of nonlinear programming are used for optimization problems of dynamic security of power systems, control of reactive power flows, design and operation of power systems, optimal power flow in the system, optimal placement of reactive power compensation and optimal location of energy sources [13].

3. Methods of dynamic programming are used for optimization of sources power of electricity generation and the optimal functioning of the electrical system at the level of a distributed system [14].

Particle Swarm Optimization (PSO) takes a special place among publications about micro-grid optimization using simulation algorithms. The main property of PSO is that the complexity and nonlinearity of the task do not affect the finding of the optimal value of the objective function [15,16].

4. Differential evolution approach method of proposed in [17]. Micro-grid is optimized with the aim of cost estimation of harmful emissions into the environment and ongoing costs of operation and maintenance of the system. A problem decision is an algorithm that takes change in the load curve in time with a corresponding variation of the batteries charge level into account. The practical implementation of the algorithm is based on central controllers for adequate response to variable conditions, such as: the weather, the intensity of solar radiation, wind speed, operating costs.

4. Application of game theory in smart grid
The solution of the optimization tasks is often carried out in conditions of uncertainty in its various forms. Correct and appropriate account of uncertainty (primary information, objectives, conditions) in appropriate mathematical modeling is often a fundamental requirement. It ensures objectivity and factual efficiency of decisions based on model analysis. Therefore, game theory is the key analytical tool in Smart grid design in order to explore complex interactions among independent rational players.

In a systematic description of game theory use in smart grid is presented. The work gives a clear idea about the basic benefits and challenges of using classic and new game-theoretic methods in the context of intelligent networks and consists of three logically related parts:

1) complex description of the existing game-theoretic applications in smart grid;
2) determination of the main open issues in smart grid that are required to be solved using game theory;
3) definition of the basic game-theoretic tools that can be adopted for the smart grid design.

Game theory is a mathematical basis that can be divided into two main branches: the theory of non-cooperative games and the theory of cooperative games. The theory of noncooperative games can be used to analyze strategic decisions of players who have fully or partially opposing interests. In fact, noncooperative games can be considered as a distributed decision-making process. The players optimize decisions without any coordination or communication between them.

In classical power grid solutions of system optimization problems are based on a centralized objective function. However, if micro-grid is included in power grid, its optimization is possible only in case of definition a specific objective function for each micro-grid. This is mainly due to heterogeneous nature of micro-grids, which often consist of different sources of energy, such as energy storage (e.g. batteries), diesel generators, wind turbines and solar panels. The values of the objective functions are elements of payment matrices (matrix games) for various strategies of selecting the energy source in variable operating conditions of the power system [18,19].

Saad et al. showed a mechanism of cooperative energy exchange in micro-grid based on the model of coalitional game in excess of domestic consumption [20]. It is necessary to create joint groups, i.e., coalitions that represent local currency energy market. Inside the coalition micro-grids can exchange power with each other locally, thus reducing power loss and increasing the independence of the micro-grid.

Another paper proposes the use of noncooperative game for the adequate modeling of interactions between sources and loads in small-scale power systems [21]. For example, advanced analytical methods and algorithms for finding Nash equilibrium and efficiency increase of power transmission are used in the problem of power control.

Pan used the theory of evolutionary game to study the cooperation between the micro-grid and the common system, focusing on the factors that affect the choice of strategy players [22]. The results of the analysis based on the evolutionary game model suppose that both parties hold a joint strategy. Unanimous choice of the players positively correlates with the benefits of their joint cooperation. Pan proposed ideas about cooperation deepening between the micro-grid and the common system.

The main problem of various control loops from the level of decision-making in the micro-grid to the level of predicting the evolutionary development of power systems with dispersed generation is the uncertainty of the upcoming operating conditions. Two fundamentally different approaches can be singled out among known approaches to solve this problem:

1) optimistic approach is able to predict the parameters of these terms and conditions accurately;
2) pessimistic one recommends to rely on the worst case.

The basis for the legitimacy of the first approach is the existence of destabilizing factors, whose parameters vary slowly (e.g., seasonal demand for electricity). It allows accurate estimating and managing the choice of energy source on the basis of monitoring of the performance indicator implementation of the micro-grid. Mathematical description of the interaction of power grid components is possible on the basis of coalitional games, which allow energy exchange in the networks [20].
The basis for eligibility of the second approach is the existence of destabilizing factors caused by the competition for energy resources, which occurs between the load and the competition for the energy supply between the sources. The model of noncooperative games for optimal control of elements is proposed [21].

The intermediate case should be presented as models of account of destabilizing factors that change faster than you can manage to predict their exact implementation, but have slowly changing limits of the possible variations in the form of some statistical averages.

5. Conclusion
The analysis in the review article shows the high energy intensity of the oil and gas industry. The given examples indicate the relevance of replacing brown energy sources with environmentally friendly renewable green energy sources. Using only one type of renewable energy source is incorrect solution. Therefore, hybrid systems including both solar energy and wind energy gain wide popularity. The management of these systems is most often carried out using Smart Grid technology and the remoteness of objects positions this class of systems as Off-Grid Power Systems.

The mathematical optimization of micro-grid data plays an important role at the design stage. The article presents a detailed analysis of the optimization models of these systems. Apparently, a reasonable compromise should be searched in integrating adaptive and game models of the grid control. Elements of adaptation are more or less evident included in many game models. This is especially noticeable in dynamic games, such as differential and multistage.

These games are composed of game situations with the changing constraints of the strategies at each step. Elements of adaptation are less obvious and less connected presented in task of strategies constraints in one-step games. Game situations are a special case of involving more than two players, and not all of them pursue antagonistic goals. In this case, we can expect a positive effect off adaptation and a joint management optimization and implementation of part of the destabilizing factors, that express the common interests of producers and consumers of electricity.

Reference:
[1] Qiao L 2013 A Summary of Optimal Methods for the Planning of Stand-alone Microgrid System Energy Power Eng. 05 992–8
[2] Malmedal K, Sen P K and Candelaria J 2011 Electrical energy and the petro-chemical industry: Where are we going? Record of Conference Papers - Annual Petroleum and Chemical Industry Conference
[3] Anon Oil & Gas - SunWize | Power Independence
[4] Anon Solar Power Solutions - Oil and Gas Industries | Ameresco Solar
[5] Shafer B 2009 Electrical wind generation for cement manufacturing, a case study: Calportland Mojave Plant’s 24 MW wind project IEEE Cement Industry Technical Conference (Paper)
[6] Anon Oil From The Sun
[7] Oliveira M F, Saidel M A, Queiroz A R S and Filho E N 2012 Renewable sources at offshore petroleum and gas production platforms Record of Conference Papers - Annual Petroleum and Chemical Industry Conference
[8] Khodr H M, Gómez J F, Barnique L, Vivas J H, Paiva P, Yusta J M and Urdaneta A J 2002 A linear programming methodology for the optimization of electric power-generation schemes IEEE Trans. Power Syst. 17 864–9
[9] Kurucz C N and Brandt D 1996 A linear programming model for reducing system peak through customer load control programs IEEE Trans. Power Syst. 11 1817–24
[10] Delson J K and Shahidehpous S M 1992 Linear Programming Applications To Power System Economics, Planning and Operations IEEE Trans. Power Syst. 7 1155–63
[11] Lima F G M, Galiana F D, Kockar I and Munoz J 2003 Phase shifter placement in large-scale systems via mixed integer linear programming IEEE Trans. Power Syst. 18 1029–34
[12] Alguacil N, Motto A L and Conejo A J 2003 Transmission expansion planning: A mixed-integer LP approach *IEEE Trans. Power Syst.* **18** 1070–7

[13] Pudjianto D, Ahmed S and Strbac G 2002 Allocation of VAr support using LP and NLP based optimal power flows *IEEE Proc. - Gener. Transm. Distrib.* **149** 377

[14] Kanchev H, Francois B and Lazarov V 2011 Unit commitment by dynamic programming for microgrid operational planning optimization and emission reduction *International Aegean Conference on Electrical Machines and Power Electronics, ACEMP 2011 and Electromotion 2011 Joint Conference* (IEEE Computer Society) pp 502–7

[15] Arya L D, Titare L S and Kothari D P 2010 Improved particle swarm optimization applied to reactive power reserve maximization *Int. J. Electr. Power Energy Syst.* **32** 368–74

[16] Laskari E C, Parsopoulos K E and Vrahatis M N 2002 Particle swarm optimization for integer programming *Proceedings of the 2002 Congress on Evolutionary Computation, CEC 2002* vol 2 (IEEE Computer Society) pp 1582–7

[17] Vahedi H, Noroozian R and Hosseini S H 2010 Optimal management of microgrid using differential evolution approach *2010 7th International Conference on the European Energy Market, EEM 2010*

[18] Mohamed F A and Koivo H N 2011 Multiobjective optimization using modified game theory for online management of microgrid *Eur. Trans. Electr. Power* **21** 839–54

[19] Maity I and Rao S 2010 Simulation and pricing mechanism analysis of a solar-powered electrical microgrid *IEEE Syst. J.* **4** 275–84

[20] Saad W, Han Z and Poor H V 2011 Coalitional game theory for cooperative micro-grid distribution networks *IEEE International Conference on Communications*

[21] Weaver W W and Krein P T 2009 Game-theoretic control of small-scale power systems *IEEE Trans. Power Deliv.* **24** 1560–7

[22] Pan C and Long Y 2015 Evolutionary Game Analysis of Cooperation between Microgrid and Conventional Grid *Math. Probl. Eng.* **2015**