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UNIT COMMITMENT AND ECONOMIC DISPATCH OF HYBRID MICROGRID WITH RESIDENTIAL LOAD

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Abstract: As the future of power systems aims towards the implementation of microgrids, the need for their stable and secure operation increases. The key to secure microgrids' operation, lies in proper optimisation. In this paper, the optimal unit commitment of an islanded hybrid microgrid is analysed. The proposed solution is based on a dynamic programming method, considering the weather conditions for distributed generator's operation, battery state of charge, and the backup generator. The presented case analyses a hybrid microgrid with a stochastic load. The test example reviews a microgrid that consists of a run-of-river power plant, wind, and photovoltaic generators.
Keywords: Microgrids, optimisation, unit commitment, distributed energy resources, dynamic programming

1. INTRODUCTION

The implementation of Renewable Energy Sources (RES) into the standard distribution networks is justified by their small capacities, increase of the reliability of power supply, and low footprint on the environment. Therefore, they are considered to be the best alternative to fossil fuel power plants for power generation. Although they depend on the weather conditions, and in that manner their power should be used at the moment of production, they make a significant contribution to the battle against climate changes. Supported with storage systems (batteries), they operate as conventional power plants, which allows using the generated power in a moment of need. RES have different power capacities which vary from hundreds of kilowatts to hundreds of megawatts. They can be installed into the distribution networks, where the generated power is locally used, or they can be installed into the transmission networks where they contribute to the whole power system [1]. The ones installed into the distribution networks are called Distributed Energy Resources (DERs).

Usually, DERs supported with storage systems enable the part of the distribution network, where they are connected, to operate in an islanded mode. That means that the networks do not necessarily have to be connected to the utility grid. The loads can be powered only from the power generated from the DERs, only if their capacities correspond to the load connected. This type of operation is defined as microgrid [1].

DERs can be used to supply industrial loads with deterministic power demand or residential loads with stochastic power demand. The latter type requires a control system to be programmed and installed into the microgrid to keep the stability of the network and proper energy management. The DERs connected to the microgrids are usually placed near the load, to minimize the power losses. Therefore, microgrids are often placed in rural areas or places with a higher rate of outages and system failures.

In this paper, the optimal unit commitment of a hybrid distribution microgrid is analysed. The system consists of three types of DERs, a storage system, a backup generator, and a residential load. The load is stochastic, which means the power usage cannot be predicted. The proposed algorithm analyses the weather condition data, which gives the information for the probability of generation of the installed power capacity of the DER. Based on that data, the optimal unit commitment for one week is forecasted.

The case study analyses a microgrid consisting of a small run-of-river (ROR) power plant, wind turbines, and photovoltaic modules. The optimisation is done following the power demand.

2. RELATED WORK

Microgrids are small-scale power systems that provide decentralized (local) power production, near to the consumers. In that way, the power losses and transmission costs are reduced. Since the power plants are mainly small-scale renewable energy sources, they can be easily managed and operated. However, the microgrids, if not properly maintained, can experience unstable and low-quality power supply. Therefore, it is of great importance that the method used for determining the operation schedule of the distributed generator is secure and reliable.

Many research projects analyse the microgrid operation and unit commitment, using many different mathematical methods. However, dynamic programming method, as a classical approach has proven to be a simple and accurate optimisation method. Reference [2] presents an approach for optimisation of operational costs in a hybrid grid-connected microgrid, including a battery system.

In [3] the dynamic programming is used optimisation of a hybrid microgrid consisting of wind turbines, photovoltaic, diesel generator, and a battery. The optimisation function minimises the costs by scheduling the DERs while taking into account the DERs limitations, emission reduction, and balancing the load and production of electrical energy. The input data to the proposed method are the information of sources, loads, and electricity market. The optimisation considers the state of charge of the battery at any moment and that is the optimisation starting point.

The method presented in [4] is used for the optimisation of the power generation in a local grid-connected microgrid with an implemented storage system. The optimisation method considers the uncertainties regarding the microgrid optimisation, such as the load, which is assumed to be manageable, and the electricity market prices. The method has been simulated in Matlab, and the results have shown that considering the uncertainties delivers better results.

A unit commitment of microgrid power units is analysed in [5]. The analysis is made based on a 24 hour ahead power planning of a microgrid with implemented storage system, micro gas turbines, and active generators. For that purpose, a dynamic programming method is used. The objective function considers the emissions from the power production units, especially CO_2 emissions, and operating costs. The system constraints include the production and demand power balance, the unit's loading level, and the microgrid operation mode. The method determines the optimal unit commitment regarding the emissions from the micro gas turbines.

In [6] an algorithm for optimal scheduling of distributed generators in a hybrid wind-solar microgrid with a diesel generator and battery system is proposed. The optimisation provides a day ahead scheduling of distributed generation usage, and battery charging and discharging time. The optimization is based on an economic point of view, providing optimal operation mode with minimal costs. The paper shows that the implementation of a battery system is a financially justified solution.

Maintaining the voltage and providing a safe and secure operation in a microgrid is a challenge which complexes the optimisation problem. Reference [7] proposes a dynamic programming based algorithm for solving the optimal energy management problem of DC microgrid. The proposed algorithm considers the voltage control and the scheduling problem, by minimising the operation costs. It uses dynamic programming to define a day-ahead optimal scheduling problem. The results show that the proposed algorithm reduces complexity and makes reasonable results.

In [8] the optimisation challenges with stochastic load are presented. The paper proposes an algorithm for optimal energy management in hybrid microgrids with a stochastic load. The algorithm considers the load uncertainty, power flow, and system operational constraints in a distribution network. The optimisation function minimises the costs.

In the literature, the optimisation function is mostly based on operational costs. In this paper, the optimisation is made on the momentary availability of the distributed generators and battery system. The paper proposes a solution to a complex hybrid microgrid, using a classical optimisation method, the dynamic programming method. The proposed algorithm unites the uncertainty of weather conditions and power demand. In [9] an algorithm for a unit commitment of distribution network with distributed generation was proposed. The algorithm optimised the availability of the DERs, uniting the weather condition index and batteries state of charge.

In this paper the optimisation is based on the probability of power generation from the distributed generators. The dynamic programming method is used for optimal unit commitment and the economic dispatch of the system. The outcome, along with information of the current battery state of charge, are the input data for the optimisation algorithm, which provides the microgrid's units scheduling plan.

3. PROBLEM DEFINITION

The problem analysed in this paper addresses the satisfaction of a residential load in a microgrid that operates in an islanded mode. This type of microgrids is applicable on islands or remote areas that do not have an access to the utility grid. The microgrids can be also placed nearby big cities and can be connected to the utility grid to support its reliability of power supply.

The microgrids usually consist of DERs placed near the load. The DERs, especially wind and solar, highly depend on the weather conditions. That means that their power should be used immediately, or should be stored for its further usage. When a load depends on this kind of electric power, it is recommended to have a backup power source for times when the DERs do not produce any power or the battery is empty.

In a microgrid, which can operate in an islanded mode, it is necessary to determine the optimal unit commitment of each of the DERs, to satisfy certain constraints. The constraints usually refer to power generation costs or power losses. ROR, wind, and solar power plants usually have low operation and maintenance costs, and power losses are reduced to a minimum by implementing the DERs near the load. Therefore in this paper, the costs and power losses are not considered as constraints. However, since it is a small-scale microgrid, keeping the voltage stability and power balance is very important for proper operation.

Power balance refers to optimising the generated power and the consumed power. In this situation, the storage system plays an important role. In the hours when the DERs produce enough power to satisfy the load, and in the hours when the DERs produce more than the power consumed, the balance is satisfied. But, when the DERs do not produce enough power to satisfy the consumption, the load has to be satisfied from the battery or the backup generator.

4. PROPOSED ALGORITHM

The proposed algorithm is based on the dynamic programming method. Dynamic programming (DP) is an optimisation method that provides a solution to a certain issue by solving the smaller sub-issues. Although the method can be classified as a “divide and conquer” group of methods, it works opposite of them [10]. The optimisation is done by analysing the smaller issues first, and then the bigger ones.

DP is an optimisation method that provides a solution using a set of algorithms. It can be used for finding an optimal solution to a wide range of input data while maximising or minimising the objective function. The problem is divided into sub-problems, so that, at any step, the expressions are simplified. The method memorises the solutions, so eventually, the main solution follows the solutions to the sub-problems. The DP method can perform forward and backward [11].

The DP method is used for solving many nonlinear problems. Its application is widely known for power system planning, optimal unit commitment in complex power systems, which cannot be solved by standard methods of nonlinear programming and energy management optimisation.

The proposed algorithm is programmed in Matlab. The code is built on forecasted data for power generation by the distributed generators, to determine the quantity of generated power and the hours when it occurs. The power losses in the inverters and cables are neglected since they are too small compared to the total power. It is assumed that the analysed hybrid system has an ideal inverter, the battery, and other components, which means the failure probability is also neglected. Also, the installed battery power can range from zero to maximum capacity, which means that it can be empty and then in the next hour it can be fully charged.

The constraints, which are the input data to the algorithm, refer to the technical limitations of the installed equipment:

- The probability for favourable weather conditions for each DER,
- Installed power capacity for each DER,
- Installed power capacity of the battery,
- Installed power capacity of the backup generator,
- Hourly power demand

The proposed algorithm is shown on a diagram in fig. 1 and fig 2.

The algorithm analyses several scenarios that can occur in the microgrid. The first scenario is the possibility of generating power from the DERs which is greater than the power needed to satisfy the load. In this case, part of the total generated power is used for satisfying the load, and part of it is stored in the battery, if the battery is not fully charged and it can store the excess power. Otherwise, if the excess power cannot be stored or consumed it is transferred to the dump load. The dump load is a device without any purpose except to use the excess power that cannot be stored.

The second scenario considers the situation when the DERs produce power enough to satisfy the load. In that case, there is no power stored, and there is no need for backup generator usage.

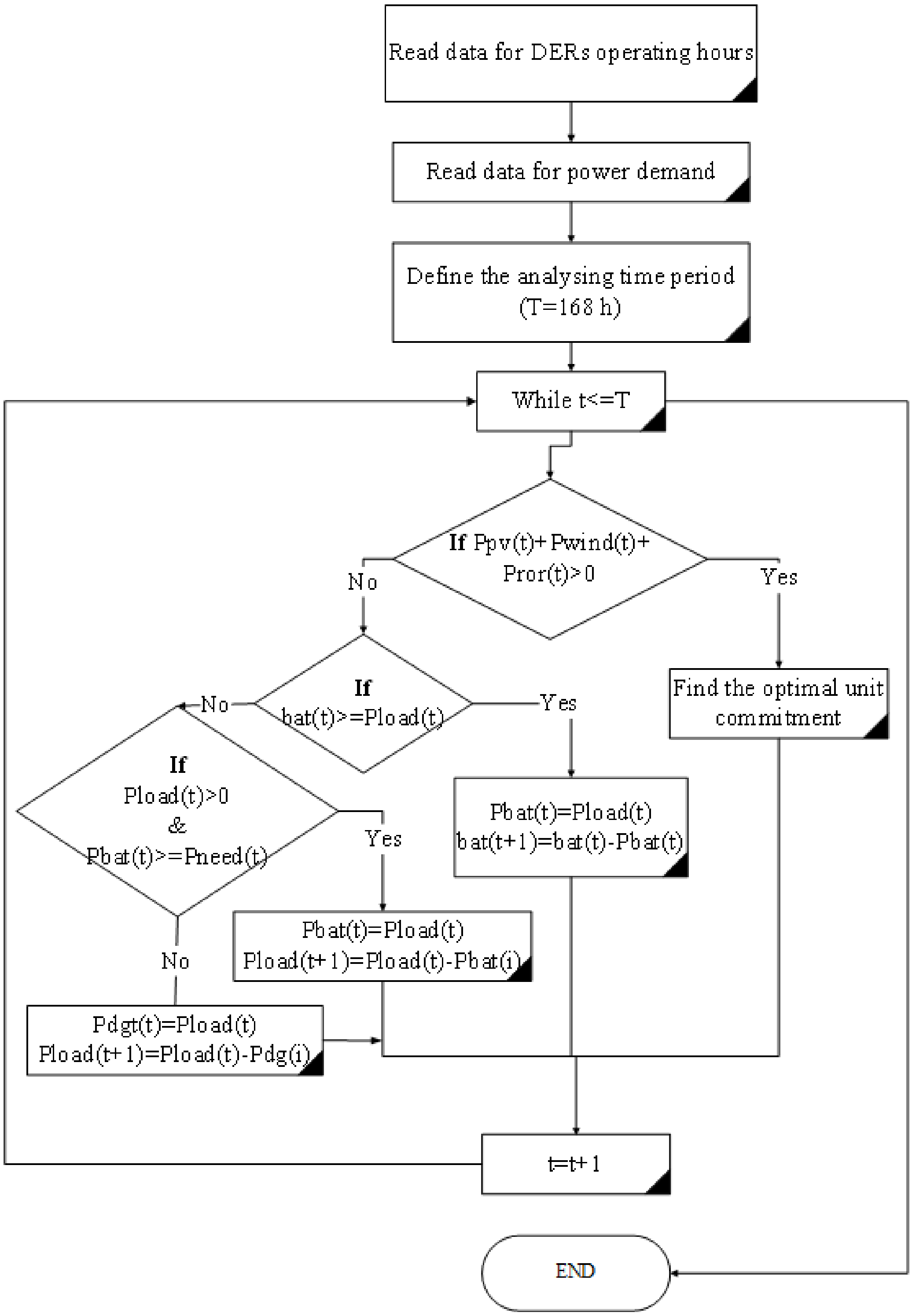

Fig. 1 The proposed algorithm for solving the unit commitment problem in a hybrid microgrid operating in islanded mode

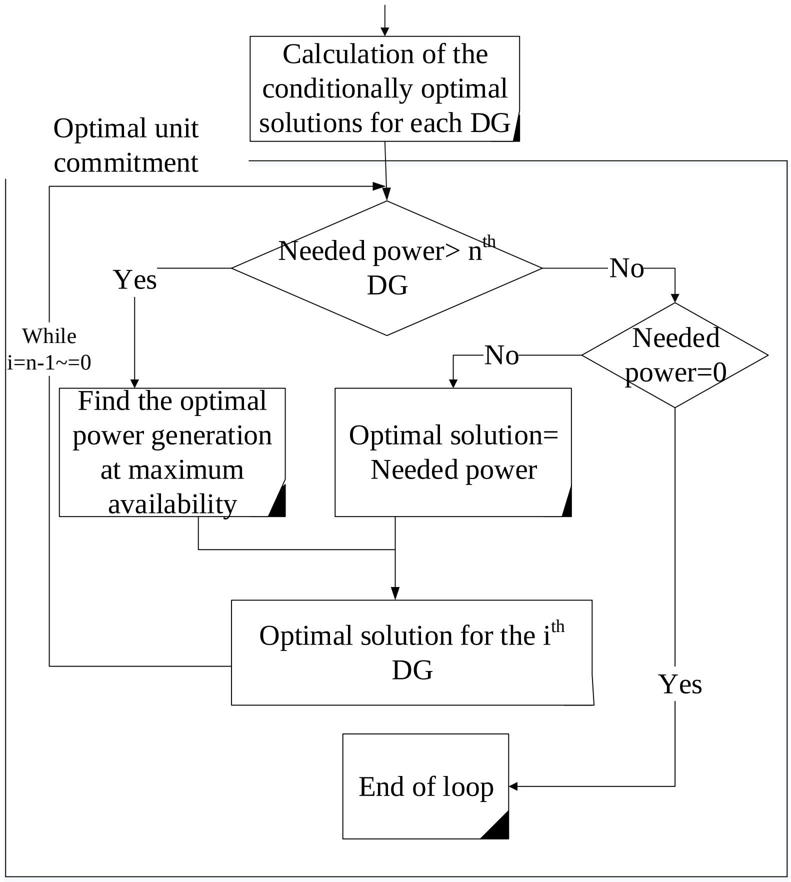

Fig. 2 The proposed algorithm for finding the optimal unit commitment

In the third scenario, the power generated from the DERs is not enough to satisfy the load. In that case, there are two subcases. The first one refers to a situation of not enough power to satisfy the load completely. Then, the power needed is taken from the battery, if there is enough power stored. Otherwise, the backup generator steps up. The second subcase refers to the hours when there is not any power generated from the DERs. In that case, the load is satisfied by taking power from the battery. But if the battery cannot satisfy the load, then the backup generator is used.

4. TEST EXAMPLE AND RESULTS

The test example analyses a microgrid which consists of three DERs: a ROR power plant, PV modules and wind turbines. The analysis is made per one week (168 hours) which is the optimal weather forecast period. The test example microgrid is presented in fig. 3 and the installed capacity of each of the installed units is presented in Table 1. The input data provides the weather conditions probability for the generation of a certain amount of power from the distributed generators.

First, the optimal unit commitment is done hour by hour, using the dynamic programming method. The optimisation is between the distributed generators, following the constraints regarding their maximum power capacity at each hour, as presented in [9]. The output is a vector containing the optimal arrangement of each of the generators.

If any of the distributed generators generates more power than it provides for power demand satisfaction, after the optimisation, the excess power is used for battery charging. If the power generated from the distributed generators is not enough for load satisfaction, then the stored power is used.

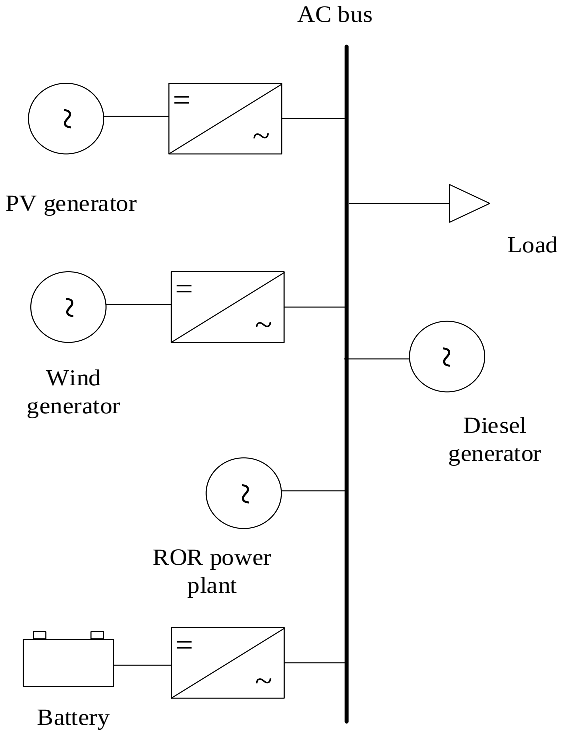

Fig. 3 Microgrid test-example

Table 1. Installed units' power capacity

Unit	***Diesel generator***	***ROR***	***Wind generator***	***PV modules***	***Battery***
Power capacity [kW]	250	250	200	150	250

The last part applies to the usage of the backup generator, which is used in cases when the other units cannot satisfy the power demand.

The results are presented in fig. 4. The graph shows that there are cases when only one distributed generator can satisfy the power demand. But not once all of the generators operate at the same time. That is because the weather conditions cannot be favourable for all types of distributed generators at once.

The graph also shows that none of the installed units nor the diesel generator are overused or exceed the installed power capacity.

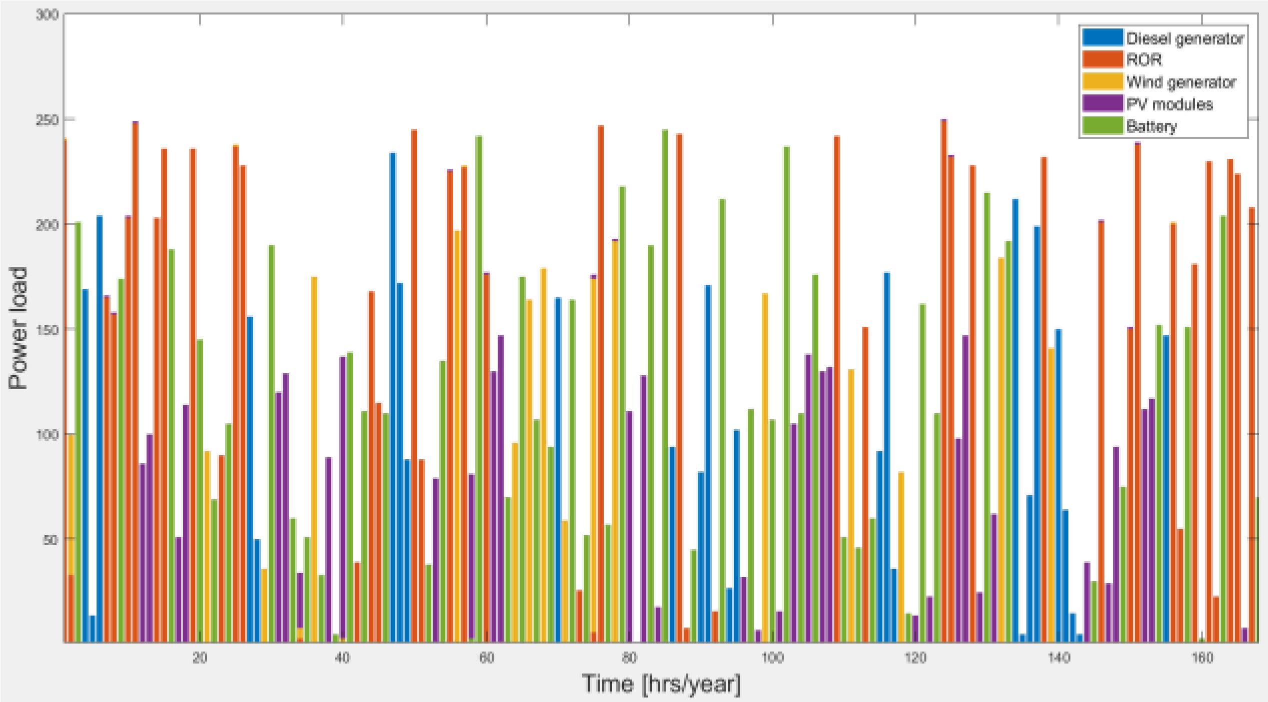

Fig. 4 Unit commitment of the distributed generators, the battery, and the backup generator

5. CONCLUSION

Microgrids are considered to be the future of power systems, providing easy, environmental friendly, and safe electric power to the communities that cannot rely on the continuous power supply from the utility grid. This paper analyses one of the most applied network configurations for small-scale remote microgrids. This type of network configuration is mostly used for rural microgrids since ROR and wind power plants require spacious fields, whatever their power capacity.

The proposed algorithm in this paper offers a solution to the unit commitment problem for islanded operation mode, which is very important for obtaining stable network frequency and voltage levels. The results show that the proposed algorithm is applicable for this type of problem, providing real and expected results. The proposed algorithm can be easily upgraded and implemented to another network configuration.

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