APPLICATION OF DYNAMIC PROGRAMMING FOR OPTIMAL UNIT COMMITMENT AND ECONOMIC DISPATCH OF DISTRIBUTION NETWORKS

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Abstract: This paper proposes a dynamic programming-based algorithm for solving the optimal unit commitment and economic dispatch problem in distribution networks with implemented distributed generators. The presented algorithm, considers the availability of the distributed generators depending on the current weather conditions and the state of charge of their battery. The optimization of different types of distributed generators with different power capacities is based on weather conditions forecast and weekly load curve.

Key words: Dynamic programming, unit commitment, economic dispatch, distributed generation.

1. INTRODUCTION

The high implementation of renewable energy sources is mainly driven by the environmental issues that we are facing today. The usage of nature's renewable resources for satisfying the electricity needs is one way of living in harmony with nature and lowering the men's footprint in today’s societies. In this way, the renewable energy sources are the force which pushes the change in the power sector, in a manner of its redefinition as decentralized power production.

Decentralized power production means that the standard distribution networks are becoming more consisting of distributed generators. The distribution generators are mainly renewable energy sources with smaller capacities designed primarily to cater to the local load. This creates the possibility of islanded work, which makes the

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[1] Extended and renewed version of the report entitled “Unit Commitment of Distributed Energy Resources in Distribution Networks Using the Dynamic Programming Method”, presented in the 2020 International Conference on Information Technologies (InfoTech-2020), IEEE Conference Rec. # 49733, 17-18 Sep 2020, Bulgaria

distribution networks self-sufficient and sustainable. As such, they should provide power at each moment. However, due to their dependability of the weather conditions, their arrangement should be according to their momentary availability.

The unit commitment problem of distributed generators implemented in a distribution network consists of an optimal schedule of the generators to minimise the costs, regarding the constraints of their availability. Since renewable energy sources have much lower costs for power production than the conventional power plants, and they depend on the current weather, the main constraint is their availability.

The dynamic programming method was used in [1] for optimal unit commitment of a distribution network with implemented different types of Distributed Energy Resources (DERs). Two cases, considering the normal operation state and an islanded work without a storage system, were analysed. Availability was considered a variable, which depends on the weather conditions and the cost for power production from each DER.

In this paper, the unit commitment of distribution networks which consists of various types of renewable energy sources, supported by storage systems, is analysed. The analysis is made using the dynamic programming method as a simple optimisation method. The availability variable is redefined, considering the state of charge of the storage system. The optimisation is made maximising the availability of the generators.

2. RELATED WORK

DERs are one of the solutions to the environmental pollution problem. They produce electrical energy using renewable energy sources, without emitting greenhouse gasses, and therefore they are a subject of interest to many researchers. Dynamic programming is an optimisation method that was set by Bellman in the 1950s [2]. The method provides a solution to a certain issue by dividing the main problem to smaller sub-issues. Although the method can be classified as a “divide and conquer” group of methods, it works opposite of them [2].

The dynamic programming method 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 an objective function. The main problem is divided into incremental steps, simpler sub-problems. The method memorises the solutions, so eventually, the conditionally optimal solutions to the sub-problems give the solution to the main problem. The optimal solution to the main problem can be found with a combination of conditionally optimal solutions of the sub-problems.

The number of research proves that the dynamic programming method is applicable for optimisation of the distribution networks and microgrids. An optimisation method based on dynamic programming method for optimal energy management in a hybrid system is proposed in [3]. The optimisation is based on minimising the costs by scheduling the DERs while taking into account the DERs power capacities, 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.

A method based on hybrid dynamic programming, genetic algorithm and particle swarm method for optimisation of complex power system consisting of hydro and thermal units, is proposed in [4]. The constraints of the power system include dam reservoirs and spinning reserves. The proposed method gives the optimal unit response, supplying customers economically.

The dynamic programming method is used in [5] for optimal dispatch of distributed generation in distribution power systems. The approach determines the active power generation of each distributed generator, while minimising the average operational cost of the distribution network and power losses. The optimisation is based on a daily load forecast. In [6], the algorithm proposed in [5] is extended to optimise the AC steady-state operation of radial distribution networks. The optimisation considers the active and reactive power flows in the distribution networks considering the physical constraints of the network.

This method is used in [7] for unit commitment of microgrid power units/ 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 (such as PV arrays). The objective function considers the emissions from the power production units, especially CO2 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.

Another application of the dynamic programming method is made in [8] for determination of the optimal power capacities of four power plants, placed on different locations. Knowing the total power demand, the optimisation is made. The objective function is based on costs for building each of the power plants minimisations, depending on the power capacity installed.

3. PROBLEM DEFINITION

Distribution networks may consist of different types of DERs. This is quite beneficial for power system reliability of power supply. It plays a huge role when an outage in the power system occurs, which may lead to islanded work of the distribution network. In that case, the optimal unit commitment of the distributed generators is needed. This is important for lowering the costs for power generation and supply, according to the set of constraints. In the case of a hybrid system, the constraints are usually the state of charge of the storage system and the capability of power production, which depends mainly on the equipment functionality, weather conditions and operational state of the local network.

In this paper, the unit commitment problem in a low voltage distribution network with distributed generators is analysed. The distributed generators are usually renewable energy sources. The prime problem of their implementation is the hosting capacity. In order to avoid frequency and voltage variations, and furthermore a drop in power quality, the implementation of distributed generators should be in an acceptable range of hosting capacity. Therefore, the storage systems and diesel generators are implemented along with the distributed generators.

One of the disadvantages of the distributed generators is that the generated power should be used by the local consumers at the moment of its generation or stored for a short period. However, if the distributed generators use feed-in tariffs, sometimes it is more cost-effective to sell the excess power to the grid, rather than storing it.

An availability variable was introduced in [1]. It unites the weather condition index and the power productions costs. In this paper, the availability variable takes into account the storage index as well. This improves the optimal unit commitment analysis for distribution systems with a distributed generator.

4. PROBLEM-SOLVING ALGORITHM

Based on a weather forecast with high accuracy for one week, the power generated from each of the distributed generators can be predicted. This means that the availability can be defined as a function of the weather condition index. Also, if a distributed generation is not available for power production, the storage system should cover the power needed. This means that the availability depends on the storage system state of charge, as well.

Additionally, the production index which depends on the costs for current power generation and the prices for selling the excess power defines the availability of the distributed generation.

The weather condition index represents the convenience of the weather conditions regarding the distributed generators' power generation and it is denoted as $W_i(P_i) \in [0,1]$. The weather condition index defines the availability of distributed generators' and power production. The state of charge of the storage system is denoted as $S_i(P_i) \in [0,1]$. The costs index for power generation by the distributed generator denoted as $C_i(P_i) \in [0,1]$ depends on the power capacity. The costs increase as power generation increases. Then, the availability defines in the following manner:

$$A_i(P_i) = f(W_i(P_i), C_i(P_i), S_i(P_i)) \quad (1)$$

where,

- A represents the availability index of the distributed generator and it is a dimensionless quantity,
- i denotes the number of the distributed generator, and
- P_i denotes the generated power of ith generator.

The optimisation represents a multi-step process in which a conditionally optimal solution is proposed. All of the distributed generators differ in power capacity and type. Therefore, this algorithm is designed to analyse all of the distributed generators installed in the distribution network, according to their power capacity limits.

The optimisation process analyses the generator in order to their power capacity installed. The process starts with calculating the conditionally optimal solutions for the distributed generator with the highest power capacity installed. The power range is from 0 MW to the power capacity of the generator installed, with a step of 1 MW. The process continues until all of the generators are considered.

Computing the optimal unit commitment process goes backwards. The power that needs to be supplied is optimally distributed among the generators.

If the power which needs to be supplied is greater than the installed power capacity of the last distributed generator analysed, then the conditionally optimal solution for that generator is considered as the optimal one. If the power which needs to be supplied is less than or equal to the installed power capacity of the generator with the smallest power capacity, then the conditionally optimal solution corresponding to the power needed is considered.

The algorithm is schematically shown in fig. 1.

The objective function is defined as in [1]:

$$A_i = \sum_j A_j(P_j) \Rightarrow \max \tag{2}$$

where, j represents the number of conditions of the distributed generators, and i is the number of distributed generators.

The optimisation equation represents a multi-step continuous process. In the first step, the power needed is set. Then, the optimal combination of available units is selected, using the following form of the recurring relation:

$$A_i^e(P_i^e) = \max\left\{A_i(P_i) + A_{i-1}^e\left(P_j - P_i\right)\right\} \tag{3}$$

where, P_i^e indicates the power needed in the i^{th} sub-problem.

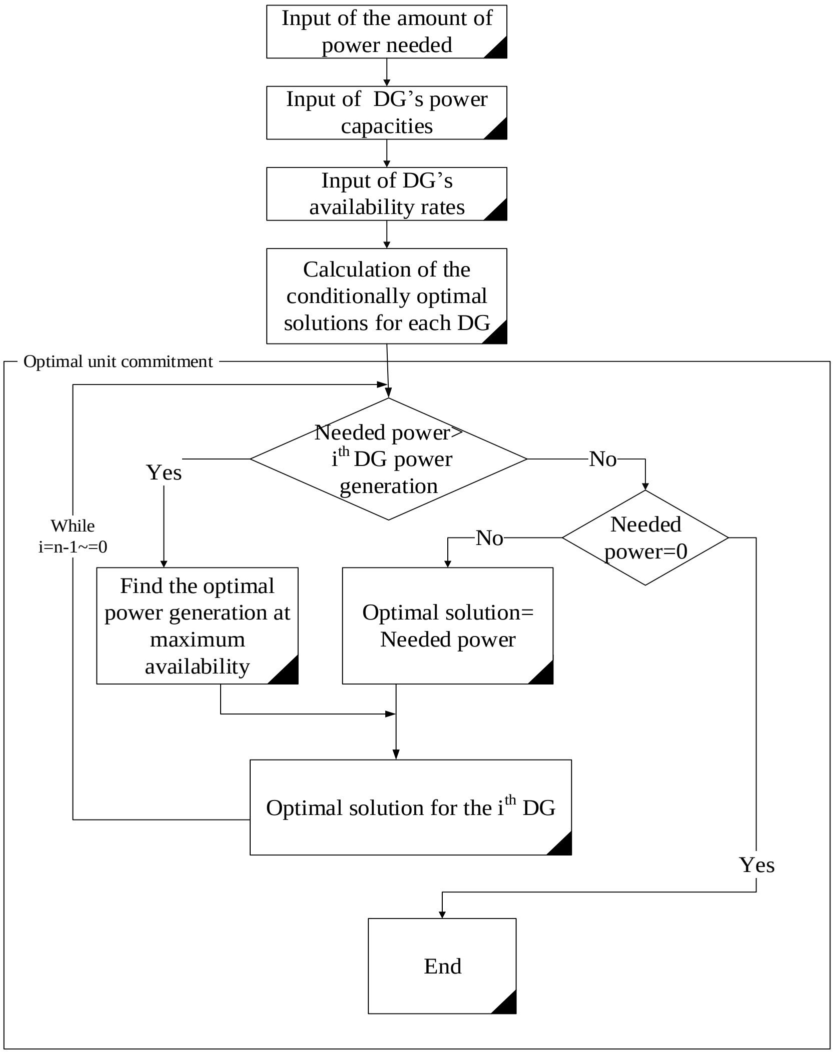

Fig. 1. Dynamic programming based algorithm in Matlab

5. STUDY CASE AND RESULTS

The case study analyses a distribution network which consists of three distributed generators, a backup diesel generator and a storage system. There is a storage system for each distributed generator. The calculated availability for each of the generators is given as a crisp number.

The diesel generator is used as a backup system in times of insufficient power generation from the distributed generators. However, in this paper, it takes part of the optimisation analysis since its availability depends on the fuel prices.

The analysed distribution network is shown in fig. 2.

In Table 1 the installed power capacities for each of the distributed generators are given.

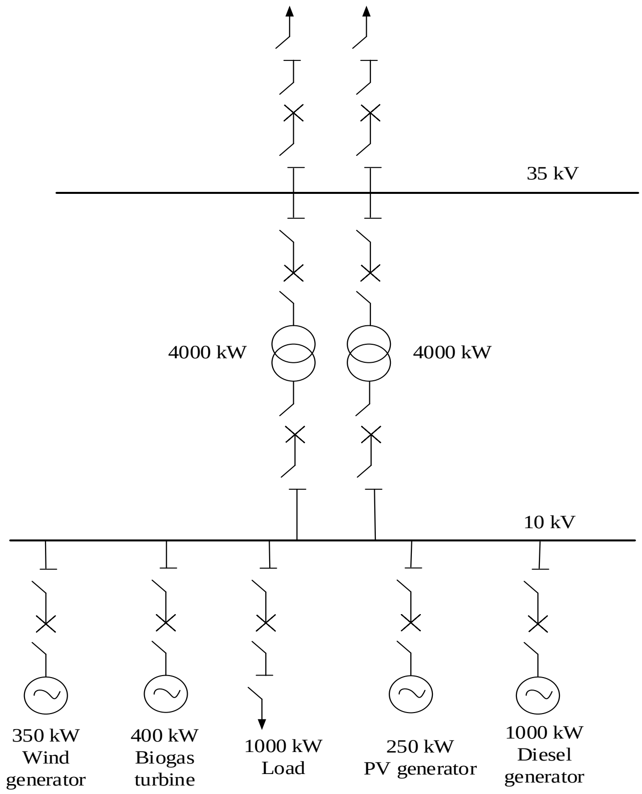

Fig. 2. Distribution network with implemented distributed generators

Table 1. Power capacities of distributed generators

Distributed generator	Power capacity [kW]
PV	250
Wind	350
Micro biogas turbine	400

In [1] the case study analysed the behaviour of the system for one hour. In this paper, the weather forecast is taken into account which allows the analysis to be done for one week (168 hours). Additionally, based on a weekly load curve, as shown on fig. 3, the optimisation is done for different power quantities over different hours in a week.

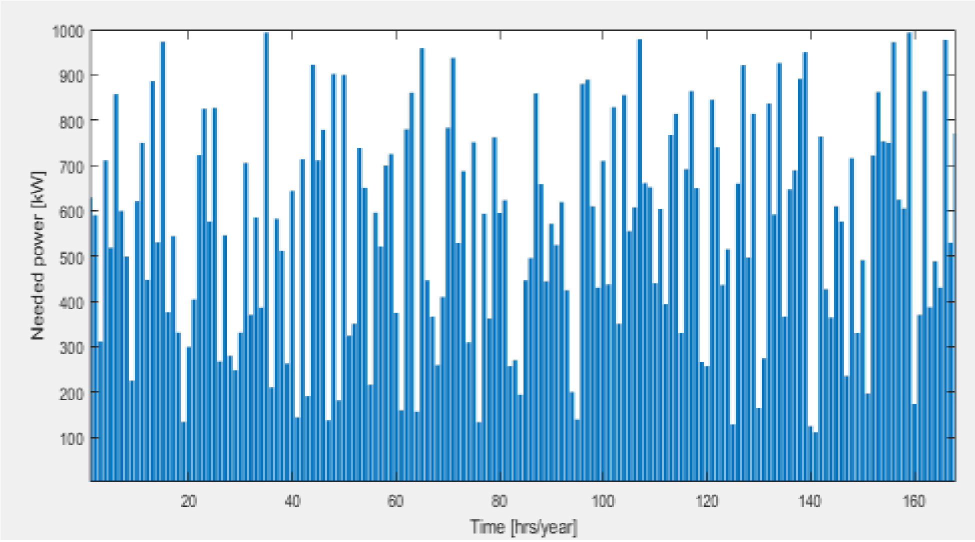

Fig. 3. Weekly load curve

Table 2. The optimal unit commitment and economic dispatch

Hour [h]	Diesel generator [kW]	Micro biogas turbine [kW]	Wind turbines [kW]	PV generator [kW]
6	130	**365**	174	188
15	**625**	68	84	196
115	28	2	55	**245**
132	193	196	**329**	119

In Table 2 the optimal unit commitment and economic dispatch of the distributed generators by hours is shown. The hours shown in the table represent the maximal power generated by each of the generators. The results show that the generated power by each of the generators differs over the hours. This is mostly due to the change of weather conditions factor, which defines the availability. The change of the fuel prices does not have big impact on the availability, because fuel prices do not change daily. However, it should be considered for further analysis.

The results are shown graphically by hours in fig. 4.

The proposed algorithm provides a solution to a very common problem in contemporary distribution networks. The results show that the system can operate as an independent unit during times of outages.

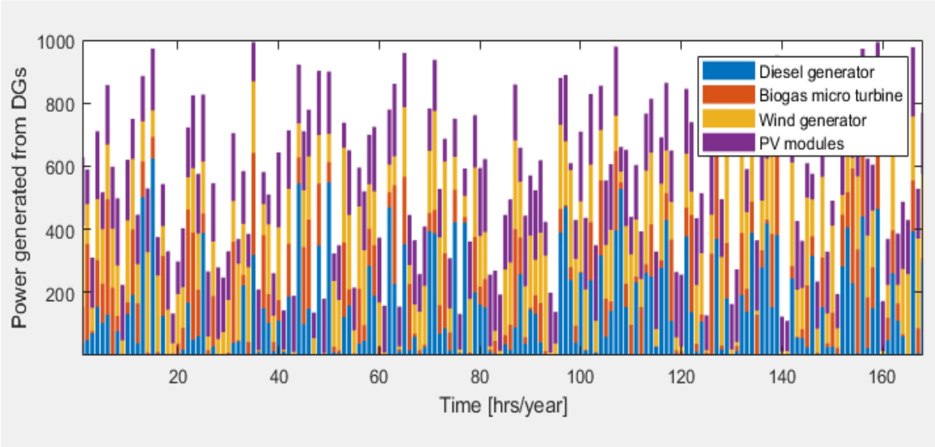

Fig. 4. The optimal economic dispatch of the distributed generators

6. CONCLUSION

Decentralizing the power generation and creating distribution networks which are self-sustained, improves the power system resilience. Also, it is environmental friendly and sustainable way of satisfying the basic need for electricity.

In this paper, a real problem present in the contemporary smart grids was analysed. The unit commitment and economic dispatch of a distribution network with multiple distributed generators were computed. For that purpose, we defined an availability variable, which depends on multiple factors. The optimisation was done by using a Matlab algorithm, based on a dynamic programming method. The algorithm considered the power capacities of the generators and their current availability. The results show that dynamic programming is an efficient mathematical tool for solving the unit commitment problem in complex networks with power generation that varies over time. Since the costs for maintenance and power production are lower compared to the standard power systems, the constraints refer to their availability.

The future challenge is to define the correlation between the impact factors in the availability function.

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