OPTIMAL ENERGY MANAGEMENT OF HYBRID STAND-ALONE POWER SYSTEM BY USING DYNAMIC PROGRAMMING

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Abstract: This paper deals with the optimal energy management in hybrid stand-alone systems, by proposing a dynamic programming-based algorithm. The algorithm considers the probability for favourable weather conditions in a stand-alone system, proposing an optimal scheduling, while continuously satisfying the power demand under defined constraints for the installed equipment. The algorithm is simulated in Matlab and tested on a PV-Wind-Diesel-Battery system.

Keywords: Optimal energy management, stand-alone system, dynamic programming.

1. INTRODUCTION

Witnessing the everyday impact of climate change on the environment and nature's live on this planet, the researchers are faced with the inevitable goal: to provide uninterrupted electrical energy by minimising the carbon dioxide footprint. Energy supply under many different weather conditions is one of the most important issues of the production and distribution companies in every county around the world. Whatever the location and conditions, there are alternative power sources that can replace standard fossil fuels. The proof for its practical usage is the numerous hybrid stand-alone power systems in the farthest areas in the desert, in the mountains or the islands located in the middle of the ocean.

These hybrid systems consist of different types of Renewable Energy Sources (RES), supported by a battery system and a backup generator. Being off-grid means that their voltage and frequency stability depends on the proper operation of the Energy Management System and the well-scheduled unit usage.

In this paper, the optimal operation of a stand-alone hybrid system is analysed. The paper proposes a dynamic-programming based algorithm for optimisation of the units installed in such system, which deals with the stochastic nature of the RES power generation and the power demand of the residential load. To analyse the power generated from the RES as an input in the optimisation algorithm, an uncertainty index is assigned to each of the input parameters. This aspect of view allows us to optimise this type of stand-alone system as a standard power system.

The algorithm is tested on a system of two photovoltaic (PV) generators, a wind generator, a battery and a diesel generator, which supplies a residential load.

2. RELATED WORK

Hybrid stand-alone systems 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, these power systems, 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 stand-alone systems' operation and unit commitment, using many different mathematical methods. However, the 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 distributed energy sources (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 the 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 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.

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 optimisation 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 that complexes the optimisation problem. Reference [7] proposes a dynamic programming-based algorithm for solving the optimal energy management problem of the 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 on the current battery state of charge, is the input data for the optimisation algorithm, which provides the microgrid's units scheduling plan.

3. PROBLEM DEFINITION

Today the many parts of world are facing an electrical power crisis, which may lead to restrictions on power usage. The exploitation of the RES for power generation is a great alternative for overcoming this problem. The RES are easily applicable, provide clean energy and do not affect nature's normal life. Indeed they depend on the weather forecast, but scientists have provided a solution to that problem too, by implementing the battery system. This means that the RES based systems can work in an islanded mode securely and stably.

The stand-alone systems consist of distributed generators placed near the load. In that way, the power losses and the costs for long-distance transmission are avoided. The distributed generators, especially wind and solar, highly depend on the weather conditions, and therefore their power should be used immediately or should be stored for its further usage. However, this should not impact the power balance in the system if we want to keep the frequency and the voltage steady.

This arises the need for proper optimisation in a hybrid stand-alone system. 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. And this has to be done with a previously determined and well-calculated schedule.

In a stand-alone system, it is necessary to determine the optimal unit commitment of each of the distributed generators, while satisfying certain constraints. Despite the technical limitations of the installed equipment, other constraints usually refer to power generation costs or power losses. Wind and solar power plants usually have low operation and maintenance costs, and power losses are reduced to a minimum by implementing the generators near the load. Therefore in this paper, the costs and power losses are not considered as constraints. However, since it is a small-scale power system it is of great importance to keep the voltage stability and power balance.

The problem analysed in this paper addresses the satisfaction of a residential load in a hybrid stand-alone system that operates in an islanded mode. This type of power system is applicable on islands or remote areas that do not have access to the utility grid. However, they can be also placed nearby big cities, for instance, in the suburbs, and can be connected to the utility grid to support its reliability of power supply.

In [9] we analysed a low voltage distribution network with implemented distributed generators. In this paper, we assume that the distributed generators operate apart from the utility grid. This complexes the problem because the stability of the stand-alone system depends only on its units.

4. DYNAMIC PROGRAMMING SOLVING 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 backwards [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.

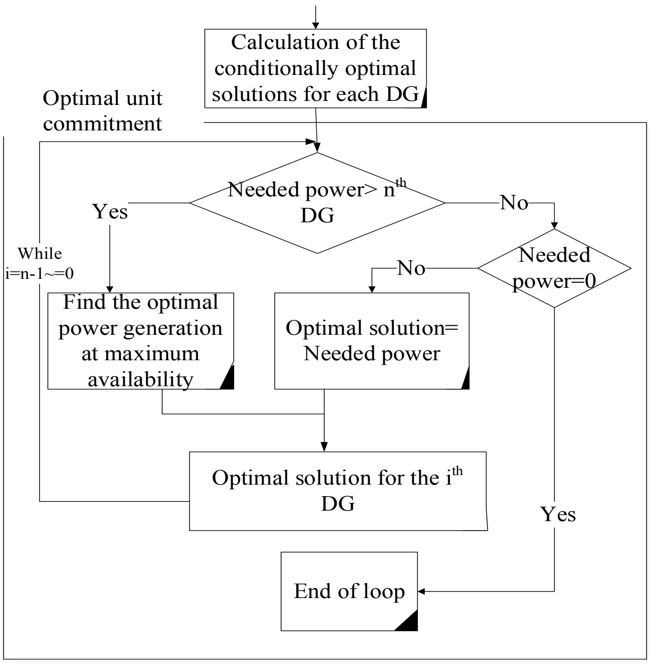

Fig. 1. Flowchart of the dynamic programming-based algorithm for finding the optimal unit commitment

The algorithm we propose, shown in fig. 1 and fig. 2, considers the power generated from each generator (wind and PV) and the power demand in each hour, proposes the optimal solution based on the probability of providing the certain power for a whole hour, and then decides if the excess power should and can be stored and whether the diesel generator should be used. The algorithm considers the defined constraints regarding the battery's and diesel generator's limits as well.

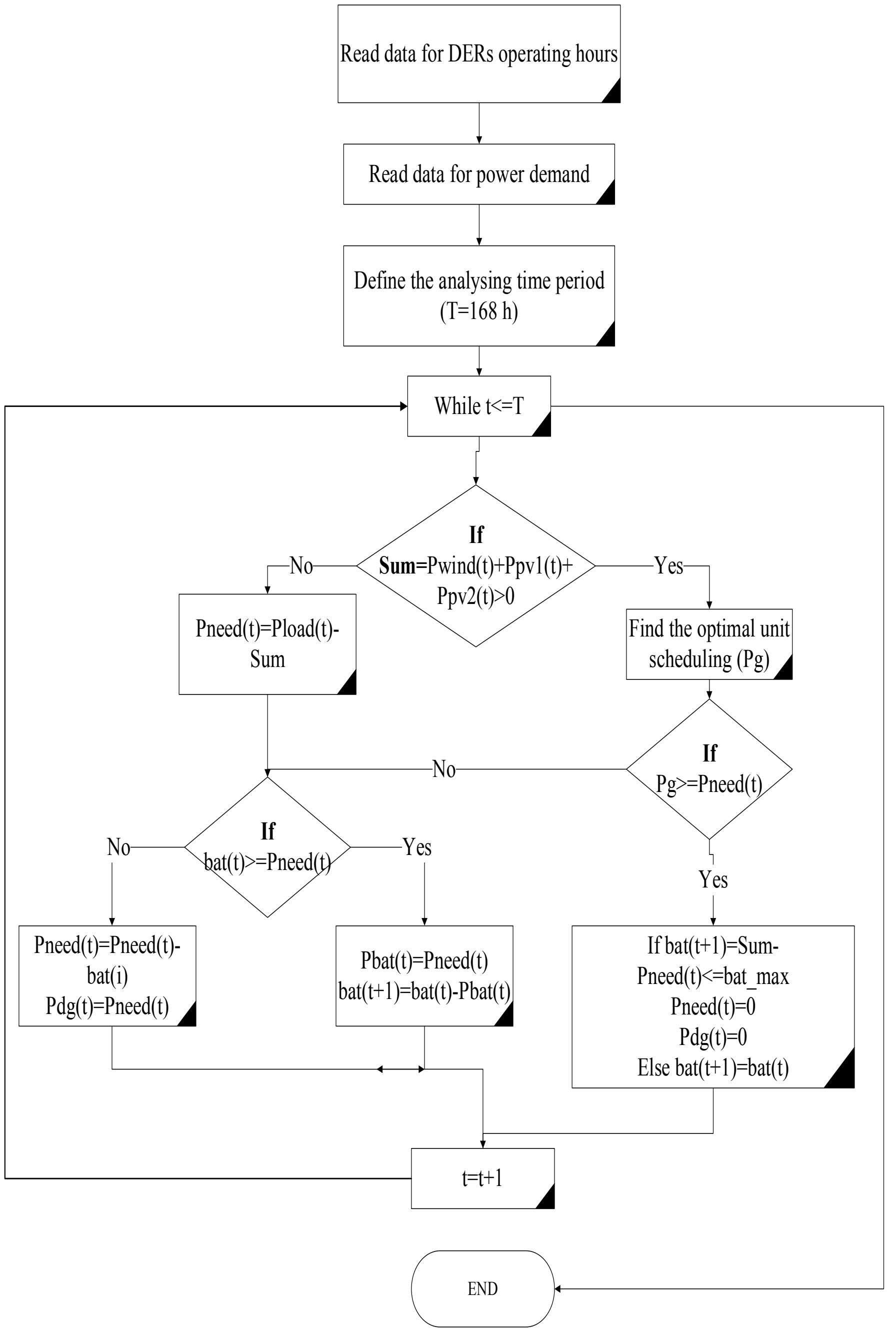

Fig. 2. Flowchart of the proposed algorithm for solving the unit commitment problem in a hybrid stand-alone system

First, the algorithm checks if there is any power generated from the wind and PV generators. If so, the optimisation is performed if the total power generated from the wind and PV generators exceeds the power load. Otherwise, there is no need for optimisation and the whole generated power is used for satisfying the load.

The optimal unit scheduling is performed by analysing the probabilities for providing a certain power by each generator. The generators cannot provide more power than the power generated at the analysed hour. After the optimisation, the power demand should be covered only by the generators.

If the total generated power is not enough to satisfy the load, then the algorithm checks if the battery can cover it. Otherwise, the diesel generator is used.

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 ideal inverters, 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 uncertainty of the weather conditions,
- Installed power capacity for each distributed generator,
- Installed power capacity of the battery,
- Installed power capacity of the backup generator,
- Hourly power demand.

5. TEST EXAMPLE

The test example analyses a hybrid stand-alone system that consists of three distributed generators: two PV generators and a wind generator. Also, a diesel generator and a battery are connected to the system. Each of the distributed generators has its inverter, as presented in fig. 3, and the installed capacity of each of the installed units are presented in Table 1.

The power load curve and the power generated from the installed generators are shown in fig. 4 and fig. 5.

Table 1. Installed units' power capacity

Unit	***Diesel generator***	***Wind generator***	***PV generators***
Installed power capacity [kW]	200	200	150

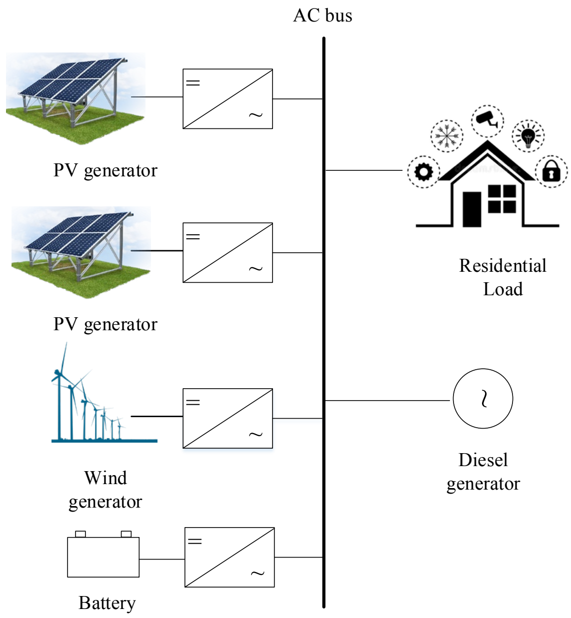

Fig. 3. Hybrid stand-alone system test example

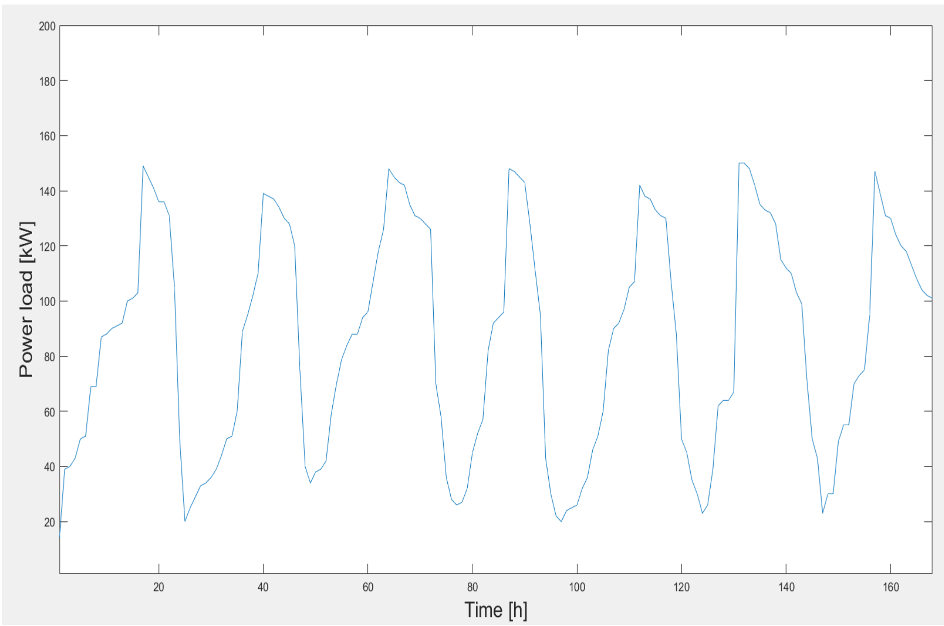

Fig. 4. Power load curve

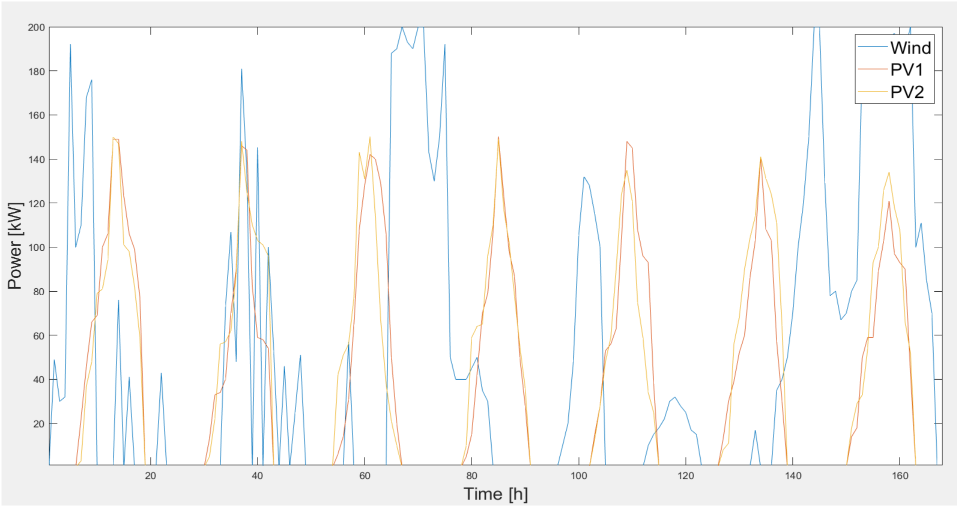

Fig. 5. Hourly power generation from the wind and PV generators

6. RESULTS AND DISCUSSION

Choosing the battery capacity depends on the investment costs and the role of the battery in the system. We tested the algorithm for two battery capacities: 300 kWh and 1200 kWh.

The results presented in fig. 6 show the optimal scheduling of the units with a battery with a 300 kWh capacity. This battery would be enough to supply the maximum load for no more than two hours.

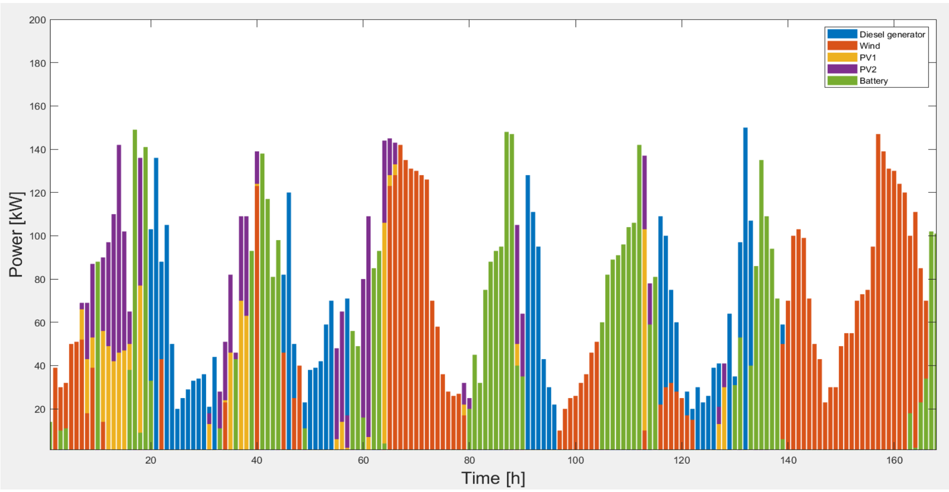

Fig. 6 Optimal scheduling of hybrid system with a 300 kWh battery capacity

It can be seen that the usage of the diesel generator is very frequent, up to 45% of the total time. In this case the investment costs would not be very high, but the fuel costs will rise the expenses.

In comparison, fig. 7 shows the optimal unit scheduling when the system is equipped with a battery with a capacity of 1200 kWh. In this case, the usage of the diesel generator is reduced to less than 6% of the total time, which means lower fuel costs and pollution.

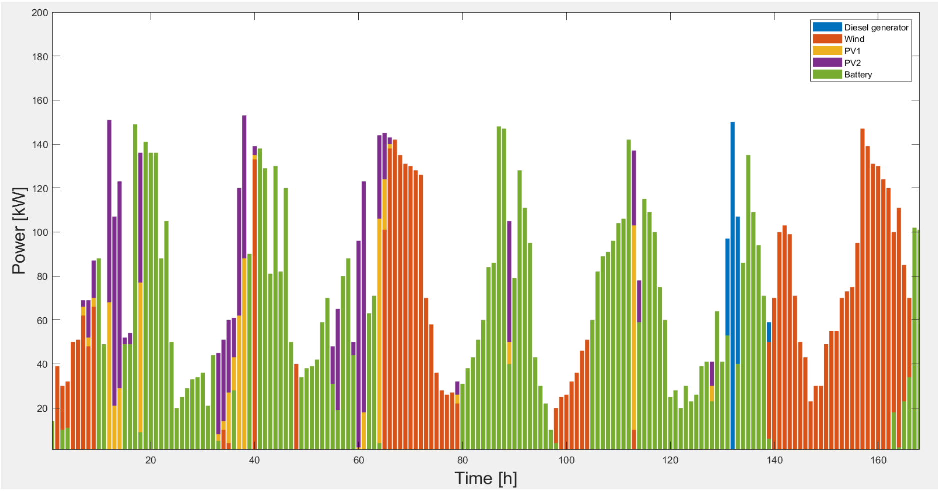

Fig. 7 Optimal scheduling of the units installed in the analysed stand-alone system

The energy market offers a palate of environmentally friendly fuels for diesel generators that do not have greenhouse gas emissions. However, despite the better alternatives, the active usage of the diesel generator should be lowered to the minimum, in order to lower the costs for running a small-scale stand-alone system and creating an economically justified power supply.

7. CONCLUSION

When it comes to the future of power systems, renewables still have the leading role in it. Many small-scale hybrid systems operate in an islanded mode, and provide power with high reliability, without relying on the utility grid. This paper analysed a commonly used hybrid stand-alone system for supplying a residential load.

We proposed an algorithm that offers a solution to the unit commitment problem for islanded operation mode, which is very important for obtaining stable network frequency and voltage levels. Applying the algorithm to a test example showed that the algorithm deals with the problem well by giving real and expected results. The test-example showed that the algorithm can be applied on a real-time data. The future work could focus on optimising the operation of a stand-alone system equipped with more than one battery and analysing the possibility of excluding the diesel generator and connecting the system to the distribution network, considering the dynamic pricing of the electricity.

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