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MICROGRID CONTROL SIMULATION AND TESTING

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Microgrid control becomes more and more developed with the application of this concept on a larger scale. This paper defines the modern microgrid concept and evaluates the possible architectures and control hierarchy. A small scale microgrid architecture is proposed. The components of the system are a wind turbine, a photovoltaic panel and a household. The model was implemented in Matlab/Simulink and a decision table control was proposed. The proposed decisions and actions are defined for both on and off grid operation, in order to benefit most of the local resources. The results of this study are promising in terms of microgrid off grid operation for single dwellings, considering that the house is grid supplied for a period of only 4 hours of the day.

Keywords: PV panel model, wind turbine model, microgrid simulation, control techniques, decision table

1. Introduction

Smart grid is the general concept developed due to the increasing integration of small power generators from renewable sources (especially photovoltaic systems), which is defined by the existence of a high degree of monitoring and control of energy. [1]

Smart Grid aims to transform the power grid into true "smart grids" that can integrate the behavior and actions of all users connected to them, namely producers, consumers and those who both ensure sustainable energy efficiency and security of supply, [1].

The use of renewable energy on the network avoids most, if not all, the disadvantages of being off-grid, [3]. The use of renewable resources at a small scale can be a good solution for both remote or on-grid electricity consumers. The notion of microgrid appeared as a response to small scale applications.

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Microgrids are a new concept for future energy distribution systems that enable renewable energy integration and improved energy management capability. Microgrids consist of multiple distributed generators (DGs) that are usually integrated via power-electronic inverters. In order to enhance power quality and power distribution reliability, microgrids need to operate in both grid-connected and island modes. Consequently, microgrids can suffer performance degradation as the operating conditions vary due to abrupt mode changes and variations in bus voltages and system frequency. [17]

The U. S. Department of Energy (DOE) has provided the following definition of Microgrids in [19]: *„A Microgrid, a local energy network, offers integration of distributed energy resources (DER) with local elastic loads, which can operate in parallel with the grid or in an intentional island mode to provide a customized level of high reliability and resilience to grid disturbances. This advanced, integrated distribution system addresses the need for application in locations with electric supply and/or delivery constraints, in remote sites, and for protection of critical loads and economically sensitive development."*

Two operation modes of microgrid can be defined as follows: [18]

- Grid-connected Mode: the microgrid (MG) is connected to the upstream network. The MG can receive totally or partially the energy from the main grid (depending on the power sharing). On the other hand, the power excess can be sent to the main grid (when the total production exceeds consumption).[27]
- Island Mode: when the upstream network has a failure, or there are some planned actions (for example, in order to perform maintenance actions), the MG can smoothly move to islanded operation. Thus, the MG operates autonomously, in „island mode", in a similar way to the electric power systems of the physical islands.

An example of an "on-grid" system operating in grid connected mode composed of solar photovoltaic systems is presented in Fig. 1.

This system cannot work without connection to the national energy grid and, also, they can send back additional energy back to the grid when it overproduces, [2]. The system in Fig. 1 is used in most residential dwellings because the energy consumed is covered if the solar system is under or over-productive in season. [26] If more energy is produced with solar panels, excessive energy is sent to the network network company, allowing it to be used when needed. Being connected to the network is beneficial because there is no need to buy a back-up system to store any surplus energy. [4]

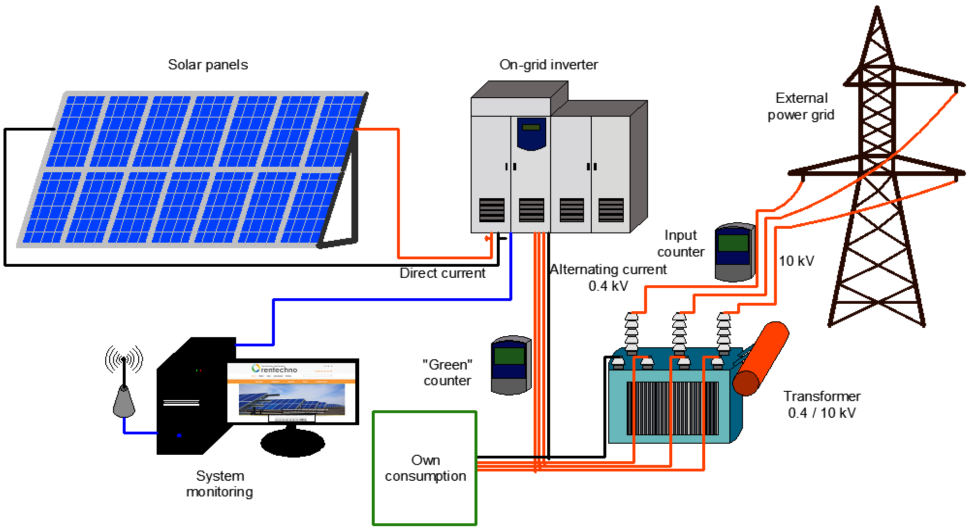

Fig 1. On-Grid system scheme, adapted after [2]

A microgrid must have the ability to operate independently when there is any disturbance in the utility grid such as faults and other contingencies. Microgrids operating without any connection to the utility grid are known to be operating in islanded mode. [7]

Off-grid microgrid allows storage of energy in batteries for use when the power supply stops or there is no network connection. These systems offer the power to cover the consumption of the grid when, for instance, the sun shines and even sends out surplus power to the grid to get credit for later use. [1]

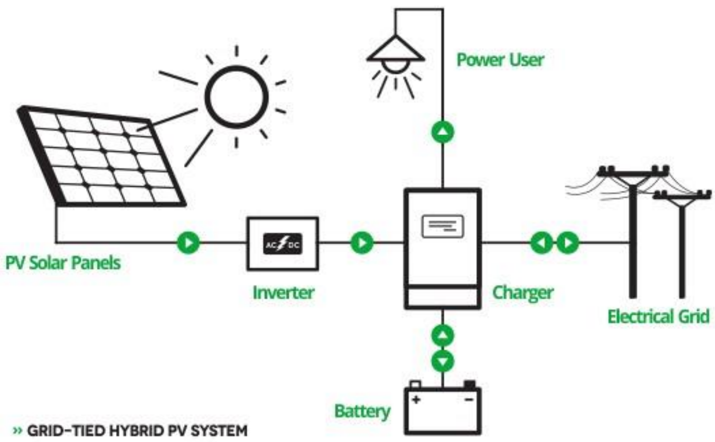

Fig. 2. Off-Grid system scheme, [1]

Off-Grid photovoltaic system represented in Fig. 2 or photovoltaic system with storage is an autonomous power plant that will produce electricity by photovoltaic solar panels to power consumers, independent of external suppliers of electricity. Off-Grid systems require a lot more specialized equipment to function that is costlier and more complex to install. Specifically, they require a central / string inverter and a charge controller as well as batteries. [4]

The proposed system architecture was modelled gradually: first the PV panel model, then the wind turbine model was validated. Also, a hybrid architecture has been proposed that contains a wind turbine and several PV panels to minimize the supply of consumers in the national grid. [20] In order to control the microgrid by means of a control strategy, several scenarios with different generation possibilities were simulated and tested together with the national network: only wind turbine, photovoltaic panel only and both in [21]. Still, a more efficient control strategy has to be found.

2. Microgrid architecture

The structure of a microgrid includes both microgenerators (lower than 5 MW, [23]) and loads, but can also include storage capacities. Microgeneration can include: micro-power plants, fuel cells, photovoltaic panels, wind turbines, diesel generators etc. The proposed microgrid comprises a PV panel and a wind turbine. A small electric system that combines wind technology with photovoltaic technology offers several advantages over the two systems taken individually.

In many locations, wind speed is low in summer, while photovoltaic panels benefit from the sun and they generate the most power. On the other hand, wind is much stronger in winter, while the sun generates less power. Since the efficiency peaks for the two systems are different, a hybrid system could generate more energy, as needed, [20].

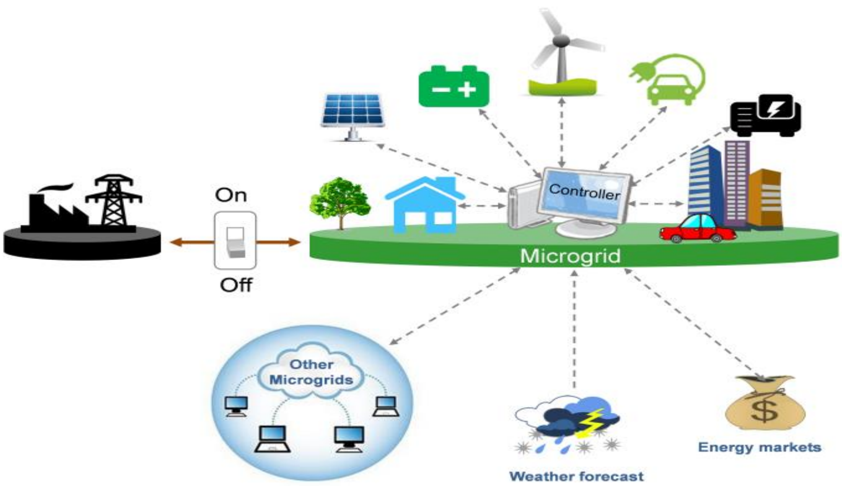

Fig. 3. Microgrid concepts

Fig. 3. presents the general microgrid concepts. A microgrid is a localized group of electricity sources that are typically connected and synchronized with a traditional centralized grid (macro-grid) but can also be disconnected and maintain autonomous operation under physical conditions.

Renewable sources request increasing interest because they are non-polluting, do not involve high operating costs and have an important role in rationalizing limited resources. The components of the proposed grid architecture are: photovoltaic panels, a wind turbine and an inverter. This structure was developed with the purpose of testing an application for better electricity management in a home.

2.1. Photovoltaic panel

Photovoltaic (PV) or solar cells, as they are often called, are semiconductor devices that convert sunlight into electricity. The photovoltaic systems can produce in direct current (DC) that is compatible with a storage battery or, through an inverter, can be connected to any conventional device, and operates in parallel and interconnected to the utility grid.

The proposed system has four photovoltaic panels of 220W.

2.2. Wind turbine

Wind turbines have two major destinations: inclusion in a wind power plant and supplying energy to isolated houses. Wind turbines can be used together with solar panels and storage batteries to constantly supply electricity regardless of the season or they can be used on their own.

A 400 W wind turbine was considered in the pilot microgrid.

2.3. Inverter

The inverter is one of the important components with which photovoltaic panels can be connected to the distribution network. Their purpose is to convert the produced DC current of the PV panel to the alternating current of the network, [1]. In the proposed microgrid, the inverters are used either to power consumers directly or to charge storage batteries.

3. Control techniques for microgrid operation

3.1. Microgrid control operation

The Department of Energy of USA defined the microgrid controller as a technology that allows both on grid and off grid operation, with microgrid energy optimization, [25].

The current approach for microgrid operation is reaching to integration within the utility grid. In order to yield the expected performance (efficiency, adequacy etc.), new and better control methods have to be investigated. These management and supervision techniques have to be classified based on technical aspects of the grid, [24]: primary, secondary and tertiary control.

The primary control is designed to satisfy the following requirements, [14-18]:

- Voltage and frequency stability at the local level: Subsequent to an islanding event, the microgrid may lose its voltage and frequency stability due to the unbalance between the generated and consumed power.
- “Plug-and-play” capability for DGs;
- Main functions include: switching logic, protection and local control

Secondary control involves a more general load control and SCADA, where voltage and frequency setpoints are set at the microgrid level, not just for a single DER unit.

Tertiary control includes optimization and dispatch functions, with a proper share of the active and reactive power dispatch among the microgrid generating units, [24]. Auxiliary functions may include: Power flow control between microgrid and main grid, optimizing the cost of operating the microgrid, Resynchronization of the microgrid with the main grid, [11-13].

Also, the basic functions for assuring energy supply quality must be considered: automatic voltage regulation, load- frequency control, protection, power flow balance (energy management). Specific operation controls were identified in [25]: grid connected to islanding transition, microgrid black start, microgrid user interface and data management, ancillary services: grid connected, microgrid resynchronization and reconnection to the grid after island operation.

Considering both technical and economic goals of the microgrid operation, often contradictory, it can be concluded that the most important objective of the control system is the load management in terms of assuring energy supply for the consumers.

3.2. Load management control with decision tables

This paper studies the load management control function. The dispatch method can use decision tables. They are composed of a schema, which is a selection of attributes, each heading a column (or row, depending on the orientation of the table) of the body, a selection of values these attributes could take. A final column (or row) represents the class attribute, and its values. This means that each row is equivalent to a rule: when the attributes take these values, then the class attribute takes this value. A particular case of decision tables is the truth table.

A truth table is a logical decision-making behavior with conditions, decisions and actions. This concept is also implemented in Matlab/Simulink. A block of the table of truth consists of a column of the table state and two or more columns decision is denoted by D1, D2 and a table of actions in the table under a column for describing each action in the columns action.

Truth tables provide resolution for the conditions that are specified. The Truth Tables function in Simulink has two components: a table section for the required conditions and a table section for the actions taken when the created conditions apply.

4. Microgrid control simulation and testing

For simulation and testing, a microgrid model composed of four photovoltaic panels of 220W, a wind turbine of 400W and a home with a maximum consumption of 2500W was modelled in Matlab/Simulink, Fig. 4.

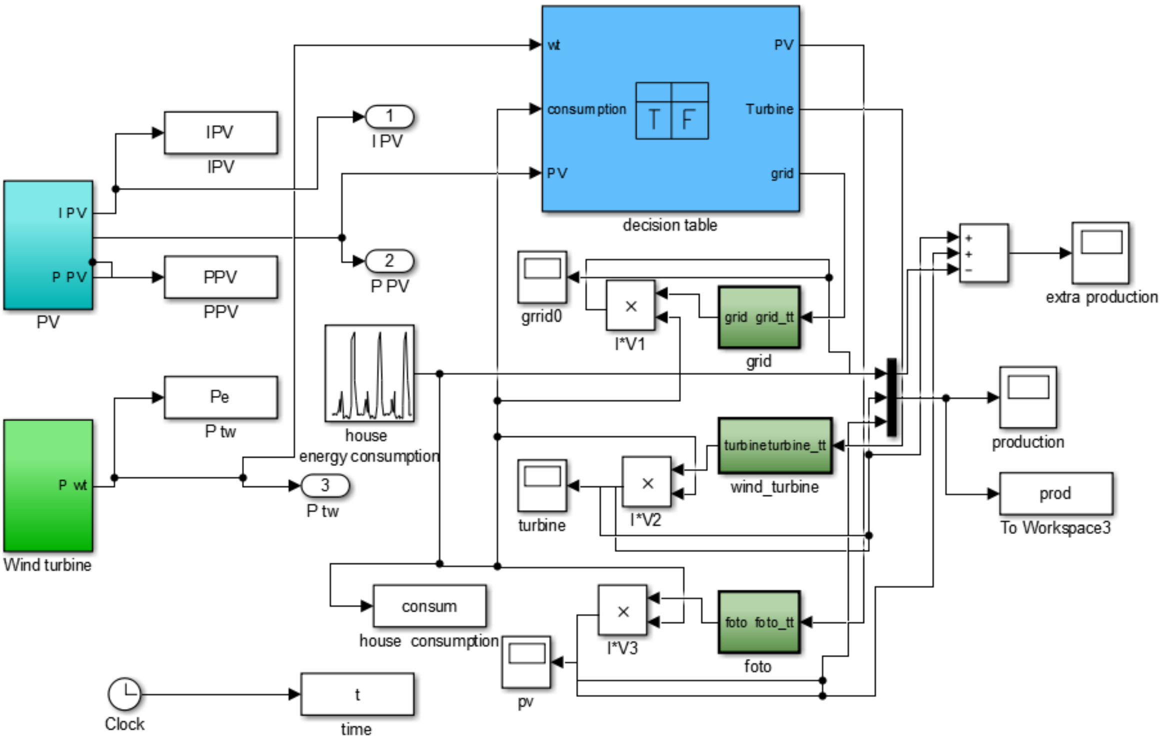

Fig. 4. Proposed microgrid model in Matlab/Simulink

The following paragraphs describe the microgrid architecture in Matlab/ Simulink simulated in operation with a control methodology with truth tables.

4.1. Decision table rules

The rules for the truth table are set for simulation of the home electricity load coverage with the microgrid generation, Table 1:

- When the power of the photovoltaic panel is lower than the house's consumption and the wind turbine power is higher, power from the wind turbine is used, Table 1 (D2).

- When the power of the photovoltaic panel and the wind power are equal to 0, the power generated by the national electricity grid will be deployed (D3).
- When the power of the photovoltaic panel is higher, and the wind power is lower than the household consumption, the electricity supply will be switched on the photovoltaic panel source (D4).

Table 1

Condition table for microgrid

Condition Table

	Description	Condition	D1	D2	D3	D4	D5	D6
1	PV	pv >=consumption	T	F	F	T	F	T
2	turbine	t >= consumption	T	T	F	F	F	T
3	PV+ turbine	pv+t >= consumption	T	-	F	-	T	F
		Actions: Specify a row from the Action Table	FotoOn	turbineOn	gridOn	FotoOn	FotoTOn	FotoOn

Table 1 describes the conditions applied for simulation of the microgrid system. Table 2 depicts the actions created to enable decisions in the table of conditions. An example of the action taken is as follows: three conditions are necessary for supply switch to the national network (PV panel not producing, wind turbine not generating and grid connection possible).

Table 2

Action table for microgrid

Action Table

#	Description	Action

1	Turn On grid	gridOn:
		PV = 0;
		turbine = 0;
		grid = 1;

2	Turn On Foto	FotoOn:
		turbine = 0;
		PV = 1;
		grid =0;

3	Turn On Turbine	turbineOn:
		turbine = 1;
		PV = 0;
		grid =0;

4	Turn On Foto+turbine	FotoTOn:
		turbine = 1;
		PV = 1;
		grid =0;

4.2. Microgrid operation simulation

The simulated model in Matlab/Simulink is based on real registered data for the day of 22 May 2016. The solar radiation input G [W/m^2] is registered for a plain area of Romania (Targoviste), data available from [9, 21]. The generated and consumed power situation for this day is presented in Fig. 5 where the red curve is the electricity consumption, the green curve is the PV panel and wind turbine production power.

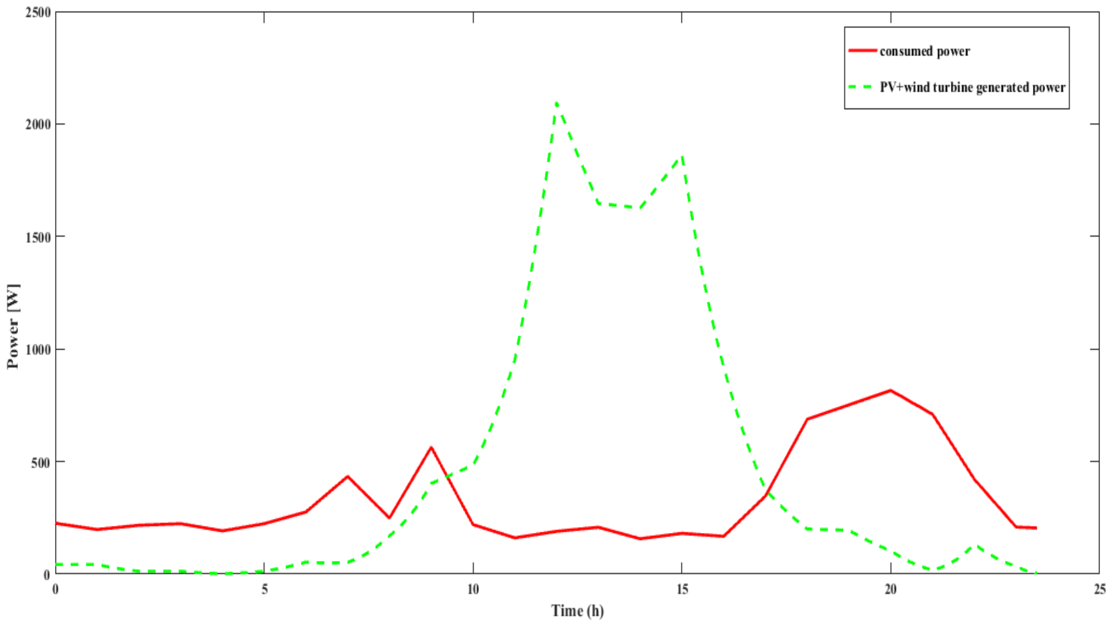

Fig. 5. Generated vs Consumed Power

Base on the control with the truth table defined in chapter 4.1, the simulation of the microgrid system load curve is presented in Fig. 6. The house electricity load is supplied by the wind turbine (blue curve), PV panel (green curve) or the grid (red curve). The diagram shows that in the period 1 AM- 5AM and 17 PM – 24 PM the consumer is supplied from the grid, but in the rest of the day, the microgrid generation is enough for the dwelling.

A small microgrid system that combines wind technology with photovoltaic technology offers several advantages over the two generating systems taken individually. The above simulation shows the energy needs of a house that must be covered by the national electricity grid over a 24-hour period, while using this microgrid system. Figure 6 shows that between 9:00 -17:00 household energy demand is covered entirely by the microgrid generation.

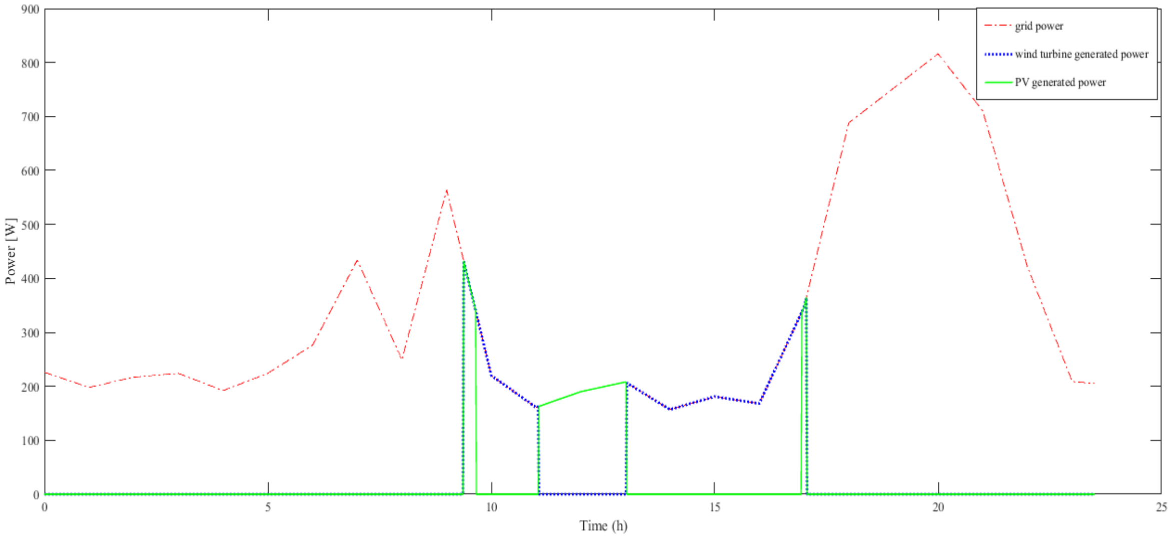

Fig. 6. Load curve coverage

5. Conclusions

The paper aims at modeling and of a hybrid system composed of a photovoltaic panel and a wind turbine.

The main contribution of the paper involves the decision tables control, the proposed decisions that and actions are defined for both on and off grid operation, in order to benefit most of the local resources. The actions considered a greater priority in PV panel use since their generating capacity is higher than the wind turbine.

The results of this study are promising in terms of microgrid off grid operation for single dwellings, considering that the house is grid supplied for a period of only 4 hours of the day.

The power generated by the microgrid shows that neither individual wind turbine or photovoltaic panel do not cover the electricity load of the house during a day (24 hours). Further work will include use of a storage battery that may overcome this disadvantage and also the study different control methods for the operation of the proposed microgrid.

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