Modeling and Control of a Microgrid with Distributed Renewable Generators

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***Abstract*-This paper presents the modelling and control of a remote all renewable energy microgrid designed to supply a vegetable greenhouse. The microgrid operates in island mode and consists of: a geothermal generator, a biomass generator, a photovoltaic generator, battery storage system and a power management system (PMS). A two level control structure is implemented to properly balance the power flow in the proposed microgrid: primary level based on droop control implemented by each unit and a secondary level base on communication implemented by the PMS.**

I. INTRODUCTION

The „Smart grid" is a power system that uses a collection of technologies: advanced sensing, communication (ICT), intelligent management algorithms and power electronics in order to improve the current grid and to facilitate better use of the electrical energy providing a wide range of services for consumers [1]. Smart grid accommodates different types of energy generators: standard generators, distributed renewable generators (DG) and mobile generators.

A microgrid is considered one of the main blocks of a Smart Grid. Usually microgrids are low voltage networks composed of interconnected distributed renewable generators, storage and loads operating as a single controllable system. The microgrid can operate either as grid connected or islanded [2]. Power electronics is usually employed to connect the different DGs within the microgrid. In this regard the microgrid is a collection of paralleled inverters and generators working together to supply the load [3]. The three main categories of power units usually encountered in microgrids are: grid forming unit, grid supporting unit and grid parallel unit. The grid forming unit controls the frequency and the voltage of the grid balancing the power of the different DGs. The grid supporting unit determines its active and reactive power based on voltage and frequency measurements. This unit is also known as grid following unit. The grid parallel unit comprises of uncontrollable loads like: PV generators, wind farms, etc. which are designed to feed maximum power into the grid [4].

Proper operation and load shearing of these units depend heavily on the control of the DG. The control methods employed in literature can be divided in: Master/Slave control and droop control [5], [6]. The Master/Slave control achieves good regulation but its main disadvantage is that is dependent on the master and on fast communication lines between the master and the other units. Failure of the master or the communication can lead to outage of the entire system. Droop control realizes power sharing through voltage and frequency deviations. Using droop control all the DG units participate in voltage and frequency regulation without communication therefore disconnection of one unit has little impact on the system functionality. One of the main drawbacks of droop control is its inherent voltage and frequency variations [7]. In order to solve these problems a three level hierarchical control of microgrids is usually employed: primary control, secondary control and tertiary control [8], [9], [10]. Primary control is responsible for the voltage and frequency control. It has current and voltage loops for ensuring proper power sharing among DG units. The secondary control is responsible for frequency and voltage restauration due to deviations produced by virtual inertias and virtual impedances. This control is also responsible for synchronization of the microgrid with the grid in grid connected mode. The tertiary control controls the power flow (P-Q import and export). Also the DG unit's set points are adjusted at this level [11, 12].

This paper presents the modelling and control of a remote all renewable energy microgrid designed to supply a vegetable greenhouse. The microgrid operates in island mode and consists of: a geothermal generator, a biomass generator, a photovoltaic generator, battery storage system and a power management system (PMS), Fig.1. Because there is no grid connection only a two level control is implemented to properly balance the power flow in the proposed microgrid.

The reminder of the paper is organized as follows: the microgrid structure is briefly described in section II; section III deals with the control of the DG units; section IV describes the simulation results and section V deals with discussions and conclusions.

II. STRUCTURE OF THE RENEWABLE ENERGY MICROGRID

The proposed structure of the proposed microgrid is presented in Fig.1. The battery inverter is the master inverter and is the grid forming unit. The biogas system is composed of a thermal engine that drives an induction generator. The geothermal generator is composed of a thermal machine based on Organic Rankin Cycle that also drives an induction generator. Both generators work as grid following units. The solar inverter works as a grid parallel unit supplying to the local grid all the available power produced from solar irradiation. The standalone microgrid is small-scale and has a 400V three phase distribution network to which the inverters and the generators are connected.

The loads supplied by the system are represented by the consumers of the vegetable greenhouse and are: fans, window opening systems, water pumps, the energy management system, ambient lighting and different electric drives. All the loads with their own consumption are presented in Tab.1.

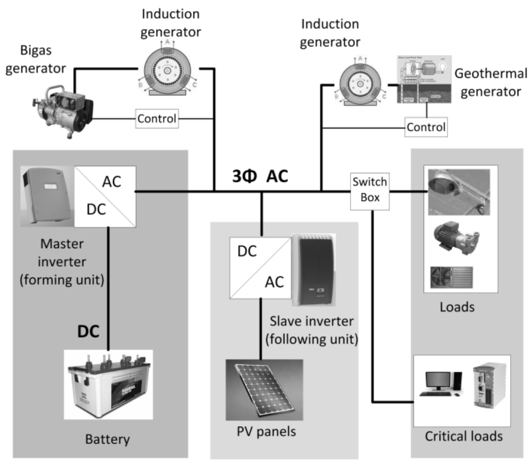


Fig. 1. Renewable energy proposed microgrid.

TABLE I

LOADS

Load	Nr.	Rated power	Maximum power
Fans	4	600 W	2400 W
Special Lamps	7	700 W	4900 W
Window opening system	1	2400 W	2400 W
Electric drives	1	100 W	100 W
Management system	1	100 W	100 W
Lighting	1	100 W	100 W
Water Pumps	8	600 W	4800 W
Maximum total power			**14800 kW**

Base on the load characteristic the size of the microgrid units are presented in Tab.2.

TABLE II

SIZE OF THE GENERATORS

Component	Item	Value
Biogas generator	Rated power(kW)	7kW
Geothermal generator	Rated power(kW)	7kW
Solar panels	Rated power(kW)	5kW
Solar inverter	Rated power(kW)	5kW
Batteries	Capacity(Ah)	500Ah/48V
Battery inverter	Maximum power(kW)	10kW

III. CONTROL CONCEPT OF THE MICROGRID

The control structure proposed to control the DG units of the microgrid is represented in Fig. 2. The proposed control concept is a combination of droop control with master/slave control that minimizes the drawbacks of both methods. Only a two level control structure is used to control the units of the proposed microgrid: the primary level of control where each slave DG unit controls its output power according to its droop characteristic and based on frequency measurements of the local grid; the secondary control level, implemented by the power management system (PMS), measures the generated and consumed power and sends to the master inverter the voltage and frequency references.

A. Primary control level

It can be observed in Fig. 2 that all the DG units of the microgrid are parallel connected to a three phase AC bus. The renewable sources are responsible of sharing the load according to their power rating and the availability of their energy resource. To maintain the AC bus voltage constant only one unit must work as voltage source the rest of the units should be operated as current sources. The Master inverter controls the local grid frequency and voltage. The frequency value is received from the PMS and is controlled in the range of [49 – 51] Hz in order to balance the power flow in the microgrid. The slave inverters will adjust their output power according to their own P-f droop characteristic.

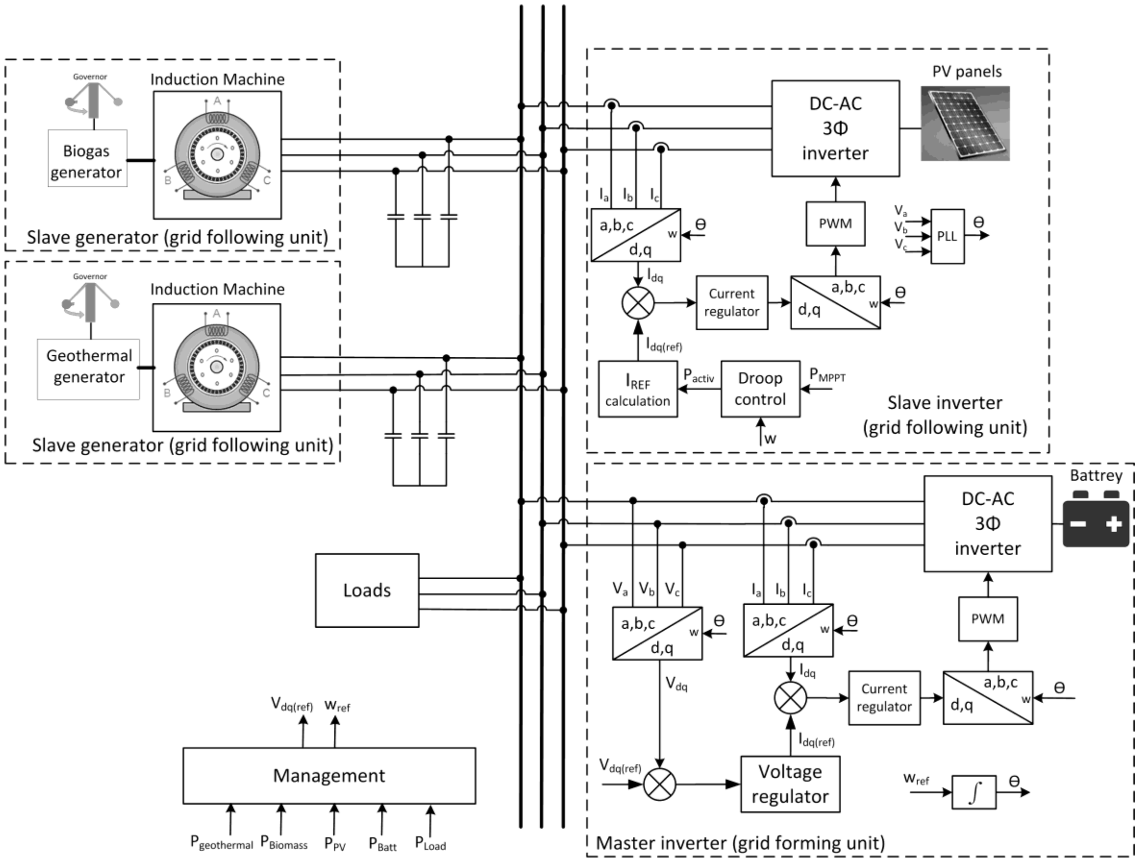


Fig. 2. Microgrid proposed control concept.

The master inverter control comprises of two loops: a current loop and a voltage loop. The two loops are implemented in rotating *d-q* frame.

After transformation classical PI controllers are employed to control the *Vd*, and *Vq* components. The PI controllers are tuned next to obtain the optimal transient response of the inverter. As can be observed in Fig. 2 the reference voltage for the inner current loop is set by the outer voltage loop. The voltage reference for the voltage loop is set by the management system. To maintain the AC bus voltage constant the master inverter will supply both active and reactive power to the grid according to the load power necessity. Furthermore the muster inverter sets the grid frequency according to the value received from the PMS. In this way the master inverter controls the output power of the other inverters and generators. Because in the proposed microgrid the power lines are short and mainly resistive the bus voltage does not vary considerably with the reactive power consumption thus a reactive power control Q-V is not used. All the needed reactive power in this case is supplied by the master inverter and capacitors.

Both the geothermal and biomass generators units use induction generators to convert the mechanical energy into electrical energy. The biomass and the geothermal generators are controlled by a governor at constant speed. This control gives the generators a natural power droop characteristic described by Eq. 1 and represented in Fig. 3.

$$P_m(f) = k_m \cdot (f_0 - f) \tag{1}$$

where k_m = 6.65 kW/Hz, and f_0 = 51 for the geothermal generator and k_m = 3.84 kW/Hz, and f_0 = 51Hz for the biomass generator.

The PV inverter is controlled in constant – current mode. This type of control enables the parallel operation of this inverter with the other generators. The current reference for the inverter is derived from the active power requirement. The active power requirement is determined from a virtual droop characteristic implemented for the control of this inverter, the power available from the PV panels (P_{mppt}) and the PMS. The droop characteristic is described by Eq. 2 and represented in Fig.3. This characteristic makes the PV system mimic the behavior of the induction generator. In this way all of the three slave generators can be connected in parallel on the three phase bus.

$$P(f) = P_o + k \cdot (f_0 - f) \quad (2)$$

where $P_0 = 5kW$, $k = 1571$ W/Hz, $f_0 = 50Hz$.

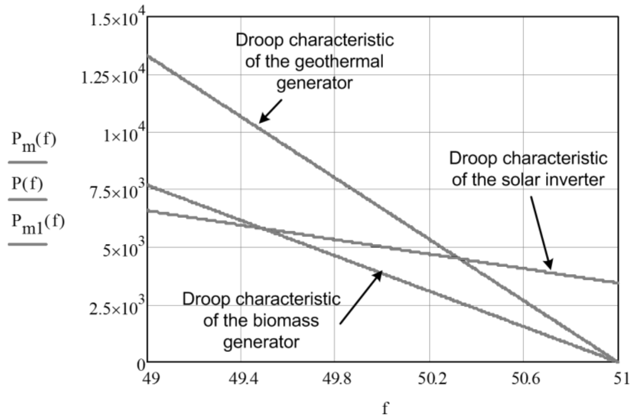


Fig. 3. Droop characteristic of the generators and the inverter.

B. *Secondary control level*

At the secondary control level the management system measures the power generation and consumption and based on the droop characteristic of each generator, Fig. 3, decides the frequency reference value and sends it to the master inverter. This secondary level is implemented in a general purpose computer and communicates data to the inverters on RS485 Modbus. The decision algorithm is presented in Fig.4.

The main tasks of the PMS are to deliver the necessary power needed by the critical loads, to keep the battery pack at a high state of charge percent, to implement the protection functions and to predict some worst case situations that involve a controlled power off sequence.

Referring to the secondary tasks of the PMS this can be mentioned as predictive control using the meteorological data, preserve the limited resources, in this case the biogas, when the total power delivered by the other generators exceeds the load required and data logger functions used for a smart control based on daily load profile.

The management algorithm has two stages. The first stage implements the start-up of the microgrid based on the available renewable resources and the current state of the equipment. The start sequence is presented in the flowchart fig. 4.

The proposed start sequence receives data from the generator units and based on the availability of the renewable resources and load demand decides which generators will be used and the power sharing between them. A first decision is made based on the battery bank state of charge, taking into account that the grid forming inverter needs to run even in the worst case scenario when all the generators go down and a safe turn off for the microgrid is sustained from the battery bank. If the information received by the PMS indicates that all the generators are available the algorithm decides the power sharing based on preserving the biogas and analyzes the need for dummy loads connection.

If not all the generator units are available the PMS decides if the maximum available power can sustain the load demand. Based on the comparison result there are three cases: 1) the load requirement exceeds the maximum power but the critical load requirement may be sustained in which case the non-critical loads are disconnected from the microgid; 2) the load requirement does not exceed the maximum power, the most favorable case in which the power demand is shared between the loads; 3) The critical load requirement exceeds the maximum available power and the PMS decides based on the state of charge of the battery bank if the critical loads can be sustained for a small amount of time or directly jump to the microgrid turn off sequence.

After the start sequence, if the grid does not enter the turn off state the microgrid management follows the logic presented in fig. 4.

Power samples are fed to the PMS from each generator unit, and the available power is computed taking into account the load demand. The meteorological data is used not only in the predictive control (not presented in this case) but also to have information about the irradiance. Based on the solar irradiance and battery state of charge the available power is computed. Knowing this value the frequency reference can be computed based on the droop characteristics of the generators in such a way to preserve the energy stored in the battery bank (maintain the power extracted from the master inverter close to 0) and the biogas resource if the available power exceeds the load demand. Else if the power demand is higher than the available power even after disconnecting from the grid the non-critical loads PMS enters the stop sequence.

If the batteries need to be recharged, the number one priority becomes the recharging and in this situation the biogas preserve condition will be disabled and if needed the non-critical loads will be disconnected until the state of charge of the batteries reach the critical load worst case autonomy.

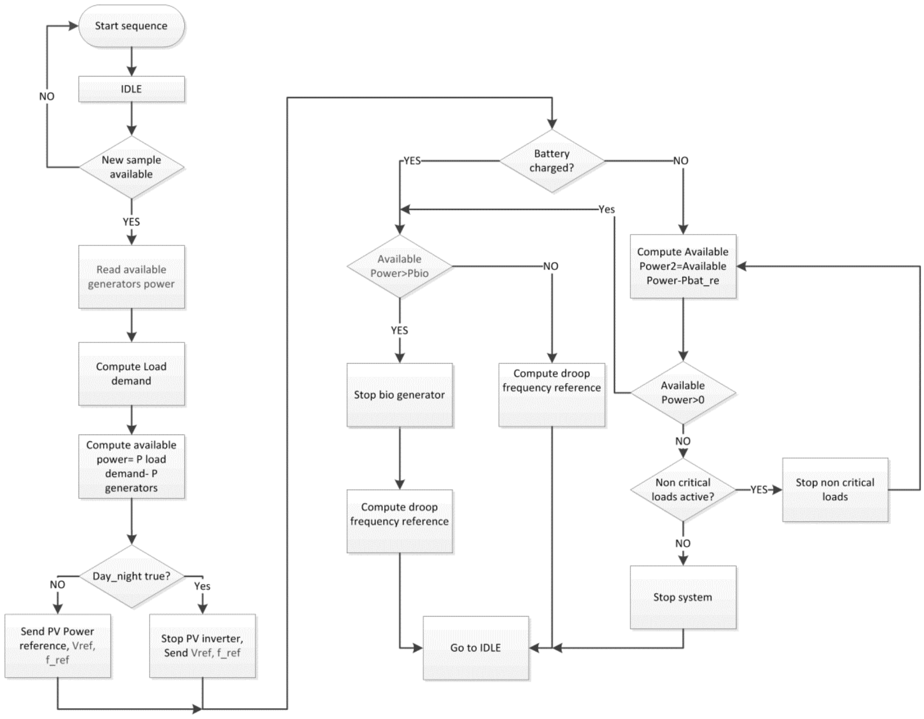


Fig. 4. Proposed energy management algorithm.

IV. Simulation and Results

A model for the proposed microgrid was developed and simulated in PSIM. Three different scenarios are presented to prove the working principle of the system.

A. Case I: Steady state operation

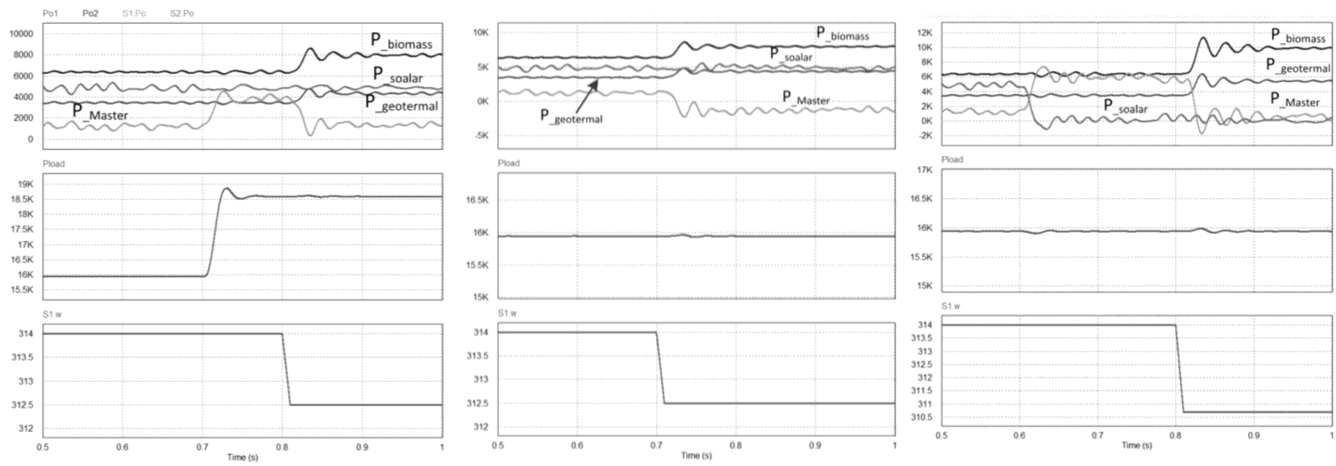
Fig. 5a) presents the steady state operation scenario of the proposed microgrid. The scenario considered is characterized by the following parameters: the solar generator power is 5kW, the geothermal power is 4kW, the biomass generator power is 6.2kW, and the load power consumption is 16kW. The scenario presents a load step of 1.5kw at 1.1s. The energy management system controls the generators in such a way that the energy subtracted from batteries is zero in steady state operation. It can be observed in Fig. 2 that first the surplus of energy is supplied by the master inverter from batteries and then the management system will decrease the system frequency reference (w_{ref}) in order to increase the geothermal and biogas generators power.

B. Case II: Battery charge

Fig. 5b) presents the battery charge operation scenario and is characterized by a 5kW solar power, constant 16kW load, 3.4kW geothermal power, and 6.35kW biomass power. At 0.7s the energy management system considers that the batteries need charging and decreases the AC bus reference frequency at 49.8Hz. As a result the geothermal generator increase its output power to 4.1kW and the biomass generator to 8kW, in accordance to their droop characteristic and because the load is constant the surplus of energy is absorbed by the master and stored into the batteries. This state will be maintained until the batteries are charged.

C. Case III: No solar irradiation

Fig. 5) presents a scenario where the irradiation decreases from 5kW to 0 at 0.6 s. As a result the master inverter will increase its output power to supplies the load from batteries. The Energy management system after a short period of time decreases the AC bus frequency in order stop the discharging of the batteries. In this way the geothermal and biomass power are increased and the master inverter power is brought back to 0.



a) b) c)

Fig. 5. Scenario results.

V. CONCLUSIONS

This paper presented the modeling and control of a renewable energy microgrid that supply a vegetable greenhouse. The considered renewable energy generators were: a geothermal generator, a biomass generator, a solar generator and battery storage. The power flow between the generators and the load in the microgrid is controlled using a two level hierarchical structure: a primary level based P-f droop control and a secondary level based on communication. The main goal of the proposed control method is to maintain the energy consumption from batteries as low as possible. The microgrid and the proposed control structure were simulated in PSIM and tested in three different scenarios. The simulation show that when a perturbation appear (load variation, solar energy variation) the master inverter acts as a buffer supplying the load from batteries for a short period of time until the power management system brings the operation of the microgrid to a new steady state operation point where the master inverter power is close to zero. The simulations prove the proper steady state operation of the microgrid for different load and climatic conditions.

VI. ACKNOLEDGEMENT

This paper is supported through the programme "Parteneriate in domenii prioritare – PN II", by MEN – UEFISCDI, project no. 53/01.07.2014.

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