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A MICROTURBINE MODEL INCLUDING ITS CONTROL FOR THE INVESTIGATION OF THE EFFECTS OF DISTRIBUTED GENERATION IN DISTRIBUTION NETWORKS

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The paper proposes a detailed model of the thermal and mechanical part of a microturbine; in fact this model accounts for three control loops: a speed controller (for primary frequency control), an acceleration control loop, which limits the rotor acceleration in case of sudden loss of load or in case of start-up, and a controller which limits the temperature of the exhaust gases below the maximum admissible temperature.

Moreover the paper adopts a PV (active power – voltage) control of the inverter for the microturbine operation on the grid; the usual scheme adopted is a PQ (active power – reactive power) control, which regulates the values of active and reactive powers injected by the inverter into the grid. The use of a PV control scheme allows to evaluate the contribution of microturbines to voltage support in distribution grids. In case of isolated operation a Vf (voltage – frequency) scheme is adopted. A test grid is implemented and the results of the simulations are described and discussed.

Keywords: distributed generation, microturbines, active and reactive power controls, voltage and frequency controls.

1. Introduction

Distributed Generation has been diffusing very much in the last times and is expected to increase even more so that electric distribution networks will transit from *passive* to *active* management. *Active networks* are electric distribution networks with a significant presence of distributed generators of small and medium size, such as microturbines, photovoltaic sources and fuel cells [1].

In this paper a microturbine plant model is presented together with a thorough description of the main controls (prime mover controls, rectifier and

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inverter controls). Two different operational configurations are considered: grid – connected operation and stand – alone operation.

The microturbine modelling has been considered in different studies [2], where the authors have focused their attention on Park's transformation based inverter controllers in order to decouple the controls of active and reactive power [2][3] and they have modelled the thermo-mechanical part of the microturbine in a simplified way.

The aim of this paper is two-fold: (a) to provide a detailed model of the thermo-mechanical part of the microturbine, which can be important to assess the real behaviour of the prime mover during severe system transients; (b) to evaluate the possible voltage support to the grid which can be provided by a microturbine by adopting a PV inverter control, instead of a traditional PQ inverter control [2].

2. Overview on the microturbine model

The detailed microturbine model, presented in Fig. 1, has been implemented in DIgSILENT PowerFactory [4]. The implemented five control loops act on:

- the synchronous generator to control speed, acceleration and the temperature of exhaust gases;
- the rectifier for the control of the DC voltage (α is the firing angle);
- the inverter.

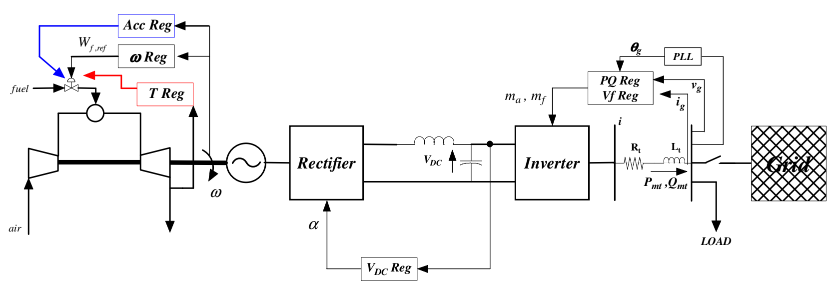


Fig. 1. Microturbine based generation plant with its control loops

3. The thermo – mechanical part

The microturbine is endowed with an acceleration control, a speed control and a control loop for the exhaust gases temperature. The speed controller is a PI controller. The other two control loops have been modelled by taking into account a heavy duty gas turbine model in [5], an Italian power system simulation tool, and by adjusting the parameter values according to [6]. The thermo-mechanical part of the microturbine with the three control loops is shown in Fig. 2.

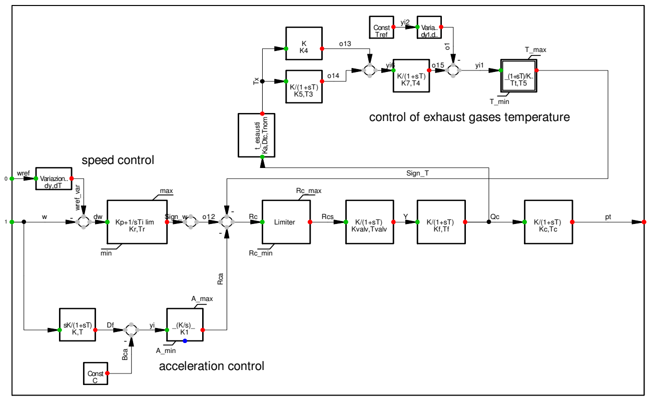


Fig. 2. Detailed scheme of the microturbine with relevant controls (acceleration, speed and temperature control)

The implemented model does not hold valid in case of microturbine start – up, because it is based on the assumption that the microturbine speed is not too different from its nominal value.

The acceleration control loop usually intervenes during start-up transients and in case of fast reductions of the system load. In these cases the implementation of an acceleration loop is essential to correctly evaluate the power system dynamics. The event of a fast load reduction will be examined in the simulations. The model also implements a control loop to limit the microturbine output in case of a too high temperature of its exhaust gases.

The considered microturbine plant contains a 150 kVA high speed synchronous generator with a nominal rotational speed equal to 70000 rpm and a nominal voltage equal to 500 V.

4. Rectifier and inverter controls

In order to keep the DC voltage constant in case of external events, a voltage controller has been implemented for the rectifier. This controller acts on the thyristors of the rectifier to keep the DC-link voltage constant.

It is a PI controller which receives the voltage error at the DC bus and it provides the firing angle. In the simulations it is evident that a higher request for power implies a partial discharge of the filter condenser. As a consequence, the mentioned voltage regulator reduces the firing angle of the rectifier and it restores the DC voltage to the predefined value.

The DC/AC converter considered is a VSI, Voltage Source Inverter, controlled by a PWM technique. A different type of control is used if the machine is connected to the external grid or if it is operating in island. In particular, in case of connection to the grid one of the following controls can be implemented: PQ control and PV control. On the contrary, in island condition the Vf control is used.

The outputs of the inverter control system are represented by the modulating signals used to implement the PWM technique on the inverter. The status of the interface switch allows to select the signals coming from the PQ/PV control or from the Vf control.

In case of PQ control [2], the controlled variables of the inverter are the active and reactive power injected by the inverter which must follow the relevant setpoints, P_{ref} and Q_{ref}. These values can be manually set or they can be provided by a remote controller.

In order to decouple the channels of active and reactive power, a vector control technique is adopted. The inverter is current controlled and the control system is implemented in the rotating reference of dq axes. Thus active power is controlled through a closed loop on the direct axis current (i_d) and the reactive power is controlled similarly by acting on the quadrature axis current (i_q).

It is thus necessary to measure the phase angle of the voltage to implement Park's trasnformation, which is realized with a PLL (Phase Locked Loop).

In case of PV control, the controlled variables are the voltage magnitude at the bus controlled by the inverter and the active power injected by the inverter, which must follow the relevant setpoints, respectively V_{ref} and P_{ref}.

The voltage error between the voltage setpoint and the magnitude of the controlled voltage is sent to a PI regulator, which provides the reference q-axis current. The d-axis control channel is still used to control the active power injected by the inverter.

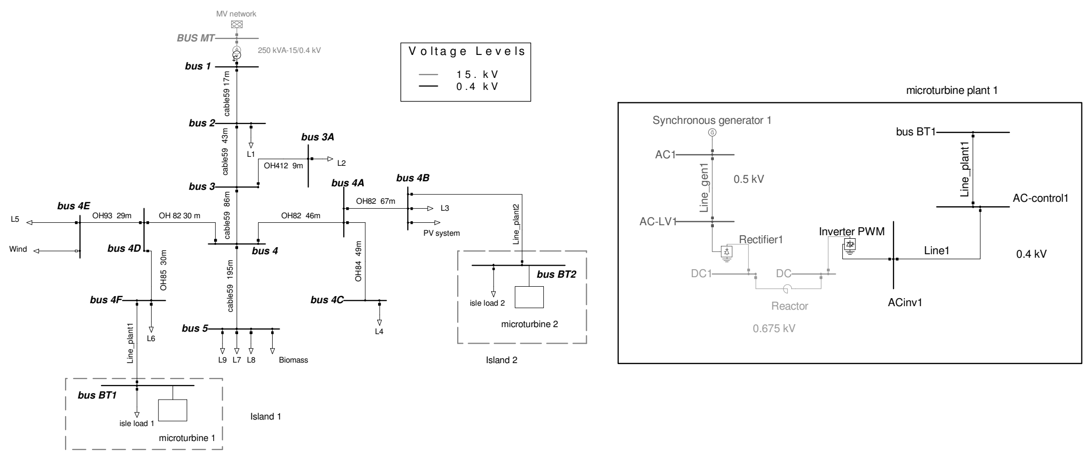
In case of Vf control (stand-alone operation) the controlled variables are the magnitude and the phase of the voltage.

In this case, the measure of the voltage pulsation by the PLL does not exist, because the grid does not impose the frequency. An internal oscillator at the desired frequency (50 Hz) is adopted and it provides the necessary signals for the inverter modulation.

5. The test system

The test system mainly consists in a rural network model derived from DISPOWER Project [7]. It is a LV distribution network with microturbine generators and simplified representations of a PV (photovoltaic), a biomass plants and of a wind generator. It consists of several radial LV feeders, a MV-LV transformer and an external MV grid. The load profile is obtained from realistic (weekly, daily and inter-hour) data about the consumptions of a typical LV distribution grid [7]. Two loads have been added to the grid at buses BT1 and BT2 to simulate the loads which can be fed by the microturbines in a stand-alone operation.

Fig. 3 shows the test system and a detail of microturbine plant 1.



(a) (b)

Fig. 3. Test system (a) and a detail of the microturbine system for plant 1 (b)

The load level assumed in the simulations corresponds to the loads on a typical Wednesday at 7.45 p.m., which represents the scenario with the worst voltage profile for the LV distribution grid. Table 1 shows the active and reactive power absorbed by the loads in this scenario. The biomass, the wind and the photovoltaic systems are out of service at 7.45 p.m., thus they are not in Table 1.

Table 1

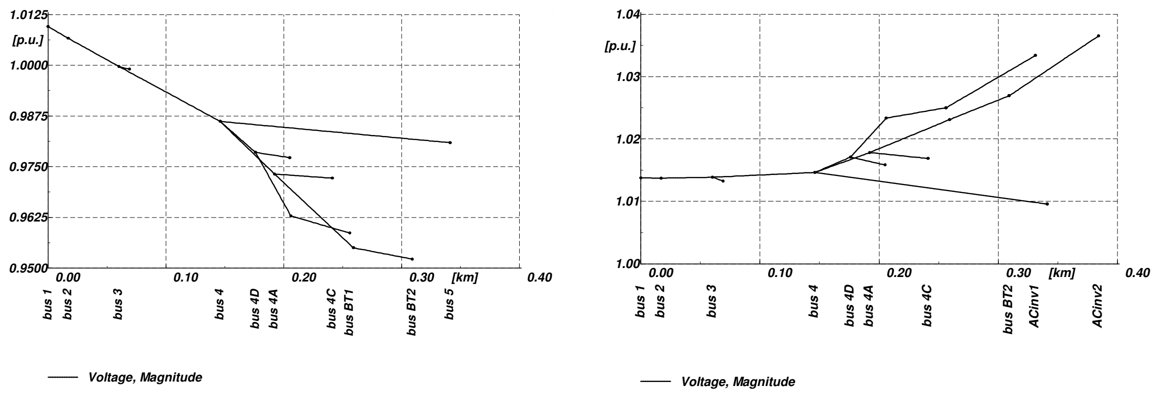
Load demand for the LV distribution grid

Load	P [MW]	Q [MVAr]	Load	P [MW]	Q [MVAr]	Load	P [MW]	Q [MVAr]
L1	0,009	0,004359	L4	0,003	0,001859	L7	0,012	0
L2	0,009	0,00675	L5	0,006	0,0045	L8	0,009	0,00675
L3	0,021	0,013015	L6	0,003	0,00225	L9	0,012	0,007437

Fig. 4(a) shows the voltage profile on the feeders of the grid under the assumption that the microturbine plants do not operate and the isle loads are respectively 0.04MW/0.01 MVAr and 0.025MW/0.01 MVAr for plant 1 and plant 2. The grid voltage is assumed equal to 1.04 p.u.

The presence of such significant isle loads at buses BT1 and BT2 makes the voltage profile quite critical; in fact the voltage drop from bus 1 to bus BT2 is equal to about 6%.

The introduction of two microturbine plants at buses BT1 and BT2 can improve the voltage profile on the grid. We assume that the inverter in island 1 is PV controlled when connected to the grid, while the other inverter is PQ controlled. Fig. 4(b) shows the voltage profile on the grid with the same assumptions about the load profile, but in case of microturbine operation; the inverter in plant 1 keeps the voltage at the controlled bus (AC-control1) at 1.025 p.u., while the active power setpoint is 0.06 MW. For microturbine 2 the active and reactive power setpoints are respectively 0.06 MW and 0.03 MVAr.



(a) (b)

Fig. 4. Voltage profile along the feeders of the LV distribution network: (a) without microturbine plants; (b) with microturbine plants

It can be noticed that the voltage trend changes the sign of its slope along the feeders containing the microturbines. Moreover, the voltage drop between bus 1 and bus 4 and the active power flow along the transformer change their sign; in this condition the LV grid exports 0.0015 MW towards the MV grid, while in the first situation it imports 0.1237 MW from the MV grid.

6. Some simulation results

This chapter analyses the results of some simulations carried out on the test grid, by adopting the dynamic models of the prime mover and of the control systems already analysed in the previous chapters. In particular, the two microturbines will operate as follows: (a) when microturbine 1 is connected to the grid its inverter will be PV controlled; (b) when microturbine 2 is connected to the grid its inverter will be PQ controlled; (c) when one of the two microturbines operates in a stand-alone mode, its inverter is always Vf controlled.

Some of the analyzed contingencies refer to the interconnected operation and others refer to the stand-alone operation. Table 2 shows a list of contingencies for the grid connected operation of the microturbines:

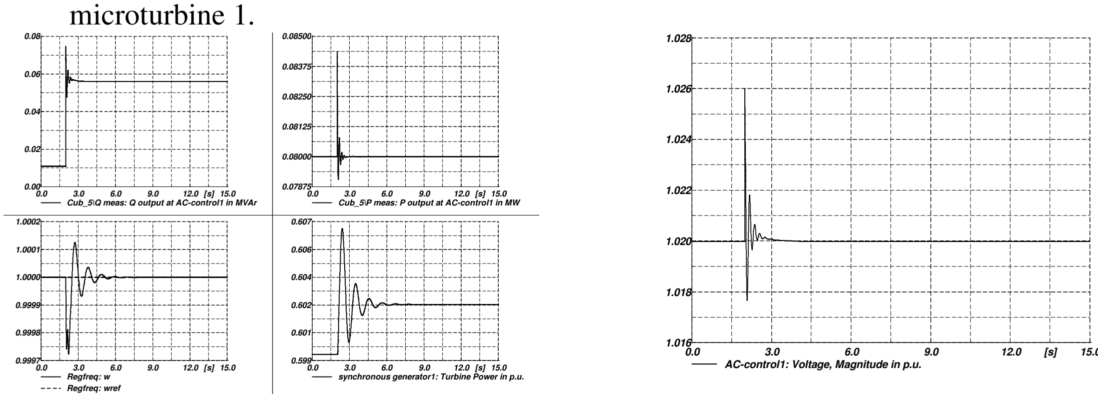
Table 2

List of contingencies in the grid connected operation

Simulations	Events	Goal
Sim_con_1	Variation of the V setpoint of the PV controller (inv. 1) from 1.02 p.u. to 1.035 p.u.	To assess the correct operation of the PV controller for inverter 1
Sim_con_2	A 200% load increase at load L3	To assess the behaviour of the two inverter controllers
Sim_con_3	Variation of the Q setpoint of the PQ controller (inv. 2)	To assess the correct operation of the PQ controller

In all the mentioned simulations the following values of active and reactive demand of the isle loads are assumed: 0.06 MW/0.02 MVAr for isle load 1 and 0.06 MW/0.01 MVAr for isle load 2. The initial setpoints for the two inverters are respectively V_{ref}=1.02 p.u.; P_{ref}=0.08 MW for inverter 1 and P_{ref}=0.08 MW; Q_{ref}=0.02 MW for inverter 2.

For the sake of brevity, only the results of simulation *Sim_con_2* will be described and discussed. In this simulation at t=2s load L3 undergoes a 200% increase of its active and reactive demand. Fig. 5(a) shows the active and reactive powers injected by inverter 1 and the speed and the turbine power related to microturbine 1.



(a) (b)

Fig. 5. (a) Reactive and active power of inverter 1, speed and turbine power for microturbine 1; (b) Voltage magnitude at the controlled bus in plant 1

The reactive power injected increases (ΔQ=+0.045 MVAr) in order to restore the voltage at the controlled bus to the predefined voltage setpoint. In fact Fig. 5(b) shows that the voltage comes back to 1.02 p.u.

As for microturbine 2, the active and reactive outputs of the inverter remain unchanged after a short transient, while the AC voltage at AC-control2 diminuishes. This causes an increase of the current provided by the inverter, thus an increase of the losses on the line which connects bus ACinv2 to bus AC control2. This in turn causes a slight increase of the turbine power (see Fig. 6).

Now Table 3 shows a list of simulations performed considering a stand-alone operation of one of the two microturbines.

Table 3

List of events in stand-alone operation

Simulations	Events	Goal
Sim_iso_1	Opening of the interface breaker for island 1 in case of initial power export	To evaluate the behaviour of the acceleration controller.
Sim_iso_2	Opening of the interface breaker for island 1 in case of initial power import	To assess the behaviour of the modelled thermo-mechanical part of the microturbine

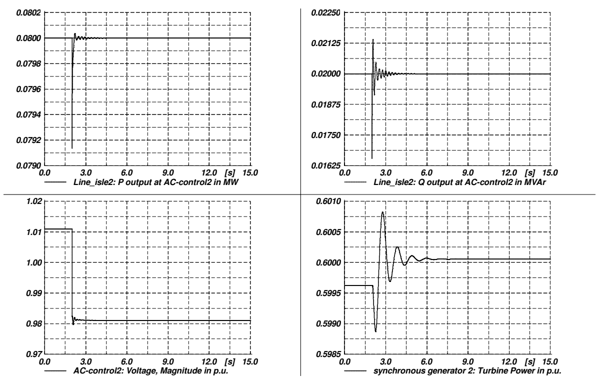
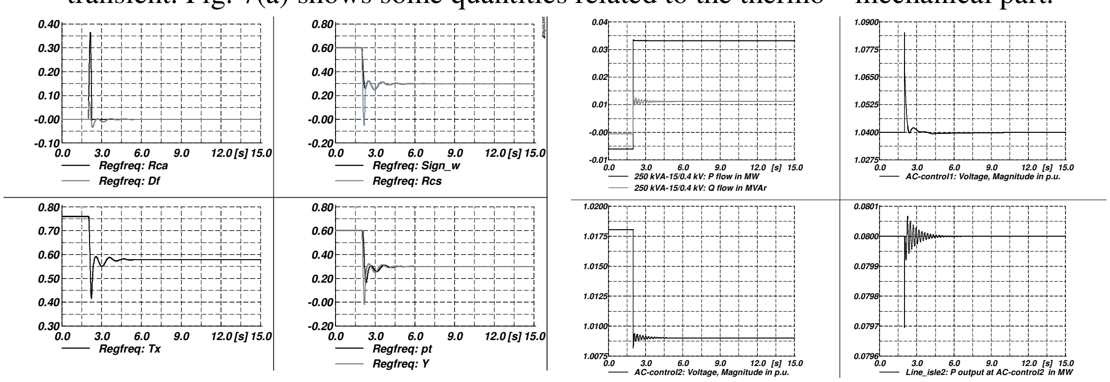


Fig. 6. P and Q of inv. 2, voltage magnitude at AC-control2 and turbine power of microturbine 2

For the sake of brevity only the results of simulation *Sim_iso_1* will be described and discussed. In this simulation at t=2 s the interface breaker at bus BT1 is opened, thus making microturbine 1 work in an isolated system (island 1). The island load absorbs 0.04 MW and 0.02 MVAr, while the active power and the voltage setpoint for inverter 1 are 0.08 MW and 1.04 p.u.. The island is initially exporting 0.04 MW and 0.0115 MVAr towards the LV grid.

The opening of the breaker determines a significant power mismatch and a consequent rotor acceleration. The excessive acceleration causes the intervention of the acceleration loop which diminuishes the fuel demand in the first part of the transient. Fig. 7(a) shows some quantities related to the thermo – mechanical part.



(a) (b)

Fig. 7. (a) Mechanical quantities related to microturbine 1; (b) P and Q flow along the MV-LV transformer, voltage magnitude at AC-control1 and AC-control2, P output of inverter 2

It can be noticed that the acceleration control intervenes because the initial speed rate is higher than the intervention threshold. This reduces the virtual signal associated to the fuel demand (R_{cs}). Also the temperature of the exhaust gases diminuishes because the power demand is drastically reduced.

Thanks to the speed controller, the speed of the microturbine comes back to the original value. The inverter outputs quickly respond to the new configuration, while the turbine power reaches its new steady state value (0.298 p.u.) after about 4 seconds.

Fig. 7(b) shows the active and reactive power flow along the MV-LV transformer, the voltage magnitude at AC-control1 and AC-control2 and the active power output of inverter 2.

The microturbine with a PQ controlled inverter shows a short transient after which the active and reactive outputs of the inverter remain at the initial values, while the voltage at AC-control2 diminuishes. In the initial condition, island 1 provides the reactive power which is requested by isle load 1 and it exports part of the reactive power and a large part of the produced active power (0.04 MW) to the LV grid. The islanding of microturbine 1 causes an inversion of the active and reactive power flow along the MV-LV transformer, which initially exports 6 kW and 0.4 kVAr.

7. Conclusions

This paper has described a detailed model of a microturbine, which can be exploited in dynamic studies for the evaluation of the effects of DG penetration into distribution networks. The paper also presents the application of a PV controller to the microturbine inverter in the grid – connected operation. The loadflow analyses show that these microturbine plants can provide an important reactive support on weak (rural) LV networks. The dynamic simulations are partly devoted to validate both the PQ and the PV controller and partly dedicated to describe the interaction of the two microturbine plants in case of contingencies.

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