MICROGRIDS OPERATION WITH MICRO DISPERSED GENERATORS AND RENEWABLES

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ABSTRACT

The biggest challenge in the contemporaneous world: maintain the supply of electric energy with reliability and quality. A lot of technological solutions, involving telecommunications, energy storage, dispersed generation (DG) with alternative sources and another usual electric generation, are in large scale implementation. Moreover, Microgrids (MG) concept is in large discussion in order to obtain better results in operation and management of this new distribution system. Local black start strategies are one of the most important implementation for that new kind of grid. In the first phase of the R&D project developed with CPFL, one Brazilian electric utility, inside of the environment of ANEEL, the Brazilian Regulatory Agency to the electric system, it was made a study concerning the technologies of distributed micro generators and connection requirements. Models and control strategies simulations have been done in order to reproduce the performance of this energy sources when connected in the grid during the practice tests. It was evaluated topologies with resistive loads, capacitive loads, and inductive/non-linear loads. These topologies are in parallel with the distribution utility grid using a special test bench able to synchronize the energy and power quality measurements of all devices.

INTRODUCTION

Recent technological advances in various types of DERs – Distributed Energy Resources, including microturbines, photovoltaics and battery banks, have created the opportunity for large-scale integration of DERS in distribution systems. The supply can be located in the most practical approach to meet the growing demand for energy, respecting the requirements for power quality, given the network structure of the concessionaire and the public environment policy.[1] There is great demand for energy to support the growth of diverse areas of the economy around the world. Although these technologies seems attractives, there is a need for in-depth studies on the impact of connecting these technologies in the distribution networks.[2] Studies on the DG connection at low voltage are preceded by thorough evaluation of the IEEE. 929-2000 [3] and IEEE Std 1547-2003 [4]. In order to maintain a high degree of quality of energy supply and reliability, an increasing competition between these companies takes place [5]. Both standards presents a great discussion about the intentional islanding, independent of the technology in use.

PROBLEM DESCRIPTION

This approach comprises the first phase of the project entitled "Analysis of Sources and their Impact on DGs utility network - phase 2" in your step number 8, and aims to expose the steps of preparation and execution of laboratory tests performed. In this study it was investigated the control characteristics of these equipments (MT and PV), starting from its operation in parallel with the laboratory loads, in different test conditions, comparing them with results obtained from simulations in Simulink – Matlab. The goal is to define what the control strategy adopted by the equipment for its operation, both in islanded and connected mode to the distribution grid.

MICROTURBINE

Among the different sources of DG, microturbines shows great promise because of the ability to use different fuels with greenhouse gas emissions very low, high efficiency and reliability. Also, thanks to the possibility of integrating them into common facilities, both in terms of gas and electricity, installation costs can be reduced [6].

Microturbines are a kind of small gas turbines and an output power of the simple cycle that can range from 25 to 300 kW. Operating at high speed (50 000-90 000 rpm) with bearings airfoil. Have reduced size and is connected to the load thru power electronics board. The main components of a microturbine are:

- Compressor: whose function is increase the air pressure using part of the power delivered by turbine [7];
- Combustion chamber: where occur the burning fuel;
- Generator: composed of a permanent magnet synchronous machine mounted on the same shaft of

turbine, being able to reach a high speed to rotation [8].

- Recuperator: responsible to leverage the thermal energy of gases exhausted from the turbine [7].
- Turbine: provide power to trigger the compressor and electrical generator that stay mounted on the same shaft [7].

The microturbine can operate in stand-alone mode, where the initial energy of the system comes from energy storage/power source (e.g. capacitors and battery) and has a constant voltage, grid-connected mode, where the grid provide the energy needed to start a prime mover and the MT operate to maintain their current constant and in dual mode, when the MT operate both ways [9].

Microturbine Model

For the black box linear model, were used second order transfer functions, correlating the input and output of the system in order to obtain a dynamic nearest the real microturbine, subjects to load variations. The data used for development of the model were obtained in practice tests with microturbine operating in islanded mode. For analysing the microturbine dynamics, was calculated the rms (root mean square) value of signals.

To find the transfer function that represent the microturbine output voltage dynamics, was used the disturbance-rejection problem, resulting the equation (1)

$$\frac{Y(s)}{q(s)} = \frac{T_i \tau K_2 s^2 + T_i K_2 s}{T_i \tau s^2 + (T_i + T_i K_1 K_2 K_c)s + K_1 K_2 K_c} \qquad (1)$$

Y(s) is the outupt voltage, Q(s) is the step load disturbance. K_c is the PI control gain, T_i is the integral constant time of PI control, K_1 is the turbine gain, τ is the turbine constant time and K_2 is the generator gain.

To obtain the PI control, turbine and generator parameters, was used a characteristic second order transfer function with one zero, given by (2).

$$FT_{CARACT} = \frac{(b_1 s + 1)\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad (2)$$

The damping coefficient ζ , the natural frequency ω_n are obtained from rms signal. The best coefficient b_1 was found through an iterative process, evaluating the coefficient of determination R^2.

The figure 1 shows the voltage dynamic model proposed for Capstone C30 microturbine, and implemented in Matlab-Simulink®.

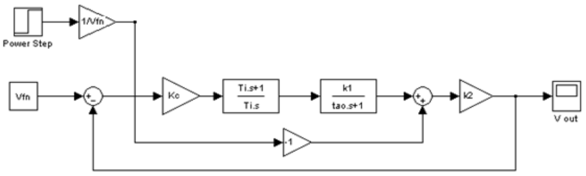

Figure 1 – Block diagram of voltage model for the Capstone C30 microturbine

PHOTOVOLTAIC

The characteristic equation which represents a photovoltaic cell is given by (1)

$$I_{SC} - I_D - \frac{V_D}{R_P} - I_{PV} = 0 \qquad (1)$$

Where I_{SC}, I_D, V_D/R_P, I_{PV} are diode current, the current which represents the photovoltaic effect, current through the shunt resistor and the current given by the photovoltaic cell respectively.

The photovoltaic modules are interconnected in order to obtain a greater energy production. The PVs are connected to inverters that convert DC into AC voltage, which allows your connection to the utility, also aiming at the protection of such equipment. The constant monitoring of the network condition, allows the automatic disconnection of the system due to a failure [10].

Photovoltaic Model

From the Kyocera KC125GT datasheet was gotten the necessary parameters for modeling the photovoltaic panel. It was used the model developed and implemented in Matlab-Simulink® (ECEN) for the photovoltaic panel, MPPT algorithm and DC/AC inverter [11]. The parameters of this models, and the control system were tuned for finding similar voltage and current performance, to thus obtained in the tests.

The injected current by the PV system on the utility connection bus, must be in phase with the utility voltage, for this reason a PLL (phase-looked-loop) controller is necessary. For modeling purpose, the PLL was implemented in a simplified way, in order to obtain a unitary sinusoidal signal in phase with the utility voltage. To obtain the reference current, the value of the power delivered by the photovoltaic panel was divided by the line-line voltage utility, then was calculated the amplitude of the current reference and multiplied by the unitary sinusoidal signal, above mentioned [12].

Knowing the reference electric current, an hysteresis control was used for commanding an H-bridge switching inverter.

The output of this inverter is a sinusoidal current, which corresponds to the current generated by the PV system.
For its operation, the PV system needs a voltage signal reference, commonly the grid voltage. In the simulations, the microturbine voltage was the reference for the PV system.
In order to protect the PV system, one control solution was implemented and it´s operate as a switch, disconnecting the PV system when the AC-voltage variation is greater than a set limit.

SIMULATIONS AND RESULTS

The performance of the Capstone C30 microturbine in islanded mode was analyzed for variation of resistive load 0-15 kW. The model implemented in Simulink-Matlab® to represent the practice test condition is shown in Figure 2.

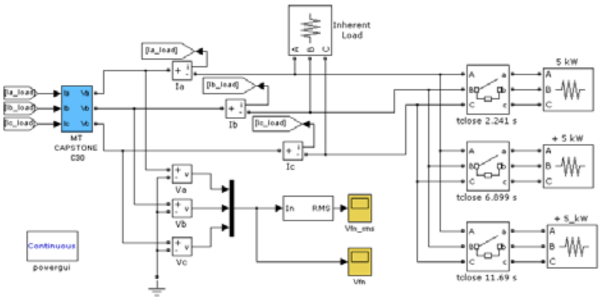

Figure 2 – Model to represent the variation of resistive load for the Capstone C30 in islanded mode

It was evaluated the transient behavior of the Capstone C30, comparing the model simulated with practice tests. It was proposed a model including the voltage control and a simplified model for the microturbine's inverter.
In the Figure 3 are shown the rms signal of voltage and current of phase A, comparing the simulated and the real answer.

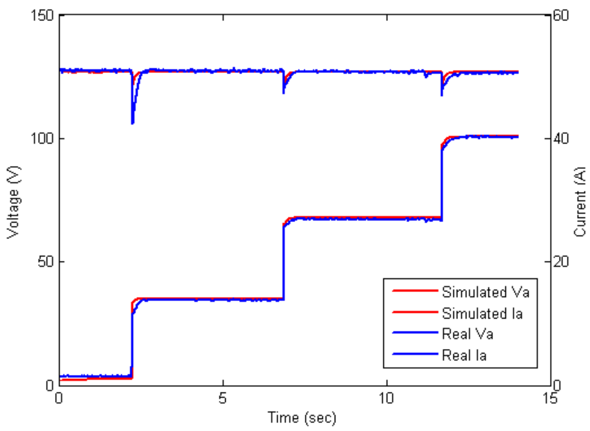

Figure 3 – Results from the practice tests and the model proposed for the Capstone C30

The outputs from the developed model presented values of voltage and current similar to the real MT. The voltage variation occurs inversely to the load variation.
The first step load (0-5 kW), showed a greater difference between the model simulated with practice tests. It could be explained because of the non-linearity of the process.

After validating the model of the Capstone C30 in islanded mode, the performance of the PV system was analyzed. A test where the microturbine voltage was used as a reference for the PV system was performed. A resistive load was varied from 5 to 20 kW, in 5 kW steps. After that, the load was taken out.

The model implemented in Simulink-Matlab® to represent the practice test condition is shown in Figure 4.

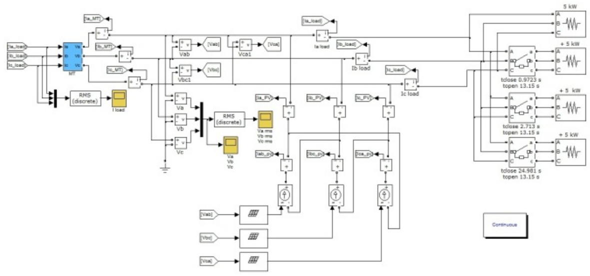

Figure 4 - Model to represent the variation of resistive load for the PV system connected with the Capstone C30

Figure 5 shows the rms voltage signal in the ac bus and the figure 6 the output PV System current.

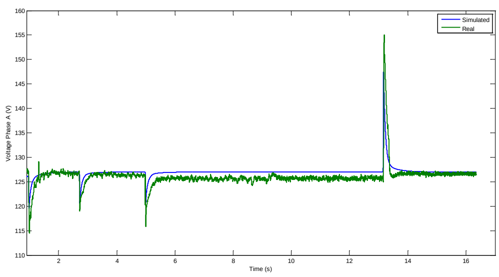

Figure 5 –Voltage rms signal when the PV system is connected with the Capstone C30.

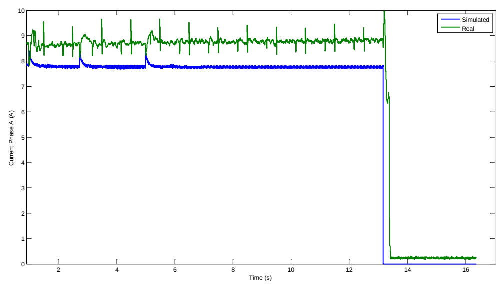

Figure 6 - Current rms signal in the output of the PV system when connected with the Capstone C30.

The outputs of the system, both for current and voltage, showed a faster dynamics for the tests with PV. The PV system current remains practically constant, indicating no change in radiation during the test. At a specific moment, the PV system lost the synchronism because of the abrupt voltage variation.
The Figure 7 presents the comparative between the simulated and measured sinusoidal currents on PV system.

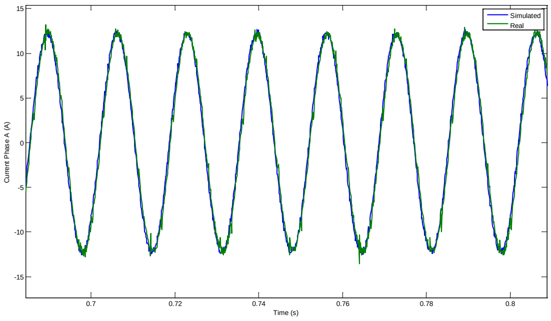

Figure 7 – Output sinusoidal current result of the PV system.

The figure 8 presents frequency spectrum of the signal showed in figure 7.

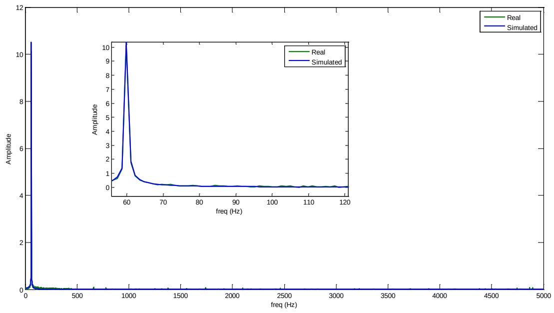

Figure 8 – Frequency spectrum of the model and practice test current

There is a good approximation of the model's response when compared to the signal recorded in the test. The differences between the measured and simulated outputs may be due to differences in the inverter’s control and the filter output.

CONCLUSIONS

In this work were proposed models for a 30kW MT and a 7,5kW PV system. The model proposed for the MT was a black box model. For the MT modeling the parameters of the proposed linear voltage control system were obtained from the practice tests.
The PV system was reproduced by an electrophysical model. A hysteresis control was used for commanding the H-bridge switching inverter.

The validation of these models was made for different configurations tests with resistive load variations, and for the interconnection of them.

Considering the conditions and restrictions recorded during the measurement process, the results obtained for the voltage and current output, compared to those of the developed model, showed great approach, thus reaching the objective proposed in this paper.

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