Wind energy conversion control with local data measurement

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***Abstract*— This paper aims to presents the results obtained in electromechanical wind speed emulator of distributed low power system. The results are obtained in insulated regime with a step up/down converter, battery bank and resistive load. All the operating regions are aimed, namely optimization and power limitation one, and also an intermediate operating region is considered in order to ensure smooth transition between these two regions. For control purpose an improved strategy is proposed. Hardware implementation is done under DS1103 controller board running under Matlab and ControlDesk® software. This paper present results from a functional low power wind system, part of a distributed multisource low power system, which offer also the possibility of implementing the behavior and the control of such systems, in grid-connected or disconnected from the national grid. Experimental results show the effectiveness of the proposed system under various conditions.**

***Keywords*— small wind energy conversion system, autonomous low power wind system simulator, PMSG, intelligent hierarchical system**

I. Introduction

Most of control approaches regarding wind systems consider the main exogenous variable, the wind speed, as disturber and also measurable variable that interferes in the control structure. Measuring wind speed can be a disadvantage due to numerical errors that can occur. Studies have been made for modeling the wind speed in relation to technical specification of the wind turbine blade length, tower high and different dynamics that can interfere. The accuracy of these models is in continuous development and is dependent of how many interfering dynamics and variables related to these are considered. The present paper uses methods of control that envisages different variables of the system measurable with system transducers, and eliminates the need of including measured wind speed. These control methods are implemented locally. The approached wind system is a low power one.

According to the technical literature, small systems architecture is based mainly on PMSG, fixed pitch and variable speed operation [1], [2], [3]. The present paper presents also a setup based o PMSG, see Figure 1. It is an experimental system for the intelligent hierarchical control of distributed systems, for producing and using electrical energy. Two main sources are connected to the system: a wind turbine with permanent magnets synchronous generator and photovoltaic panels, both supplying, via frequency converters with MPPT function, into a 48V DC Bus, further to electrochemical batteries and to an active filter (APF) connected to the three-phase national grid, through a 1:1 galvanic isolation transformer [4].

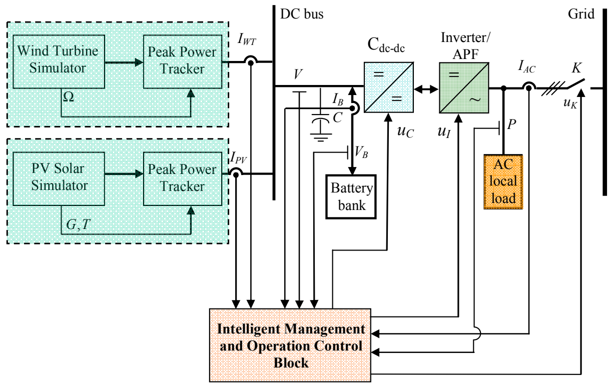


Fig. 1. Structure of the distributed low power system [4]

The experimental rig represents a strong support for further testing scenarios in relation to the grid. In the present paper, only wind turbine side contribution is evaluated enclosing the transmission to the DC Bus and the supply of the DC loads. The power electronics is represented by a DC buck-boost converter. Local control approaches were used for the DC conversion structure: Perturb & Observe (P&O) and Incremental Conductance (IC) method. They have the advantage of not needing an external command, being based only on the data acquisition used for monitoring the system operation.

II. THEORETICAL ASPECTS

The DC-DC converter structure has a SEPIC topology that meets two main requirements: ensures the needed input-output voltage range and the power module design can be easily converted to a boost topology. The PMSG output voltage after the diode rectifier stage can be up to 90V, as it can be seen on the below characteristic. The chopper output voltage is imposed by the DC Bus (48V) and depends mainly on battery bank charging state. Because the second energy source used in the experimental rig is a PV panel emulator with up to 30V output, it should be interfaced to DC Bus by a boost chopper. The same PCB can be used for both SEPIC and boost converters structures [5] and this gives the possibility of an easier manufacture procedure.

The chopper design is detailed in [5]. Due to the compact PCB implementation that can be seen in Figure 2, with the power components, transducers and dsPIC controller on the same board, some basic rules had to be followed during design and manufacture stages:

- low interference path – separating the ground paths avoiding the ground loops, shielding;
- strengthened paths for high current;
- analog inputs filtering;
- overvoltage limiting with care on possible overvoltage that can occur at accidentally battery disconnection.

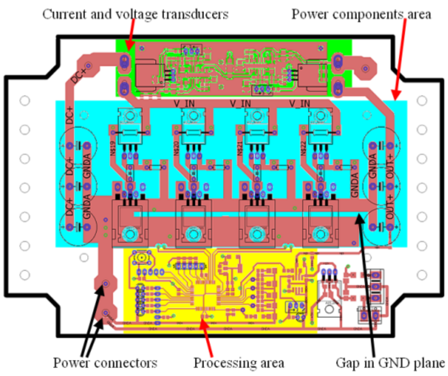


Fig. 2. DC-DC converter PCB [5]

The chopper final structure is presented in Figure 3. A small HMI with display is used for local monitoring and control type selection.

The chopper can be piloted by local control or remote. For the remote control, only the PWM reference is needed as chopper input and this allow different type of control to be implemented externally.

The results presented in this paper are based on local control. Two Maximum Power Tracking (MPPT) algorithms were used: P&O and IC method.

Fig. 3. DC-DC convertor used for the PMSG connection to the DC Bus: inductors and capacitors box, PCB and conectors box, user interface

The classical P&O [6] was improved with a second loop that minimizes the used perturbation in order to reduce the searching time and limit the possible overshoots:

```
while labs(ppv_pert-ppv_c)<=(ppv_c shr 6) do
begin
d_fu:=d_fu+1;
set_fu_4x_PWM(fu+d_fu); delay_us(100);
read_analog_inputs();
```

The IC method implemented was described in [7]. In short terms, IC method resumes at the following test, on each iteration. The *ppv* notation means computed input power and *upv* means measured input voltage.

```
if ((ppv_c>ppv_old) and (upv_c<upv_old)) then fu:=fu+5;
if ((ppv_c>ppv_old) and (upv_c>upv_old)) then fu:=fu-5;
```

The PMSG output voltage is proportional to the estimated shaft rotational speed. The relation between the output power and the shaft rotational speed is not linear, as it can be seen in Figure 4.

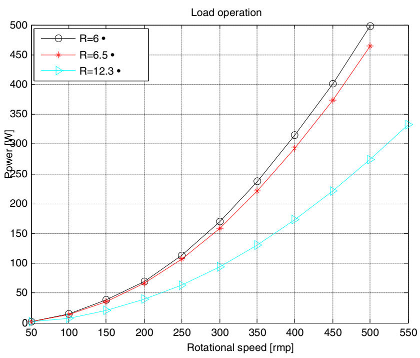


Fig. 4. Output power – rotor speed characteristics of the PMSG [4]

III. EXPERIMENTAL RIG

The wind energy conversion system (WECS) are systems for which the real-world validation of various control laws through off-line simulations involves new technical approaches concerning the outside wind speed, but in controlled wind speed regime [8], [9], [10], [11], [12].

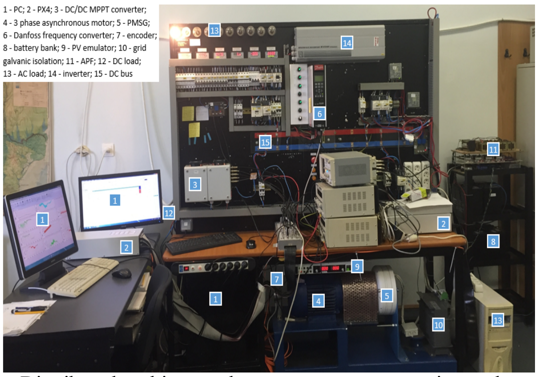


Fig. 5. Distributed multisource low power system experimental setup [4]

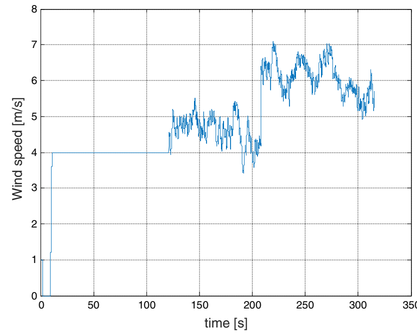
Figure 5 displays physical elements of the experimental setup used in this paper. The experimental rig is composed of: a 3 kW squirrel cage 3ph asynchronous motor, a 5kW frequency converter Danfoss VLT 5000 Flux, an encoder, a PMSG, GL-PMG-1500 type [13], with a rated power of 1.5 kW, a SEPIC converter with MPPT function, batteries and a computer connected to the dSPACE® controller board DS1103. Based on Matlab software and ControlDesk „Hardware-In-the-Loop" – HIL simulation concept [1], [9], [10], [14], [15] is ensured. The acquisition board was embedded into a box dSPACE PX4 connected to a PCI Express board of the PC through an optical cable. A PV emulator based on a controllable voltage source was also considered. An electrical connection ensures electrical energy transfer from the wind turbine and PV emulators to a battery bank and to a group of mono phase local loads via an inverter. The 5kVA galvanic isolation 1:1 was considered for connecting the rig to the national three phase network [4].

IV. Experimental Results

Next will be presented the results obtained with the proposed local control solutions. The first analyzed method is Perturb and Observe (P&O). Figure 6 presents the evolution of main wind turbine variables obtained when this method is applied and also when a resistive load is present. The starting wind speed value is 4 m/s. To this value the control loop is coupled.

Next the wind speed profile is changed to a variable wind speed profile, mean value being changed step by step from 4 m/s to 6 m/s. In Figure 6a is presented the evolution of the wind speed. Wind turbine torque and electromagnetic torque are presented in Figure 6b. Optimal and measured rotational speeds shaft are presented in Figure 6c.

Tip speed ratio evolution is presented in Figure 6d. Voltages measured to chopper's input and output ports is presented in Fig. 6e, while developed powers are presented in Figure 6f. Analyzing these results can be observed that tip speed ratio is kept to the optimal value this showing that the operating point is on the ORC and the capture power is maximized. Also can be observed from chopper's voltages evolution that DC converter works in boost regime and also can be observed that chopper command has a gentle variation.



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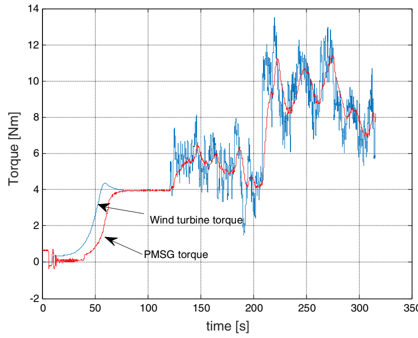

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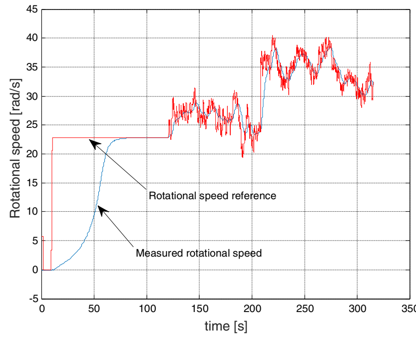

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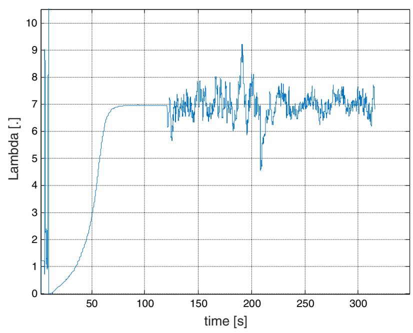

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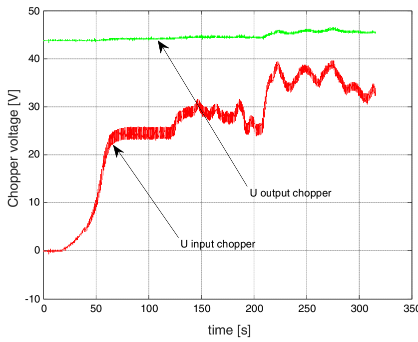

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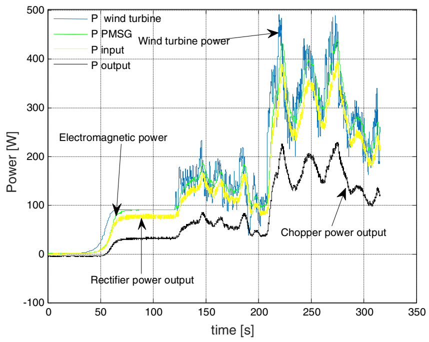

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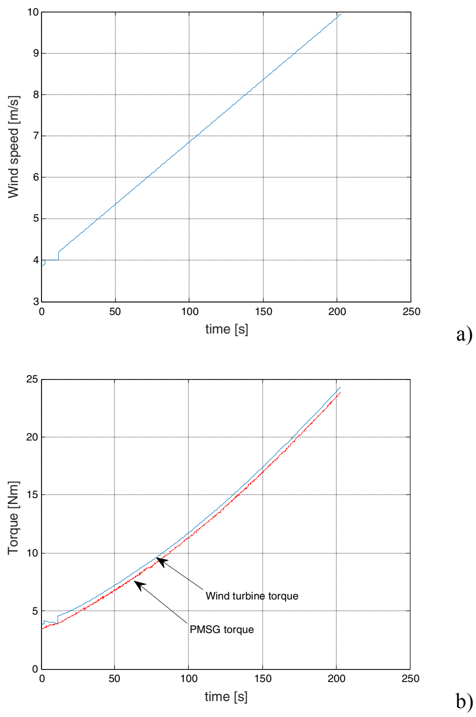
Fig. 6. Wind system variables evolution when P&O metod is used with a resistive load and variable wind speed profile

In Figure 7 are presented the main variables, in case of P&O control method when the wind speed has a ramp variation, and system works with bank capacitors and resistive load. Analyzing the results can be seen that to a wind speed variation from 4 m/s to 10 m/s, tip speed ratio has small deviation around optimal value, and system stability is kept (see to 180 seconds simulation time) when the resistive load is connected, because the chopper output voltage.

In Figure 8 the main wind system emulator variables are presented for the second control approach, called Incremental Conductance (IC), when battery bank and resistive load are used. The starting value of the wind speed is 4 m/s, after 185 seconds the wind speed profile is changed to a variable wind speed profile, and at 280 seconds is changed the mean value from 4 m/s to 6 m/s.



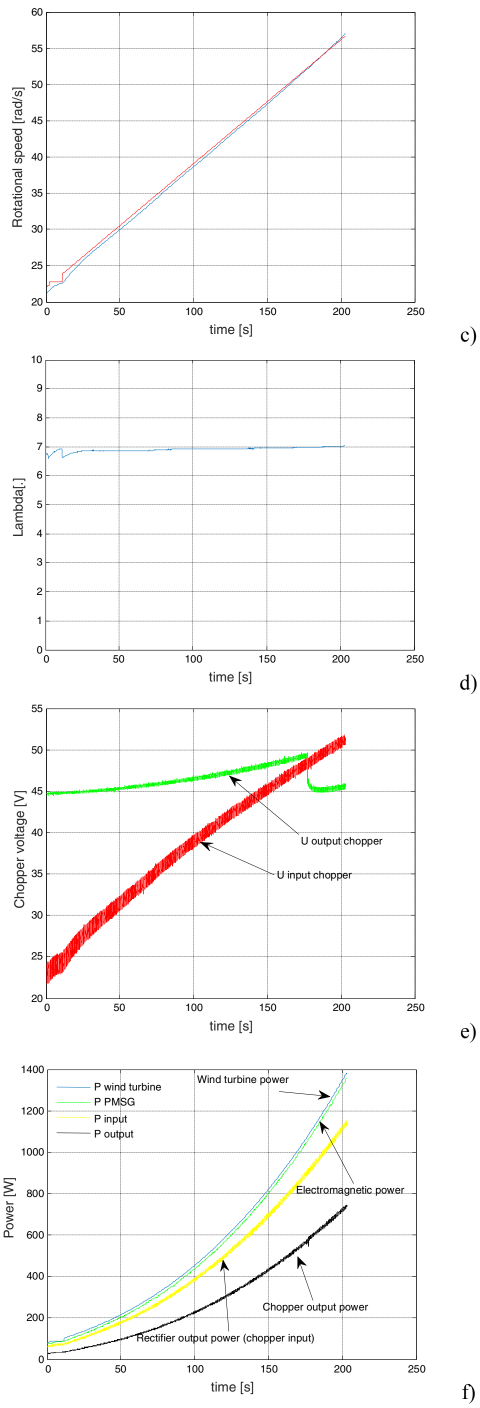
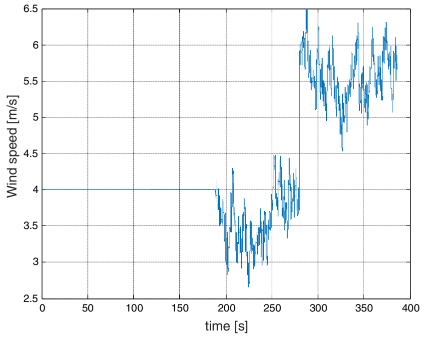


Fig. 7. Wind system variables evolution when P&O metod is used with bank capacitors and resistive load



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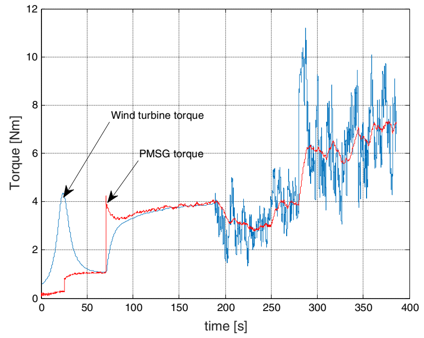

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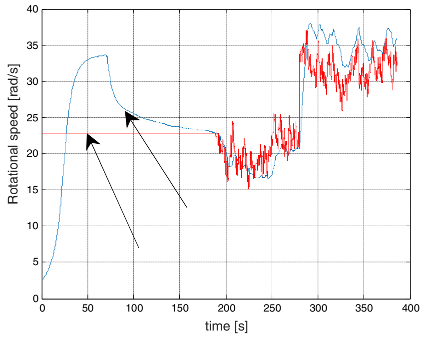

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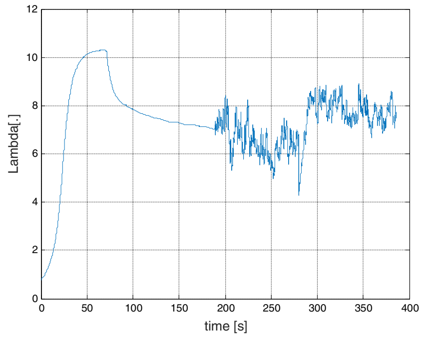

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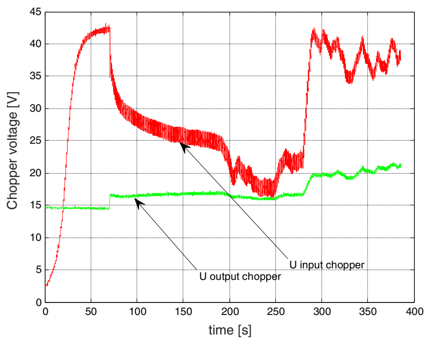

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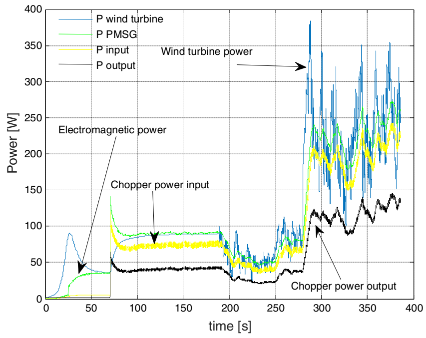

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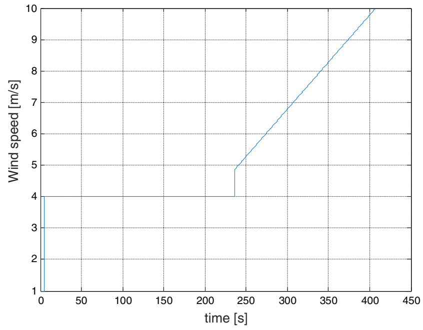
Fig. 8. Wind system variables evolution when IC metod is used with bank capacitors, resistive load and variable wind speed profile

The results presented in Figure 9 for the same method IC, are obtained using battery and resistive load, for a wind speed variation in ramp. At 30 seconds the control loop is coupled, and at 240 seconds the wind speed profile was changed to ramp profile. The results are comparable with the one presented in Figure 8.



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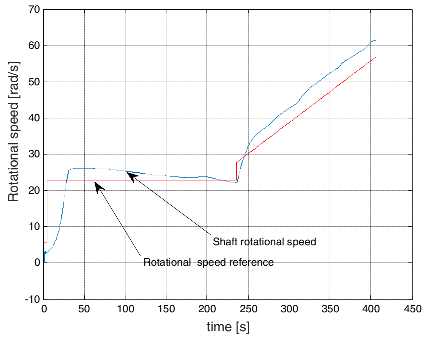

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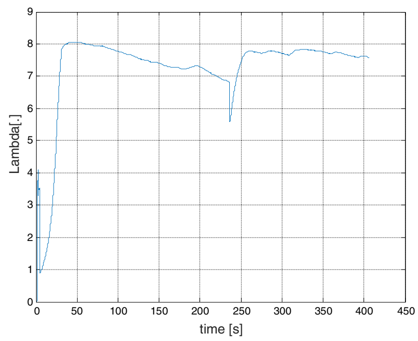

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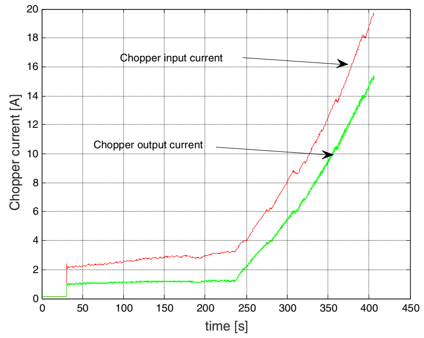

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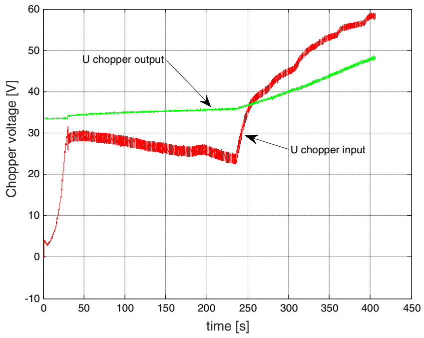

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Fig. 9. Wind system variables evolution when IC metod is used with bank capacitors, resistive load and ramp wind speed profile

V. CONCLUSION

The present paper presents the performances of a wind turbine electromechanical simulator of a hierarchical distributed multisource system for several control approaches. These control methods are: Perturb and Observe (P&O) and Incremental Conductance (IC). All methods are implemented locally and are its have the advantage of not depending on wind speed or shaft rotational speed measurement. For control purpose are used only data obtained from acquisition, usually used for system monitoring.

Both methods are usually used for PV control. When used for wind energy conversion, P&O cannot be applied because it implies waiting for the perturbation effect for each step, and the turbine time constant is about 15 seconds. That means an unacceptably big response time. IC method works, but it is disturbed by the fact that the rectified voltage from the generator is pulsating, and whenever a strong disturbance is chosen - will affect the mechanical operation of the generator, or erroneous decisions or long response times are accepted.

The test rig is a result of an Young Team research grant. The presented results are only for wind system side operation in insulated regime with battery bank and DC load.

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