Contribution to frequency control by a PMSG Wind Turbine in a Diesel-Wind Turbine microgrid for rural electrification

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***Abstract*-- The electrification of rural areas in developing countries and beyond is attracting particular interest in the last years. In this paper a Diesel-Wind Turbine microgrid for rural electrification is examined. A PMSG Wind Turbine model has been developed in RTDS's dedicated software RSCAD and its performance has been tested in a Power Hardware-in-the-loop environment. Three different operation strategies for the wind generator have been studied. In the first method the wind generator does not contribute to frequency control. In the second method the wind generator contributes to the inertial response of the system and in the final method pitch control deloading strategy is applied. The network under study is a rural Low Voltage grid that consists of one synchronous generator, constant and variable loads and finally a PMSG wind turbine.**

***Index Terms* -- rural electrification, Power hardware-in-the-loop, microgrid, wind turbine.**

I. Introduction

A large number of remote rural areas around the world have no access to the utility grid since they are geographically isolated [1]. In addition, the variability of landscapes and weather conditions in those areas further aggravate the problem of connectivity with the utility grid. The absence of electricity from such areas is one of the main factors that hinder overall development of communities, thus inhibiting the improvement of living standards of their population. However, rapid development in the field of electrical generation with renewable energy resources has provided a solution for the electrification of remote rural areas in a decentralized mode. Especially microgrids, which consist of both RES and diesel generators, are a widely acknowledged technology and a reliable option for such applications [2].

One of the main challenges in rural electrification with microgrids is the frequency support which in fact is of paramount importance for the proper and stable operation of electrical grids in general. In power systems, this operation is mainly performed by the power generators which continuously adjust their production according to the load demand variations so as to maintain a constant frequency. This can be done either automatically by local control and inertial response of the generators by changing their droop characteristics [3], [4]. In order to improve this operation, previous works have proposed the participation of wind turbines in the frequency support as a means of achieving faster response and smaller frequency disturbance [5], [6].

In order to examine the ability of a microgrid to maintain its frequency, a Power Hardware-in-the-Loop (PHIL) simulation is a promising approach. PHIL simulation allows testing under realistic conditions of an actual power device or system through its connection to a real-life system which is simulated on dedicated real-time hardware [7]. A major advantage of this technique is that the simulated system can be changed easily and quickly without the need for hardware adaptations; therefore various experiments can be performed repeatedly and conveniently. In a PHIL environment, services like voltage and frequency support by distributed generation units can be studied. Due to the specific characteristics of rural networks like high impedance lines or low generator's inertia, these phenomena are of major importance. A PHIL simulation environment focusing on distributed generation and microgrids has been developed at the National Technical University of Athens (NTUA) [8].

II. PMSG Wind Turbine Model

The model of the PMSG Wind Turbine include the aerodynamic part, the mechanical part as well as the electrical part together with all the control components that are necessary for its operation (e.g the pitch controller) [13].

The overall logic of the model is as follows. The wind speed is transmitted to the aerodynamic model, which also has as input the angular velocity of the blades, and the pitch angle of the blades. The output of the aerodynamic model is the available wind power and is transmitted as input to the mechanical model. The mechanical model also has a second input that is the electromagnetic power from the electrical generator part [13]. The output of the mechanical model is the angular velocity of the blades. The angular velocity and the voltage are the inputs of the electrical part. The pitch angle mentioned above occurs as the output of the pitch controller. All subsystems are presented below.

A. Aerodynamic part

The power of a stream of air is:

$$P_w = \frac{1}{2} \rho \pi R^2 V_w{}^3 \qquad (1)$$

Where

ρ: the density of air at standard conditions and is equal to 1.25Kg / m3

R (m): the radius of a theoretical cylinder in which the air is moving

V_w (m/sec): The velocity of the wind

The wind turbine obviously does not absorb all the kinetic energy of the wind but a portion. This portion is determined by the power coefficient C_p. The power that the Wind Turbine can absorb is given by (2)

$$P_t = C_p P_w \qquad (2)$$

The wind turbine operates in the logic of maximum absorption power for wind speeds lower than the nominal speed. In this case the Cp gets the maximum value C_{pmax}. When the turbine operates at wind speeds above the nominal limits the value of C_p is reduced [12].

The wind power as an exit from the above model is expressed in per unit.

$$P_t = \frac{\frac{1}{2}\rho C_p \pi R^2 V_w^3}{\frac{1}{2}\rho C_{p\_max} \pi R^2 V_{w,nom}^3} = \frac{C_p V_w^3}{C_{p\_max} V_{w,nom}^3}$$

$$= \frac{C_p}{C_{p\_max}} \left(\frac{V_w}{V_{w,nom}} \right)^3 \qquad (3)$$

B. Pitch controller

The Wind Turbine studied in this paper has a pitch controller that is responsible for maintaining the aerodynamic power and the rotational speed of the rotor at nominal values for wind speeds above the maximum value [12]. In particular, for values of wind speed below nominal, the aerodynamic power that can be extracted from the wind is less than the nominal value. Therefore, the controller is inactive. The angle of the blade takes its minimum value, usually b = 0°. For wind speeds greater than the nominal value, the angle b is increased so that the aerodynamic power remains equal to the nominal.

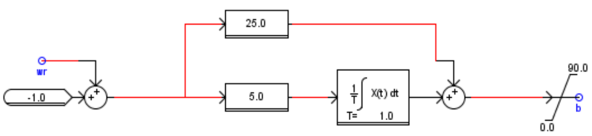

Figure 1. Pitch controller model in RSCAD/RTDS

C. Mechanical part

The differential equation for the speed of the rotor of the turbine can be expressed as [13]

$$\omega_t = \frac{1}{J}\int (T_M - T_E)dt \qquad (4)$$

Where

J: The moment of inertia of the rotor

The kinetic energy can be expressed as a function of the nominal power Po as follows:

$$\frac{1}{2} J\omega_s^2 = HP_o \qquad (5)$$

If we replace the above equation (5) in (4) we have

$$\omega_t = \frac{1}{2H}\int (T_m - T_e)dt \qquad (6)$$

Thus the mechanical model has as input the mechanical torque and as output the angular velocity of the rotor blades.

D. Electrical part

For the configuration of the electrical part of the Wind Turbine a PMSG (Permanent Magnet Synchronous Generator) has been used [13]. The equations are transformed in d-q frame and the output of the system is the electrical power of the Wind Turbine. The control algorithm is presented in Figure 3.

E. Inertia response

In this configuration of the model, the Wind Turbine is able to contribute to the total inertia of the system [9], [10]. This is possible by increasing the reference output active power by releasing its rotational speed. This extra term is affected by the rate of change of the grid frequency. Therefore, when there is a drop in the frequency of the network, it will be translated as a power increase reference, so more energy will come from reducing the rotational speed of the rotor.

The following figure shows the format of this extra term.

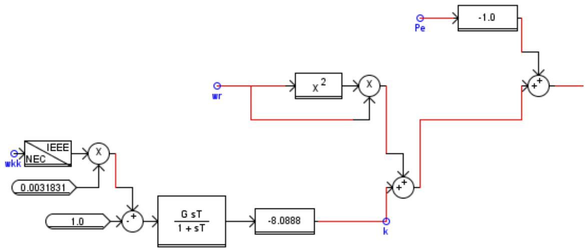

Figure 2. Inertia response input to the original model.

F. Pitch deloading

In this mode the Wind Turbine is possible to participate in the regulation of the frequency by means of droop control [11], [12]. The model now adopts droop curve and depending on the change in the frequency, it can change the output power that is injected to the grid. This is achieved through the following configuration.

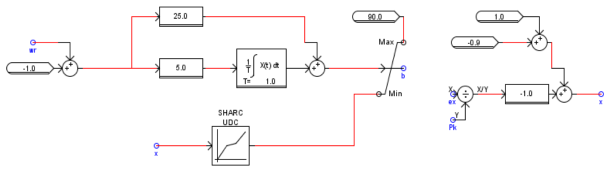

Figure 4. Pitch controller in pitch deloading mode.

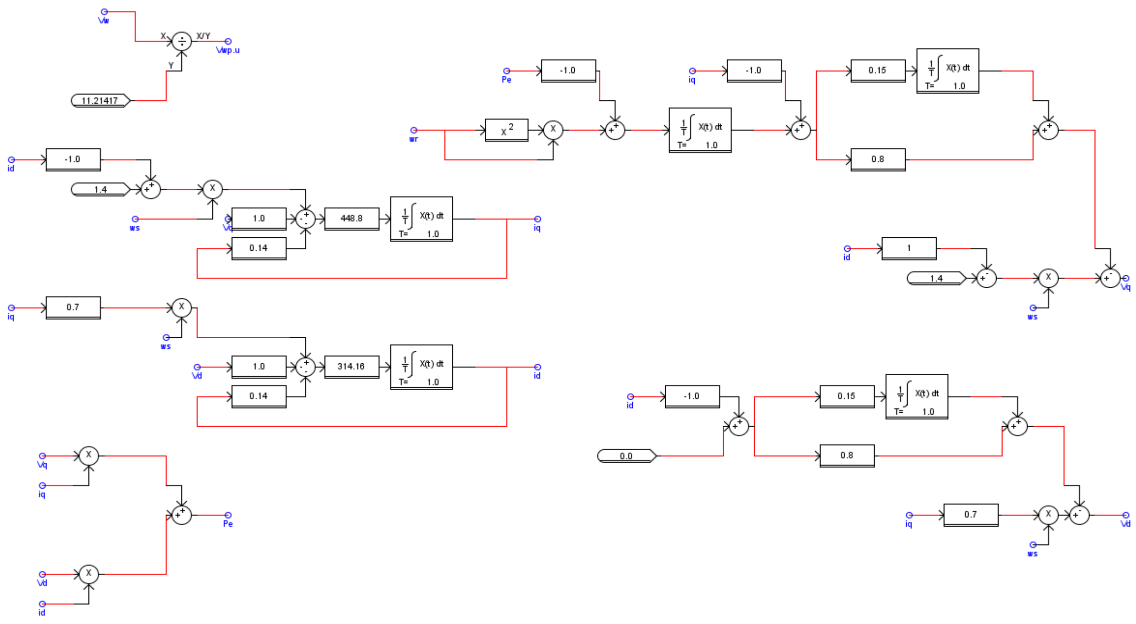

Figure 3. Electrical part of the PMSG Generator designed in RSCAD/RTDS

III. Power Hardware in-the-loop tests

A. Test setup

The RTDS is a fully digital device suitable for real time simulation of electrical power systems and networks. It has the ability to solve power system equations fast enough to generate realistic output conditions that represent conditions in the actual operation of the network. When a power device is tested, a Power Interface is needed to allow the interaction of the device with the simulated power system, as the RTDS cannot produce or absorb power. The Power Interface exchanges low level signals with the RTDS and power with the tested device. In this setup, a Power Interface composed of a switched-mode converter (AC/DC/AC) and a current sensor, is used. A reference low-level signal is transferred from the RTDS to the Power Interface, via a D/A and A/D converter, which represents the voltage at the Point of Common Coupling (PCC). This reference voltage is amplified by the converter and then applied to the real PV inverter. In order to close the loop of the simulation, the current fed by the PV inverter, is transferred back to the A/D converter of the RTDS after being properly scaled down [8], [14].

Using the aforementioned setup PHIL tests have been performed in order to investigate how a PMSG Wind Turbine can support the frequency of the system when the load changes. In the RSCAD/RTDS software environment a PMSG Wind Turbine model has been designed included all its parts as mentioned before and has been used as the renewable energy source unit in the system. The simulated Low Voltage network consists of one synchronous generator, LV lines, constant and variable loads. Three PHIL experiments have been performed in which different operation strategies for the wind generator have been studied. In the first method the wind generator does not contribute to frequency control. In the second method the wind generator contributes to the inertial response of the system and in the final method pitch control deloading strategy is applied. The simulated network is shown in figure 5.

B. Experimental results

In order to evaluate the three different operation strategies for the PMSG WT a testing scenario was applied. In this testing scenario, disturbance in the rural network's frequency by load change was provoked and the results in the frequency response of the system were collected. The results can be seen in figures 6-8.

As shown in Figure 6, when the wind turbine does not contribute to the frequency control, the synchronous machine picks up the increased load by means of governor control. As a result, the frequency response in this case is the worst since the WT reduces the total inertia of the system. However, for the inertial response control of the PMSG, shown in Figure 7, the maximum frequency drop is reduced because the WT contributes to the total inertia of the system. The wind turbine increases the output active power, but only for a limited time, and then its output active power reaches the initial value. As a result, this does not affect the steady state value of the frequency, since inertial control can only contribute to the dynamic response of the system.

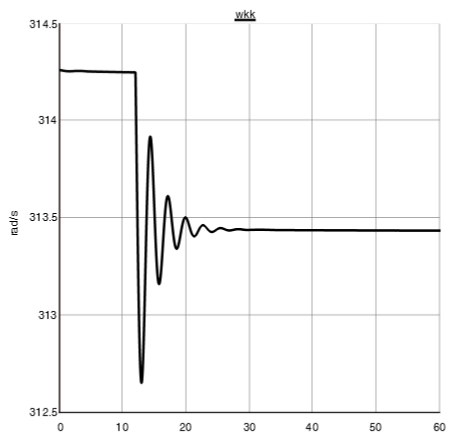

Figure 6. Frequency of the system where the WT does not contribute to frequency control.

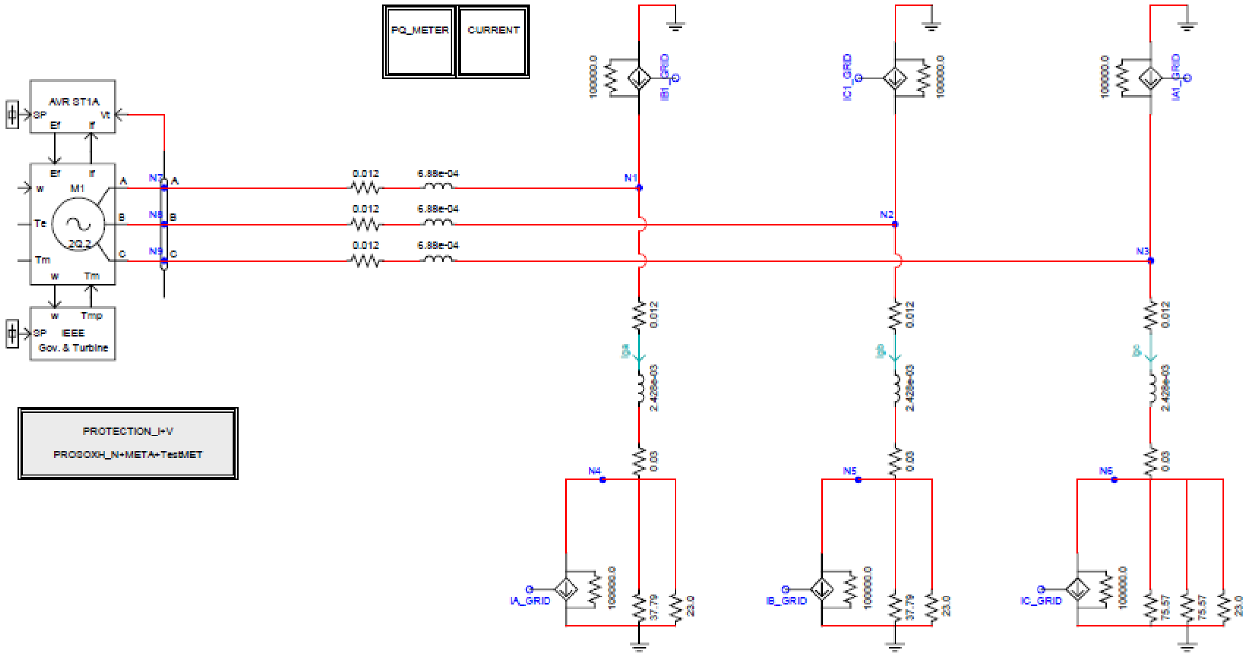

Figure 5. Simulated system in RSCAD/RTDS software environment.

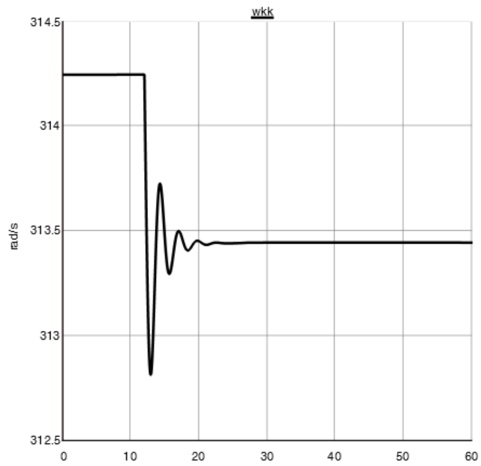

Figure 7. Frequency of the system where the WT contribute to inertia response

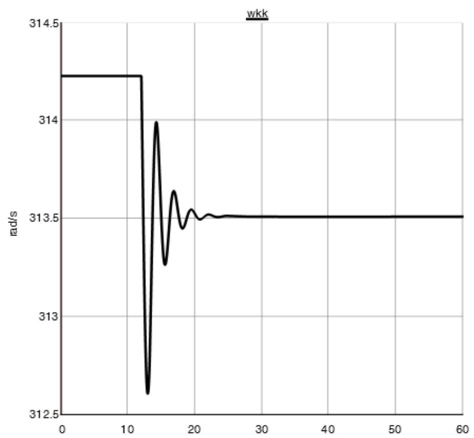

Figure 8. Frequency of the system where the WT contribute to frequency control through pitch deloading strategy.

For the pitch control deloading method Figure 8 shows that the final value of the frequency is improved compared to the previous methods as a result of the droop control operation of the WT. That is because the WT can increase its output active power with respect to its droop curve hence contributing to the increased load demand.

IV. CONCLUSIONS

In this paper a Diesel-Wind Turbine microgrid for rural electrification was examined. A complete model of a PMSG WT including the aerodynamic part, the mechanical part as well as the electrical part together with all the control components necessary for its operation (e.g the pitch controller), was implemented in the RSCAD. A PHIL simulation technique was selected to evaluate the ability of the system to regulate its frequency when an increase of the system's load occurs. Three different control methods for the PMSG WT were tested and their effect in the frequency response of the system was evaluated. For the first method, the wind turbine does not contribute to the frequency control of the system and the synchronous machine picks up the increased load by means of governor control. This is the worst case, since PMSG reduces the total inertia of the system. For the second method the PMSG operates with inertial response control loop. Results for this case show that the maximum frequency drop is reduced, since inertia from wind turbine is added, however this method does not improve the final value of the frequency. In the last method pitch control deloading strategy is applied, thus the wind turbine can increase its output active power, because in this case the wind turbine has a droop control. As a result, the final value of frequency is improved.

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VI. BIOGRAPHIES

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