Real Weather Condition Based Simulation of Stand-Alone Wind Power Generation Systems Using RTDS

Min-Won Park*, Sang-Geun Han and In-Keun Yu†**

Abstract - Cost effective simulation schemes for Wind Power Generation Systems (WPGS) considering wind turbine types, generators and load capacities have been strongly investigated by researchers. As an alternative, a true weather condition based simulation method using a real-time digital simulator (RTDS) is experimented in this paper for the online real-time simulation of the WPGS. A stand-alone WPGS is, especially, simulated using the Simulation method for WPGS using Real Weather conditions (SWRW) in this work. The characteristic equation of a wind turbine is implemented in the RTDS and a RTDS model component that can be used to represent any type of wind turbine in the simulations is also established. The actual data related to weather conditions are interfaced directly to the RTDS for the purpose of online real-time simulation of the stand-alone WPGS. The outcomes of the simulation demonstrate the effectiveness of the proposed simulation scheme. The results also signify that the cost effective verification of efficiency and stability for the WPGS is possible by the proposed real-time simulation method.

Keywords: real time simulation, SWRW, RTDS, wind power generation systems, wind turbine

1. Introduction

Throughout the last decade, global concerns about environmental issues have led to different actions or measures worldwide, for instance; the Kyoto protocol on climate change, policy of several industrial companies, states, or governments for the reduction of emissions of greenhouse gases, and incentive measures in many countries for the development of renewable energy sources. Increases in consumer awareness correspond to a willingness to pay a premium price for clean electrical energy generated by renewable energy sources [1, 2].

The technology costs of renewable energy have been declining rapidly, and wind power is now knocking at the door of coal, nuclear and even gas as the most economical energy source in developed countries. This has resulted in an increased demand for a simulation scheme and operational technologies for not only utility interactive (grid connected) but also stand-alone wind turbine and generation systems [3, 4]. Due to the high cost of actual systems, the cost effective simulation schemes that can be applied to both stand-alone and utility interactive WPGS readily under various conditions considering the types of wind turbine, the kind of generators, and load capacities as well are strongly expected and emphasized among researchers [5].

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As an initial stage of the real-time simulation, a stand-alone WPGS is simulated using the SWRW in this paper. Fig. 1 shows the conceptual diagram of the SWRW.

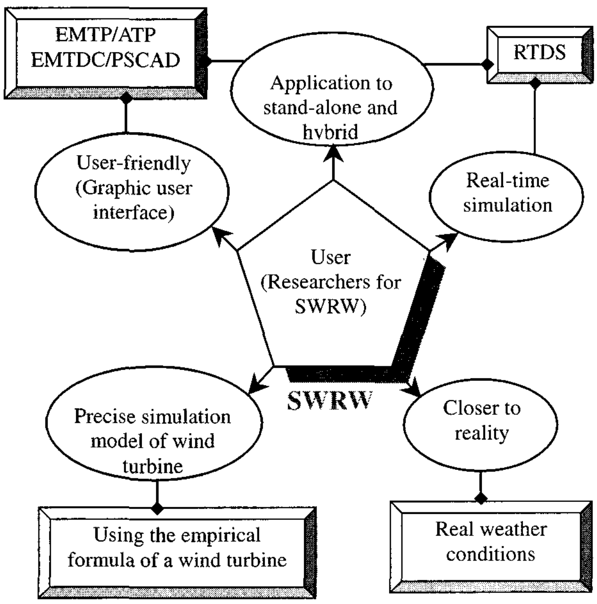

Fig. 1 Conceptual diagram of the SWRW

As far as the simulation method is concerned, there are several keywords that have been emphasized by the researchers related to the WPGS study as listed below.

a) user-friendly method from the researchers point of view
b) applicability to both stand-alone and hybrid (grid connected) systems

c) precise simulation model of wind turbine
d) directly connected to the actual weather conditions for real-time analysis

As shown in Fig. 1, the SWRW could be a unique simulation method to realize the requirements of researchers as mentioned above.

The authors propose a novel simulation method, which is based on the RTDS, for the WPGS under real weather conditions. The RTDS is a combination of advanced computer hardware and comprehensive software [6]. Power system networks are created on the RTDS by arranging electrical components from the customized component model libraries. Analogue signals can be interfaced between the RTDS and the external equipments via analogue input ports for the real-time simulation.

In this paper, the modeling method of the wind turbine in the transient simulation tools; EMTP/ATP, PSCAD/EMTDC, RTDS, and the interface method of the real weather conditions are introduced [7, 8]. The paper also presents a computer simulation model of a unified wind turbine-synchronous generator interface scheme using RTDS. The characteristic equation of a wind turbine is represented in the RTDS, and the factual data of weather conditions are interfaced to the RTDS through the analogue input ports of the RTDS for the purpose of real-time simulation of the stand-alone WPGS.

The outcomes of the simulation demonstrate the effectiveness of the proposed simulation scheme. The results indicate that the cost effective verification of efficiency and stability for the WPGS is possible by the proposed real-time simulation method.

2. Simulation using real weather conditions

2.1 Wind turbine characteristics

The blades convert wind energy into rotational forces that drive the generator. Although these blades are rigidly attached to the generator, the pitch angle of the blades is variable. The blades change pitch during operation by passively twisting. The blades start at pitch-up position and flatten-out as the turbine speed increases. This allows the pitch angle to be adjusted in such a way to operate the wind turbine at its optimal performance. Hence, the power extracted from the wind turbine is being maximized in a wide variety of wind speeds.

The wind turbine is characterized by the nonlinear curves of coefficient of performance *Cp* as a function of tip speed ratio λ. The λ is the ratio of linear speed of the tip of blades to the rotational speed of the wind turbine. The λ can be expressed as in (1).

$$\lambda = \frac{r\ \omega_m}{v_m} \tag{1}$$

where, r : radius of the rotor [m], ω_m : mechanical angular velocity of the rotor [rad/s] and v_m : wind speed [m/s]. From (1), the tip-speed ratio for a fixed-speed wind turbine varies across a wide range depending on the wind speed.

The *Cp* is also known as the power coefficient. The *Cp* versus λ is given in Fig. 2. For the wind turbine used in the study, the *Cp* is expressed as a function of λ. That is,

$$C_p = (0.044 - 0.0167B)\sin[\frac{\pi(\lambda - 3)}{15 - 0.3B}] - 0.00184(\lambda - 3)B \tag{2}$$

where, B : pitch angle [deg].

It is shown that the C_p varies with the tip-speed ratio. It is assumed that the variable wind turbine is operated at high C_p values most of the time.

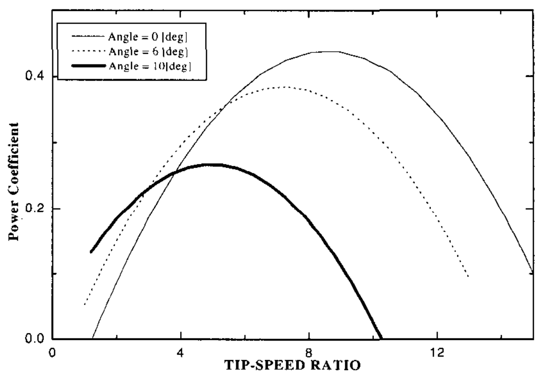

Fig. 2 Power coefficient versus tip-speed ratio

In a fixed-frequency application, the rotor speed of the induction generator varies by a small percentage above the synchronous speed while the speed of the wind may vary across a wide range.

The output power and torque of the wind turbine P_{wind} and T_{wind} may be calculated by the following equations.

$$P_{wind} = \frac{1}{2} A\rho v_m^3 C_p(\lambda) = \frac{1}{2}\rho Ar \frac{C_p(\lambda)}{\lambda} v_m^2 = \frac{1}{2}\rho Ar\, C_T(\lambda) v_m^2 \tag{3}$$

$$T_{wind} = \frac{P_{wind}}{\omega_m} = \frac{1}{2} A\rho C_p(\lambda) \frac{v_m^3}{\omega_m} \tag{4}$$

$$C_T(\lambda) = \frac{C_p(\lambda)}{\lambda} : torque \quad coefficient \tag{5}$$

$$\rho = \frac{P}{R \cdot T} = \rho_0 - 1.194 \cdot 10^{-4} \cdot H_m \qquad (6)$$

$$\rho_0 = 1.225\ [\mathrm{kg/m^2}](14.7\ \mathrm{psi},\ 15^\circ\ \mathrm{C}) \qquad (7)$$

where, A : area swept by the rotor blades [m²], ρ : air density [kg/m^3], H_m : the site elevation [m], P : air pressure, T : temperature on the absolute scale and R : gas constant, respectively.

In Fig. 2, the change of the C_p -tip speed ratio curve as the pitch angle is adjusted is also shown. In low to medium wind speeds, the pitch angle is controlled to allow the wind turbine to operate at its optimum condition.

In the high-wind-speed region, the pitch angle is increased to shed some of the aerodynamic power. The power captured by the wind turbine may be written as (3). From (3), it is clear that the power production from the wind turbine can be maximized if the system is operated at maximum C_p.

2.2 The SWRW based real time simulation

Many researchers have attempted in various ways to develop reasonable simulation methods for the WPGS. Since the output power and torque characteristic equation based wind turbine model has been developed, a precise output power and torque characteristic equation is being applied, in general, for the simulation. It is hardly possible to reproduce the actual weather conditions in the simulation tool of the WPGS. Therefore, simulation reliability or stability is not guaranteed without knowledge of the external parameters of real weather conditions. In order to overcome the problems, on-line real time simulation of the WPGS under real weather conditions is achieved using the RTDS in this work.

Tandem processor cards are utilized by the RTDS to maintain the required computation rates for real time operation. The real weather data from the anemometer are interfaced to analogue input ports of the RTDS through the Optical Isolation Card (OIC), which allows the RTDS user to interface the RTDS equipment with any type of analogue signals safely.

Fig. 3 shows the conceptual diagram of the real time simulation for the WPGS under the real time conditions. Also, by using the interface between the anemometer and the analogue input of the RTDS, a simulation is possible under actual weather conditions.

The measured analogue signals of wind speed are interfaced to the analogue input ports of the RTDS. Fig. 4 shows the entire processes of the proposed simulation method and the interface between the measured analogue inputs of the RTDS via the OIC. As indicated in Fig 4, using part of the input, users can flexibly modify the sort of wind turbine, the rate of the wind turbine, as well as the type of generators and load capacities, which are the key advantages of the proposed simulation method.

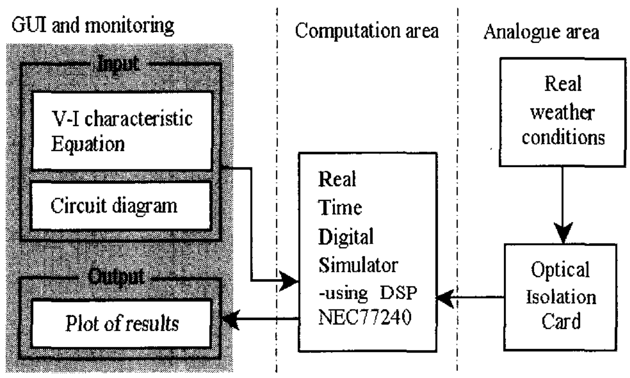

Fig. 4 Process of the proposed simulation and interface between measured analogue signal and the analogue input of the RTDS via the OIC

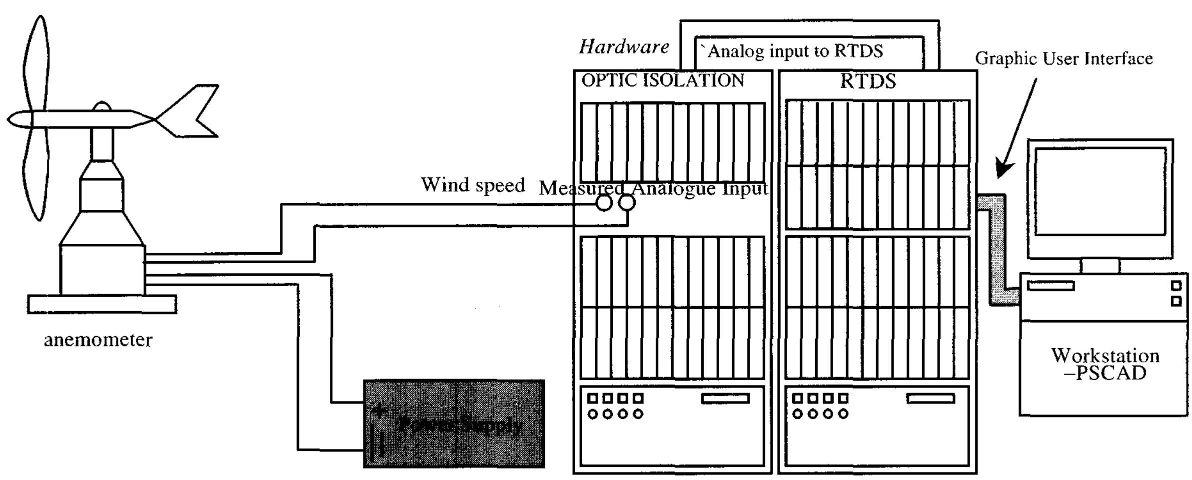

Fig. 3 Conceptual diagram of the real time simulation for the WPGS under actual weather conditions

2.3 Control of a wind turbine

Fig. 5 shows the conceptual diagram of simulation component for a wind turbine.

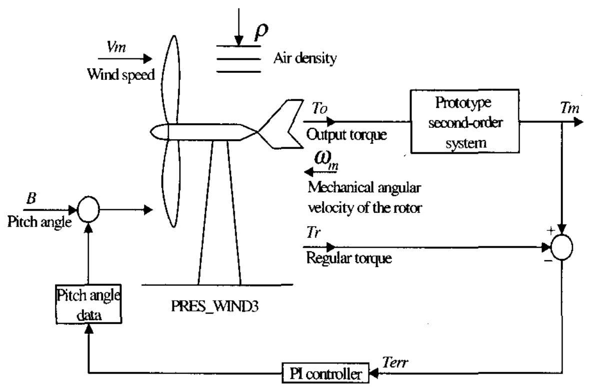

Fig. 5 Conceptual diagram of a wind turbine simulation

The real field data of wind speed are inserted into the wind turbine characteristic equation, and the obtained output torque *Tm* is treated as an input torque of the generator. Moreover, in this component, the inertia of turbine is considered, and the pitch speed control is conducted by using the prototype second-order system. Using the turbine component proposed in this paper, the turbine capacity and the length of blade are also considered during the simulation, thus the research period and cost for the study of WPGS can be reduced.

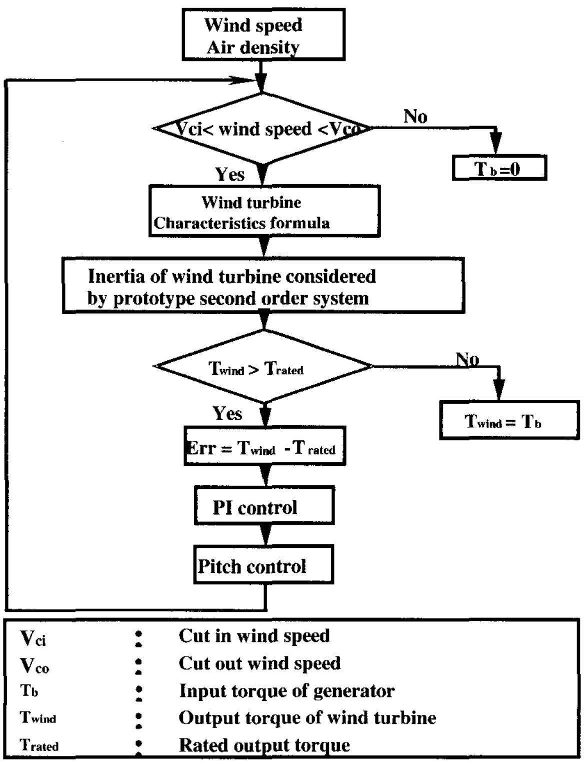

Fig. 6 Control algorithm of the pitch angle

Fig. 6 shows the control algorithm of the pitch angle. By inputting the wind speed and air density, output torque is computed by using the characteristic equation of the wind turbine. When wind speed exceeds the cut-out wind speed, the turbine will be stopped by controlling pitch angle to 90°, otherwise it will be controlled to steady-state operation.

Because the inertia of the wind turbine should be considered under the active region of wind speed, it is taken into account using prototype second order system in this work. Pitch control governs the output torque with the pitch angle determined by the feedback of error between reference torque and output torque. After all, rotation speed of the wind turbine will be within a permitted limit of synchronous generator.

3. Numerical example on a stand-alone WPGS

In order to confirm that a wind turbine modeled in the simulator operates as an actual wind turbine, a hypothetical wind turbine is simulated. Fig. 7 shows the conceptual diagram of the simulated stand-alone WPGS.

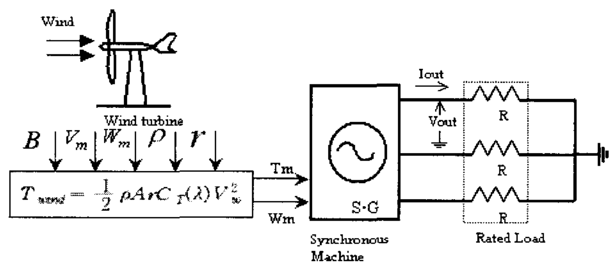

Fig. 7 Schematic diagram of simulation for a stand-alone WPGS

The characteristic parameters of the wind turbine are given in Table 1.

Table 1 Characteristic parameters of a wind turbine

Radius of turbine	24 [m]
Rated power	750 [kW]
Cut-in wind speed	4 [m/s]
Cut-out wind speed	25 [m/s]
Rated wind speed	16 [m/s]

The characteristic parameters of wind turbines can readily be modified in this simulator depending on the system size and analysis purpose. The actual wind speed data are applied to the modeled components so that the variation of the output torque according to the variation of the real wind speed may be detected. Fig. 8 represents the measured data of the wind speed for 100[sec].

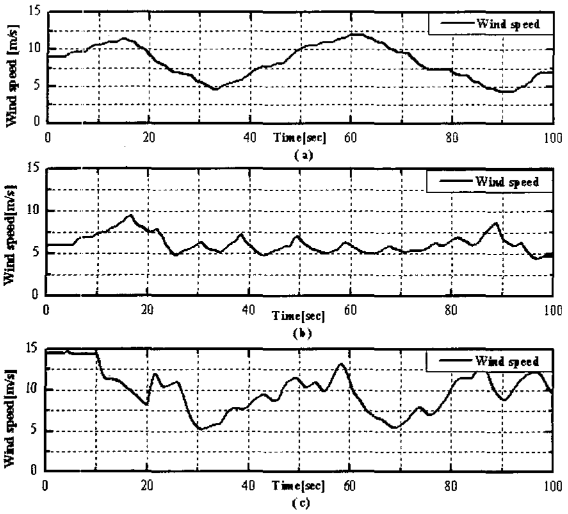

Fig. 8 Real weather conditions with fluctuations of wind speed for three different cases (a, b, c)

Under the conditions given above, a stand-alone WPGS is simulated and operational characteristics are analyzed using the proposed SWRW based method. The output current, voltage, torque and power of the stand-alone WPGS are analyzed. The output torques of the simulated 750[kW] wind turbine under the three diverse cases of wind speed conditions given in Fig. 8 are shown in Fig. 9, and the output powers of the generator are also represented in Fig. 10, respectively.

In this paper, only the real power outputs of the generator are considered. However, the power factor can easily be changed by modification of the synchronous generator components so that reactive power may be taken into account as well. It is confirmed through Fig. 8 to Fig. 10 that the analysis for the outputs of the wind turbine and the generator under various wind speeds can be achieved using the proposed simulation scheme.

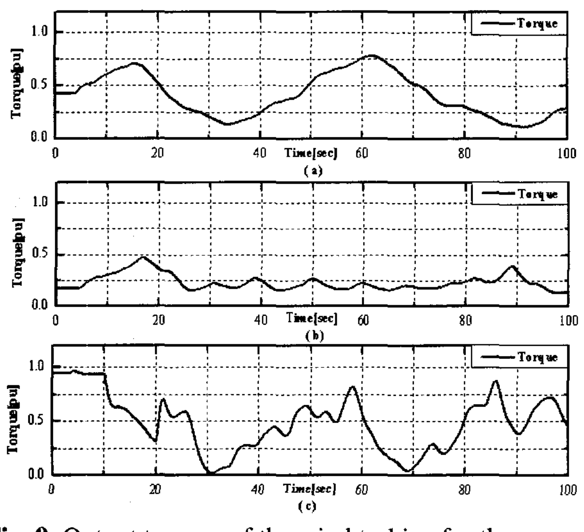

Fig. 9 Output torques of the wind turbine for three cases

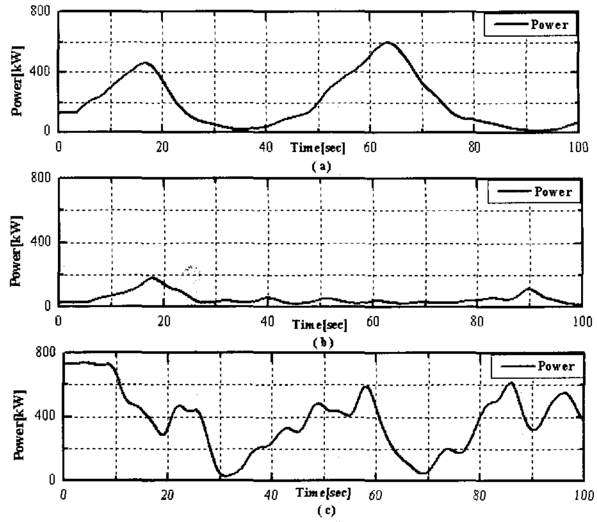

Fig. 10 Output powers of the generator for three cases

It is also possible to analyze transient characteristics of the WPGS using the SWRW based simulation method. Fig. 11 and Fig. 12 depict the generator voltage and current of phase A under the sudden variations of wind speed for short-time duration, respectively. The results can be used to analyze the transient features of the WPGS. These show the transient trend of the generator output voltage and current caused by the sudden change of wind speed. The changing shapes of voltage and current are slightly

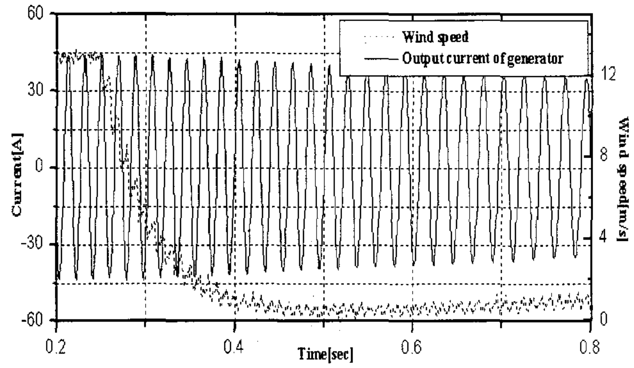

Fig. 11 Output current of generator

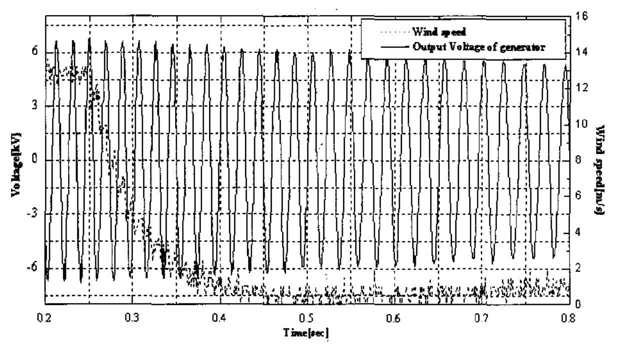

Fig. 12 Output voltage of generator

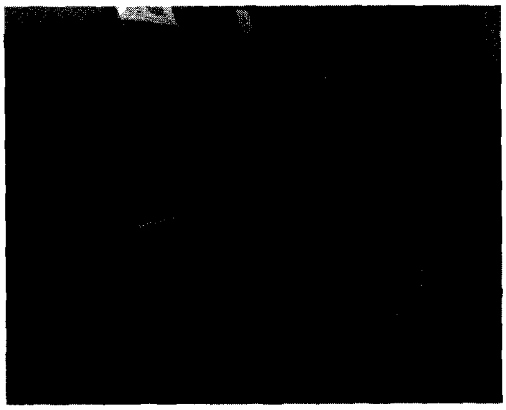

Fig. 13 The RTDS based built-in simulator for the WPGS

decreasing due to the sudden drop of the wind speed, which represents that the inertia of the wind turbine is well influenced in the simulation model. Fig. 13 depicts the hardware structure of the RTDS based built-in simulator for the WPGS.

4. Conclusion

The authors propose a RTDS based flexible real time simulation method for the stand-alone WPGS. A hypothetical network of the WPGS is created on the RTDS by arranging electrical components from the model libraries. The real weather conditions are interfaced through the analogue input ports of the RTDS for real time simulation.

A wind turbine model is achieved in the proposed system using the wind turbine characteristic equation. Then the real weather conditions are imported directly to the analogue input ports of the RTDS for the purpose of making the on-line real time simulation of the WPGS possible.

The simulation results are discussed in detail and the outcomes of the simulation on both steady state and transient state demonstrate the effectiveness of the proposed simulation technique. The results show that the cost effective verification of the efficiency or availability and stability for the WPGS under different loads and weather conditions, and different control schemes are the major advantages of the proposed simulation scheme. Various operational performance tests on both the stand-alone and the grid-connected WPGS, which will be the next research work scope, can be effectively performed using the proposed simulation method.

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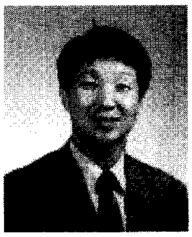

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