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Investigate and Improve the Reliability of Small Size Wind Energy Conversion Systems Connected to the Network

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Abstract

With the increasing expansion of electronic power converters in industrial applications, converter reliability.Power electronics have become very important. Electronic converters as intermediaries in systems Power generation from PV and Wind is also important in electrical drives and the aerospace industry. This article introduces comprehensive methods for assessing reliability. Methods reviewed Used for power extraction systems from WECS wind energy based on PMSG permanent magnet generator Placed. In these systems, it is usually a diode rectifier with a step-up converter and inverter on the side The network is exploited. The task of the inverter on the network side is to stabilize the DC link voltage and adjust the reactive power. The amplifier converter is also responsible for regulating the output voltage of the rectifier in order to obtain maximum power. in this Thesis uses both ordinary incremental inverter and interleave increment inverter and the capability Reliability is analyzed.

Keywords: Wind energy, wind turbine systems, reliability, electronic power converters
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1. Introduction

The WECS wind energy conversion system is designed to generate energy from wind for grid and offline applications and includes converters such as inverters, choppers and rectifiers. At low power levels, the use of permanent magnet generators with diode rectifier arrangement, amplifier converter and inverter is common.

Due to the intrusion of WECS in the network, their outage will cause problems in the network. Therefore, the need to use systems that have high reliability is essential. In this dissertation, the reliability of electronic power converters including boost converter, diode rectifier and inverter is calculated. The effect of different parameters on reliability has also been analyzed. Initially, a WECS system was simulated at three wind speeds of 12-10-14 m / s and reliability was evaluated at each wind speed.

Reliability is the probability that a component, subsystem, or system will function properly over a period of time. The reliability function is the probability of operating a system without error in the period from 0 to t. Therefore, system reliability is a function of time. The reliability of a system decreases over time. For commercial equipment, this time should cover the warranty period.

The failure rate of an element indicates the "failure potential" of that element after time t. A failure rate curve based on a function of time is known as a bathtub curve. Based on this curve, the lifespan of an element is divided into three time parts[4]:

– burn-in time
– useful time and
– wear-out time

During the burn-in time, the element undergoes special tests and during the manufacturing process, the probability of its failure will be high. After that, the failure rate stabilizes and is almost constant, and then wear-out begins. During the wear-out time, the element completes its mission. Therefore, the useful period failure rate is of special importance for reliability calculations [7].

The failure rate $\lambda(t)$ depends on the reliability function R(t):

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t+\Delta t)}{R(t)\Delta t} = -\frac{1}{R(t)}\frac{dR(t)}{dt} \tag{1}$$

Therefore, reliability is calculated as follows:

$$R(t) = e^{-\int_0^t \lambda(\tau)d\tau} \tag{2}$$

In many reliability models, failure rates of elements and subsystems are assumed to be time independent. We have this assumption:

$$R(t) = e^{-\lambda t} \tag{3}$$

The expected time until the MTTF failure occurs. Unlike MTTF reliability, it is not specific to a specific point in time. This indicator shows the average operating time of the element. The large MTTF does not imply greater reliability during a process. The relationship between reliability and MTTF is as follows:

$$MTTF = \int_0^\infty R(t)dt \tag{4}$$

$$MTTF = \frac{1}{\lambda} \tag{5}$$

This index is the average estimated time until the system recovers from the error mode. Repair time depends on factors such as error detection and element availability. Availability The probability of a system operating at a given time. The average value of availability is the average availability of a part of the system over time. For a repairable system, if the system operates as before after repair, the average availability is determined as follows:

$$A_{avg} = \frac{MTTF}{MTTF + MTTR} \tag{6}$$

As a result, MTTF must be increased and MTTR reduced to increase availability. This index is used for systems where availability is more important than high reliability. Figure (1) shows the typical failure rate for an element:

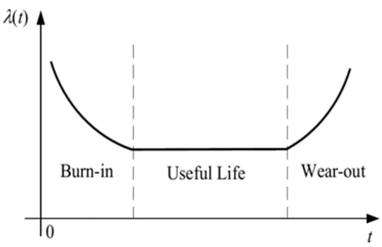

Fig. 1. Typical failure rate for an element

Wind turbines are divided into two types of fixed speed and variable speed. For fixed speed turbines, the generator is connected directly to the mains. The rotor speed is kept constant so that it matches the electrical frequency of the network. In this type of system, it is not possible to store wind energy in a rotating manner in the system, so changes in speed will lead to changes in power and changes in frequency. As a result, it will adversely affect the quality of power. The range of speed changes should not exceed 1% [1].

In variable speed wind turbines, the generator is controlled by electronic power equipment, which controls the rotor speed. Wind power changes can be controlled by changes in rotor speed and therefore the power delivered to the grid can be controlled. In this type of turbine, electric frequency and other power quality parameters can be controlled [2].

Four major topologies for wind turbines are presented:

- Constant speed turbines with induction generators
- Variable speed turbines with squirrel cage induction generators or synchronous generators
- Variable speed turbines with synchronous generators with more poles or synchronous generators with permanent magnets with more poles
- Variable speed turbines with dual feed induction generator

In this article, the third structure is used, which will be examined in the following explanation. The converters used in this system must withstand the full power of the PMSG. The task of the inverter is to stabilize the DC link voltage and regulate the reactive power delivered to the network. The job of the chopper is to adjust its input voltage to the extent that the maximum power can be extracted from the wind.The job of the diode rectifier is to convert the AC output power of the generator to DC power.

Interleave can be used to reduce the input current ripple in the amplifier converter.Figure 2 shows the converter details of PMSG generators.

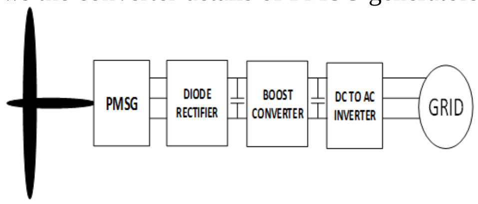

Fig. 2. The converter details of PMSG generators

This system uses a dc / dc converter between the inverter and the rectifier, whose main task is to control the output voltage of the rectifier. Of course, different types of dc / dc converters have been used as this intermediate converter, the most important of which is buck-boost converter and boost converter. One of the main problems of using a diode rectifier on the generator side is the inability to control the generator current and high current THD. Figure 3 shows the block diagram of the proposed system.

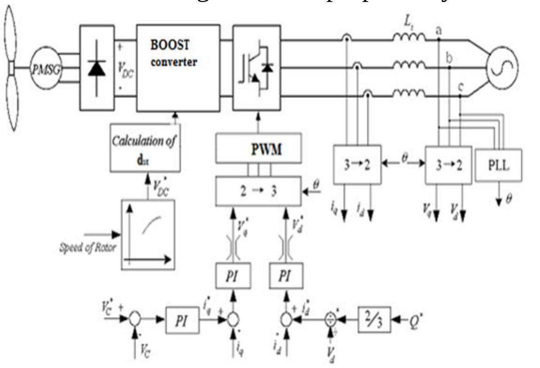

Fig. 3. Block diagram of the proposed system

The most important advantages of using a diode rectifier in the generator output are[10]:

- Simplicity: Compared to other rectifiers, using a diode rectifier is much less complicated.
- Cost: Due to the very low price of the diode compared to the switch, the cost of making a diode rectifier is less than other types of rectifiers.
- Higher efficiency: Diode rectifier has a higher efficiency than active rectifiers because the system has no switching losses.

Turbine output power depends on the amount of rectifier output voltage. The value of this DC voltage is imposed by the three-phase network. The output voltage of the boost converter is sampled and this voltage is stabilized to an arbitrary value using a PI controller. In the performed simulations, the mains voltage is 76 volts (phase to phase) and the dc link is set to 190 volts. Using an estimator that estimates the output voltage of the rectifier according to the wind speed, the amount of operating time of the incremental converter is obtained and therefore the output voltage of the rectifier is stabilized at a value corresponding to the maximum power. the dq method has also been used to control the active and reactive power. The purpose of the control system is to stabilize the active and reactive injected into the AC network in desired values. To control this system, we use proportional-integral PI control in synchronous framework. In the synchronous framework, the power relationship is equal to[11]:

$$P = \frac{3}{2}(v_d i_d + v_q i_q)$$
$$Q = \frac{3}{2}(v_d i_q + v_q i_d) \quad (7)$$

If we zero the value of Vq using the PLL phase loop lock block (ie do the dq transformations using the phase angle of the grid itself), then the values of the reference currents in the synchronous framework will be obtained using the following equations:

$$i_d^* = \frac{2}{3v_d} P^*$$
$$i_q^* = \frac{2}{3v_d} Q^* \quad (8)$$

These reference currents will then be tracked using proportional-integral controllers within the synchronous framework. How to calculate dst in the incremental converter is as follows:

$$D = 1 - \frac{v_{iref}}{V_{DC}} \quad (9)$$

Which is the output voltage of the rectifier corresponding to the maximum power and voltage of the DC link and the operating cycle of the boost converter.

2. Diode rectifier analysis and its reliability

The three-phase diode rectifier is one of the uncontrolled AC / DC converters that has 6 diodes.

The relationship between the DC output voltage and the effective line-to-input voltage value is as follows:

$$V_{DC} = \sqrt{2} V_{L-L}(\text{rms}) \quad (10)$$

Figure 4 shows a three-phase diode rectifier:

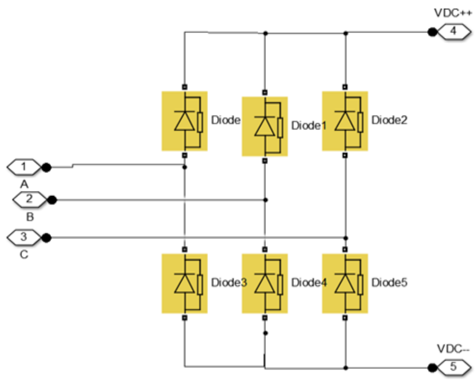

Fig. 4. Three-phase diode rectifier

If one of the rectifier diodes fails, the entire rectifier will go out of circuit.In the Markov loop below state 1 means healthy state and 0 means system loss. Therefore, the probability of being in mode 1, which is the reliability of the system, is calculated as follows:

$$R^C(t) = e^{-(6\lambda_D)t} \quad (11)$$

Figure 5 shows the Markov model of a diode rectifier.

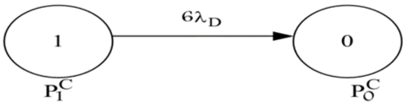

Fig. 5. Markov model of a diode rectifier

Diode failure rate varies under the following factors:

$$\lambda_D = \lambda_0 \pi_T \pi_S \pi_Q \pi_E \pi_C \tag{12}$$

The base failure rate is also considered in the reliability calculations equal to 0.0038. The temperature coefficient is also determined using the following equation:

$$\pi_T = \exp(-3091(\frac{1}{T_j + 273} - \frac{1}{298}) \tag{13}$$

The connection point temperature depends on the losses:

$$T_J = \mathrm{T}_C + \theta_{JC} P_D \tag{14}$$

The temperature of the case to the connection point of the diode datasheet is assumed to be 10 degrees per watt. Other coefficients are related to the environmental coefficient and the quality of construction and the coefficient of electrical stress, which is considered equal to 1.

3. Incremental Converter Analysis

Figure 6 shows the equivalent circuit of the incremental converter:

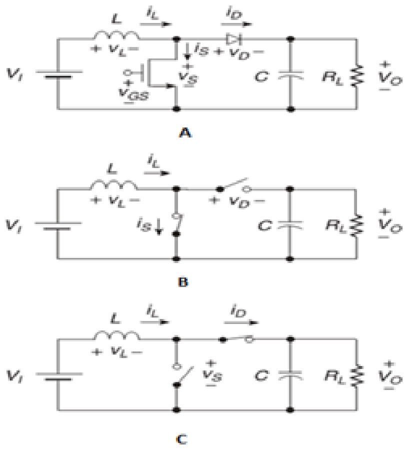

Fig. 6. Equivalent converter converter circuit

And its conversion function:

$$M_{VDC} = \frac{V_0}{V_I} = \frac{I_I}{I_0} = \frac{1}{1-D} \tag{15}$$

Figure 7 shows the Markov model of the amplifier converter.

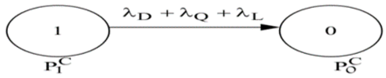

Fig. 7. Markov model of incremental converter

The following formula shows the reliability of the incremental source:

$$R^C(t) = e^{-(\lambda_Q + \lambda_D + \lambda_L)t} \tag{16}$$

4. Interleave converter

An interleave converter is actually created by paralleling several incremental converters. Each parallel increment converter is called a phase. The most important advantage of this converter over a conventional incremental converter is its low input current ripple, which in applications such as solar cells and fuel cells increases the life of distributed generation sources. Because less current enters the sources of stress. Figure 8 shows a two-phase interleave converter:

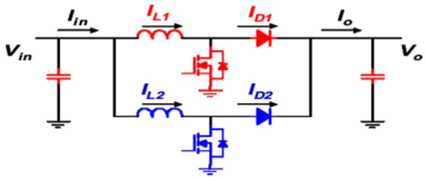

Fig. 8. Two-phase interleave converter

Figure 9 shows the input current ripple in a two-phase interleave converter:

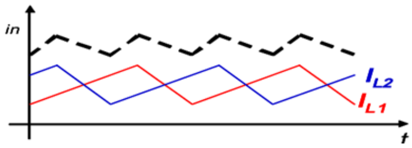

Fig. 9. Input current ripple in two-phase interleave converter

Markov model: equation 11 indicates the full power state of 10 states with half capacity (ie one of the parallel boost converters is out of circuit) and 00 is out of circuit with both phases out of circuit.For Markov relations we have three modes for multi-phase converters:

$$\frac{d}{dt}\begin{bmatrix} P_1^I \\ P_2^I \\ P_3^I \end{bmatrix} = AP(t) = \begin{pmatrix} -\lambda_1 P_R - \lambda_3(1-P_R) & 0 & 0 \\ \lambda_1 P_R & -\lambda_2 & 0 \\ \lambda_3(1-P_R) & \lambda_2 & 0 \end{pmatrix}\begin{bmatrix} P_1^I \\ P_2^I \\ P_3^I \end{bmatrix} \tag{17}$$

Due to these relationships, the reliability of the multi-phase converter (two-phase) is as follows.

$$R(t) = 1 - P_3^I = -\frac{(\lambda_2 - \lambda_3(1-P_R))e^{-(\lambda_1 P_R + \lambda_3(1-P_R))t} - \lambda_1 P_R e^{-\lambda_2 t}}{\lambda_1 P_R + \lambda_3(1-P_R) - \lambda_2} \tag{18}$$

Figure 10 shows the Markov model of an interleave converter.

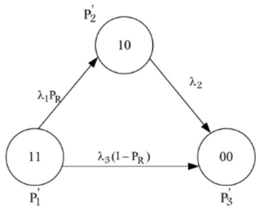

Fig. 10. Markov model of interleave converter

Two scenarios can be considered:

- After an error in one of the phases, the other phase will operate at half output power.
- After an error in one of the phases, the other phase will pass all the power, which requires design considerations for selecting the switch and inductor.

In the first scenario:

$$\lambda_1 = 2(\lambda_{QH} + \lambda_{DH} + \lambda_{LH}) = \lambda_3 = 2\lambda_2 \tag{19}$$

In the second scenario:

$$\begin{aligned} \lambda_1 &= 2(\lambda_{QH} + \lambda_{DH} + \lambda_{LH}) \\ \lambda_2 &= \lambda_{QF} + \lambda_{DF} + \lambda_{LF} \\ \lambda_3 &= 2(\lambda_{QH} + \lambda_{DH} + \lambda_{LH}) \end{aligned} \tag{20}$$

Failure rate and effect of losses on interleave converter elements:

$$\lambda_{part} = \lambda_b \prod_{i=1}^{n} \pi_i \tag{21}$$

$$T_C = T_a + \theta_{CA} P_D \tag{22}$$

$$T_J = T_C + \theta_{JC} P_D \tag{23}$$

$$\begin{aligned} T_{HS} &= T_a + 1.1 P_D \\ \Delta T &= 125 P_D / A \end{aligned} \tag{24}$$

Tables 1, 2 and 3 show the effect of losses and loss rate and temperature coefficients of elements, respectively.

Table.1.
Baseline values used for failure rate and connection point temperature relative to the case

	λ_b	Junction to case thermal resistance [°C/W]	T_a[°C]	π_Q Quality Factor	π_E Environmental Factor
MOSFET	0.06	10	25	1	1
Diode	0.0038	10	25	1	1
Inductor	0.00003	-	25	1	1

Table.2.
The element loss model

	Equivalent Circuit	Power Loss
MOSFET	v_T $R_{DS(on)}$	$P_D = i_S^2(t) R_{DS(on)} + i_S(t) v_T$
Diode	v_F r_D	$P_D = i_D^2(t) r_D + i_D(t) v_F$
Inductor	r_{esr}	$P_D = r_{esr} i_L^2(t)$

Table.3.
The temperature coefficients for the various elements

MOSFET	$\pi_T = \exp\left[-1925\left(\frac{1}{T_j+273} - \frac{1}{298}\right)\right]$
Diode	$\pi_T = \exp\left[-3091\left(\frac{1}{T_j+273} - \frac{1}{298}\right)\right]$
Inductor	$\pi_T = \exp\left[\frac{-0.11}{8.617\times 10^{-5}}\left(\frac{1}{T_{HS}+273} - \frac{1}{298}\right)\right]$

5. Inverter analysis

Inverter is a device for converting DC voltage to AC, which is used in two types of single-phase and three-phase. The inverter is actually a static power supply[12]. This means that there are no moving members in the building (unlike generators) and alternating voltage generation is done only by switching using semiconductor devices (FET, BJT, IGBT, etc.) that have the ability to switch at very high speeds. To take This has caused the inverter output voltage control (amplitude and frequency control of the output waveform) to be done much faster than dynamic sources (generators). Inverter construction is also simpler than dynamic sources and therefore much cheaper.

Power losses of semiconductor converter devices can be divided into two main parts:

- Conductivity losses due to current passing through components and voltage drop across them.
- Switching losses: which is related to the on and off time of the switch and diode

Loss calculation:

$$P_{sw-ssi} = 3*\left(\frac{2f_s}{\pi}(E_{on} + E_{off} + E_{rr})\frac{I_m V_{dc}}{I_{bsw} V_{bsw}}\right) \tag{25}$$

Figure 11 shows the simulation of the block calculator running in MATLAB software.

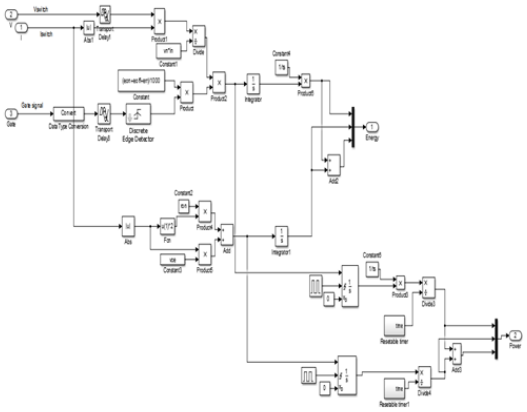

Fig. 11. The simulation of the block

6. Simulation results

Below figures, show the different part of system simulation results.

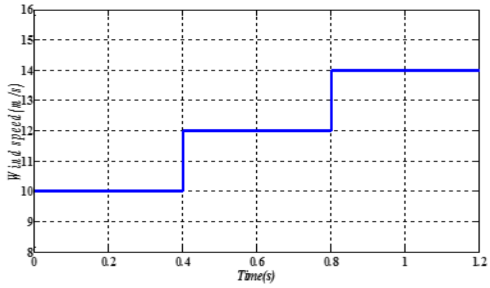

Fig. 12. Wind speed

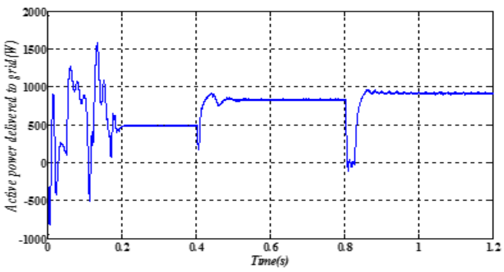

Fig. 13. Active power delivered to the network

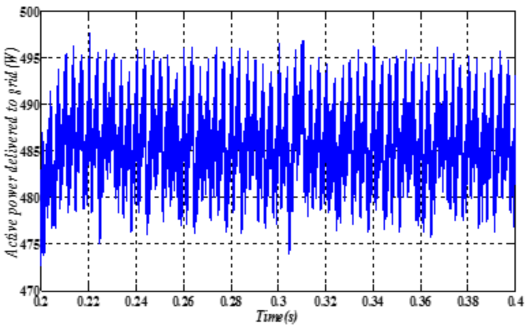

Fig. 14. Active power at wind speed 10

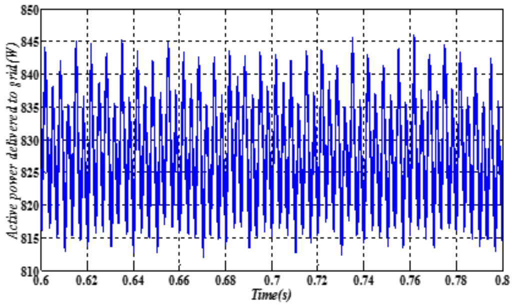

Fig. 15. Active power at wind speed 12

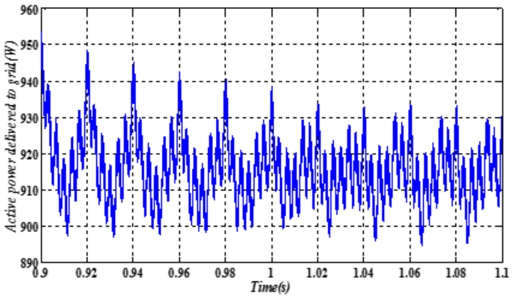

Fig. 16. Active power at wind speed 14

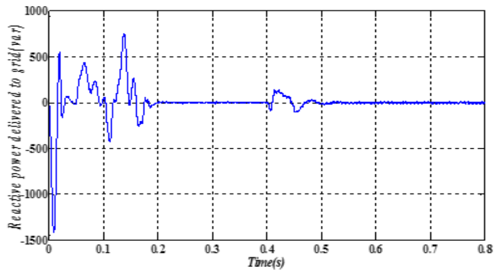

Fig. 17. Reactive power delivered to the network

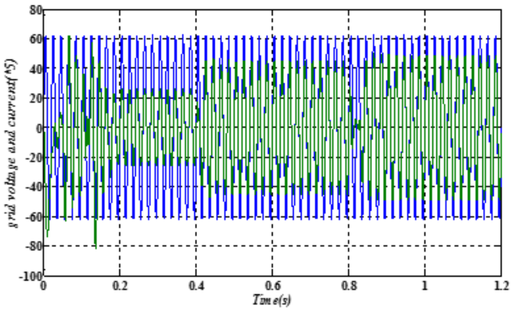

Fig. 18. Grid current

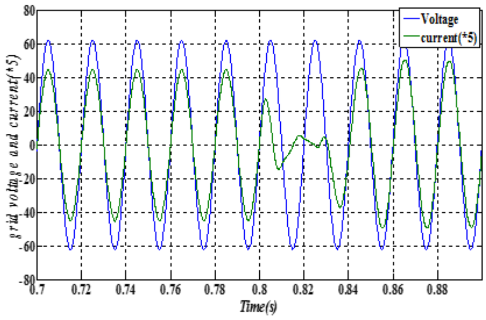

Fig. 19. Mains voltage

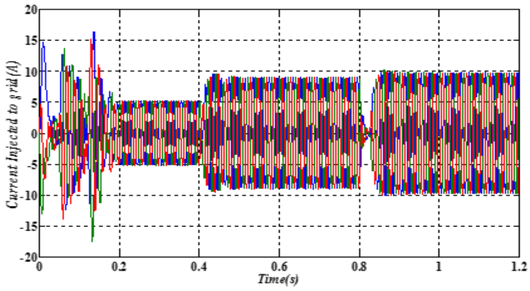

Fig. 20. Inject current into the network

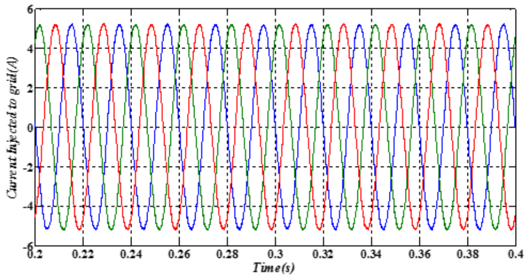

Fig. 21. Injection current into the network at a wind speed of 10

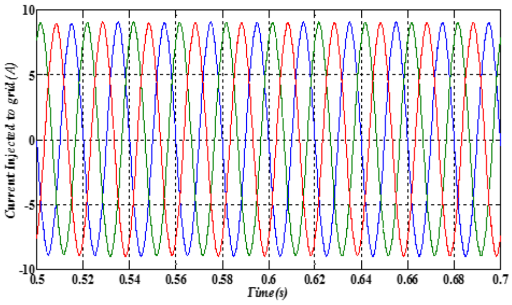

Fig. 22. Injection current into the network at wind speed 12

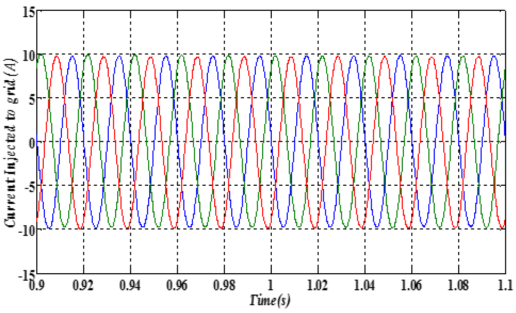

Fig. 23. Injection current into the network at wind speed 14

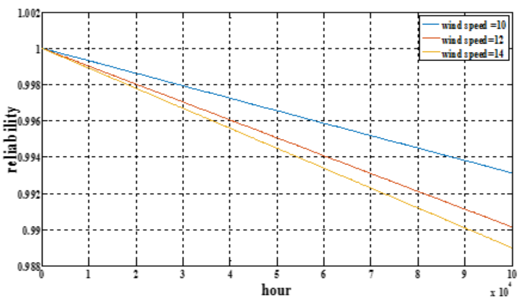

Fig. 24. Link voltage dc

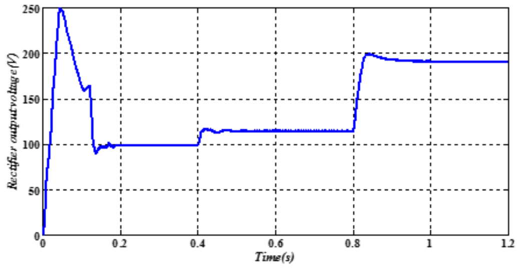

Fig. 25. Rectifier output voltage

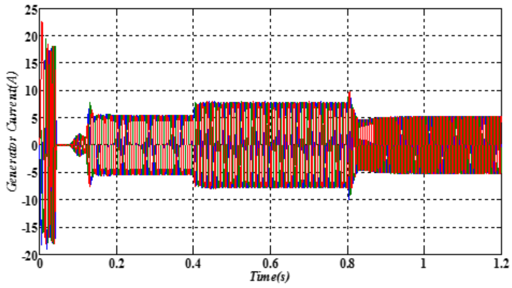

Fig. 26. Generator flow

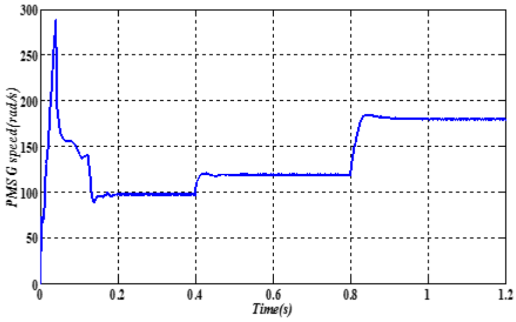

Fig. 27. Generator speed

Simulation results to assess reliability are shown from Figure 28 to 39.

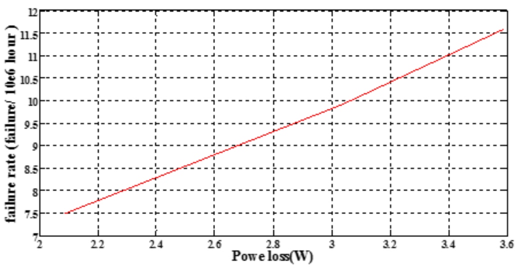

Fig. 28. Diode failure rate

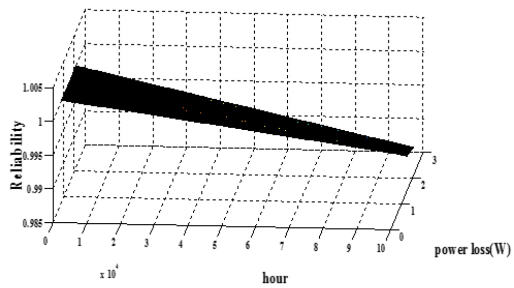

Fig. 29. Reliability in terms of losses and operating time

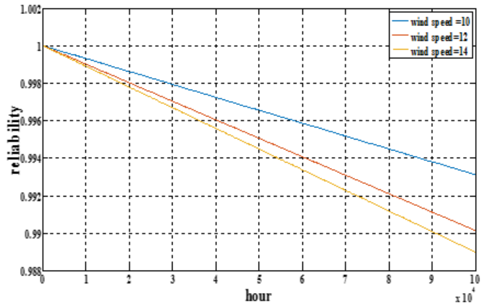

Fig. 30. Reliability at different wind speeds

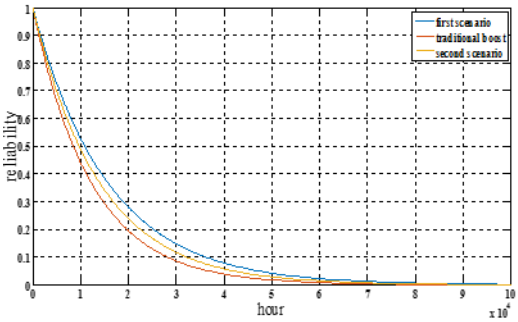

Fig. 31. Reliability in different scenarios

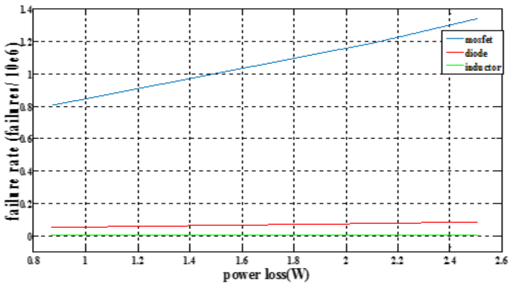

Fig. 32. Element failure rate

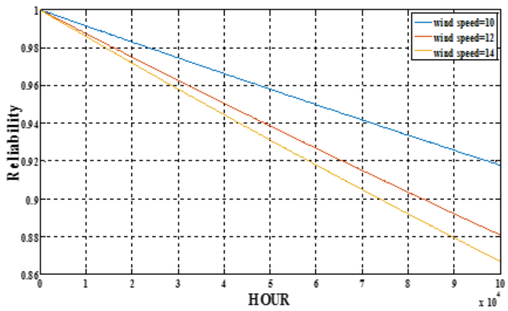

Fig. 33. Reliability at different wind speeds for conventional booster converter

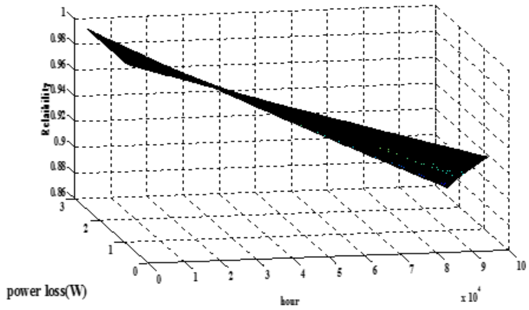

Fig. 34. Reliability in terms of losses and time For a typical incremental converter

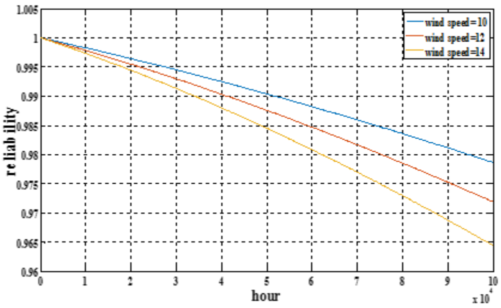

Fig. 35. Reliability at different wind speeds for interleave booster converter

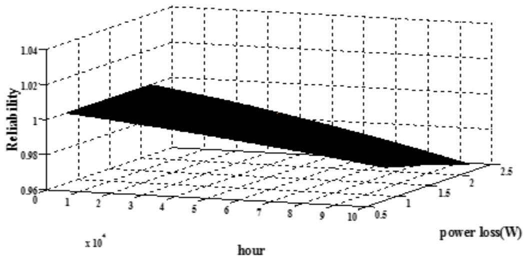

Fig. 36. Reliability in terms of losses and time For non-interleave increment

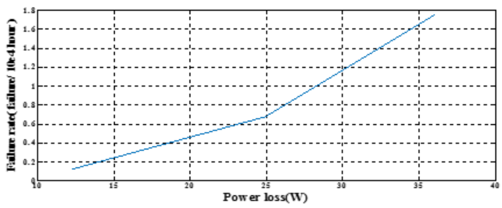

Fig. 37. Inverter switch failure rate

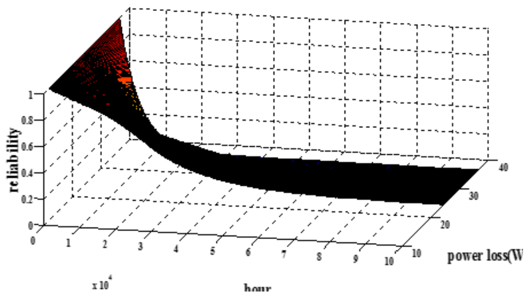

Fig. 38. Inverter reliability in terms of losses and time

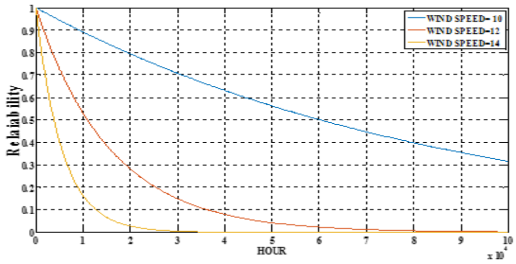

Fig. 39. Inverter reliability at different wind speeds

The reliability of the whole system are shown in Figure 40 and 41.

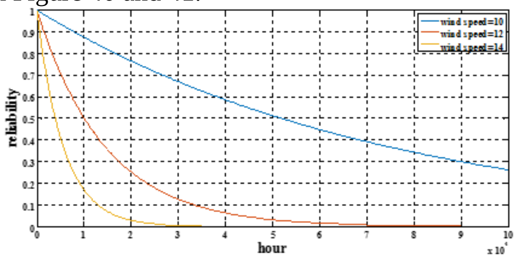

Fig. 40. Reliability of the whole system at different wind speeds

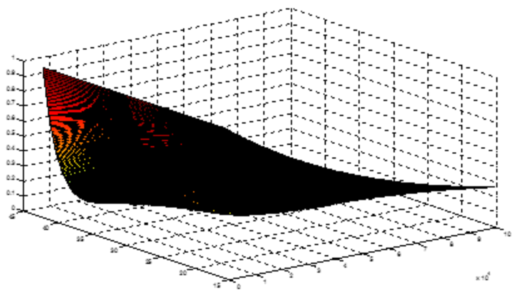

Fig. 41. Reliability of the whole system in terms of losses and time

7. Conclusion

In this article, first, a review of reliability and important indicators in this field was performed. Then, the method of evaluating the reliability of electronic power converters was presented. Then the methods of extracting power from wind turbines were investigated. In order for PMSG to inject active power into a three-phase network, a diode rectifier with an amplifier converter and inverter must be used. The function of the inverter is to regulate the DC bus voltage and the function of the converter is to increase the output voltage of the rectifier to a value at which the maximum power can be extracted from the PMSG. This system was simulated. Then the reliability of each converter including booster converter, rectifier and inverter was evaluated. Interleaved boost converter was used to improve the reliability of the amplifier converter and reduce the input current ripple. The simulation results showed the effect of wind speed on power and losses as well as reliability and the accuracy of the calculations was confirmed.

References

[1] J. Hu and Y. He " Dynamic modeling and robust current control of wind-turbine driven DFIG during external AC voltage dip", J. Zhejiang Univ. Sci. A, vol. 7, no. 10, pp.1757 -1764, 2006

[2] R. Pena , J. C. Clare and G. M. Asher " Double fed induction generator using back-to-back PWM converter and its application to variable-speed wind-energy generation", Proc. IEE B Electr. Power Appl., vol. 143, no. 3, pp.231 -241, 1996.

[3] R. Datta and V. T. Ranganathan " Direct power control of grid-connected wound rotor induction machine without rotor position sensors", IEEE Trans. Power Electron., vol. 16, no. 3, pp.390-399 , 2001.

[4] Khosroshahi, A.; Abapour, M.; Sabahi, M., "Reliability Evaluation of Conventional and Interleaved DC–DC Boost Converters," in Power Electronics, IEEE Transactions on , vol.30, no.10, pp.5821-5828, Oct. 2015.

[5] J. Matevosyan, T. Ackermann, S.M. Bolik, Comparison of international regulations for connection of wind turbines to the network, in: Proceedings of Nordic Wind Power Conference (NWPC'04), Gaoteborg, Sweden, March, 2004, pp. 1–2.

[6] J. Sveca, L. Saoder, Wind power in areas with limited export capabilities, in: Proceedings of the World Wind Energy Conference and Exhibition, Berlin, Germany, July 2–6, 2002.

[7] R.A. Abul'wafa . Reliability/cost evaluation of wind power delivery system. Electr. Power Syst. Res. , 873 - 879

[8] L. Wei, J. McGuire, and R. Lukaszewski, "Analysis of PWM frequency control to improve the lifetime of PWM inverter," in REcord of IEEE Energy Conversion Congress and Exposition, Sept 2009, pp. 900–907.

[9] R. White and F. Miles, "Principles of fault tolerance," in Record of Applied Power Electronic Conference and Exposition, vol. 1, 1996, pp. 18–25.

[10] M. Held, P. Jacob, G. Nicoletti, P. Scacco, and M.-H. Poech, "Fast power cycling test of IGBT modules in traction application," in Records of International Conference on Power Electronics and Drive Systems, 1997., vol. 1, 1997, pp. 425–430

[11] C.-M. Hong, C.-H. Chen, and C.-S. Tu, "Maximum power point tracking-based control algorithm for PMSG wind generation system without mechanical sensors," Energy Conversion and Management, vol. 69, pp. 58-67, 2013.

[12] Reliability prediction of electronic equipment," Department of Defense, Tech. Rep. MIL-HDBK-217F, 1991.