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Manufacture and characterization of stealth wind turbine blade with periodic pattern surface for reducing radar interference

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ABSTRACT

This paper presents a stealth wind turbine blade that reduces signal interference with electromagnetic wave based surrounding infrastructures. This study employed a method based on periodic patterns made of resistive materials to reduce the reflected radar signals from the wind blades. The wind blade with a lossy periodic pattern surface can absorb the incident electromagnetic energy and decrease the radar cross section. In this study, the periodic pattern surface was design with the radar absorbing characteristics at 10.0 GHz frequency. The fabricated lossy periodic pattern surface was applied to the outer surface of the wind blade in order to achieve radar absorbing characteristics. The measure results show that the radar cross section of the stealth wind blade section was reduced by more than 90% for whole azimuth angles at the target frequency.

1. Introduction

Most developed countries are interested in renewable energy produced from natural resources, such as wind, solar, and water. With limitless sources and environmental-friendly characteristics, the renewable energy resources are considered as a promising alternative energy to supplant fossils and unclear fuels. About 16% of global energy consumption was supplied by the renewable energy in 2009. Among the sources of this energy, wind power is growing very rapidly, at a rate of 27% annually, and is widely used in many developed countries as well as growing countries [1].

The electric capacity of wind power has been continuously increased during the past 10 years. The power output of wind turbine is determined from a function of the blade's size and the blade's rotating speed, and thus wind blades are becoming larger. As a result, the wind turbine blades have a large radar cross section (RCS) and various linear velocities. However, the RCS and the rotation of the wind turbine blades can have significant impacts on the operational capabilities of surrounding infrastructures using electromagnetic (EM) waves, such as commercial and military radar or antenna systems. Because the rotating wind blades with a large RCS causes a Doppler frequency shift, shadowing, and clutter due to the reflected EM signals from the wind blade structures. Also, these effects degrade the target acquisition and tracking capabilities of the radar systems. Consequently, a number of proposed wind farm projects across the globe have been postponed and canceled due to these signal interference problems [2–4].

Adverse effects such as Doppler shift, shadowing, and clutter are caused by unwanted reflected radar signals from the wind blade structures. These problems can be solved by application of radar absorbing structures, such as Salisbury screen and Dallenbach layer, to the wind blades in order to absorb incident EM waves [5–8]. However, these radar absorbers have an inherent limitation of increasing the structural weight because the Salisbury screen needs a thick substrate and the Dallenbach layer uses additional lossy materials such as dielectric and magnetic nano-fillers, to achieve the radar absorbing characteristics at the resonance frequency [9,10]. Above all, weight increment is a critical disadvantage in the wind blades, because the operating cost and efficiency of the wind power generation are closely related to the weight increase of the wind blades. Therefore, development and application of the lightweight radar absorbing structure for the wind blade systems are necessary to solve the radar interference problems.

The purpose of this research is to present a wind turbine blade that offers reduced signal interference with the electromagnetic waves, which emitted by surrounding radar or antenna systems. In this study, we fabricated a stealth wind blade section to show the possibility of the proposed method to absorb incident EM waves. The applied radar absorbing technique is based on periodic patterns, which made of a resistive material that compromising a conducting polymer with a polyurethane binder. The fabricated

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periodic pattern surface was applied to the outer surface of the wind blade to absorb the incident EM waves and to decrease the unwanted reflected signals form the wind blades. The radar absorbing characteristics of the developed wind blade section were evaluated and the feasibility of the stealth wind turbine blade is discussed.

2. Experimental

2.1. Concepts of stealth wind blade

Wind turbine blades are made of lightweight structural materials, such as glass fiber cloths, carbon fiber cloths, urethane foam cores, and balsa cores, using a resin transfer molding (RTM) process [11]. The proposed stealth wind blade should be produced by the conventional production process using existing blade's materials. Therefore, a radar absorbing technique is integrated into the current manufacturing process and applied to the structural component of the wind blades. Consequently, the applied technology allows the wind blade to absorb incident EM energy and to minimize reflected signals without compromising the structural strength.

In this study, we applied a radar absorbing structure with a periodic pattern surface (PPS) made of resistive materials to the wind turbine blade in order to reduce the signal interference with radar systems. The RAS is based on the circuit analog absorber, which consists of lossy periodic patterns and a thin grounded substrate, can absorb the incident radar energy [12–14]. The radar absorbing mechanism is wave cancelation result from destructive interference between the reflected waves. In addition, heat dissipation by ohmic losses of induced currents is involved, which caused by constant field change of the EM waves at the resistive patterns [9,10,14].

In the concept of stealth wind blade, a resistive periodic pattern surface is embedded in the outer surface of the conventional wind blade. The wind blade structures can be roughly categorized into two types according to their construction: single structure and mixed structure. In brief, the PPS is placed above the skin layer composed of glass fiber fabrics, while the carbon fiber fabrics for the ground layer is inserted in the bottom of the skin layer in both of the structures, as depicted in Fig 1. In other words, the skin layer with a conductive sheet acts as a grounded substrate for the RAS with lossy periodic patterns. Consequently, the proposed wind blade with a periodic pattern surface can be achieved radar absorbing capability and reduced the reflected signals.

2.2. Radar absorber with lossy periodic patterns

Electromagnetic wave absorption of the stealth wind blade is accomplished by a radar absorbing structure comprised of a resistive periodic pattern surface and a thin grounded substrate. Thus, the design of the periodic patterns surface is directly related to the radar absorbing performance. The lossy periodic patterns can be described by an equivalent *RLC* circuit that contains elements of resistance (R), inductance (L), and capacitance (C). Therefore, the impedance of (Z_{PPS}) of the lossy periodic pattern surface is represented through the *RLC* series combination, as shown in Eq. (1). In the equation, the resistance component is achieved with electrical conductivity of the used material and inductance; and capacitance components are associated with the pattern's geometry [10,14].

$$Z_{PPS} = R - jX = R - j\left(\frac{1-\omega^2 LC}{\omega C}\right) \tag{1}$$

According to the previous studies, the equivalent input impedance (Z_{RAS}) of the RAS with the resistive periodic pattern surface can be interpreted as a parallel combination of the impedance (Z_{PPS}) of the lossy PPS and the impedance (Z_{GDS}) of the grounded dielectric substrate [14,15]. Consequently, the input impedance (Z_{RAS}) of the RAS with resistive PPS can be derived into the both real and imaginary parts of Eqs. (2) and (3) as reported by Costa's study [15].

$$\mathrm{Re} = \frac{RZ_{GDS}^2}{\left(\frac{1-\omega^2 LC}{\omega C} - Z_{GDS}\right)^2 + R^2} \tag{2}$$

$$\mathrm{Im} = \frac{(-\omega L Z_{GDS})\left(\frac{1-\omega^2 LC}{\omega C} - Z_{GDS}\right) + \left(\frac{1}{\omega C} Z_{GDS}\right)\left(\frac{1-\omega^2 LC}{\omega C} - Z_{GDS}\right) + R^2 Z_{GDS}}{\left(\frac{1-\omega^2 LC}{\omega C} - Z_{GDS}\right)^2 + R^2} \tag{3}$$

Theoretically, the input impedance (Z_{RAS}) of the RAS should be matched the free space impedance ($Z_0 = 377\ \Omega$) in order for the RAS to absorb the incident radar signals, that is a zero reflection condition. In the Eq. (3), when the grounded dielectric substrate's impedance (Z_{GDS}) and the reactance component (X) of the PPS impedance assume almost the same, the imaginary part of the RAS becomes nearly zero [14,15]. Consequently, by varying the substrate thickness and pattern geometry such as shape, array, and coating thickness, the input impedance of the RAS can be

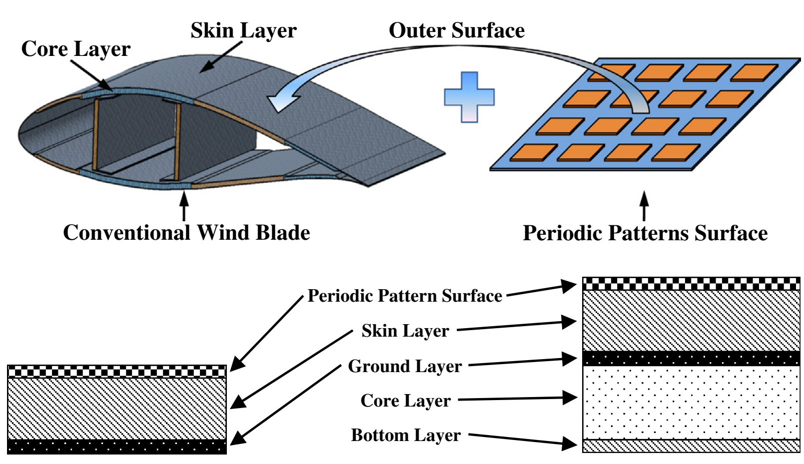

Fig. 1. Design concept of stealth wind turbine blade.