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Sensorless Variable-Speed Wind Energy System

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Abstract:
Only when the turbine rotates at optimum speed can the maximum power be extracted from the wind. Therefore, the maximum power point (MPP) tracking (MPPT) technique is important for wind energy conversion systems. To achieve MPPT control, the generator speed measurement is needed in each moment. Using a rotor speed sensor for this purpose poses some obstacles to practical implementation and has an impact on drive's cost, machine size, reliability, and noise immunity. In this paper a cost-effective sensorless reduced switch count PMSG based wind energy system is proposed in which the generator speed is estimated by an observer method. Due to deterioration of fossil fuel and policies on greenhouse gas mitigation, wind energy systems (WESs) has gained traction as one of the most promising renewable energy systems for electric power generation during the past years. At a specific wind speed, the captured wind power by WES is a function of wind turbine speed. Simulation results are presented to verify the performance of the proposed wind energy system under steady state and transient conditions.

Keywords:
Wind Energy System; Maxinmm Power Point Tracking; Reduced Switch Count Converter; Sensorless Control

I. INTRODUCTION:

Due to deterioration of fossil fuel and policies on greenhouse gas mitigation, wind energy systems (WESs) has gained traction as one of the most promising renewable energy systems for electric power generation during the past years [1-2].

Extracting maximum power from wind and feeding the grid with high quality electricity are two main objectives for wind energy conversion systems (WECSs) [3]. Power electronics provides the feasibility of these objectives for WESs [4] since they can perform active and reactive power control, injecting the high quality power into grid, as well as make the variable speed operation of wind turbine possible. In the variable-speed generation system, the wind turbine can be operated at the maximum power operating point (MPP) for various wind velocities by adjusting the generator speed optimally [5], [6]. Variable-speed wind energy conversion systems (VSWECSs) can be implemented with doubly fed induction generators (DFIGs) , squirrel cage induction generators (SCIGs) , or PMSGs [2]. Among electrical generators, PMSGs are favored in WECSs due to their advantages such as higher efficiency, high power density, reasonable price, and possibility of smaller turbine diameter in direct drive applications [7].

Recently, significant attention has been given to reduced switch count converters as low cost power converters in WECSs [1][7]. A recent reduced switch count structure for WECSs proposed in [8] is called six-switch ACI AC converter. This converter was first suggested as multi output inverter for control of two motors [9]. This configuration has the lowest number of active switches among three-phase to three phase ACI AC converters proposed hitherto in the literature [8]. Eliminating the generator rotor speed sensor is another trend towards cost reduction in WECS especially low power WECS [10]. Typically for measuring the generator speed, a rotor speed sensor is used that presents several disadvantages such as increasing the cost, machine size, reducing the reliability, and noise immunity. In this paper, a new sensorless six switch ACI AC converter based WES is proposed. The proposed WES has cost advantages compared to other configurations since it has the lowest number of active switches and also does not require to rotor speed sensor.

Wind Power:

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

Features of Wind Power Systems:

There are some distinctive energy end use features of wind power systems

a. Most wind power sites are in remote rural, island or marine areas.Energy requirements in such places are distinctive and do not require the high electrical power.
b. A power system with mixed quality supplies can be a good match with total energy end use i.e. the supply of cheap variable voltage power for heating and expensive fixed voltage electricity for lights and motors.
c. Rural grid systems are likely to be weak (low voltage 33 KV). Interfacing a Wind Energy Conversion System (WECS) in weak grids is difficult and detrimental to the workers' safety.
d. There are always periods without wind. Thus, WECS must be linked energy storage or parallel generating system if supplies are to be maintained.

Power from the Wind:

Kinetic energy from the wind is used to turn the generator inside the wind turbine to produced electricity. There are several factors that contribute to the efficiency of the wind turbine in extracting the power from the wind. Firstly, the wind speed is one of the important factors in determining how much power can be extracted from the wind. This is because the power produced from the wind turbine is a function of the cubed of the wind speed. Thus, the wind speed if doubled, the power produced will be increased by eight times the original power. Then, location of the wind farm plays an important role in order for the wind turbine to extract the most available power form the wind.The next important factor of the wind turbine is the rotor blade.

The rotor blades length of the wind turbine is one of the important aspects of the wind turbine since the power produced from the wind is also proportional to the swept area of the rotor blades i.e. the square of the diameter of the swept area. Hence, by doubling the diameter of the swept area, the power produced will be fourfold increased. It is required for the rotor blades to be strong and light and durable . As the blade length increases, these qualities of the rotor blades become more elusive. But with the recent advances in fiberglass and carbon-fiber technology, the production of lightweight and strong rotor blades between 20 to 30 meters long is possible. Wind turbines with the size of these rotor blades are capable to produce up to 1 megawatt of power. The relationship between the power produced by the wind source and the velocity of the wind and the rotor blades swept diameter is shown below.

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$$P_{wind} = \frac{\pi}{8} dD^2 v_{wind}^3$$

The derivation to this formula can be looked up in [2]. It should be noted that some books derived the formula in terms of the swept area of the rotor blades (A) and the air density is denoted as δ□ .

Thus, in selecting wind turbine available in the market, the best and efficient wind turbine is the one that can make the best use of the available kinetic energy of the wind.

Wind power has the following advantages over the traditional power plants.

- Improving price competitiveness,
- Modular installation,
- Rapid construction,
- Complementary generation,
- Improved system reliability, and
- Non-polluting.

Wind Turbines:

There are two types of wind turbine in relation to their rotor settings. They are:

- Horizontal-axis rotors, and
- Vertical-axis rotors.

In this report, only the horizontal-axis wind turbine will be discussed since the modeling of the wind driven electric generator is assumed to have the horizontal-axis rotor.

II. SIX SWITCH AC/AC CONVERTER:

The six-switch ACI AC converter that is shown in Fig. has been proposed in [9] as a low cost alternative for conventional back to back converter and nine switch converter. The six switch converter, as its name expresses, employs only six active switches and hence the number of active switches is reduced by 50% and 33%, respectively, compared with back to back and nine switch converters. This converter can be considered as two separate B4 converters with two common switches and hence a special PWM method is required to independently control its three-phase terminals, see Fig.. This method has two reference signals (V,'e(I & Vrej2) for each phase legs which are related to input and output terminals respectively. In addition, two offset values (offseti and offset2) are added to reference signals to prevent interferences between modulation waveforms.

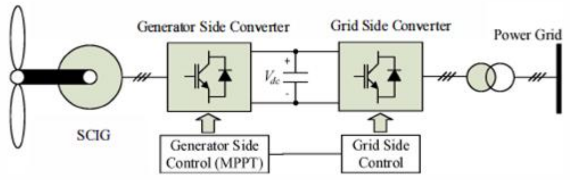

Figure 1. Connection of wind power generation system to grid through back to back inverters

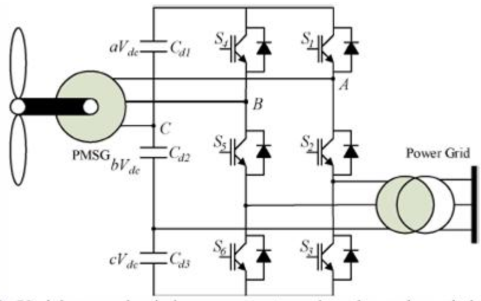

Figure 2. Variabe speed wind energy systems based on six switch AC/AC converter

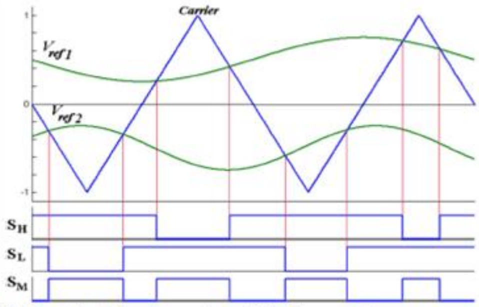

Figure 3. PWM method for six-switch AC/AC converter

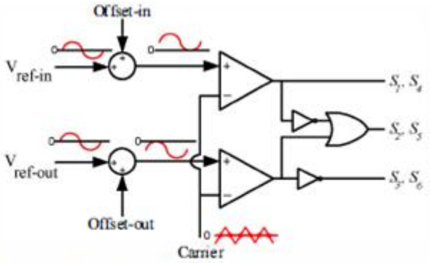

Figure 4. Block diagram of gate signal generator

$$V_{ref1} = m_1 \sin(2\pi f_1 + \varphi_1) + offset_1 \quad (1)$$

$$V_{ref2} = m_2 \sin(2\pi f_2 + \varphi_2) + offset_2 \quad (2)$$

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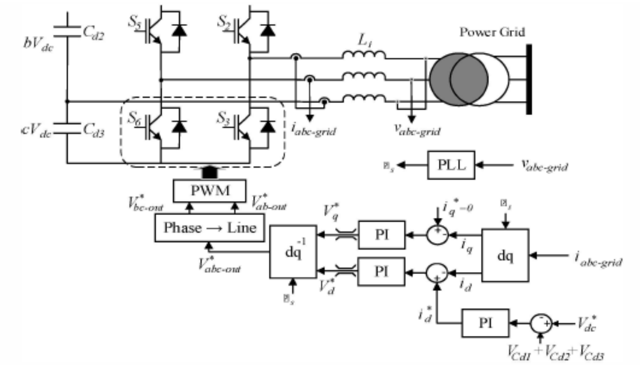


Figure 8. Block diagram of control of power delivered to the grid

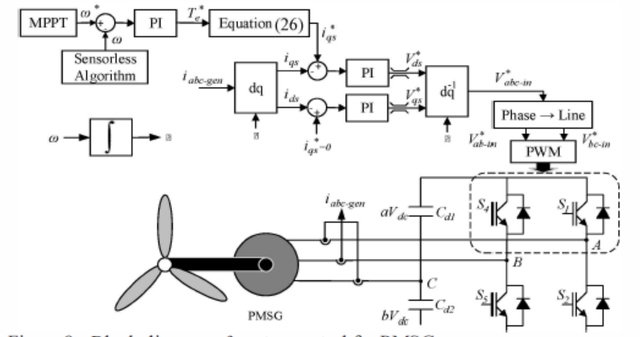


Figure 9. Block diagram of vector control for PMSG

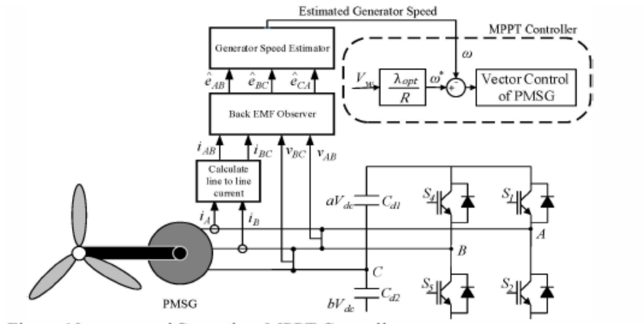


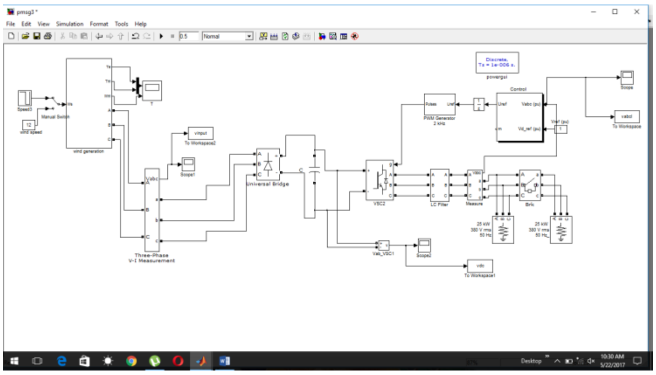
Figure 10. proposed Sensorless MPPT Controller

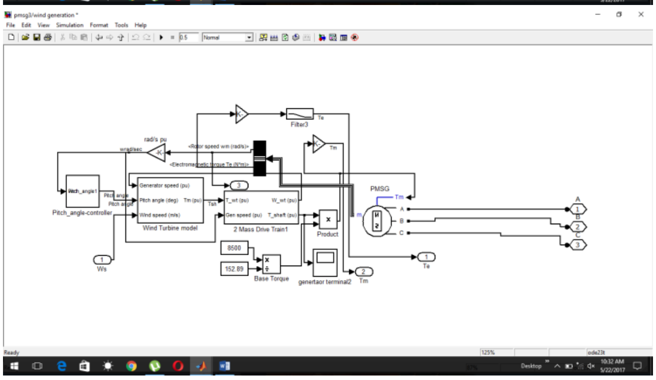
Results:

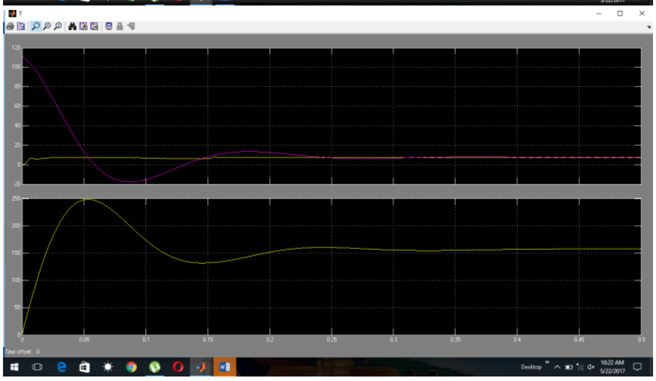
In this section, simulation results are presented to verify the validity of operations of the proposed system under steady- state and transient conditions. The simulated system parameters are listed in Table T. These simulations were performed using control systems mentioned in Section TV. The variable frequency mode of six switch AC/AC converter is selected since two three phase terminals of the converter work with different frequency.

Table 1. Simulation Parameters

PMSG Parameters		
Stator resistance (R_s)		0.05 Ω
Inductances (L_d and L_q)		0.0795 mH
Flux linkage established by magnets		0.192 V.s
Inertia (J)		0.011 kg.m^2
Friction factor (F), Pole pairs (p)		0.001417 N.m.s, 4
Nominal power, Nominal speed		28 kW, 3000 rpm
Grid parameters		
Phase to phase rms voltage and Frequency		380 V, 60 Hz
Source resistance and inductance		0.02 Ω, 10 mH
Converters parameters		
Switching frequency (f_{sw})		10 kHz
DC link voltage (V_{DC})		2200 V
DC link capacitors (C_{d1},C_{d2},C_{d3})		3000, 1500, 3000 uF
Sensorless MPPT method parameters		
TSR	λ_{opt}/R	3 π
Sensorless	H[1], H[2]	3000, -49500







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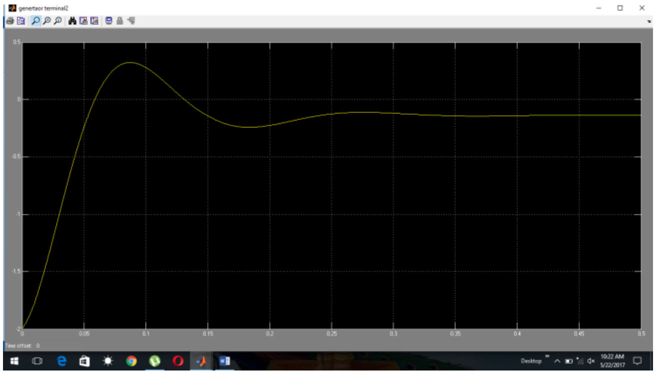

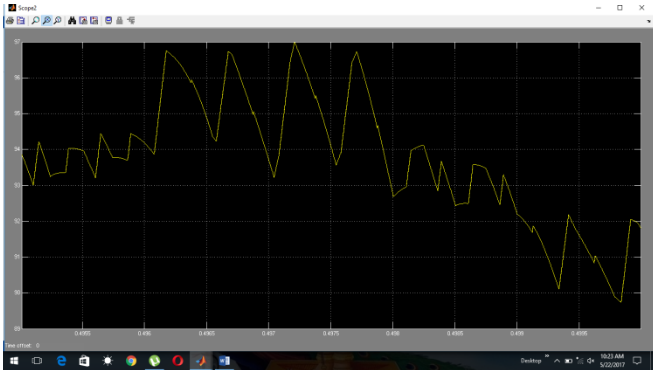

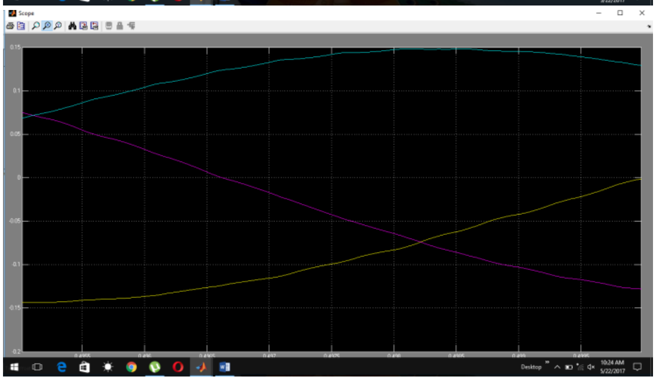

CONCLUSION:

In this paper, a new sensorless reduced switch count VSWECS with six-switch ACI AC converter is proposed. Six-switch converter is used for maximum power tracking control and delivering power to the grid, simultaneously. The proposed sensorless algorithm is based on an observer method. The proposed system is simple and has cost advantages compared to conventional WECS, because the number of switching semiconductors is reduced to six and also there is no need to the rotor speed sensor. The effective operation of the proposed converter and its ability to track the maximum power operating point of WES without rotor speed sensor in both steady state and transient condition were demonstrated by simulation results.

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