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Applications of Z-Source Inverter & PMSG in Wind Energy Systems

Mr.R.Pradeep*
PG Scholar, Dept. Of EEE,
K.S.R.College Of Engineering,
Tiruchengode,India
pradeep.rajan@hotmail.com

Mrs.E.Vani
Assistant professor, Dept. Of EEE,
K.S.R.College Of Engineering,
Tiruchengode,India
vanialagesh@gmail.com

Abstract: Existing wind power generating systems are mostly of large capacity (over 100 kw) and high-priced (about 1000 US$/kW). Because of the erratic change of wind power and of smoothing peak power, ACmC converter-fed battery system is recommended. We adopt compact permanent magnet type synchronous generator, which doesn't need exciting current, and step up/down buck-boost chopper to wind power generating system of a few kW output without position or speed sensor. With the growth of wind energy conversion systems (WECSs), various technologies are developed for them. Permanent-magnet synchronous generators (PMSGs) are used by these technologies due to special characteristics of PMSGs such as low weight and volume, high performance, and the elimination of the gearbox. In this paper, a new variable-speed WECS with a PMSG and *Z*-source inverter is proposed. Characteristics of *Z*-source inverter are used for maximum power tracking control and delivering power to the grid, simultaneously. A maximum boost control is presented to produce the maximum voltage boost (or voltage gain) under a given modulation index. Two control methods are proposed for delivering power to the grid: Capacitor voltage control and dc-link voltage control. In this paper the simulated results of Z-Source Inverter with constant dc obtained from the PMSG is shown.

Keywords: ACmC converter-fed battery system, Permanent-magnet synchronous generators, *Z*-source inverter

I. INTRODUCTION

With growing application of wind energy conversion systems (WECSs), various technologies are developed for them. With numerous advantages, permanent-magnet synchronous generator (PMSG) generation system represents an important trend in development of wind power applications [1]–[6]. Extracting maximum power from wind and feeding the grid with high-quality electricity are two main objectives for WECSs. To realize these objectives, the ac–dc–ac converter is one of the best topology for WECSs [2]–[6]. This configuration includes diode rectifier, boost dc–dc converter and three-phase inverter. In this topology, boost converter is controlled for maximum power point tracking (MPPT) and inverter is controlled to deliver high-quality power to the grid [2]–[4]. The *Z*-source inverters have been reported recently as a competitive alternative to existing inverter topologies with many inherent advantages such as voltage boost. This inverter facilitates voltage boost capability with the turning ON of both switches in the same inverter phase leg (shoot-through state). Moreover, reliability of the system is greatly improved, because the short circuit across any phase leg of inverter is allowed. Also, in this configuration, inverter output power distortion is reduced, since there is no need to phase leg dead time.

The recently presented Z source inverter [1][2][3] shown has additional zero vectors: shoot-through switching states that are forbidden in the traditional V-source inverter. For the traditional V-source inverter, both switches of any phase leg can never be gated on at the same time or a short circuit (shoot through) would occur and destroy the inverter. The new Z-source inverter advantageously utilizes the shoot through states to boost the DC bus voltage by gating on both upper and lower switches of a phase leg. Therefore the Z-source inverter can boost voltage and produce a desired output voltage that is greater than the available dc bus voltage. In addition, the reliability of the inverter **is** greatly improved because the shoot through can no longer destroys the circuit. Thus it provides a low-cost, reliable, and high efficiency. The power delivery and MPPT control of system are explained. Finally, simulation results are presented to verify the performance of the proposed system.

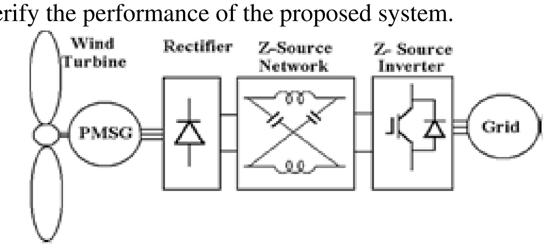

Figure.1.General Block diagram of the proposed System

II. Z-SOURCE INVERTER

The *Z*-source inverter is shown in Fig. 2. This inverter has an impedance network on its dc side, which connects the source to the inverter. The impedance network is composed of two inductors and two capacitors. The conventional voltage source inverters have six active vectors and two zero vectors. However, the *Z*-source inverter has one extra zero vector (state) for boosting voltage that is called shoot-through vector. In this state, load of any one phase leg, any two phase legs, or all three phase legs.

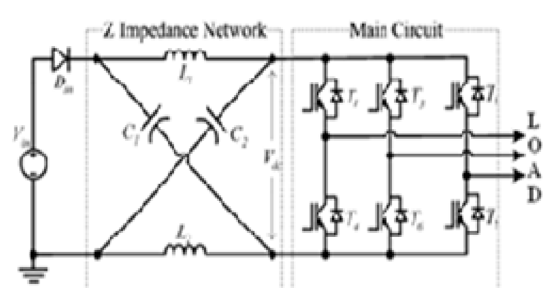

Figure.2.Equivalent circuit for Z-Source Inverter

As described in [7], the voltage of dc link can be expressed as

$Vi = BV_{dc}$ ----------(1)
Where V_{dc} is the source voltage
B is the Boost factor, that is determined by
$B=1/(1-2(T_0/T))$ ----------(2)
Where T_o is the shoot-through time interval over a switching cycle T.
The output peak phase voltage V_{ac} is
$V_{ac} = M\,B\,V_{dc}/2$------------(3)
M = Modulation index.
The capacitors voltage can expressed as
$V_c = V_{c1} = V_{c2} = T_1 V_{dc}/(T_1 - T_0)$-----------(4)
$T_1 = T - T_0$ --------------(5)
Fig. 3 illustrates the simple PWM control method for *Z*-source inverter. This method employs two extra straight lines as shoot-through signals, V_{SC} and $-V_{SC}$. When the career signal is greater than V_{SC} or it is smaller than $-V_{SC}$, a shoot through vector is created by inverter. The value of V_{SC} is calculated by
$V_{SC} = T_1/T$ ---------------(6)

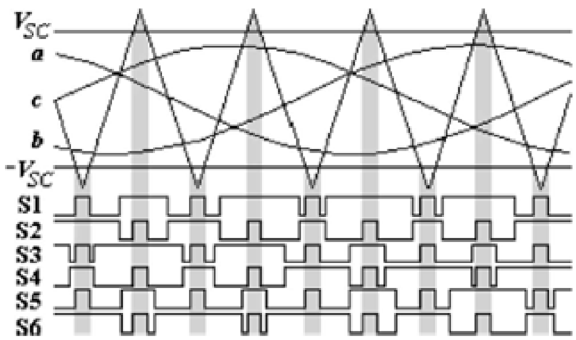

Figure.3.PWM Control method for inverters

In the proposed WECS, a diode rectifier bridge with input capacitors (C_a, C_b, and C_c) serves as the dc source feeding the Z-source inverter. This configuration is shown in Fig. 4. The input capacitors suppress voltage surge that may occur due to the line inductance during diode commutation and shoot through mode of the inverter [9].

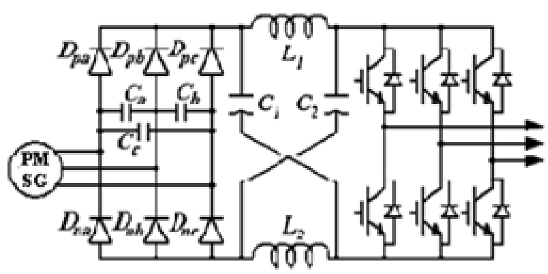

Figure.4.Z-Source Inverter fed with a diode rectifier bridge

III. PERMANENT MAGNET SYNCRONOUS GENERATOR

Wind energy is a quiet alternative to remote diesel generation, generation that sometimes depends on excessive transportation and fuel storage cost, and an economically justifiable alternative to a grid connection. Wind turbines, however, are not always very efficient in the wind speeds that are most common to a region. Typically, wind energy systems are designed to be highly efficient in high wind speed and have a cut-off wind speed below which no energy is captured. In remote locations where wind energy is used for battery charging, the energy lost below the cut-off wind speed could be used for trickle charging or maintaining a battery's fully charged state.

Wind turbines are most efficient when they are operated at one specific tip-speed to wind-speed ratio. Therefore, for the efficient capture of wind power, turbine speed should be controlled to follow the ideal TSR, with an optimal operating point which is different for every wind speed.

Permanent - magnet synchronous generators (PMSGs) are used by these technologies due to special characteristics of PMSGs such as low weight and volume, high performance, and the elimination of the gearbox. With numerous advantages, permanent-magnet synchronous generator (PMSG) generation system represents an important trend in development of wind power applications. As the reasons of high cost, we consider that there are two factors to make system expensive; one is converter and the other is generator.

This PMSG, which makes smooth generating power or smooth peak power in a day. It is necessary to detect or estimate position (Synchronous generator) or speed. PMSG has many advantages against to the other generator, e.g. no exciting current, high efficiency, etc. Moreover, we use Z-Source inverter with smoothing capacitor to control battery charging current.

The main advantage of PMSG is given below.

A. The fundamental displacement factor of SG is unity
B. Production cost is very low
C. No reverse flow of power flow will occur

A simple system and control method for small scaled wind power generating system using permanent magnet type synchronous generator whose output is from 2 to *5* kW or so, has been proposed. We consider that we set many generating units generator to chopper) in parallel and only one power storage, inverter and total power control unit. Therefore, we *can* introduce this system according to budget. Permanent magnet type synchronous generator has been expensive before. But, this type machine has been adopted in many industrial fields recently and with increasing popularity the cost has come down because of its superior driving characteristics compared to induction machine. Also the proposed system has no speed sensor. In addition, as generating unit does not need microprocessor like DSP for the control the system, this unit *can* be produced in low cost. We expect that use of this type synchronous machine adopted with the proposed simpler control methodology will be able to make an inexpensive alternative for small-scale wind power generation systems.

IV. MAXIMUM POWER POINT TRACKING METHODS

As the power supplied by wind turbine depends upon the speed of the wind, it is necessary to control the operating point to extract the maximum power from the wind turbines. The Z-Source converter proposed is adopted as a maximum power tracking methodology. The Z-Source network which is connected next to the rectifier circuit which grabs the minimum voltage that is obtained from the rectifier side and gives the maximum boost voltage as the output from network. This is the maximum power tracking method that is used. There are various MPPT methods available for tracking maximum power and feeding that power to the grid, the technique used here to track the maximum power is the Z-Source Network and the inverter circuit connected to the network. The input voltage given is multiplied with the charges stored in the inductors and that was given as output i.e. the boosted voltage.

Number of methods for Maximum Power Point Tracking (MPPT) has been reported in the literature. Some of the MPPT techniques are listed below,

A. Voltage Based MPPT
B. Current based MPPT Method
C. Look up table Method.
D. Perturb & Observe method
E. Incremental Conductance Method

V. CONTROL SYSTEM

The power equations in the synchronous reference frame are given by

$V_i = 2V_C - V_{dc}$ --------------(7)

$P = 3/2(v_d\, i_d + v_q\, i_q)$ ------------(8)

$Q = 3/2(v_q\, i_d - v_d\, i_q)$ -------------(9)

Where P and Q are active and reactive power, respectively, v is grid voltage, and i is the current to the grid. The subscripts "d" and "q" stands for direct and quadrature components, respectively. If the reference frame is oriented along the grid voltage, vq will be equal to zero. Then, active and reactive power may be expressed as

$P = 3/2(v_d\, i_d)$ --------------(10)

$Q = -3/2(v_d\, i_q)$ ---------------(11)

According to earlier equations, active and reactive power control can be achieved by controlling direct and quadrature current components, respectively. Two control paths are used to control these currents. In the first path, with given reactive power, the *q*-axis current reference is set. To obtain unit power factor, the *q*-axis current reference should be set to 0. In the second path, an outer capacitor voltage control loop is used to set the *d*-axis current reference for active power control. This assures that all the power coming from the rectifier is transferred to the grid. For this control, two methods are proposed: 1) capacitor voltage (*VC*) control and 2) dc-link voltage (*Vi*) control.

VI. MAXIMUM POWER POINT TRACKING

The mechanical power delivered by a wind turbine is expressed as

$P_m = 0.5\rho A c_p v_m^3$ ---------------(12)

Where ρ is the air density, A is the area swept out by the turbine blades, v_m is the wind velocity, and c_p is the power coefficient defined as the ratio of turbine power to wind power and depends on the aerodynamic characteristics of blades. The maximum power output occurs at different generator speeds for different wind velocities. The torque is determined by the generator speed and the wind speed. The steady-state-induced voltage and torque equations of PMSG are given by

$T = K_t I_a$ ----------------(13)

$E = K_e \omega$ ----------------(14)

Where ω is rotor speed and I_a is stator current. Also, we have

$E^2 = V^2 + (I_a \omega L_s)^2$ ----------------(15)

Where *V* is terminal voltage of PMSG and *Ls* is its inductance. The rectified dc-link voltage may be obtained using

$V_{dc} = 3\,V\,((6^{\hat{}(1/2)})\,/\pi)$ --------------(16)

From (14) to (16), the rectified dc voltage may be written as

$$V_{dc} = \frac{3\sqrt{6}}{\pi}\omega\sqrt{K_e^2 - \left(\frac{TL_s}{K_t}\right)^2}. \qquad (17)$$

The torque is determined by the generator speed and the wind speed, therefore according to (18), it is possible to obtain a prediction for the dc voltage as a function of the generator speed and the wind speed. As result, the generator speed can be regulated by setting the dc voltage.

VII. SIMULATION

To verify the performance of the proposed WECS, several simulation tests are performed. The simulated system parameters are listed in Tables I.

Table I

Parameter	Values
V_g	100V
L_1, L_2	15mH
C_1, C_2	200μF
F_s	10KH

The parameters used for PMSG used in the simulation circuit is given below

0.1:0.8 N_m, 300V_{dc}, 3000 rpm – 0.8N_m

The theoretical analyses of all these values which was chosen by building a prototype using Matlab and results are displayed below.

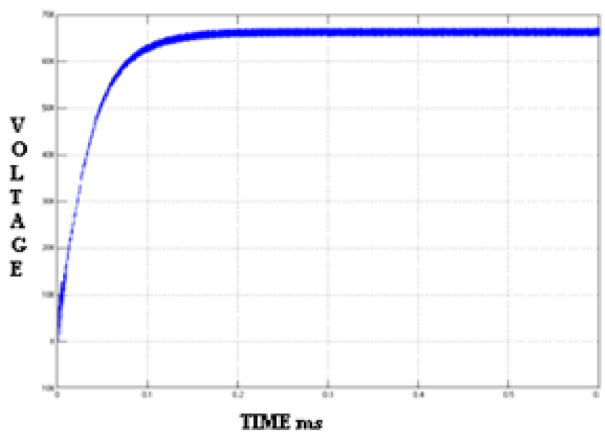

Figure.5.Simulation Output of the Boost Voltage

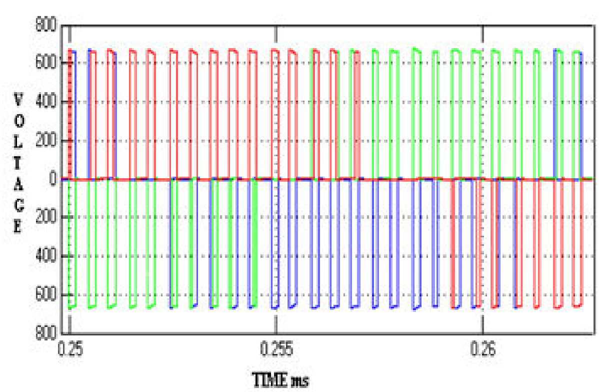

Figure.6. Simulation output of the Output Voltage

VIII. CONCLUSION

In this paper, a PMSG-based WECS with *Z*-source inverter is proposed. *Z*-source inverter is used for maximum power tracking control and delivering power to the grid. The number of switching semiconductors is reduced by one and reliability of system is improved, because there is no requirement for dead time in a *Z*-source inverter. Here comparing to the older techniques the total harmonic distortion slightly reduced. The simulation output of the proposed system is shown in the results.

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