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Performance of Multiple Wind Turbines Interfacing PWM Current Source-Based DC Transmission

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***Abstract*: - In this Project, performance of Multiple Wind Turbine Interfacing in PWM Current Source Based DC Transmission. The wind turbine generator system requires a power conditioning circuit called power converter that is capable of adjusting the generator frequency and voltage to the grid. Several types of converter topologies have been developed in the last decades; each of them has some advantages and disadvantages. Mainly two converter topologies are currently used in the commercial wind turbine generator systems. The system simulation confirms the performance of the proposed system with no interaction between wind turbine modules and satisfying performance with grid integration. . Finally, a brief comparison between conventional line-commutated converter-based systems with filter and the proposed PWM current source converter based system is implemented and analyzed by using MATLAB/SIMULINK 2009a**

1. INTRODUCTION

However, the dc transmission and grid integration for such a configuration remains a challenge. A current source line commutated converter (LCC), which uses thyristors for the main switching devices, has an established, proven track record over five decades in high voltage direct current (HVDC) transmission. Its main advantages are low conversion losses and high-overload capacity. Such a system has been investigated for wind energy conversion systems. Chen and Spooner [3] and Chen [4] focus on the reactive power and harmonic compensation technique for the LCC in wind energy applications. The LCC was further improved in [5]–[7] using a 12-pulse scheme with better harmonic performance, without a reactive power compensator. Instead of single wind turbine interfacing, an LCC-based system has been investigated to directly interface a dc network based wind farm [8], where each wind turbine is individually controlled by an LCC, series connected and integrated to a common dc bus. The advantage is that the dc-link voltage can accumulate without an additional transformer or a step-up converter. Being line-commutated, its switching frequency is restricted by the ac network power frequency. In addition, it has the following disadvantages: require large passive filters to mitigate low-order frequency harmonics, slow dynamic response, dependent active and reactive power control, large footprint, and susceptibility to ac network disturbance [9]. A pulsewidth modulation (PWM) voltage source converter (VSC)-based dc transmission system, using self-commutated devices, such as the insulated gate bipolar transistor (IGBT) as a main switching device, is a developing direction of present and future progress for wind energy integration. It has significant performance benefits and can mitigate most of the shortcomings of LCC-based systems. It allows the use of high-frequency PWM (with a switching frequency of the order 1–2 kHz), resulting in fast dynamics response, small ac filters, independent control of active and reactive power, and grid fault ride through capability, although at a cost of higher switching losses. Conventional two-level VSC has been investigated for wind energy application [10], [11]. The wind turbine is individually controlled by a full rated VSC and parallel connected to a common dc link. The dc link is integrated to the grid and controlled by a VSC. Multilevel VSCs were developed to address limitations of two-level converters in high-voltage applications. A common voltage source multilevel converter is neutral-point clamped [12]. It generates lower harmonic distortion, requires approximately half the switching frequency of that of a two-level converter to generate output voltage with the same quality, lower voltage stress across a single switch, and higher power rating [13]. However, the main disadvantages include more switches, more complex control, and the requirement for a neutral-point or clamping capacitor balancing mechanism [12]. For both two-level and multilevel VSCs, a large decoupling capacitor is required at the dc side to maintain constant dc-link voltage, which is critical for high-power high-voltage applications [14]. Electrolytic capacitors for this purpose are heavy, bulky, expensive, and voltage limited. The dc-link capacitor deteriorates with time, which represents a major system lifetime limiting factor [15]. In addition, the dc-link capacitor makes the system vulnerable to short circuit faults. In addition to the two power transmission and grid integration systems introduced, a current source converter (CSC)-based system using self-commutated devices is also attracting interest. As self-commutated devices are employed, the problems of the LCC-based system can be addressed, and performance similar to that of a VSC-based system can be achieved. In addition, as the dc-link capacitor is replaced by a relatively large inductor, the system is inherently robust to both dc and ac short circuit faults [16]. Furthermore, as the current is defined, the system controller is simpler when injecting power into an ac network which is a voltage source. Active and reactive power control of the PWM CSC in wind energy applications has not been extensively investigated in the literature, the configuration and control strategy of an associated wind farm also needs further study. In [17], a back-to-back CSC-based system is used to interface a single wind turbine to the grid. The dc-link current is controlled to a minimum to reduce system losses. The generator power value is fed forward to the inverter controller to ensure system stability and dynamic performance. However, the main problem is that communication is required between the generator and the inverter grid side. This paper presents a PWM current source wind energy conversion system based on a parallel configuration HVdc for multiple wind turbine interfacing. The proposed controller adjusts the average dc-link voltage with a feed-forward loop while independently controlling reactive power according to the grid code.

II. LITERATURE SURVEY

A grid-commutated Thyristor inverter based power electronic interface for a direct-drive modular permanent magnet generator in a variable-speed wind energy conversion system is described. The AC/DC/AC power electronic interface consists mainly of a diode rectifier and a thyristor inverter. The inverter ignition angle can be adjusted continuously to control turbine speed so that the optimal energy capture is achieved. The reactive power and harmonic characteristics of the thyristor converter system have to be compensated to meet the standards for grid connection. An active compensation system is discussed to minimize the harmonic distortion and to provide reactive power control. A simple method of deriving the reference current for the active compensator is proposed on the basis of optimal operation conditions. Several compensation schemes are considered. Experimental results from a laboratory model are presented along with computer simulation results, which are in good agreement.

This paper presents the performance study of several compensation schemes for a line-commutated SCR converter operating under a wide range of dc voltage. The studied reactive power and harmonic compensation schemes include passive filters, active filters, and hybrid compensation methods for a SCR interfaced permanent magnet generator based variable speed wind turbine. The effectiveness of the compensation schemes has been investigated in terms of reactive power and harmonics. The required compensation current ratings of these schemes are presented. The effects of higher pulse number of the converter on the compensation schemes are also considered.

The paper presents a current-source inverter (CSI) topology tailored for large multi-megawatt wind turbine applications. The cable distance between the generator and the mains enables the realization of a significant portion of the DC-link inductance. In order to improve the efficiency and to allow the possible utilization of rugged inexpensive thyristors, PWM modulation is not used in the main conversion chain. Unity fundamental power factor at the mains is guaranteed at any load condition while the 5th and 7th harmonics of the mains line currents are reduced by choosing a proper nominal operating point for the turbine. Further harmonic reduction is achieved through an active filter controlled via a newly proposed methodology suitable for digital signal processor (DSP) implementation. Such a controller relies on a real-time minimization of a proper functional and is capable of implementing true-feedback current regulation. A part of design simulation results, aimed at constructing a 10 kW prototype, are presented.

This paper presents a current-source inverter topology that is suitable for multi-megawatt wind turbines. The proposed scheme utilizes two series-connected three-phase inverters that employ fully controllable switches and a proper interconnection transformer with the mains. In order to improve the efficiency and to allow the use of high-power devices, the inverters are switched at the mains frequency. The axial-flux permanent-magnet (PM) generator is directly coupled to the turbine (gearless solution), and its design reduces the dependence of the output voltage on the load current. The overall control technique allows to independently impose two desired quantities that can be selected out of the set of three composed of: 1) the total average voltage at the dc side of the inverters, which is directly related to the turbine speed; 2) the fundamental power factor at the mains interconnection point, which can be chosen unitary, leading, or lagging; and 3) the amplitude of one desired component of the spectrum of the mains line currents. The two chosen quantities univocally determine the third one. At specific operating points of the turbine, a significant reduction of the fifth and seventh harmonics can already be achieved without additional filters and/or active harmonic compensation. Nevertheless, the introduction of an active harmonic compensator is necessary to provide the required harmonic reduction (also up to higher orders) more independently and on a wider range of operating conditions. The almost independent regulation of the dc-link current allows further control of the average generator torque. Experimental results that are obtained from a 10-kW prototype with an axial-flux PM generator are presented.

The paper presents a current-source inverter topology tailored for large multi-megawatt wind turbines. The proposed topology can inherently benefit from the distance between the generator and the mains because the consequent length and possible layout of the power cables may enable the realization of a significant portion of the dc-link inductance. In order to improve the efficiency and to allow the possible utilization of rugged inexpensive thyristors, pulse width modulation (PWM) modulation is not used. Unity fundamental power factor at the mains is guaranteed at any load condition while the fifth and seventh harmonics of the mains line currents can be reduced by proper system design at a desired turbine speed, considered most suitable for its operation. Further harmonic reduction is achievable through an active filter controlled via a newly proposed PWM methodology that does not belong either to a carrier-based or to a classical space vector modulation approach. Such a controller relies on a real-time minimization of a proper functional and is capable of implementing true-feedback current regulation. Experimental results from a 10 kW prototype are presented and validate the developed analytical computations.

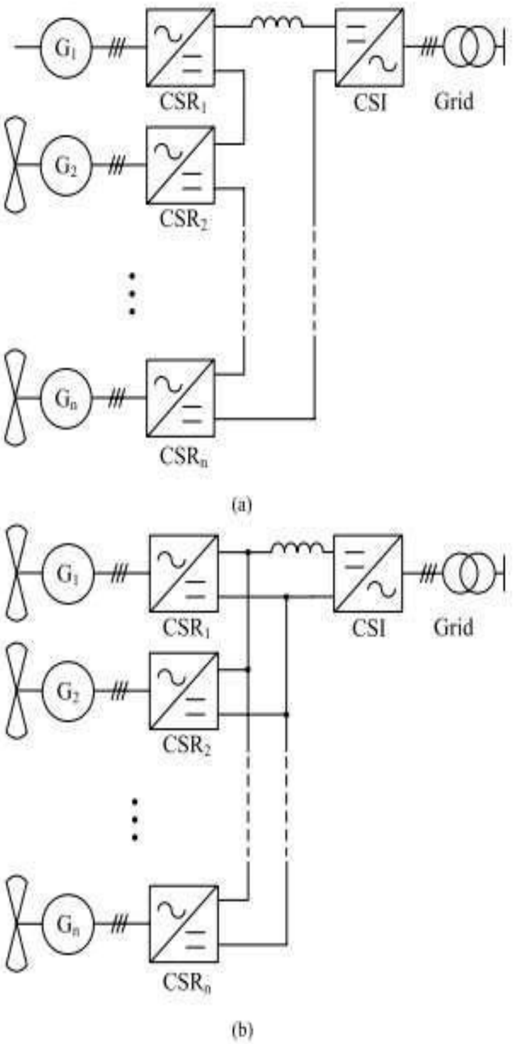


Fig.1. CSC-based wind farm. (a) Serial connected wind turbines. (b) Parallel connected wind turbines.

III.WIND TURBINES

3.1 Introduction

If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a Wind mill. A wind turbine is a machine for converting the kinetic energy in wind into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a wind generator. As wind turbines increase in size and rise to greater heights to take advantage of higher energy winds, their towers require more materials and comprise a larger percentage of the project's cost. Efficient construction methods can optimize material quantities and reduce costs.

In this chapter section 3.2 discuss about the types of wind turbines like horizontal axis wind turbines, vertical axis wind turbines and their advantages and disadvantages. Section 3.3 discusses the power in the wind. Section 3.4 is about working of wind turbine. Section 3.5 is discusses about self-excitation of wind turbine generating system. Finally Section 3.6 summarizes the chapter.

3.2 THE POWER IN THE WIND

The wind systems that exist over the earth's surface are a result of variations in air pressure. These are in turn due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another. There are global wind patterns related to large scale solar heating of different regions of the earth's surface and seasonal variations in solar incidence. There are also localized wind patterns due the effects of temperature differences between land and seas, or mountains and valleys. Wind speed generally increases with height above ground. This is because the roughness of ground features such as vegetation and houses cause the wind to be slowed .Wind speed data can be obtained from wind maps or from the meteorology office.

Unfortunately the general availability and reliability of wind speed data is extremely poor in many regions of the world. However, significant areas of the world have meant annual wind speeds of above 4-5 m/s (meter per second) which makes small-scale wind powered electricity generation an attractive option. It is important to obtain accurate wind speed data for the site in mind before any decision can be made as to its suitability. Methods for assessing the mean wind speed are found in the relevant texts (see the 'References and resources' section at the end of this fact sheet).

The power in the wind is proportional to:

- The area of windmill being swept by the wind
- The cube of the wind speed
- The air density - which varies with altitude

The formula used for calculating the power in the wind is shown below:

Power = density of air x swept area x velocity of the wind cubed/2

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^{3}$$

Where,

P is power in watts (W)

ρ is the air density in kilograms per cubic meter (kg/m^3)

A is the swept rotor area in square meters (m^2)

V is the wind speed in meters per second (m/s)

The fact that the power is proportional to the cube of the wind speed is very significant. This can be demonstrated by pointing out that if the wind speed doubles then the power in the wind increases by a factor of eight. It is therefore worthwhile finding a site which has a relatively high mean wind speed.

3.3 WORKING OF WIND TURBINES

Wind turbines use large blades to catch the wind. When the wind blows, the blades are forced round, driving a turbine which generates electricity. The stronger the wind, the more electricity produced.

There are two types of domestic-sized wind turbine:

➢ Pole mounted: these are free standing and are erected in a suitably exposed position, often around 5kW to 6kW

Building mounted: these are smaller than mast mounted systems and can be installed on the roof of a home where there is a suitable wind resource. Often these are around 1kW to 2kW in size.

Wind turbines are eligible for the UK government’s Feed-in-Tariffs which means you can earn money from the electricity generated by your turbine. You can also receive payments for the electricity you don't use and export to the local grid. To be eligible, the installer and wind turbine product must be certified under the Micro generation Certification Scheme (MCS) . If your turbine is not connected to the local electricity grid (known as off grid), unused electricity can be stored in a battery for use when there is no wind. of wind turbines as Horizontal Axis Wind Turbines, Vertical axis wind turbines and their advantages and disadvantages are described. And also gives The power in the wind, and the working of turbines. The self-excitation of wind turbine generating system (WTGS) with an asynchronous generator takes place after disconnection of wind turbine generating system (WTGS) with local load.

IV.PROJECT DESCRIPTION AND OPERATION

4.1 Series/Parallel Csc-Based Hvdc Connection

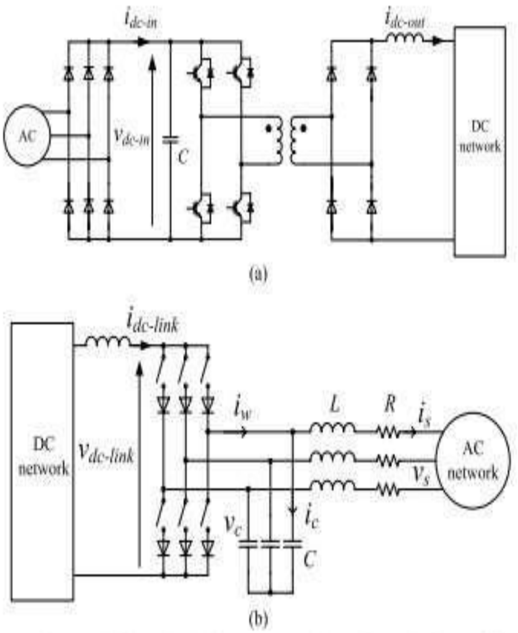
There are two possible wind energy conversion-based HVDC grid connections for CSC-based systems, series or parallel, as shown in Fig. 1(a) and (b), respectively. In [18], a series connected generator-side converter configuration, as shown in Fig. 1, is proposed based on the CSC. The advantage is that the high dc-link voltage is achieved without transformers. In this system, the dc-link current is controlled by the current source inverter (CSI) Fig. 1. CSC-based wind farm. (a) Serial connected wind turbines. (b) Parallel connected wind turbines. according to a lookup table to minimize losses when the dc-link power is low. Pop at et al. [19] further develop this concept by adapting multiple series connected grid-side CSIs. Thus, the power and voltage ratings for individual CSIs decrease. However, the series configuration suffers from the following disadvantages: 1) If one of the modules fails, a current bypass path must be established. Therefore, extra switches may be required. In addition, if many converters fail, given finite boosting of the grid connect CSI, the remaining converters will need to increase their output voltage, beyond their normal operating voltage. 2) It is difficult to incorporate or remove a series connected wind turbine module for integration or maintenance if the system is already in operation. 3) Conduction losses increase as all modules are in series connection, hence all modules carry rated current.

4) Output voltage sharing of the generator-side converters is an issue, as their output voltages are not balanced [20] (experience voltage depends on output power). 5) Converters are not at ground potential. To mitigate these drawbacks, the novel configuration shown in Fig. 1(b), which is similar to a Voltage source Inverter-based dc network, is proposed. The wind turbine modules are parallel connected, while the CSI delivers the power into the grid and controls the dc link. To the authors’ knowledge, such a system configuration has not been investigated. It has the following advantages. First, output voltage balancing is not required for parallel connected current source rectifiers (CSRs), as the CSR large output reactance decouples the CSRs. Second, the cable inductance and CSR output inductor can be utilized by the CSI, eliminating extra bulky and expensive passive components. A novel control technique for the grid connected CSI is proposed, superficially similar to that used in traditional HVDC, to properly control such a Wind Energy Conversion System (WECS) with high performance and stability during all network operating conditions. .

4.2 System Control Scheme

The function of the grid-side CSI is not only to deliver high quality power into the grid but also to properly control the dc link. A straightforward approach is to maintain a constant dc link current as it is an inherent CSI feature. However, as shown in Fig. 1(b), the output current of the generator-side converters share the dc-link current, as the individual modules are parallel connected. If the dc-link current is maintained constant by the Fig. 2.

(a) Full bridge dc/dc converter with a diode bridge rectifier. (b) PWM CSI. CSIs, then the output current of each individual generator-side converter depends on the ratio of its output power to the system total power. If the power increases from one wind turbine and the other wind turbine powers remain constant, then the output current of the first wind turbine increases, while the currents in the others drop. Because of the instantaneous wind power changes for each wind turbine, module interaction is inevitable. Such interaction is undesirable and degrades system performance, triggering possible system oscillations. In some extreme situations, it may cause failure of the generator-side converters. For example, consider two turbines, one delivering low power due to low- wind speed, while the other output is rated power as the wind speed is high. In such a case, the wind turbine with a low power contributes a small dc-link current, while the other provides most of the dc-link current, which could damage the generator-side converter due to increased current stressing. Due to such possible problems, the grid-side CSI should not maintain constant dc-link current. The generator-side converters are parallel connected as in a VSC-based WECS. A possible way to control such a system is to maintain a constant dc-link voltage. In such a case, the generator-side converters are decoupled without interaction, as their output voltage is controlled constant. Since the system is CSI-based, the dc-link voltage at the CSI side is a switched voltage. The idea is to maintain the average dc-link voltage constant; therefore, the generator-side converters being current sources can be readily decoupled.



(a)

(b)

Fig. 2. (a) Full bridge dc/dc converter with a diode bridge rectifier. (b) PWM CSI.

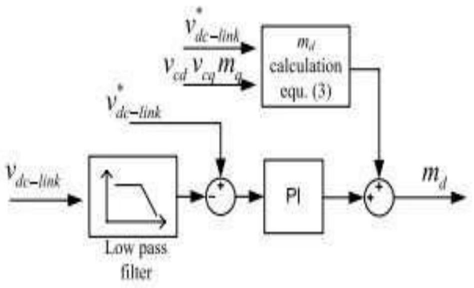


Fig. 3. DC-link voltage control block diagram.

4.3 DC-Link Voltage Control

The CSI control presented in this section is based in a synchronously rotating reference frame, where the d-axis is oriented to the grid voltage vector. A grid-voltage phase-locked loop is used to obtain the instantaneous angular frequency and synchronization angle. Space vector modulation (SVM) for the CSI generates the gate signals [23].

V. SIMULATION RESULTS

5.1 Simulink diagram of proposed system

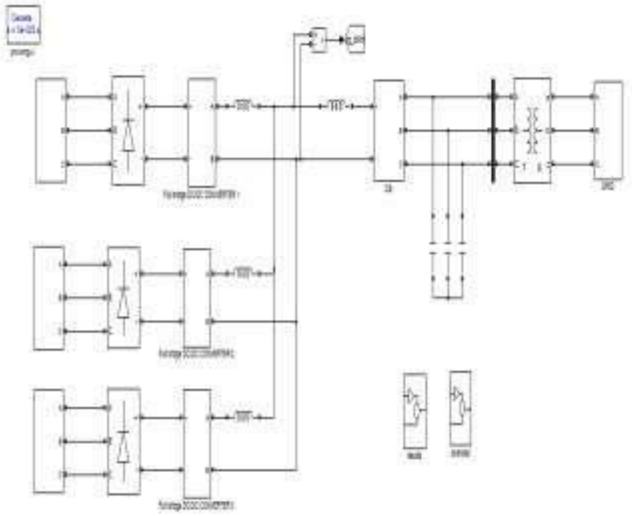


Fig:4 Proposed system

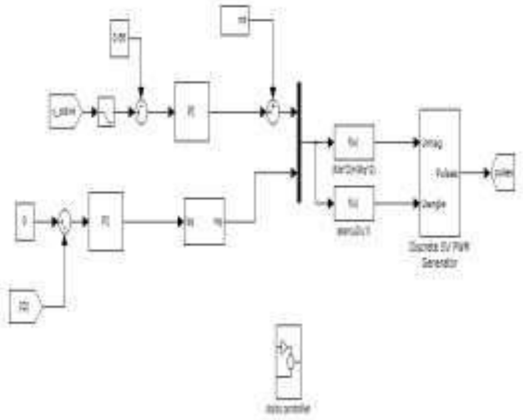


Fig: 5 Control system

The proposed WECS with its controllers is simulated in MATLAB/Simulink software. The WECS includes three 16-kW wind turbine modules and a 50-kW CSI, as shown in Fig. 7. The CSI stabilizes the average dc-link voltage and controls the reactive power, while the dc/dc converter controls its associated wind turbine. The system parameters are summarized in Table I. The simulation results for the three wind turbines are shown in Figs. 8–10. Fig. 8(a)–(c) shows the wind speed, rotor speed, and Cp of turbine 1, respectively..

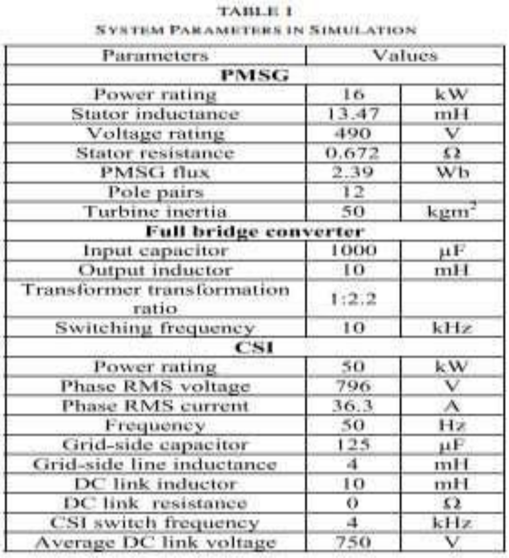


TABLE I
SYSTEM PARAMETERS IN SIMULATION

Parameters	Values	
PMSG		
Power rating	16	kW
Stator inductance	13.47	mH
Voltage rating	490	V
Stator resistance	0.672	Ω
PMSG flux	2.39	Wb
Pole pairs	12	
Turbine inertia	50	kgm^2
Full bridge converter		
Input capacitor	1000	µF
Output inductor	10	mH
Transformer transformation ratio	1:2.2	
Switching frequency	10	kHz
CSI		
Power rating	50	kW
Phase RMS voltage	796	V
Phase RMS current	36.3	A
Frequency	50	Hz
Grid-side capacitor	125	µF
Grid-side line inductance	4	mH
DC link inductor	10	mH
DC link resistance	0	Ω
CSI switch frequency	4	kHz
Average DC link voltage	750	V

Fig:7 Rotor speed

TURBINE-1 Simulation Results

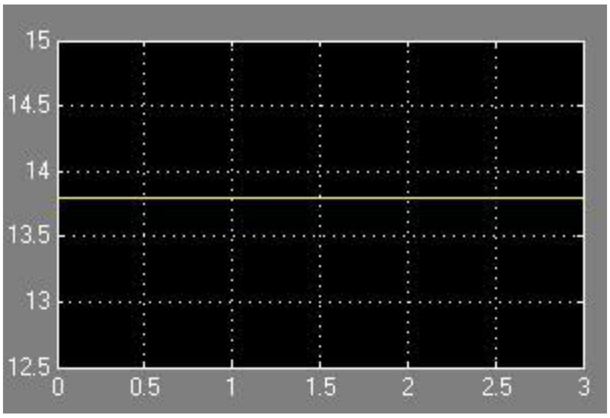


Fig:6 wind speed

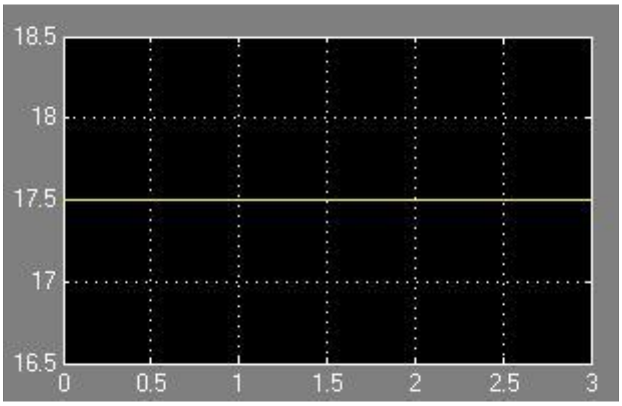
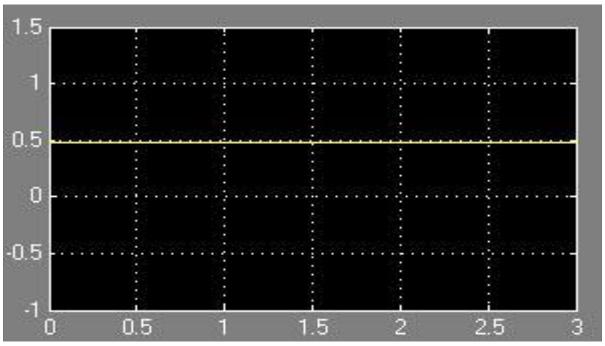


Fig: 8 Cp



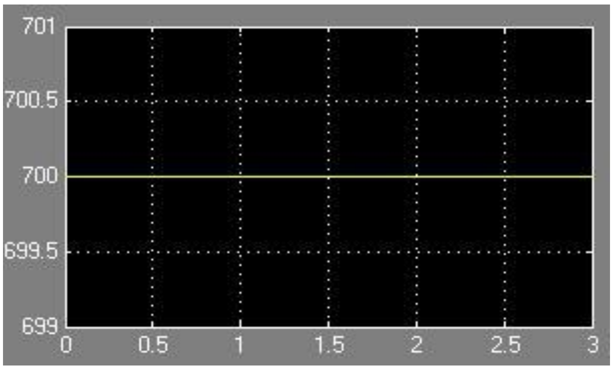


Fig:9 Full-bridge converter input voltage

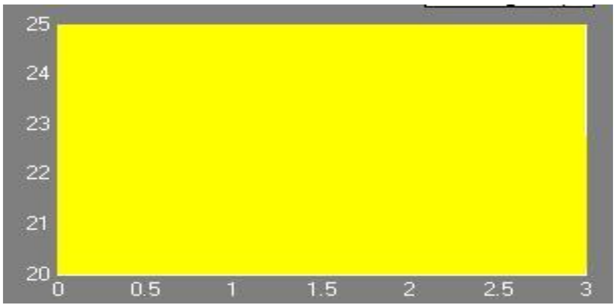


Fig:11 Full-Bridge converter input current

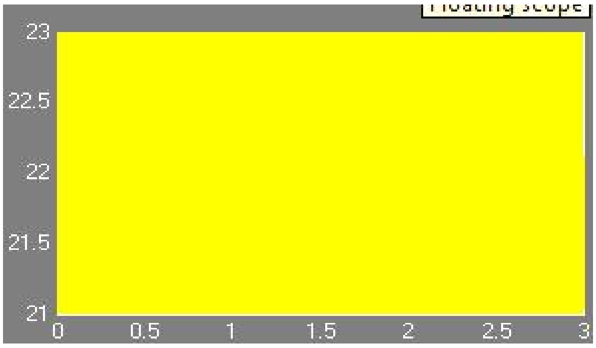


Fig:10 Full-Bridge converter output current

In addition, the simulation results of the corresponding three generator-side converters are also shown in Figs. 8–10, showing dc/dc converter input voltage, input current, and output current. The three wind turbines are decoupled, and each dc/dc converter tracks the MPP by regulating the converter input voltage and current. The input current has large low frequency ripple, while any low-frequency ripple is suppressed on the output side. The average dc-link voltage is maintained at 750 V by the CSI. Since the CSI switching frequency is 4 kHz, a 400-Hz cutoff frequency low-pass filter is used to obtain the average dc-link voltages. The average generator- and inverter-side dc-link voltages are shown in Fig. 11(a) and (b). As the dc-link resistance is neglected, there is no voltage drop between the generator and the inverter sides. Fig. 11(c) shows the dc-link current that varies with wind speed changes. Fig. 11(d) shows the CSI active and reactive powers. The active power flow between the dc and ac sides is balanced, while the reactive power is controlled at zero. The active and reactive powers are decoupled and independently controlled. The ac-side capacitor voltage and output phase current are shown in Fig. 11(e) and (f), with a Total Harmonic Distortion (THD) of 1.18% and 0.22%, respectively. dq values are shown in Fig. 11(g) and (h). The simulation results confirm the ability of the proposed system to achieve good dynamic performance. The CSI is able to control the average dc-link voltage to a constant value, while all three parallel connected wind turbines are individually controlled for MPPT without any interaction.

VI. CONCLUSION

A PWM current source-based wind energy conversion system for a parallel configured HVDC application has been proposed.Similar to voltage source-based system, the generator-side converters are parallel connected to a common dc transmission network. This has some of the advantages of the VSC-based system, but is inherently robust to both dc and ac short circuit faults. Furthermore, this configuration overcomes some disadvantages of a current source-based series connected system. A new inverter control technique was proposed based on this configuration, with independent control of average dc-link voltage and reactive power. The concept and performance of the proposed system have been confirmed by system simulation. The inverter control system was further verified by practical implementation. Finally, a comparison of characteristics between the proposed system and conventional current source-based HVDC systems was present.

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