

Control Scheme for Series-Connected Current Source Converter-Based Wind Energy Conversion System

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Abstract—The series-connected high voltage direct current (HVDC)-based wind energy conversion system (WECS) can eliminate the use of the bulky and costly central substation, resulting in substantial cost and size reductions. One of the biggest challenges for the series-connected WECS is achieving maximum power point tracking (MPPT) for all turbine-generator units under different wind speeds. To address this issue, a control scheme is proposed for a current source converter-based series-connected WECS. The proposed control scheme achieves individual MPPT under different wind speeds while ensuring high efficiency of the system. The control scheme is analyzed, and its performance is verified by simulations.

Keywords— Current source converter, maximum power point tracking, series-connected wind energy conversion system

I. INTRODUCTION

As shown in Fig. 1, in the series-connected HVDC-based wind energy conversion system (WECS), the outputs of the generator-side converters are connected in series to achieve an HVDC level, thereby eliminating the central substation. As a result, the system cost, footprint, complexity, and power loss are reduced. Voltage-source converters (VSCs), including two-level VSCs, neutral point clamped converter (NPC), and modular multilevel converters (MMCs), have been investigated for this configuration [1]–[3]. However, one of the major technical challenges is achieving MPPT for all turbine-generator units under different wind speeds. In contrast, the current-source converter (CSC) features variable DC-voltage operation, making it a promising candidate for series-connected HVDC-based WECSs [4]–[7]. In this paper, a control scheme is proposed to ensure individual MPPT for all turbine-generator units under different wind speeds.

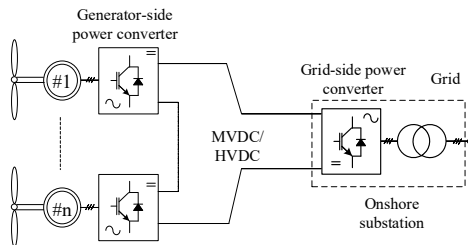


Fig. 1. Series-connected WECS.

II. SERIES-CONNECTED WECS

In a series-connected WECS, the power converters can be categorized into generator-side converters and a grid-side converter. The generator-side converter in [7] consists of a phase-shifting transformer, a multi-pulse diode rectifier, and

a DC–DC converter, as shown in Fig. 2. In this work, two turbine-generator units are considered as an example for analysis of the control scheme. On the grid side, a conventional pulse-width-modulation (PWM) current-source converter (CSC) is employed for grid connection.

III. PROPOSED CONTROL SCHEME

The control of the WECS consists of generator-side and grid-side control schemes. The proposed control scheme shown in Fig. 2.

The generator-side control includes MPPT and generator speed control. MPPT is used to ensure the maximum power is captured and transferred. In this control scheme, MPPT is implemented based on the optimal tip speed ratio, where the generator speed reference is determined according to the wind speed. And then the generator speed controller generates the duty cycle for the DC–DC converter gating signals to achieve the generator speed control according to its reference. To ensure generator-side control, for each module, there is a minimum generator-side DC-link current requirement:

$$I_{dc_gen} = \frac{3\sqrt{2}mV_{s1} - \sqrt{18m^2V_{s1}^2 - 12\pi\omega_s L_t P_{gn}}}{6\omega_s L_t} \quad (1)$$

where ω_s is the electrical angular speed of the permanent magnet synchronous generator (PMSG), mV_{s1} is PMSG output AC voltage, L_t is equivalent leakage inductance of the phase-shifting transformer, and P_{gn} is captured wind power by the turbine # n . The n modules in the wind system generate n generator-side DC-link reference currents, numbering from I_{dc_gen1} to I_{dc_genn} .

To ensure maximum power capture from the wind, individual MPPT for all turbine-generator units must be achieved under different wind speeds.

The grid-side control includes the DC-link current and the reactive power control. The CSCs are controlled using voltage-oriented control (VOC) with modulation-index and delay-angle control. A space vector modulation (SVM) scheme is applied to the CSC. Since these control schemes are well established, they are not discussed here.

To achieve grid-side control and minimize power loss, a minimum grid-side DC-link current is required:

$$I_{dc_grid} = \sqrt{\left\{ \left(1 - \omega_g^2 L_f C_f \right) \left(\frac{2}{3} \frac{P_g}{V_{gd}} \right) \right\}^2 + (\omega_g C_f V_{gd})^2} \quad (2)$$

where ω_g is the grid angular frequency, L_f and C_f the grid-side filter, V_{gd} the d -axis component of the grid voltage, and P_g the total power. For the control scheme for each module, please refer to [7] for details.

To ensure all the control objectives to be achieved simultaneously on both sides and minimize the power loss of

the system, the maximum DC-link current of above currents is selected as reference.

$$I_{dc} = \max \{I_{dc_gen1}, \dots, I_{dc_gemn}, I_{dc_grid}\} \quad (3)$$

As all turbine-generator units share the same DC-link current and are controlled independently, they can achieve their own MPPT.

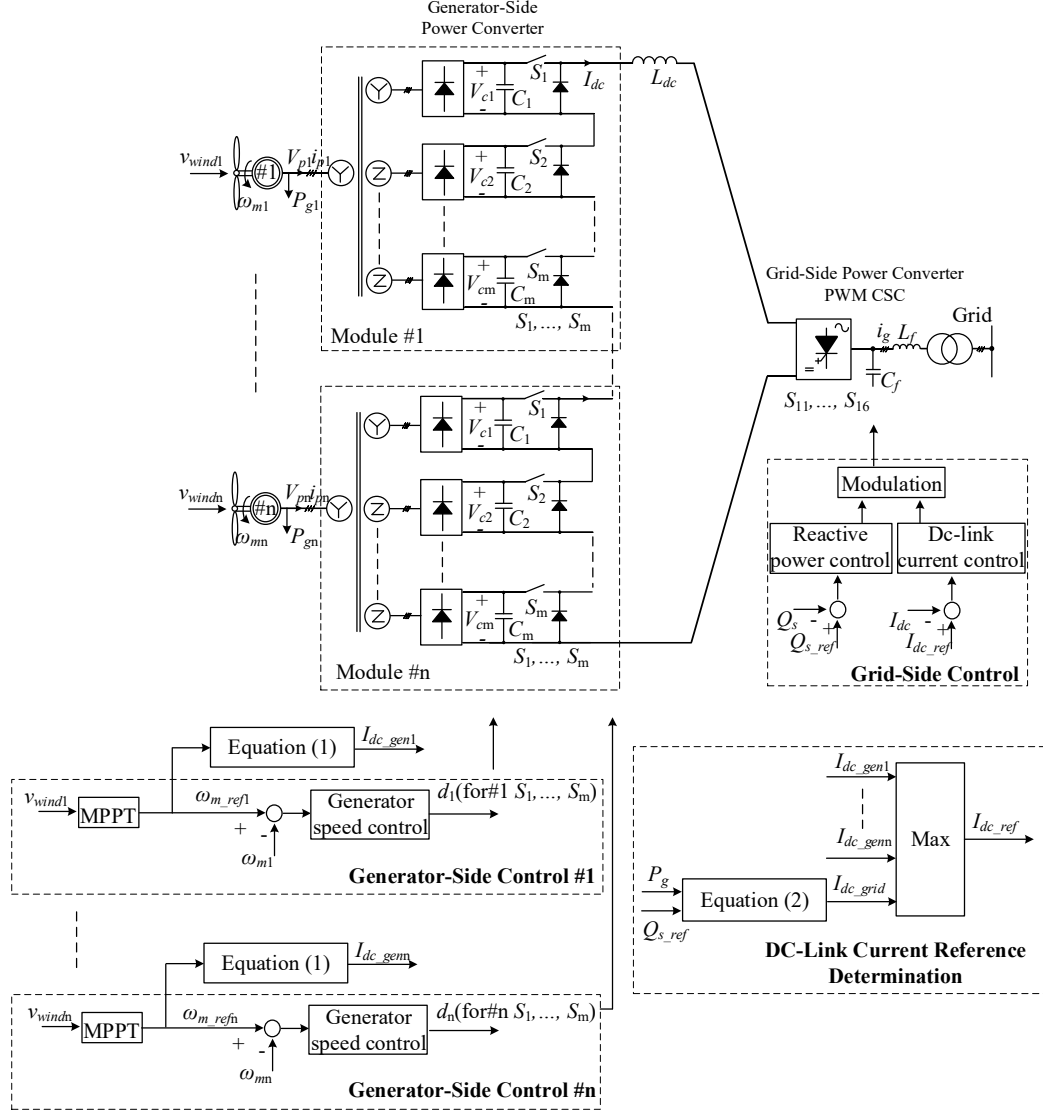


Fig. 2. Series connected WECS using converter proposed in [7] and the proposed control scheme.

IV. SIMULATION RESULTS

The proposed control scheme is investigated using MATLAB/Simulink simulation and the main parameters used are listed in Table I. The simulation results are shown in Fig. 3.

Before $t = 4s$, the wind speeds of the two wind turbines are 8 m/s and 10 m/s, respectively, with the rated wind speed set to 12 m/s. The generator speeds are proportional to the wind speeds and are regulated by the generator-side converters. Accordingly, the generator-side DC currents of the two modules vary. The maximum

value among $I_{dc\ gen1}$, $I_{dc\ gen2}$, and $I_{dc\ grid}$ is selected as the DC-link current reference.

Between $t = 4$ s and $t = 5$ s, the generator of Module 1 operates at the rated speed, and the maximum DC current, $I_{dc\ gen1}$, is selected as the DC-link current reference. After $t = 5$ s, both generators are controlled at the rated speed. The DC-link current, real power P_g , reactive power Q_s , and grid-side current vary accordingly. Overall, the two generators are controlled independently according to their wind speeds to achieve individual MPPT. In addition, unity power factor control is achieved under both steady-state and dynamic conditions.

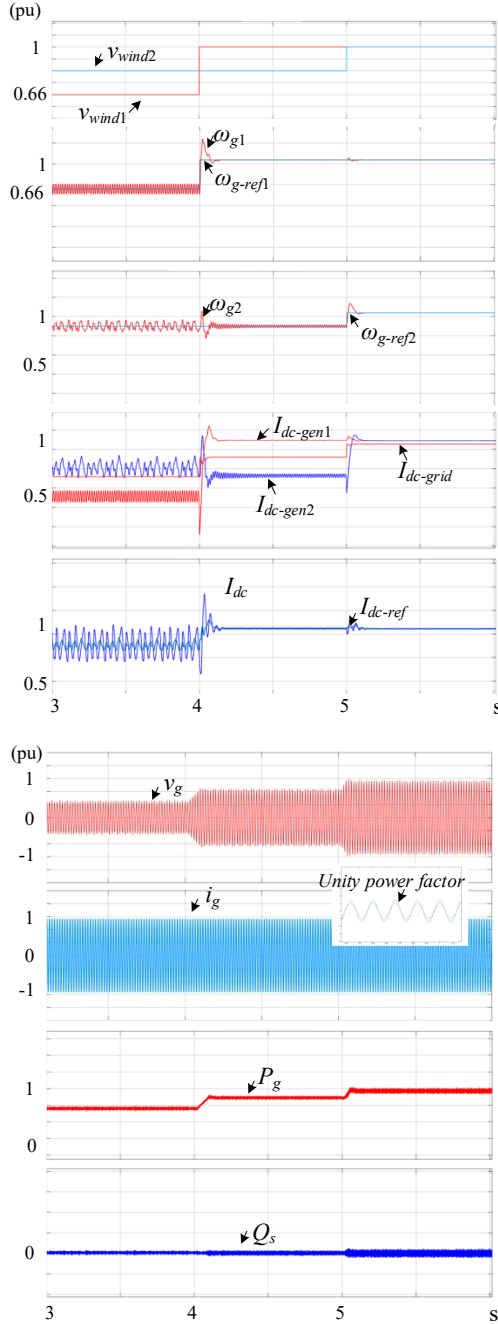


Fig. 3. Simulation results.

TABLE I. SIMULATION PARAMETERS

Parameters	Simulation
Module Count	$n = 2$
Grid Nominal Power	2 MW
Grid Voltage	4160 V
Grid Frequency	60 Hz
Single PMSG Nominal Power	1 MW
PMSG Nominal Voltage	4000 V
Nominal Frequency	53.33 Hz
DC-link Inductor	45 mH
Grid-Side Inductor	5 mH
Grid-Side Capacitor	77 uF
CSC Switching Frequency	540 Hz

V. CONCLUSION AND FUTURE WORK

This paper proposes a control scheme for a CSC-based series-connected WECS that provides independent control of each turbine-generator unit and simultaneously satisfies the control objectives on both the generator side and the grid side. Moreover, individual MPPT can be achieved for each module, enabling the system to capture the maximum available wind power. Simulation results validate the effectiveness of the proposed control scheme. Future work will focus on downscaled experimental verification.

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