Variable Droop Voltage Control For Wind Farm

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***Abstract*—Converters of variable speed wind turbines in a wind power plant may possess different levels of reactive power capacity under variable power generation of each WT due to wake effects. This letter proposes a variable droop gain control scheme that seeks to mitigate voltage fluctuations at point of common coupling (PCC) by fully utilizing the voltage regulation capability of each WT converter. Droop gain of voltage controller in each WT converter is adaptively adjusted based on its current maximum reactive power capacity so that WT converters at back rows that have higher reactive power capacity can contribute more to PCC voltage regulation.**

***Index Terms*—Droop control, voltage regulation, wind turbine.**

I. Introduction

When the penetration of wind energy is high, the voltage profile at point of common coupling (PCC) in a wind power plant (WPP) is constantly fluctuated [1]. In fact, with the traditional droop control [2], which mimics the primary frequency control of parallel operation of synchronous generators (SGs) in power systems, additional reactive power can be provided or absorbed by WT converters and the voltage variations at PCC can be somehow mitigated. However, under the generally adopted fixed droop gain for voltage controller of each WT converter, improper gain setting may lead to unsatisfactory performance. E.g. a larger gain can ensure improved voltage profile, but might cause WT converters to frequently reach the maximum operating limits, which can increase wear outs to the converters. Meanwhile, a small gain guarantees normal operation of WT converters, but provides limited contribution to voltage regulation. Moreover, each WT converter might contain different level of reactive power capability under variable outputs of WTs due to wake effects in a WPP. Therefore, same droop gain scheme is certainly not optimal. To better explore the reactive power support capability of each WT converter and regulate voltage profile at PCC, a variable droop gain control is proposed that discriminates the WT converter's contribution to voltage support at PCC. The droop gain of voltage controller is adaptively adjusted depending on its current maximum reactive power capability so that converters with higher reactive power capabilities may contribute more to voltage support.

Manuscript received October 30, 2016; revised January 31, 2017; accepted June 24, 2017. Date of publication July 12, 2017; date of current version December 14, 2017. This work was supported in part by Hong Kong RGC Theme Based Research Scheme under Grants T23-407/13N and T23-701/14N, in part by the National Natural Science Foundation of China under Grant U1509218, and in part by the National Key R&D Plan under Grant 2017YFB0903004. Paper no. PESL-00198-2016. *(Corresponding Author: Zhao Xu.)*

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Digital Object Identifier 10.1109/TSTE.2017.2726355

II. Proposed Variable Droop Scheme For System Voltage Support

In the conventional droop control, the relationship between reactive power/voltage can be expressed as:

$$Q_i^t - Q_i{}^* = -\frac{1}{R_u}(V_{\mathrm{PCC}}^t - V^*) \tag{1}$$

where the values V^* and Q_i^* correspond to the reference for the voltage at PCC in a WPP and reactive power for each WT converter, respectively. Q_i^t and V_{PCC}^t are the measured reactive power of each WT converter and voltage at PCC at time *t*, separately. The coefficient $1/R_u$ denotes droop gain and is set the same value based on steady-state performance criteria [3].

A. Overview of the Proposed Control Scheme

In a WPP, the active power outputs of WTs in a WPP are variable due to variable wind as well as wake effects. As such, each WT converter may have different level of reactive power capacity for voltage support at PCC. Especially, back row WT converter with less active power output contains larger reactive power capability. To improve reactive power support capability of WPP, the proposed variable droop scheme differentiates the contribution of voltage support from each WT converter based on its current maximum reactive power capability. There are many ways to set the different droop gains of voltage controllers depending on the design purpose. The droop gains are set to be proportional to their current maximum reactive power capacity to fully exploit WTs capability.

The active output power from each WT can be defined by,

$$P_i^t = \frac{1}{2}\rho A C_{p\max} v_{w,t}^3 = K_{\mathrm{opt}} v_{w,t}^3 \tag{2}$$

where ρ is the air density, A is swept area by WT blade, $v_{w,t}$ is the wind speed at time *t*, $C_{p\max}$ is the maximum power coefficient by maximum power point tracking (MPPT) algorithm and K_{opt} is the concerned parameter, respectively. For simplicity, assume each WT converter is with the same nominal capacity, the current maximum reactive power capacity of each WT converter that

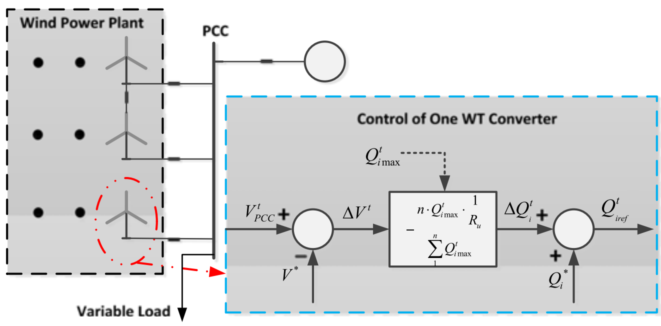

Fig. 1. Proposed variable droop scheme for system voltage support.

can be provided for voltage support is as follows,

$$Q_{i\,\max}^{t} = \sqrt{{S_c}^2 - K_{\text{opt}}^2 v_{w,t}^6} \tag{3}$$

where S_c is the capacity of each WT converter. Q_i^t max is the current maximum reactive power capacity of the ith WT converter. In this paper, the droop coefficient of each converter $1/R_i$ ($i \in$, assume there are n WTs in a WPP) is proportional to Q_i^t max, as follows,

$$\frac{1}{R_i} \propto Q_{i\,\max}^{t} \tag{4}$$

Fig. 1 shows the proposed variable droop control scheme, where droop coefficient $1/R_i$ is adaptively adjusted based on the current maximum reactive power capacity of each WT converter Q_i^t max. Consequentially, the back row WT converter with more Q_i^t max (less active power generation P_i^t) adopts higher droop gain for voltage support at PCC, which makes sure more reactive power support can be provided from WT converters in a WPP. Moreover, the possibility of reaching maximum operating limits of WT converters is reduced, which improves the reliability of the system. In order to realize the relationship described in (4), the following expression holds,

$$R_i \cdot Q_{i\,\max}^{t} = R_j \cdot Q_{j\,\max}^{t} = \frac{1}{\alpha} \tag{5}$$

where α is the concerned proportional parameter.

B. Variable Droop Selection

In order to better compare the performance of the proposed control and the traditional same gain based droop control, the selection of α in (5) is based on precondition of exerting same reactive power under same voltage variation at PCC via two control schemes so that voltage regulation ability by two schemes can be fairly compared. Therefore, the following expression holds,

$$\sum_{i=1}^{n} \frac{1}{R_i} = \sum_{i=1}^{n} \alpha \cdot Q_{i\,\max}^{t} = n \cdot \frac{1}{R_u} \tag{6}$$

TABLE I
ACTIVE POWER, RATED CAPACITY OF CONVERTER, MAXIMUM REACTIVE POWER CAPACITY, AND GAINS OF CONTROLLER

	Col.1 (WT1)	Col.2 (WT2)	Col.3 (WT3)
Wind Speed	14 m/s	12.8 m/s	11.9 m/s
Active Power	1.95 MW	1.49 MW	1.20 MW
Rated Capacity	2 MW	2 MW	2 MW
$Q_{i\,\max}$	0.44 MVar	1.33 MVar	1.6 MVar
Same Gain $1/R_u$	30	30	30
V^*/Q_i^*	1.0 p.u./ 0	1.0 p.u./ 0	1.0 p.u./ 0
Variable Gain $1/R_u$	11.75	35.52	56.97

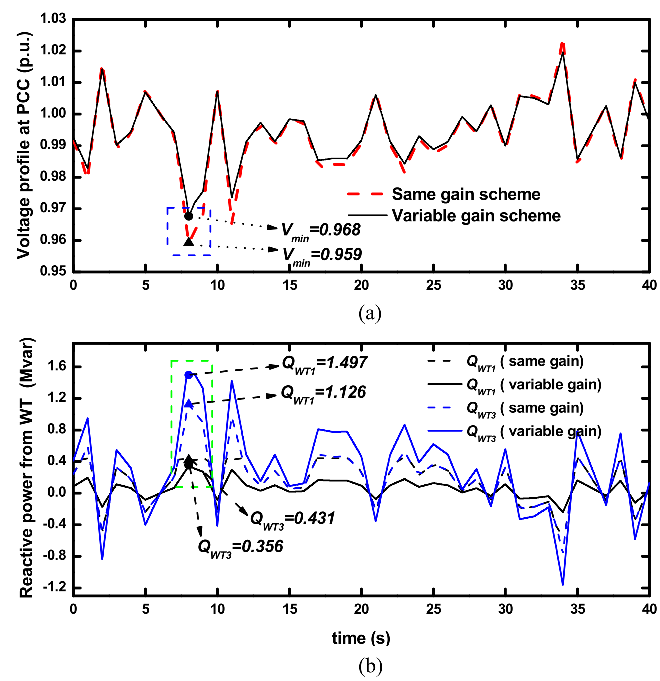

Fig. 2. Dynamic response of controller under voltage variation at PCC.

Combined (4), (5) and (6), the variable droop coefficient of each WT converter can be written in (7),

$$\frac{1}{R_i} = n \cdot Q_{i\,\max}^{t} \cdot \frac{1}{R_u} \Big/ \sum_{1}^{n} Q_{i\,\max}^{t} \tag{7}$$

III. CASE STUDIES

A WPP consisting of 9 (3 × 3) units of DFIG is modeled as shown in Fig. 1. The rating of each WT converter is set the same as 2 MW. The grid voltage is maintained as 1 p.u. by the exciter of a 50 MW SG. In this letter, constant wind speed for a WPP is considered for simplification, which is calculated by the well-studied Park model [4]. Voltage fluctuations at PCC result from one connected variable AC load in Fig. 1, whose exchanged reactive power obeys a normal distribution with the average absorbed reactive power of 0.3 MVar and the stand deviation is 1MVar. The proposed variable droop gain strategy is validated in the *DIgSILENT/ PowerFactory*.

Due to the different active power generated by WTs in a WPP, the WT converters contain different level of maximum reactive power capacities, as shown in Table I. The droop gain of same gain based scheme is selected as 30. Correspondingly, the proposed variable gain for each WT converter is calculated as 11.75, 35.52 and 56.97 respectively. It is clearly seen that back row WT (WT3) has higher droop gain.

It is clearly seen from Fig. 2(a) that the voltage variation at PCC is effectively mitigated with variable gain scheme compared to the conventional same gain scheme. Specifically, with traditional same gain based scheme, the reactive power generated by front row WT (WT1) is constrained to 0.431 MVar at $t = 8$ s, which results in the limited voltage support at PCC. The voltage nadir reaches to 0.959 p.u. compared to 0.968 p.u. with variable gain scheme.

IV. Conclusion

This letter has proposed a variable droop gain strategy that can mitigate voltage variation at PCC in a WPP. The droop gain of voltage controller is adaptively adjusted based on the current maximum reactive capacity of each WT converter so that more reactive power can be exerted for voltage support. The proposed control scheme has proved to be high potential application, especially with high wind penetration. In the future work, the interaction model of WT and turbulence wind model should be discussed to further optimize the droop coefficients of WT.

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