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Effects and Analysis of Minimum Pulse Width Limitation on Adaptive DC Voltage Control of Grid Converters

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***Abstract*— This paper presents an adaptive dc-link voltage controller for the purpose of decreasing the operating dc-link voltage in a back-to-back converter system. An outer loop to control the maximum modulation (Mmax) index is added to the conventional dc-link voltage controller, and hence the system can online adapt its dc-link voltage reference based on the system operating state. Furthermore, the relationship between current THD, minimum pulse width limitation and Mmax index reference is analyzed in order to obtain an optimized performance of the system. Finally, the dynamic performance and analysis of controller is investigated by experimental results.**

Keywords—dc/ac converter; dc voltage adaptive control; Minimum Pulse Width Limitation

I. INTRODUCTION

Wind energy is one of the fastest-emerging renewable alternatives for the electrical supply, and wind turbines are installed with exponential capacity over the past years around the world [1]. The general state-of-the-art wind turbine system is shown in Figure 1. Back to back (B2B) converters are widely applied to realize the controllability and power processing. Two vector control structures are implemented on generator-side and grid-side converters, respectively. The objective of the control scheme for the generator-side converter is to obtain the optimal power tracking for maximum energy capture from the wind by adjusting the speed of the wind turbine. The control of grid-side converter is to coordinate the energy balance between grid and generator, and it can be also responsible for controlling reactive power flow between grid and converter [4].

The grid converter synchronizes with the grid voltage, and the control normally includes an inner current loop and an outer dc-link voltage controller. Normally the dc-link voltage reference is fixed, and set to a level that allows the converter operation over the entire power and grid voltage range. However, decreasing the energy stored in the dc-link can benefit the efficiency of both grid and generator converters due to reduced switching losses [4]. Also for some applications that converter are installed at high altitude, the effect of reduced energy stored in dc-link improves the reliability by decreasing the failure rate based on cosmic rays [5]. The energy storage in dc-link can be reduced by adaptively adjusting the dc-link voltage reference according to different system states. In [6], a method based on calculation of an offline table for the dc-link voltage reference was introduced. However, the performance of this offline calculation method depends on the accuracy of the system model, which is practically affected by various factors, such as operating temperature of the generator, grid voltage, grid impedance and grid filter impedance.

Adaptively adjusting the dc-link voltage reference online can eliminate the calculation errors based on the involved systems modelling. In [4], an outer loop is added to the dc-link voltage controller, which adapts the dc-link voltage reference by controlling the maximum modulation (Mmax) index. The controller shows an improved efficiency implemented in a wind turbine converter. However the Mmax index is simply set as 0.999 in that work. In a practical system, Minimum pulse-width (MPW) limitation is normally imposed on power converter for the purpose of protection but introduce the current distortion. It influences the modulation and needs to be taken into account.

This paper improves the adaptive dc voltage controller proposed in [4] for grid converter, and further studies the effects of MPW limitation in order to optimize the performance of controller. The rest of paper is organized as follows: Section II demonstrates the Mmax adaptive dc voltage control strategy

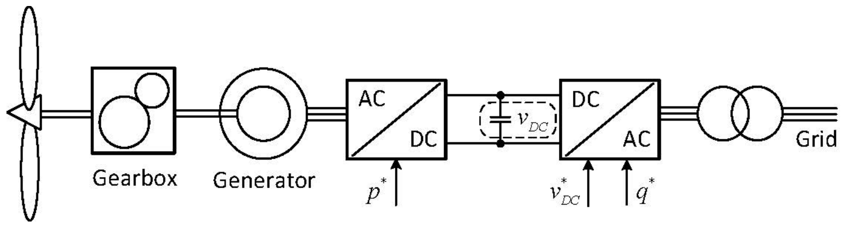


Fig. 1 Wind turbine system with full scale converter

in detail, and gives an explanation on the Mmax index detection and effects of MPW limitation. Section III shows the experimental results and the parameters guidance of Mmax controller on a 2 kW converter prototype. Finally, Section IV gives the conclusion and future research directions.

II. ADAPTIVE DC VOLTAGE CONTROL

To achieve an online adaptation of the dc-link voltage reference, a control loop can be implemented as shown in Fig. 2. Instead of setting a fixed dc-link voltage reference, the Mmax index reference is controlled taking the feedback from the input modulation index to the modulator.

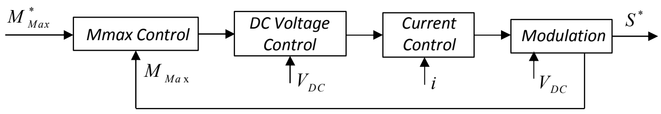


Fig. 2 Proposed adaptive dc-link voltage controller

A. Control structure

The detailed control structure for a typical grid converter with LCL filter is shown in Fig. 3. The inner loop is current control loop which is decoupled in synchronous reference frame (d-q frame) [8]:

$$\begin{bmatrix} \dot{i}_d \\ \dot{i}_q \end{bmatrix} = \frac{v_{DC}}{L}\begin{bmatrix} d_d \\ d_q \end{bmatrix} + \begin{bmatrix} -\frac{R}{L} & \omega \\ -\omega & -\frac{R}{L} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} - \frac{1}{L_{line}}\begin{bmatrix} v_{gd} \\ v_{gq} \end{bmatrix} \qquad (1)$$

where i_q and i_d, d_q and d_d are DC-like currents and duty ratios aligned with q and d rotating axes, respectively, while R and L are per phase resistance and inductance of the ac filter including line impedance.

The typical out loop contains only a dc voltage regulator with the smaller bandwidth than current loop. Here, a *Mmax* index regulator is added to voltage control loop by detecting the Mmax index to modulator. Hence, the output dc-link voltage reference will adapt to the converter system state, and at all power levels, the operating dc-link voltage is reduced significantly.

B. Mmax Index detection and reference

According to the results in [4], the Mmax index reference is direct proportional with the grid voltage, current, impedance and additional harmonic voltage respectively and inverse proportional with the dc-link voltage. Because Mmax index is in relationship with so many parameters, it is optimal to online detect it. In this paper, the Mmax value of modulation duty ratio is updated in each fundamental period. In this way, Mmax index is the maximum value of duty ratios of three phases.

In [4], the reference of Mmax index is directly set as 1. However, the Mmax is also affected by system states, such as grid condition, transferred power and MPW limitation. Among those factors, MPW limitation directly influences the maximum modulation index. Therefore, the Mmax index cannot be set as the ideal value of "1" in a practical system.

C. Minimum Pulse Width limitation

MPW limitation is usually imposed by the manufacturers of the active power electronic devices used in converters.

Such limitation has to be enforced to prevent the introduction of power stress on the devices, especially in high power applications [7]. Commonly there are three MPW methods, as is shown in Fig. 4.

- Pulses dropped if they are lower than a minimum width
- Pulses are hold as minimum width value if they are lower than minimum width.
- Pulses are dropped if they are lower than half MPW, but held to MPW value if they are slightly higher than the MPW.

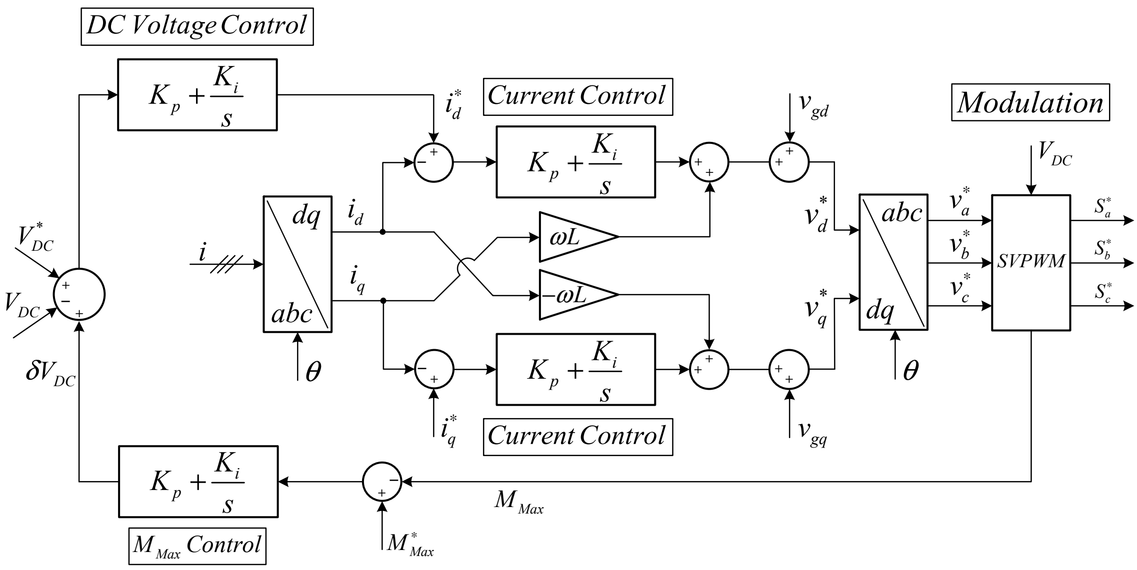


Fig. 3 Grid converter d-q adaptive control structure

This paper the third condition is applied. Setting a maximum modulation index reference above the voltage reserve for the MPW filter can introduce additional distortion on the output current. Therefore the maximum Mmax reference should be experimentally determined in order to comply with the harmonic standards.

Finally, the modulation scheme and MPW limitation is presented in fig. 5.

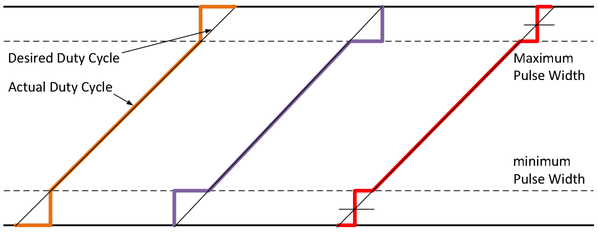


Fig. 4 minimum pulse width limitation methods

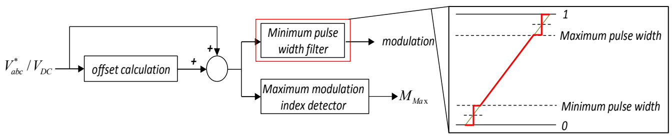


Fig. 5 Modulation and MPW limitation

III. EXPERIMENTAL RESULTS

The simulated control from Fig.3 was implemented in a dspace1006 control platform. The converter prototype is a two-level 2.2 kW Danfoss converter connected to the 400 V grid. The test setup is shown in Fig.6. The grid LCL filter had a total inductance of 3.6 mH and a delta connected capacitor bank of 9 µF. The converter is modulated with continuous space vector pulse width modulation, switching and sampling at a frequency of 10 kHz.

A. Dynamic test

The dynamic operation of proposed Mmax controller is showed in Fig.7. The converter starts operating at a fixed dc-link voltage reference of 600 V, operating at light load in rectifying mode. The Mmax controller was enabled at 1.8 s with reference as 0.985. The dc-link voltage is regulated at an adaptive reference of around 565 V with a response of 1 s and the dc-link voltage is reduced by 35V.

B. MPW limitation test

To study and analyze the effect of MPW limitation on the Mmax controller, the experimental tests are implemented respectively when MPW value is between 1% and 4% of the switching period and Mmax ref is between 98% and 100%. The dc power source input is kept constant at 2 kW to simulate the wind generator. Fig. 8 shows the experimental results in MPW value is 0.02. Fig.8a shows the Mmax ref increase from 0.98 to 1 with a step of 0.005. The MPW limitation can be observed in Fig.8b when Mmax ref is 0.98. Converter-side current and zoomed spectrums are presented in Fig.8c.

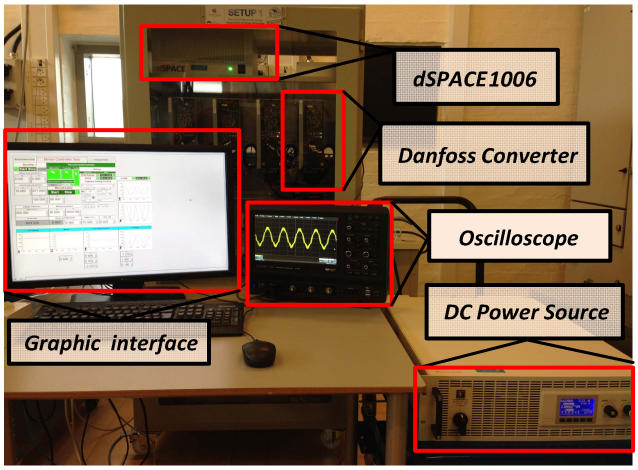


Fig.6 Experimental test setup.

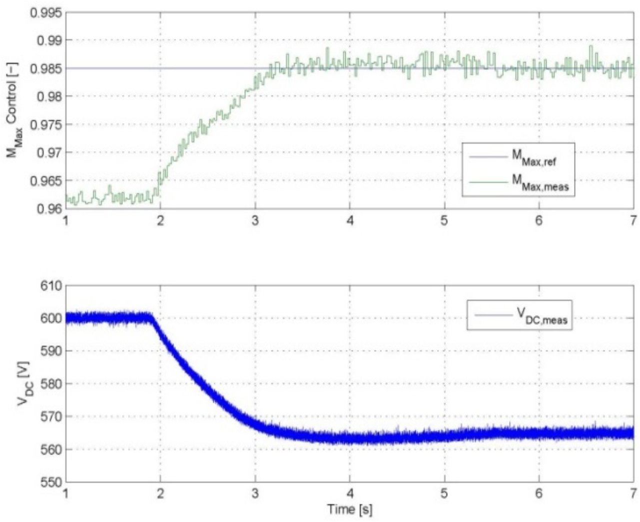
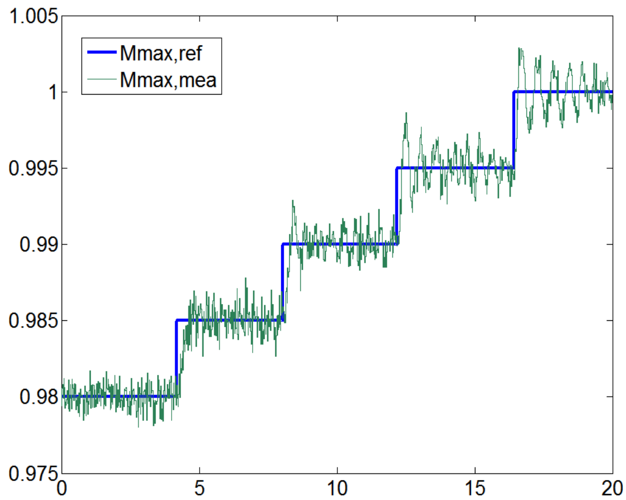
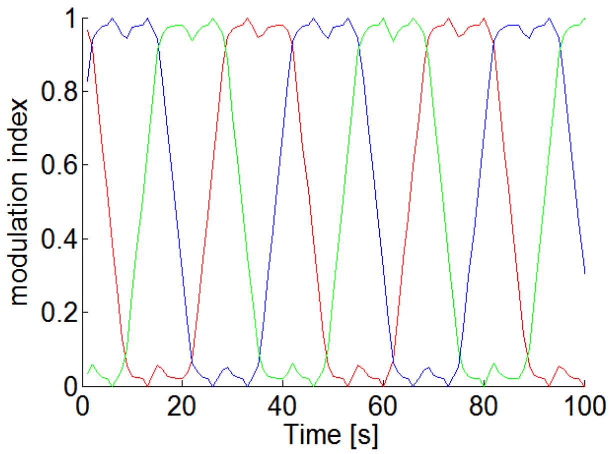


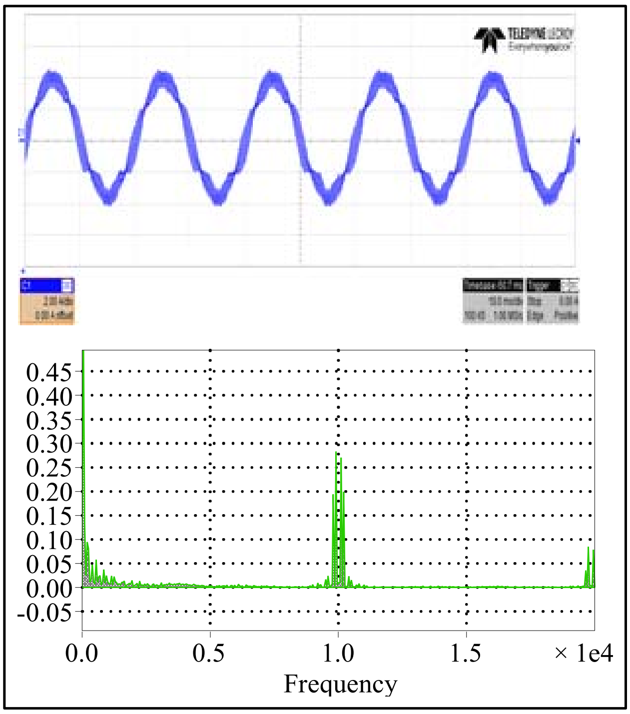
Fig. 7 dynamic operation of *Mmax* controller



a. *Mmax* reference in MPW=0.02



b. modulation index in *Mmax* ref=0.995, MPW=0.02



c. Converter-side current and zoomed spectrum in *Mmax* ref=0.995, MPW=0.02

Fig.8. Experimental results of MPW=0.02

Finally 20 groups of data are obtained and imported to MATLAB to analyze the relationship between current THD, dc voltage, MPW limitation and Mmax ref. The current THD and voltage in different system states are listed in Table I and II, and plotted in Fig. 9 and 10.

It is observed from Fig. 9 and 10 that the THD of converter-side current increase slightly with the Mmax ref increasing when MPW value is below 0.03, while THD boosts critically more than 3% when MPW value is over 0.03. It can be also observed that, dc link voltage decreases with the Mmax ref increasing and reaches its minimum value to when Mmax is 1.

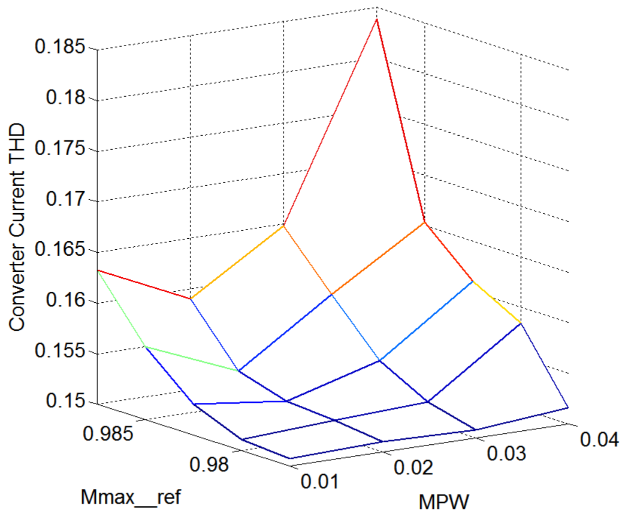


Fig.9 Converter-side Current THD in Different System States

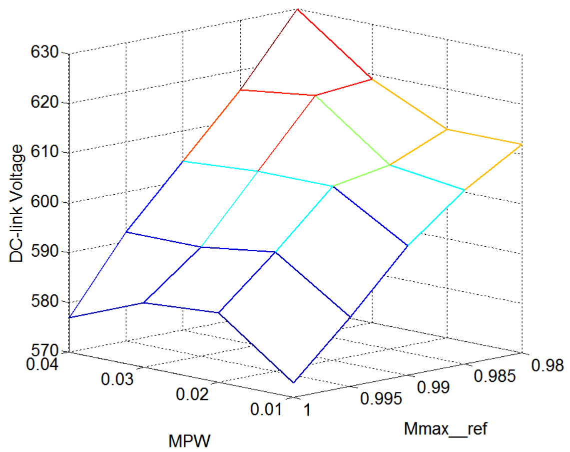


Fig.10 dc-link voltage in different system state

TABLE I. Converter-side Current THD in Different System States

*Mmax*_ref / MPW	0.980	0.985	0.990	0.995	1.000
0.01	15.1%	15.1%	15.3%	15.7%	16.3%
0.02	15.1%	15.2%	15.2%	15.4%	15.9%
0.03	15.1%	15.0%	15.5%	16.0%	16.5%
0.04	15.2%	15.8%	16.1%	16.5%	18.4%

TABLE II. dc-link voltage in different system state (V)

Mmax _ref / MPW	0.980	0.985	0.990	0.995	1.000
0.01	612	605	596	584	573
0.02	612	607	605	594	584
0.03	619	618	605	592	583
0.04	630	616	604	592	577

From the experimental results, it can be concluded that the MPW increases the harmonics and reduces the effective applied voltage, thus requires higher dc link voltage for the given modulation.

As a trade-off, it may be recommended that the Mmax ref is set as “1” to obtain the minimum dc link voltage when MPW is from 0.01 to 0.03; when the MPW value is larger than 0.03, the Mmax ref can be reduced to decrease the current distortion.

IV. CONCLUSION AND FUTURE WORK

An improved and simple controller that adaptively regulates the dc-link voltage is used for B2B converter in wind turbine system in this paper.. The dynamic of operation was investigated and the relationship between current THD, dc voltage, MPW limitation and Mmax ref are analyzed in detail by experimental results on a 2kW prototype. The Mmax reference is chosen in trade-off between minimum dc voltage and current THD.

As future works, the Mmax controller operation with discontinuous PWM schemes will be investigated, and stability of the proposed control strategy will be analyzed.

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