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MODIFIED CONTROL STRATEGY OF CASCADED H-BRIDGE MULTILEVEL CONVERTER IN GRID CONNECTED WIND ENERGY SYSTEM

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Abstract-- The range of the output power is a very important and evident limitation of two-level inverters. In order to overcome this disadvantage, multilevel inverters are introduced. Recently, Cascade H-Bridge inverters have emerged as one of the popular converter topologies used in numerous industrial applications. In this paper we have discussed about a particular circumstance that the RMS value of the inverter output voltage fluctuates with certain frequency and amplitude. This paper presents the application of this special-outputting cascaded H-bridge (CHB) multilevel converter, grid-connected wind turbine converter testing. In this paper, by comparing with the other control strategies new control strategy is proposed which is simple and effective and also the modeling and analysis of this particular RMS value feedback control strategy is elaborated. Simulation work is done using the MATLAB software and experimental results have been presented to validate the theory.

I. INTRODUCTION

Now a days industrial applications needs higher power rating which reached to mega watt range. For a medium voltage grid. It is troublesome to connect only one power semiconductor switch directly. As a result, multilevel power converter structure has been introduced as an alternative in high power and medium voltage applications.

A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for medium voltage high power drives, distributed energy sources and hybrid electric vehicles. The range of output power is limited in two level inverters, this disadvantage is overcome by multilevel inverter and they have features such as high reliability due to its modular topology, less distorted input current and less switching losses. Among the topologies of multilevel inverter Cascade Multilevel Inverter (CMIL) is one of the most important topology because of following features such as no specially designed transformer is needed as compared to multi pulse inverter, occupies less space and ability to synthesize better harmonic spectrum. With the advantages over other multilevel converters such as neutral point clamped converter [2] and flying capacitor converter [3], CHB multilevel converters are playing a more and more significant role in power converter family for high-power, high-voltage applications due to comparatively low cost, no need for numerous capacitors and diodes, ease of control, excellent performance and capability of fault tolerant. The major applications of the CHB multilevel converter are VAR compensation, middle-voltage variable speed drive and back-to-back system. Many researchers have contributed to the research of CHB multilevel converters.

Nowadays, renewable energy systems are undergoing an important development. Among them wind energy stands out for its installed capacity, power generation steady growth. In this paper based on CHB structure wind turbine testing system control strategy is investigated. A grid connected wind turbine converter testing system. is constructed through the combination of CHB multilevel converter, three-phase PWM converter and transformers as depicted in Fig.1. In order to simulate a 35 kV-power grid and produce a fluctuating voltage whose RMS value fluctuates with certain frequency and amplitude, the control of CHB multilevel inverter should be conscientiously designed provided that the DC-link voltage is permanent and each phase is controlled separately as a single-phase inverter. The combination of three single-phase CHB multilevel inverters constructs a three-phase system in which every single CHB multilevel inverter works as a single-phase inverter. As a corollary to this statement, the control strategy of single-phase inverter can be considered as reference for CHB multilevel converter control.

Many control schemes have been proposed during past decades for single-phase inverters, but those control strategies bring about draw backs, for instance, difficulty in modeling, complex design and

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hardware implementation, sensitive to system parameters and loading conditions, or simply steady state errors. Moreover, majority of these control strategies ordinarily only concern about the particular types of loads which shrinks the scope of the benefit discovered. Based on the controller structure, applying a single voltage regulator is enough for the control of single-phase inverter AC voltage, but this is not enough when dealing with more demanding applications with higher performance requirements, where usually at least one current-loop is required as well.

Multiloop current-voltage PID control strategy is able to represents a simple solution when designed using frequency-response techniques providing a number of advantages in terms of design and ease of implementation, ultimately achieving good regulation and a well-defined region of predictable stability for the converter operation. These multiloop PID schemes usually use either filter inductor [35]- [38] or filter capacitor [39]-[43] current as feedback variables, or a more complex structure, both filter inductor current and load current as feedback variables [36]-[40], [44]-[48]. The demerit of this control is that it is subject to steady state errors due to its finite loop gain at fundamental frequency, and also that it has a variable dynamic response depending on the loading conditions. To overcome these shortcomings, several control schemes have been proposed including adding proportional plus resonant (PR) or PID plus resonant (PID+R) compensator into the outer voltage regulation loop, [40], [48]-[51], [59], or using singlephase d-q frame controls with orthogonal stationary β-axis terms [49]-[56], [59], the inverter can theoretically achieve zero steady-state error and fast dynamic response respectively.

The comparison of these multiloop controls is given in [40], [59]. But all of these lead to inconveniency in practical applications because of the following reasons: 1) owing to the variation of the fluctuating frequency, parameter of the resonant compensator is hard to choose; 2) since the PR or PID+R compensator is always nonideal, zero steady-state error can't be achieved in practice; 3) because of the high power rating and high voltage, the controller parameter design should be simple and reliable; 4) current sensors with high ratings and wide bandwidth must be used which, in most cases, makes these multiloop controls economically unattractive; 5) what's more, difficulty in modeling, complex design and sensitive to system parameters and load conditions.

This paper comprehensively investigates divergent multiloop controls for single-phase inverters and presents a special RMS feedback control with the advantages of ease of implementation and excellent performance. The experimental verification of the control strategy is carried out in the 35 kv-6 mw wind turbine converter testing equipment.

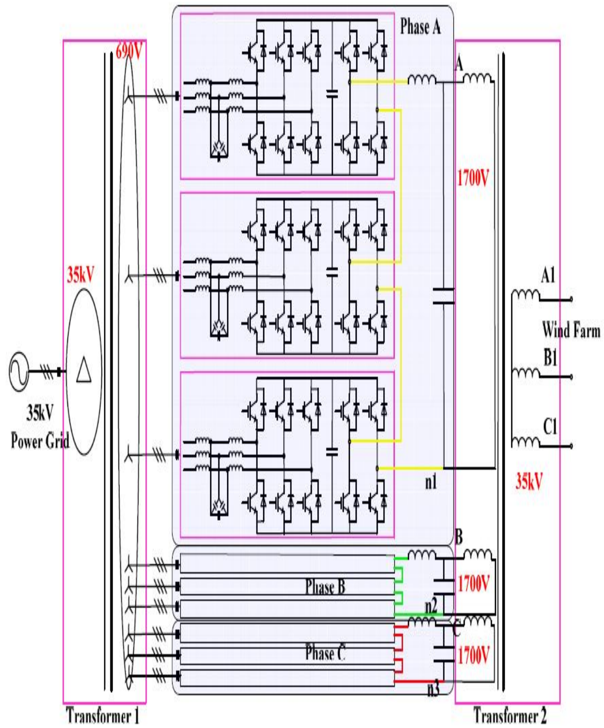


Fig. 1 Main circuit topology of the wind turbine low-frequency disturbance testing system

II. PROPOSED TOPOLOGY

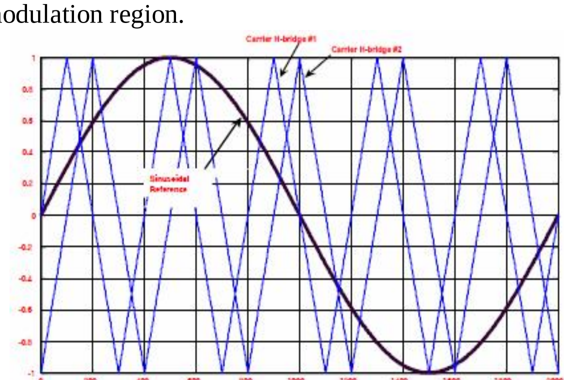
The modulation control techniques for multi level inverters can be classified according to switching frequency. Modulation techniques which have many commutations for the semi conductors in one period of the fundamental output voltage have high switching frequency. Very popular methods in industrial application are carrier based PWM with triangular carriers, they are: phase shifted carrier based and level shifted carrier based PWM schemes.

Modulation control techniques that work with low switching frequency generally perform one or two commutation of the power semi conductors during one cycle of the output voltage. generating stair case wave form. For this low switching frequency, popular control technique is selective harmonic elimination pwm method.

A. PSC-PWM CHB Multilevel Converter:

The phase-shifted carrier PWM (PSC-PWM) is a widely utilized modulation strategy for CHB multilevel converter due to its low THD, good linearity and wide bandwidth. Nonetheless, since the PSC-PWM has divergent types of variations, the performance differentiates from each other, such as different phase-shifted angle [60], various modulations for every single H-bridge (two-level modulation and three level modulation). Some of these are only straightforward variations of previous approaches, while others make differences in intrinsic principle. In psc pwm all the triangular carriers have the same frequency and same peak-peak amplitude .but there is a phase shift between any two adjacent carrier waves. For m Voltage levels (m-1) carrier signals are required and they are phase shifted with an angle of θ=(360°/m-1). The gate signals are generated with proper comparison of carrier wave and modulating signal .

This paper applies a specific PSC-PWM, in which every single H-bridge uses double frequency modulation, or so-called three-level modulation. Therefore, the output voltage of the CHB multilevel inverter has $2n + 1$ levels and the equivalent switching frequency is $2nk$ (n is the number of the cascaded H-bridges, k is H-bridge carrier frequency). Note that for analysis purpose, the CHB multilevel inverter can be incorporated within the control loop as a fixed gain factor which equals to n times of the modulation index, provided that the switching frequency is much higher than the required output frequency and the inverter is not operating in over-modulation region.



B.Multi loop V-I Control:

Multiloop current-voltage control is the most prevalent control scheme due to its ease of implementation and excellent performance [59]. Fig. 2 and Fig. 3 are the aforementioned control schemes that are widely utilized. These controls are the promotion of multiloop PID controls as mentioned before.

Fig. 2 shows the filter capacitor current feedback control adding PR or PID+R compensator into the voltage regulation loop. When economic efficiency is taken into consideration, this control is the best choice for Uninterruptible Power Supply (UPS) with satisfactory steady-state and transient performance [40], since it requires only one current measurement with a relatively low cost current sensor. However, this scheme cannot incorporate inverter over current protection since the inverter output current is not available to implement an over current fault.

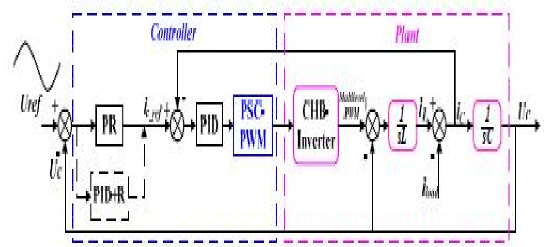


Figure 2. Filter capacitor current feedback control

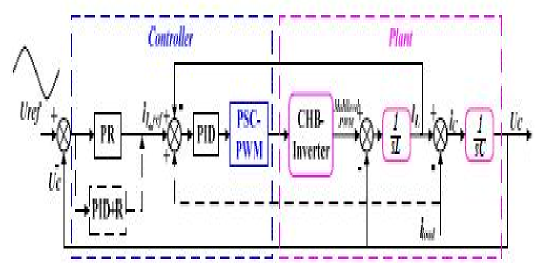


Figure 3. Filter inductor current feedback control (or adding load current feedback control)

Fig. 3 shows the filter inductor current feedback control adding PR or PID+R compensator into the voltage regulation loop. This allows overcurrent protection to be easily added to the control circuitry. The measurement of inductor current however requires the use of current sensors with a higher rating and wider bandwidth, since the inductor current contains most of the harmonics drawn by the load. Furthermore, the transient performance of the control system will be compromised due to comparatively small bandwidthand lower low-frequency loop gain.

Furthermore, by adding load current feedback (not so called Feed forward [59]) into the feedback loop which is also depicted in Fig. 3, it achieves the performance advantage ofthe filter capacitor current feedback scheme whilst also allowing inverter overcurrent protection to be implemented. Note that this kind of control is the most expensive one sinceit needs two high performance current sensors per phase measuring load and inductor current. Additionally, it can be observed how the LCF helps to further reduce the voltage error due to the low-frequency loop-gain improvement, especially under heavy loading condition. Moreover, thePID+R adding load and inductor feedback controller presents the highest bandwidth and loop gain which results in small steady state error and best dynamic response. Nevertheless, with the bandwidth and loop gain increased comparing with the conventional multiloop PI control; these controls suffer from instability with second order loads, such as LC filter loads [59].

C.Proposed Control Scheme

From the proposed control scheme, the wind turbine works as a current source load pulling and feeding power into the testing equipment or the power grid, the RMS feedback control is a better choice for ease of control parameters design, precise output amplitude, and large stability margin (Fig. 4). Control diagrams are depicted in Fig. 6 and Fig. 7. Modeling andanalysis of this RMS feedback control is given in [61]. As mentioned before, the output voltage fluctuates with certain frequency and amplitude, therefore, the mathematical expression of this fluctuating signal is given by

(1)

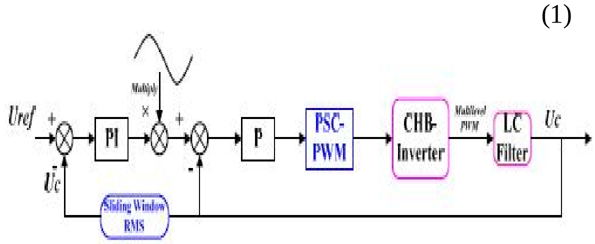


Figure 4. RMS feedback voltage control (adding sinusoidal signal in the instantaneous inner-loop)

Where,

$V_{distrub}$ - fluctuating signal

A- Amplitude

- Angular frequency

and φ- Phase

of the modulated sinusoidal signal respectively.

a_m- Amplitude

- Angular frequency

and - Phase

of the modulating sinusoidal signal respectively. Expanding (1) gives

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– (2)

It can be observed apparently that $V_{distrub}$ has three frequency components, they are fundamental component and two components that distribute symmetrically apart from the fundamental frequency by , which is the fluctuating frequency.

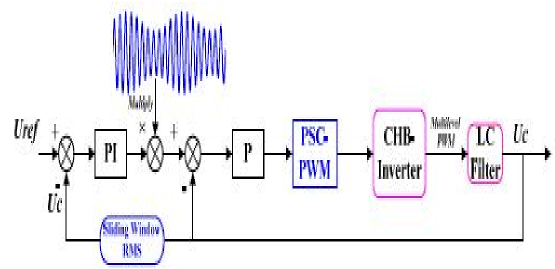

Figure 5. RMS feedback voltage control (adding perturbation signal in the instantaneous inner-loop)

According to the conventional RMS feedback control, theinstantaneous inner-loop reference signal is what needs to beproduced. When simply replacing the sinusoidal reference bythis fluctuating signal (Fig. 5), the accuracy of the fluctuating output will be deteriorated for the following reason: the outer loop reference is a constant value, while the feedback is the sliding window RMS of the fluctuating voltage which fluctuates as well, therefore the reference and the feedback can never match. Fig. 8 shows the proposed control scheme.Unlike the conventional control, the reference of the outer loop is the sliding window RMS value of the perturbation signal. Note that the inner-loop uses a P controller for thesake of preventing single-side integral saturation which leads to transformer magnetic biasing [62].

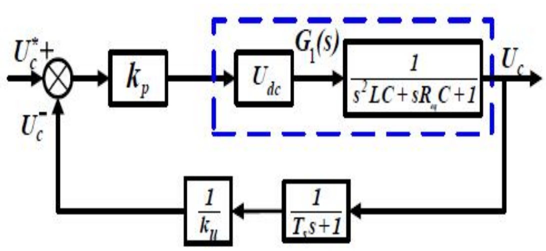

Figure 6. Control diagram of instantaneous inner-loop

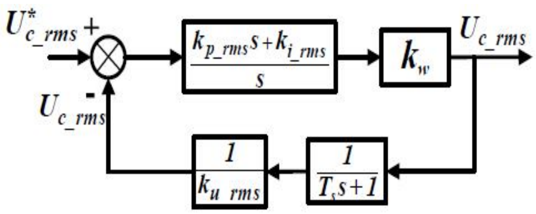

Figure 7. Control diagram of RMS outer-loop

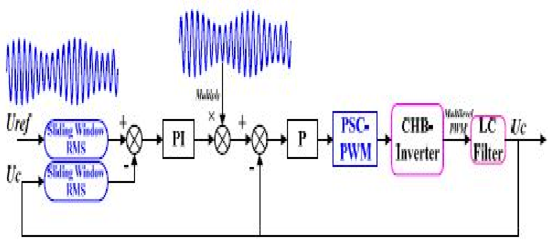

Figure 8. Proposed control scheme

III. SIMULATION RESULTS

MATLAB-simulink simulations of the control strategy of cascaded H-Bridge multilevel converter system were performed. This paper presents an improved RMS feedback control which is suitable for this wind turbine converter testing system is simulated. The testing equipment topology is showed in Fig. 1, and the system parameters are as follows, LC Filter: L = 100 ^{1}H, C = 90 ^{1}F; carrier frequency: 2 kHz, DC-link voltage: 1000 V. For the sake of safety in this high-power and high-voltage application, voltage waveform data is collected by Fluke-1760 and is analyzed by MATLAB (FFT analysis). In Fig. 9 and Fig. 10, the target fluctuating frequency is 10 Hz and fluctuating amplitude is 10% of the fundamental voltage. It is obvious that the experimental result under the proposed control is identical to the mathematical expression in (2), while the perturbation components under the conventional control exceed their theoretical value. Fig. 11 and Fig. 12 are the output voltages with a fluctuating frequency and amplitude of 10%, 12 Hz and 9%, 1 Hz. It can be observed that the voltage waveform is well regulated which is identical to the theoretical derivation results.

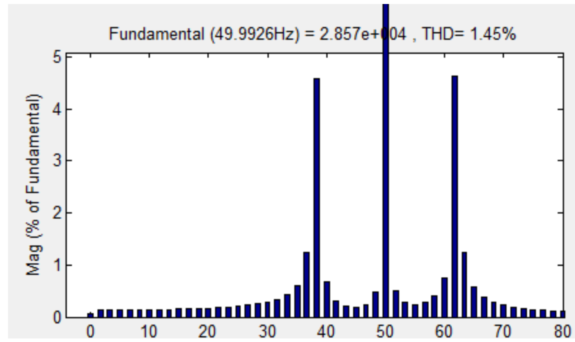

Figure 9. Spectrum of the output voltage (10%-12Hz)

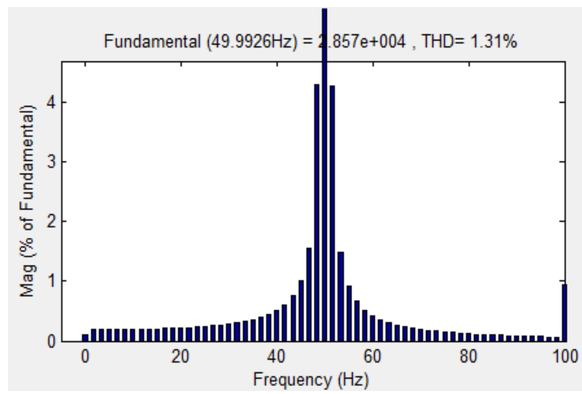

Figure 10. Spectrum of the output voltage (9%-1Hz)

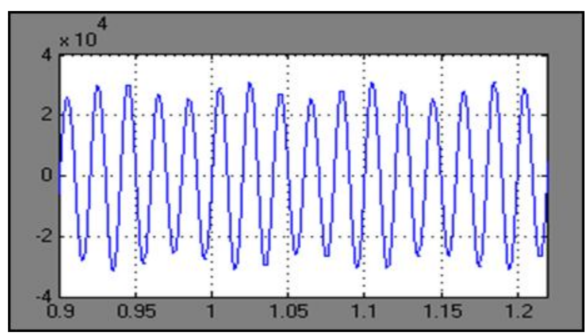

Figure 11. Fluctuating output voltage (10%-12Hz)

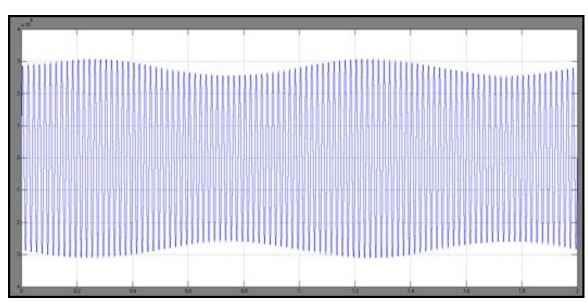

Figure 12. Fluctuating output voltage (9%-1Hz)

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IV. CONCLUSION

This paper presents an improved RMS feedback control which is suitable for this wind turbine converter testing system. The inner-loop P controller inherently leads to steady state error but free of phase lag, the RMS outer-loop guarantees the amplitude accuracy of the demand. Therefore, it successively achieves the control aim. All the theoretical findings are validated experimentally in the 35 kv-6 mw wind turbine converter testing equipment.

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