Design of A Novel Multi-Functional 35kV Voltage Disturbance Generator

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Abstract. The topological structure and related control algorithm of a novel multi-functional 35kV voltage disturbance generator are proposed. Using a 10-stage H-bridge cascade topology in each phase, subsequently a voltage disturbance generator is formed. Combined with the topology of the main circuit, the corresponding control strategy in d-q synchronous coordinates is proposed. The modeling and simulation of the proposed device is implemented by Matlab/simulink, and simulation results show that the topology of the device’s main circuit is feasible and the control strategy is effective.

1. Introduction
With the rapid development of power electronics technology, the trend of power electronic power system is becoming more obvious. In particular, the explosive growth of the installed capacity of renewable energy power plants has drawn more attention to the coordination of power electronic equipment and power grids. For grid-connected wind farms and photovoltaic power, the grid-connected inverters must be able to ride through various faults within the time required by the standard, however, with the completion of the asynchronous grid connection between Yunnan Power Grid and China Southern Power Grid, the characteristics of power grid also change. In order to meet the requirement of testing the adaptability of renewable energy plants under the new characteristics of grid, it is necessary to design a new multi-function voltage disturbance generator.

In the literature [1] [2], it is proposed to combine a two-level PWM rectifier with a three-level PWM inverter to form a back-to-back topology, which effectively improves the equivalent switching frequency and reduces the output voltage harmonics. However, the voltage level of the scheme is only 380V, which is not proposed for the high voltage level. In the literature [3~7], the h-bridge cascaded topology is adopted. The cascade structure makes the device voltage level up to 10kV and increases the capacity of the device. However, the series structure cannot simulate the frequency failure. In the literature [8], the solution is to couple the disturbance voltage to the grid voltage through an isolation transformer, but it is impossible to simulate the grid frequency fault. In addition, the program's rectifier circuit does not have the energy feedback function, and it cannot be used for power generation equipment testing. In the literature [9][10], after the controllable rectification, the voltages are sent to the two three-phase inverters to obtain the desired waveform. In which, the fundamental voltage generates in the inverter 1 and the harmonic voltage generates in the inverter 2, and finally the two are superposed...
by the transformer coupling to get the desired waveform. The program is a low-voltage high-current design, however, the output of the inverter 1 will contain larger harmonics. In summary, the current research on voltage disturbance generator has made some achievements, but the controllable voltage disturbance generator with high voltage level, large capacity and comprehensive function still needs to be studied.

In this paper, a new design scheme of multi-function voltage disturbance generator is proposed. The scheme adopts the structure of phase-shifting transformer and multi-stage H bridge cascade, so that the voltage level of the device reaches 35kV. The device can output high-precision, and smooth disturbance voltage, It can generate 2-25th harmonic voltage whose voltage percentage is 10%. The output basic frequency can reach 70Hz. The three-phase voltage unbalance degree reaches 30%. The range of voltage fluctuation and flicker is -30% ~ 30% and the range of modulation frequency is 0.5Hz ~ 25Hz.

2. The main circuit of the voltage disturbance generator

The voltage disturbance generator generates various disturbance sources by superimposing the system voltage, and it can be used to assess the power grid adaptability of the renewable energy unit. The main circuit of the new voltage disturbance generator is shown in figure 1.

![Figure 1. Main circuit topology](image1)

![Figure 2. The series power cells and voltage waveform](image2)

The main circuit structure adopts three-phase H-bridge cascade topology, each phase has 10 power conversion units, and the inverter terminal of each power conversion unit inverts DC power into AC power. Due to the large number of cascades, the high-power and the high switching frequency can be achieved, and the output voltage waveform can be close to the sine wave perfectly, which can simplify the design of LCL filter and reduce the loss caused by equipment testing. The series power cells and voltage waveform is shown in Figure 2.
3. The control strategy of the voltage disturbance generator

The voltage disturbance generator designed in this paper can detect the system voltage and the test load voltage in real time. Receiving the instruction of disturbance, it can control the inverter output the voltage disturbance and make the DC voltage of the rectifier maintain stability. The control strategies include the following aspects.

3.1. The phase-locked grid voltage

According to the principle that when $\bar{U}_{sq} = 0$, the direction of $d$ axis and $\bar{U}_d$ is the same, the voltage vector can be phase-locked by controlling the grid voltage of the $q$ axis is $\bar{U}_{sq} = 0$. The schematic diagram of the three-phase voltage SPLL control is shown in the figure below.

![Figure 3. The schematic diagram of the SPLL control](image)

3.2. The control strategy of rectifier inverter

The Block diagram of the rectification control is shown in figure 4. The outer ring controls the dc bus voltage. When the difference between the actual DC bus voltage $U_{dc}$ and the given DC bus $U_{ref}$ is the input of the DC voltage PI regulator, and the reference value of the d-axis current corresponding to the active power $I_d^*$ is the output of the DC voltage PI regulator, it can make dc bus voltage work at a given reference voltage $U_{ref}$ by adjusting the active power transmitted by the inverter to the power grid $P$.

The inner loop is a current control loop. Under the d-q coordinate system rotating synchronously with the voltage vector of the grid, two PI regulators are used to decouple the d-axis and q-axis components of the inverter output current. The output of the PI regulator is $U_d^*$ and $U_q^*$ respectively. Based on $U_d^*$ and $U_q^*$ and the voltage vector rotation angle $\theta$ of the grid, a modulation waveform of the three-phase reference voltage $u_a^*, u_b^*, u_c^*$ can be calculated by using a 7-segment space vector PWM modulation algorithm. When $I_q^* = 0$, The output power factor of the inverter is 1.
3.3. The carrier phase shift control
Cascade converter is composed of multiple voltage single-phase full bridge inverter circuits. The method in the paper is single polarity modulation. N carrier phase shift Angle of $\pi/N$ in turn, it makes the N SPWM pulse stagger certain Angle, the equivalent carrier frequency to 2nf, and the output phase voltage will be 2N+1 level staircase, line voltage is 4N+1 level of staircase.

4. The main parameter design of the voltage disturbance generator

4.1. System level calculation
The system adopts three-phase H-bridge cascade topology, each phase has 10 power conversion units in series, the unit dc voltage target is set at 930V, and the maximum voltage is $V_{in} = 13.1kV$. The advantage of this structure is that it can provide higher output voltage and lower output harmonics.

4.2. The design of Power unit
The rectification side adopts two 400a (80) IGBT modules in parallel to form a single-phase bridge, and the output side adopts three 300a (80) IGBT modules in parallel to form a single-phase bridge; The rated current of 25° on the rectifying side can reach 1200 A, and the rated current of 25° on the inverting side can reach 1350A. It can fully meet the high and low Voltage Ride Though test and may generate large grid-connected current of the fan photovoltaic converter.

5. Simulation results and analysis
Based on the above control strategy and main parameters, The modeling and simulation of the proposed device is implemented by MATLAB/simulink, the whole simulation model is shown in figure 1. The power unit model is shown in figure 5, in which reconciler control implements bi-directional controllable rectification control as shown in figure 4. IGBT Rectifier is a three-phase controllable rectifier circuit composed of IGBT. The model can be used to simulate various power quality problems.
Set a given command to generate 20% voltage dip at 0.01s and restore voltage at 0.6s with constant ramp voltage, so that the device produces the output waveform of low voltage ride through. The given command curve is shown in Figure 6 (a), and the output simulation waveform is shown in Figure 6 (b). Set a given command to generate a 130% voltage dip at 0.1s, and reduce with a constant slope at 0.1s, so that the device produces the output waveform of high voltage ride through. The given command curve is shown in Figure 7 (a), and the output simulation waveform is shown in Figure 7(b). Set the parameters to produce the 5th, 7th, 13th and 25th harmonic voltage disturbance, the output simulation waveforms are shown in figure8(a), (b), (c), (d), respectively. Set the parameters to produce a 40Hz, fluctuation ± 25% Voltage wave disturbance, the output simulation waveform is shown in Figure 9.

![Figure 5. Model of the power cell](image-url)
In Figure 6, the peak value of command voltage is 42kV, the peak output voltage is 41.63kV, the precision is 99.11%. In Figure 7, the peak voltage of command voltage is 53kV, the peak value of output voltage is 52.48kV and the accuracy is 99.02%. From Figure 6 to Figure 9, it can be seen that the circuit structure, parameters and related control strategies of the voltage agitator are effective, and the voltage disturbances such as the low/high voltage ride through, imbalance, flicker and harmonics can be effectively generated to simulate various grid voltage quality problem.

6. Conclusion
In this paper, A large-capacity integrated function voltage disturbance generator based on H-bridge cascade topology is proposed. The voltage disturbance device designed can simulate the possible disturbances in the power grid, and plays an important role in improving the adaptability of the power grid and the renew energy power plants. Moreover, the design of the four quadrant converter adopts multi-level cascade topology, it achieves high voltage and high power, simplifies LCL filter design, improves power conversion efficiency, and reduces device test losses.

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