Adaptability Evaluation of GCPVS under Voltage Sag

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Abstract. A basic LVRT strategy widely used in engineering practice is taken in this paper and manages to ride through both symmetrical and asymmetrical sag conditions. Precise current reference is calculated based on the reactive current curve in China National Grid Code, derivation of current is realized in this way by eliminating NS current. The role of hardware protection has been discussed in detail.

1. Introduction

Photovoltaic energy occupy a large proportion in renewable energy and new energy, and be considered as the most promising new energy technologies. GCPVS inverter plays a significant role in power conversion and DC-voltage stabilization. Meanwhile, various types of control structure have been proposed to realize accurate power control to help achieve LVRT during sag conditions.

Grid synchronization is vital in maintaining the orderly operation of GCPVS, it requires obtaining accurate amplitude and phase of the fundamental component in a fast way. Conventional SRF-PLL cannot will encounter problems during the asymmetrical fault because of the double-frequency oscillation and cannot lock the phase angle correctly[1]. Yet several types of PLL[2] adapted to asymmetrical or harmonic voltage condition has been proposed to overcome this situations. Mostly, the power balance on the DC side is the focus. Topologies such as single-stage [3]-[5] and two-stage systems [6], [7] have been researched these years as the most popular in practical use. Single-stage systems take advantages of the P-V curve to lower PV array output power during the fault, while two-stage systems need to promote the boost converter control systems, Sliding Mode Control is used in both boost converter and GSC to realize coordinate control of both sides and enhancing post-fault performance in [6].

In this paper, the photovoltaic adaptability under single-stage and two-stage GCPVS was investigated. Assistant methods such as improvement in control strategies and addition of hardware protection is present in the paper, and it is conducive to build a simulation model close to engineering practical. A 500-kW GCPVS model is established, and its simulation under different test conditions is carried out to verify the adaptability of GCPV in MV network.
1.1 System description

Two-stage and single-stage systems are both widely used in power generation systems. While single-stage system is more efficient but unstable due to variable DC voltage setpoint to track maximum power point (MPP) due to environment change. Yet, two-stage systems can operate at a wider PV input voltage range with a boost converter online. In this paper, both types are carried out for investigation into adaptability of GCPVS during sags.

Asymmetric sag condition is considered in view of that single-phase fault is the most common fault in power system. Fast and accurate Detection of fundamental PS voltage component is achieved by employing the DDSRF-PLL introduced in [8], even under unbalanced voltage conditions. Conventional double closed-loop control structure is adopted in both cases to conduct grid-side converter operate in both normal-operating mode.

1.2 Response characteristics and concerns about GCPVS under sag conditions

The overvoltage risk on the DC-side not only brings about the protection action problem, but also cause the saturation of the integration. With the error between measured DC voltage and referenced DC voltage, DC voltage controller is disabled and requires long adjusting time to come back to work after the grid voltage recovery. Anti-wind-up PI controller is introduced in [5] to realize normal operation of PI controller during faults. In this paper, DC voltage controller is cut-off instantly to avoid integration saturation while d-comment current reference is generated through other methods, which will be discussed followed.
As grid faults occur, GCPVSs experience sag events and voltage signals are detected instantaneously. Both symmetrical and asymmetric fault will bring down PS component yet NS component exists only in asymmetric voltage conditions. As a result, the response characteristics of GCPVS during asymmetric sags are discussed separately in this section.

Most commonly, single-phase-to-ground or phase to phase faults occurs. Double-frequency oscillation will appear by adopting conventional SRF-PLL. Yet with the help of DDSRF-PLL, oscillations in PS component are attenuated, and NS component is extracted accurately. Same as the occasions during symmetrical faults, PS component of voltage decreased, power balance is destabilized and DC voltage increased. Yet NS component of voltage is none-zero value, dq-component can be expressed as

\[
\begin{align*}
\mathbf{u}_{dq} & = \hat{\mathbf{u}}_{dq} + \mathbf{u}_{dq} e^{-j\omega t} \\
\mathbf{i}_{dq} & = \hat{\mathbf{i}}_{dq} + \mathbf{i}_{dq} e^{-j\omega t}
\end{align*}
\]

Active and reactive power injected into grid can be written as

\[
\begin{align*}
\mathbf{P} & = \frac{3}{2}(u_{d}i_{d} + u_{q}i_{q}) = P_d + P_{d2} \cos(2\omega_t) + P_{q2} \cos(2\omega_t) \\
\mathbf{Q} & = \frac{3}{2}(u_{d}i_{q} - u_{q}i_{d}) = Q_d + Q_{d2} \cos(2\omega_t) + Q_{q2} \cos(2\omega_t)
\end{align*}
\]

The coupling effects of PS and NS components of currents and voltages cause double-frequency oscillations in both active and reactive power. And the active power oscillation brings about double-frequency ripples on the DC bus. In order to eliminate NS current injected into grid, referenced NS component is set as zero to guarantee that balanced three-phase current is injected into grid. Yet, active power oscillation cannot be eliminated. Once satisfying the control strategies and protection above, GCPCVS is called to meet LVRT requirement and get the permission to keep grid-connection.

2. Simulation scenarios and results

In this section, GCPVS model with MATLAB/Simulink software is established. Simulation test on the adaptability during sag conditions, its simulation under different test conditions is carried out, the schematic diagram of the test circuit is shown in Fig.3. Grid faults are simulated at Bus3 close to main grid.

![Schematic Diagram of the Test Circuit](image)

**Figure 3.** Schematic Diagram of the Test Circuit

The GSC rated power is set to 500 KVA, the voltage operating range and link capacitance of DC is set to 400-280 V and 30 mF. The Grid line voltage is set to 270√2V. The AC filter inductance is set to 0.08 mH. The Inverter switching frequency is set to 19.5 Hz, the DC voltage set point is set to...
500V/547V. The Voltage and current controller parameter is set to 5/600V and 0.35/25. The single-stage model operates at 547V in standard test conditions (STC). Boost converter switching frequency is set to 5000Hz, the MPPT controller parameter is set to 0.001/5. Test conditions is carried out in reference to LVRT curve in the grid code GB/T 19964-2012, as Table 1 illustrated.

| Sag case | Sag Amplitude (pu) | Duration(ms) | Fault occurrence(s) | Fault clearance(s) |
|----------|--------------------|--------------|----------------------|---------------------|
| 1        | 0.015              | 150          | 0.1                  | 0.25                |
| 2        | 0.5                | 1250         | 0.1                  | 1.35                |

Figure 4. Simulation result of the adaptability test under 0.75 p.u, sag conditions

Two-stage system under STC and test condition (Irradiance:600W/m²/ Temperature: 25°C/PV Output power 0.58p.u.) is tested in sag case 1. Simulation results are illustrated in Fig.4. When the irradiance drops from 1000W/m² to 600W/m², the output power from PV array drops from 1 p.u. to 0.58 p.u.. In the situation that PCC voltage drops to 0.75 p.u. under low irradiance, power balance can be maintained. At the same time, DC voltage controller can be kept in the system during the sag to generate referenced d-component current and reactive current regulation is met. Generally speaking, power balance influence whether the DC controller will be cut-off during faults.

Single-stage system under STC is tested in sag case2. Simulation results are illustrated in Fig.5 a). A three-phase to ground fault occurs at 0.1s and lasted for 625ms. DC voltage arise due to the unbalanced power between two sides while lower the output power from PV array. A new steady state
is reached as the PV array power equals inverter output active power. During the whole period, no additional protection has been activated. The system ride through the fault in stably and smoothly.

Single-stage system under STC is tested in sag case 2. Simulation results are illustrated in Fig. 5 b). An two-phase to ground fault is set to Bus 3. As is mentioned in the previous section, NS components brings about active and reactive power oscillation. Although the NS current is set to 0, active power oscillation is not mitigated and double-frequency ripples appears at DC bus. With the strategy online, NS current is eliminated and balancing of the phase currents is kept, overcurrent in phase is avoided.

![Simulation result of the adaptability test of single-stage systems](image)

**Figure 5.** Simulation result of the adaptability test of single-stage systems

3. Conclusion

In this paper, the adaptability of GCPVS is tested by modeled and simulated both single-stage and double stage system using MATLAB/Simulink tool. A brake chopper is added to DC link in two-stage system to help improving the ride-through ability. Simulation results show that the strong adaptability of the GCVPS, it can reduce the output current and avoid over-voltage problems, and ultimately promote grid voltage support capability.

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