Photovoltaic Fuzzy Logic Controller on Solar Power Generation by Large-Scale Grid-Connected Cascaded

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Abstract

The penetration of photovoltaic (PV) solar power generation in distributed generation (DG) systems is growing rapidly. This condition imposes new requirements to the operation and management of the distribution grid, especially when high penetration levels are achieved. Under this scenario, the power electronics technology plays a vital role in ensuring an effective grid integration of the PV system, since it is subject to requirements related not only to the variable source itself but also to its effects on the stability and operation of the electric grid. This paper proposes an enhanced interface for the grid connection of PV solar systems. The relationship between output voltage components of each module and power generation is analyzed with the help of a newly derived vector diagram which illustrates the proposed power distribution principle. On top of this, an effective control system including active and reactive components extraction, voltage distribution and synthesization, is developed to achieve independent active and reactive power distribution and mitigate the aforementioned issue. Finally, a 3-MW, 12-kV PV system with the proposed control strategy is modeled and simulated in MATLAB. Simulation and experimental results are provided to demonstrate the effectiveness of the proposed control strategy for large-scale gridconnected cascaded PA full detailed model is described and its control scheme is designed. The dynamic performance of the designed architecture is verified by computer simulations and Further Extension can be done using Fuzzy Logic Controller.

Keywords: Photovoltaic, Fuzzy Logic Controller, Distributed Generation, Solar Power Generation, Large-Scale Grid-Connected Cascaded.

1. Introduction

GLOBAL energy crises and environmental concerns [1]– [3] from conventional fossil fuels have attracted more and more renewable energy developments in the worldwide. Among of these renewable energy, solar energy is much easier to be harvested, converted, and delivered to grid by a variety of power converters [4]–[14]. In particular, large-scale grid-connected photovoltaic (PV) systems playa major role to achieve PV grid parity and have been put forward in high penetration renewable energy systems [15]. As one type of modular multilevel converters, cascaded multilevel converters share many merits of modular multilevel converters, e.g., lower electromagnetic interference. low device rating, improved harmonic spectra, modularity, etc., but also is very promising for the large-scale PV system due to its unique advantages such as independent maximum power point tracking (MPPT) for segmented PV arrays, high ac voltage capability, etc. [11]–[14]. However, cascaded multilevel converters in PV systems are different from their some successful application such as medium voltage motor drive, static synchronous compensator (STATCOM), harmonic compensator, solid state transformer, which are connected with symmetrical segmented dc sources. PV systems with cascaded multilevel converters have to face tough challenges considering solar power variability and mismatch of maximum power point from each converter module due to manufacturing tolerances, partial shading, dirt, thermalgradients, etc. In a cascaded PV system, the total ac output voltage is synthesized by the output voltage from each converter module in one phase leg, which must fulfill grid codes or requirements. Because same grid current flows through ac side of each converter module, active power mismatch will result in unsymmetrical ac output voltage of these modules [14]. The converter module with higher active power generation will carry more portion of the whole ac output voltage, which may cause over modulation and degrade power quality if proper control system is not embedded into the cascaded PV system. Several control strategies have been proposed for the cascaded PV system with direct connection between individual inverter module and segmented PV arrays. But they did not consider the fact that PV arrays cannot be directly connected to the individual inverter module in high-voltage large-scale PV system application due to the PV insulation and leakage current issues. Even if there are low-frequency medium-voltage transformers between the PV converters and grid, there are still complicated ground leakage current loops among the PV converter module. Therefore,

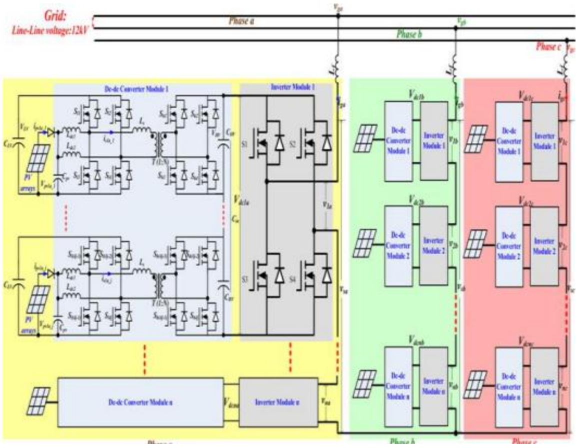


Fig-1: Proposed grid-connected PV system with cascaded multilevel converters at 3 MW.

those methods in are not qualified for a practical large-scale grid-connected cascaded PV system. Moreover, reactive power compensation was not achieved, which largely limits the functions of the cascaded PV system to provide ancillary services. Proper reactive power compensation can significantly improve the system reliability, and in the meantime help the MPPT implementation for the cascaded module under unsymmetrical condition as well as comply with the system voltage requirement simultaneously. A reactive and active power control strategy has been applied in cascaded PV system with isolated dc–dc converter. If symmetrical active power comes from each module, active and reactive power can be equally distributed into these modules under traditional power control. However, if unsymmetrical active power is generated from these modules, this control strategy will not be able to achieve decoupled active and reactive power control. Reactive power change is along with the active power change at the same direction, which may aggravate output voltage over modulation during unsymmetrical active power outputs from segmented PV arrays. In order to solve the aforementioned issues, this paper proposes a large-scale grid-connected cascaded PV system including current-fed dual-active-bridge (CF-DAB) dc–dc converters and cascaded multilevel inverters as shown in Fig. 1. A decouple active and reactive power control system is developed to improve the system operation performance. Reactive power from each PV converter module is synchronously controlled to reduce the over modulation of PV converter output voltage caused by unsymmetrical active power from PV arrays. In particular, the proposed PV system allows a large low-frequency dc voltage ripple for each PV converter module, which will not affect MPPT achieved by CF-DAB dc–dc converters. As a result, film capacitors can be applied to replace the conventional electrolytic capacitors, thereby enhancing system lifetime.

2. Related Work

The proposed large-scale grid-connected PV system is presented in Fig. 1, which demonstrates a three-phase two-stage power conversion system. It includes n cascaded multilevel inverter modules for connected to j cascaded CF-DAB dc–dc converter modules with high voltage insulation [2]. This configuration features many impressive advantages comparing with traditional PV systems with line-frequency transformer. The cascaded multilevel inverters are directly connected to the grid without big line-frequency transformer, and the synthesized output voltage from cascaded modules facilitates to be extended to meet high grid voltage requirement due to the modular structure. Each dc–dc converter module is interfaced with segmented

PV arrays and therefore the independent MPPT can be achieved to harvest more solar energy. Moreover, it is immune to the double-line-frequency power ripple propagation into PV arrays. Particularly, the ground leakage current and PV insulation issues are effectively suppressed. In addition, flexible control strategies are able to be explored and applied in this topology each phase, where each inverter module is owing to more control variables and control degree-of-freedom. Although there is no accurate number about the cost benefits comparing with the traditional PV system with line-frequency transformer, it is obvious that the proposed PV system will have lower cost due to high power density and modular structure, which will significantly reduce the cost of the power platform using to install the PV system. This paper is focused on active and reactive power distribution control of the cascaded multilevel inverters in the proposed PV system. The detailed dc–dc converter design has been provided in [3] and will not be repeated in this paper. The selected application is a 3-MW/12-kV PV system in this paper. The n is selected to be 4 considering the tradeoff among the cost, lifetime, passive components, switching devices and frequency selection, and power quality. As a result, power rating of each inverter module is 250 kW. The average dc voltage of each inverter module is 3000 V based on the requirement of inverter output voltage, power devices as well as power quality. The second-order voltage ripple on the dc side is allowed to 20% even higher. Hence, film capacitor with 400 μF, Cin, is eligible to improve the system lifetime. In addition, the modular structure enables the high-voltage high-frequency SiC power devices for the HVHP PV application. The switching frequency for each power device is 5 kHz. Due to the phase-shift carrier based phase-width modulation (PWM) control, the PV inverter will generate nine level output voltage and the equivalent output PWM frequency is 40 kHz for each phase. The current ripple of ac inductor is selected to be less than20% of the rated output current. Therefore, the ac inductor with 0.8 mH, Lf, is acted as the filter. In each dc– dc converter module, Ldc1 and Ldc2 are dc inductors, and Ls is leakage inductor. CPV is high-frequency filter capacitor paralleled with PV arrays. High-frequency transformer with turn ration N is connected between lowvoltage side (LVS) converter and high-voltage side (HVS) converter.CLV are LVS dc capacitor and CHV are HVS dc capacitor.

3. Implementation

3.1 Fuzzy logic controller:

A fuzzy logic controller has four main components as shown in Figure 2: fuzzification interface, inference mechanism, rule base and defuzzification interface. FLCs are complex, nonlinear controllers. Therefore it's difficult to predict how the rise time, settling time or steady state error is affected when controller parameters or control rules are changed. On the contrary, PID controllers are simple, linear controllers which consist of linear combinations of three signals. Figure.2. Output and control signals for crisp PD control system Implementation of an FLC requires the choice of four key factors: number of fuzzy sets that constitute linguistic variables, mapping of the measurements onto the support sets, control protocol that determines the controller behavior and shape of membership functions. Thus, FLCs can be tuned not just by adjusting controller parameters but also by changing control rules, membership functions etc. The main advantages of adaptive fuzzy control over non adaptive fuzzy control are: better performance is usually achieved because the adaptive fuzzy controller can adjust itself to the changing environment, and less information about the plant is required because the adaptation law can help to learn the dynamics of the plant during real time operation. However, these approaches still have some problems. In many applications, the structure of the model of the plant may be known, but its parameters may be unknown and/or change with time. Recently, the concept of incorporating fuzzy logic control into the model reference adaptive control has grown into an interesting research topic.

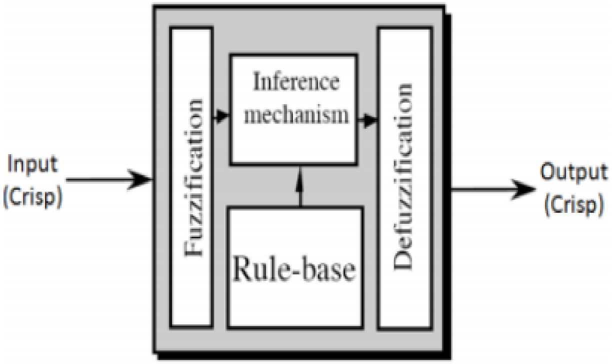


Fig-2: Fuzzy Logic Controller

Moreover, it can eliminate multiple harmonics in the circulating current with a single repetitive controller. However, the repetitive controller and the FUZZY controller are paralleled. Such an arrangement imposes unnecessary limitation on the FUZZY controller design and also complicates the repetitive controller design. This paper proposes a different repetitive-plus-FUZZY control scheme. The improved plug-in configuration of the repetitive controller avoids the above problems while keeping all the advantageous features.

4. Experimental Work

The large-scale grid-connected cascaded PV system with the proposed control strategy is simulated in MATLAB. The equivalent switching function model in phase a is shown in Fig.3. The same model can be used in phases b and c. Considering the characteristics of PV arrays, the equivalent input current source i_ PV and voltage source V _ PV are developed in this model. The duty cycle D determines the LVS voltage as shown in Fig. 3(a) and equivalent dc voltage in cascaded inverter side V _ dc is controlled to be constant in Fig. 3(b). Therefore, the equivalent voltage source (1 − D) V _ d c N and current source (1 − D) i_ s N can be integrated into this model, which i_ s is the equivalent primary side transformer current and N is the transformer turn ratio. The equivalent dc inductor L_dc is connected between V _ PV and (1 − D) V _ d c N. The transferred power by CF-DAB dc–dc converters is determined by both D and ϕ[3]. Accordingly, the equivalent current source f(D,ϕ) i_ s N can be obtained and connected with voltage source (1 − D) V _ d c N by equivalent leakage inductor L_ s , which f(D,ϕ) can be derived from [3, (7) and (8)]. The equivalent inverter output m_V _ dc is connected with grid voltage source vga by grid inductor Lf . The equivalent current source m_iga is integrated in the middle circuit of this model. The key circuit parameters in simulation are listed in Table I. In this simulation, the fixed simulation step is set to be 1 μs considering the synchronization between simulation points and switching instant [7]. In this paper, the reactive power injection into grid (inductive reactive power) is defined as negative and reactive power absorption from grid (capacitive reactive power) is defined as positive. The active power injection into grid is defined as positive and active power absorption from grid is defined as negative.

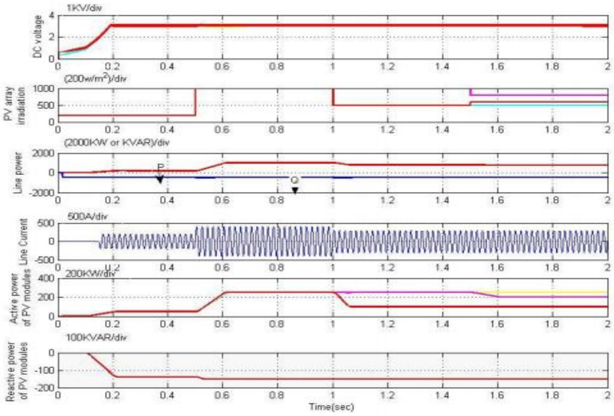


Fig-a: Simulation results of PV system with decoupled active and reactive power control in phase a.

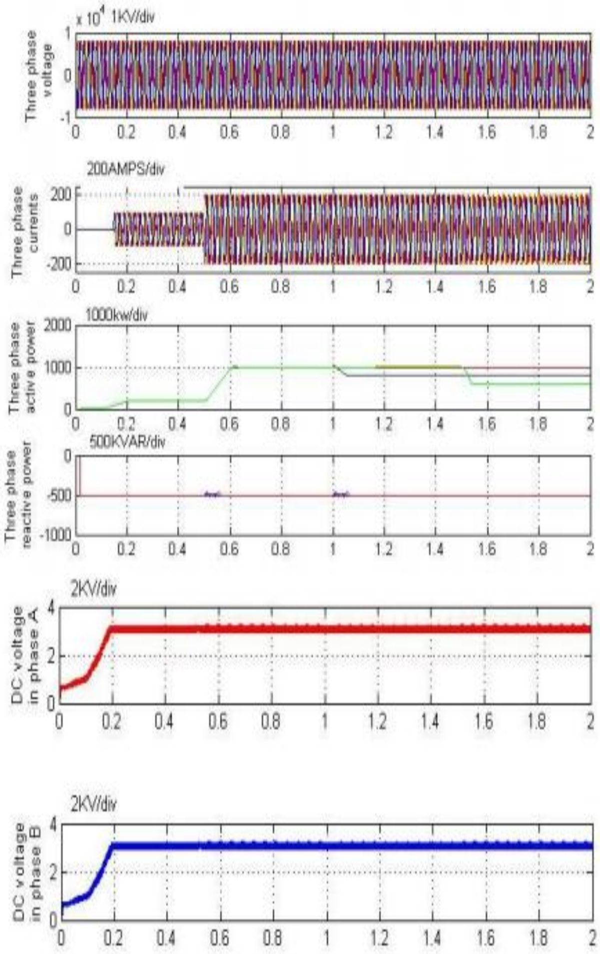
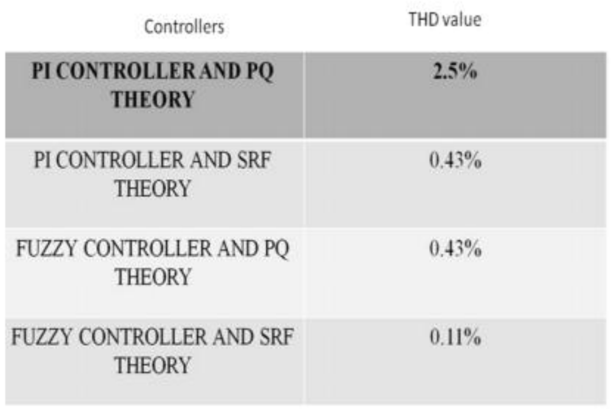


Fig. b. Simulation results of PV system with the proposed control in three phase power distribution.

Table-2: Comparison of THD



Controllers	THD value
PI CONTROLLER AND PQ THEORY	**2.5%**
PI CONTROLLER AND SRF THEORY	0.43%
FUZZY CONTROLLER AND PQ THEORY	0.43%
FUZZY CONTROLLER AND SRF THEORY	0.11%

5. Conclusion

This paper addressed the active and reactive power distribution among stability for the large-scale grid connected cascaded PV system. The output voltage for each module was separated based on grid current synchronization to achieve independent active and reactive power distribution. A decoupled active and reactive power control strategy was developed to enhance system operation performance. Here in this paper we had proposed Fuzzy Logic Based Control of Grid-Connected Photovoltaic Systems Using Cascaded Modular Multilevel Converters where the controlling circuit or the controller is fuzzy which gives a better results when compared to the previous PI controller. This particular concept of fuzzy controller provides an remarkable reduce of THD values of the previous circuit which is employed by PI controller.

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