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Performance of multilevel shunt active filter for smart grid applications

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ABSTRACT

Active power filters are the most efficient tool to reduce harmonics produced by the power electronic converter used in integration of renewable energy resources with grid. In this work, a control method for active power filter was designed for grid connected photovoltaic system. The shunt active filter (SAF) topology consists of five level cascaded multilevel inverter with fuzzy PI controller to regulate the dc side voltage. Synchronous reference frame theory is tailored for the computation of SAF reference current. Constant switching frequency sub-harmonic pulse width modulation (CSFSHPWM) was implemented to generate switching pulses to voltage source inverter. This approach not only accomplishes the compensation of harmonics, but also transfers the active power at unity power factor to the grid. It can be also used to fuse the power generated by the renewable energy source in the grid and function as SAF. This system eradicates the supplementary equipment required to improve the power quality. The control system operation was simulated using the MATLAB/Simulink power system toolbox and experimental results are furnished to verify the efficiency of this method.

Introduction

In recent years, environmental pollution due to fossil fuels and shortage of energy, have led to the development of non-polluting energy sources such as renewable energy sources (RES). Among these RES, solar power systems are the affable solution for electrification. Nowadays, photovoltaic system [PV] has been increasingly used in medium sized grid. To interface this RES, power electronic converters [PEC] were used. The penetration of PEC may create a hazard to network in terms of power-quality problems such as harmonics. These harmonics has to be reduced, since it may lead to malfunctioning of protective relays and other control unit. There are number of techniques available to reduce harmonic related power quality problems, which has many disadvantages like electromagnetic interference, possible resonance problem, fixed compensation and bulkiness [1,2] etc.

Shunt active filters can be implemented in the existing systems and widely used in the practical application which has been accepted as the most valuable technique for harmonic compensation [3–7].

Fig. 1 illustrates the configurations of a photovoltaic interactive shunt active power filter system [8]. PV array consists of number of solar cells to convert sunlight into electricity. As the photovoltaic power varies with the climatic conditions, to obtain the maximum power from PV array, it is coupled with a maximum power point tracker. The power generated from the RES requires power conditioner to ensure the voltage level of filter [9–12]. For this purpose, DC-DC converter is employed. The output obtained from the DC-DC converter is coupled with dc link capacitor which in turn connected to grid through inverter. The voltage source inverter transfer active power from RES and also operates as SAF to compensate the current harmonics [13,14].

In the absence of sunlight, the PV system is decoupled from the grid by the dc capacitor and then the individual control of converters on dc-link is activated. As the asymmetrical cascaded multilevel inverter upholds different voltage source [15], this method is well suited for solar power system. H-bridge inverters connected in series, forms a cascaded multilevel inverter [CMLI]. The output voltage of the inverter equals the sum of the voltage generated by each cell. An s-level CMLI consists of $(s-1)/2$ single-phase full bridges and the output voltage levels are $2s+1$, where s is the number of cells. Fig. 2 shows single phase cascaded multilevel inverter with each bridge connected with a dc source. It can be easily extended to required number of levels. The output voltage of multilevel inverter for a single phase is shown in Fig. 3.

The controller plays the vital role in designing SAF. The exact model of the system and its sensitiveness of variation to system parameter makes the conventional controller outdated. So there's a great tendency to use intelligent control techniques [16] like

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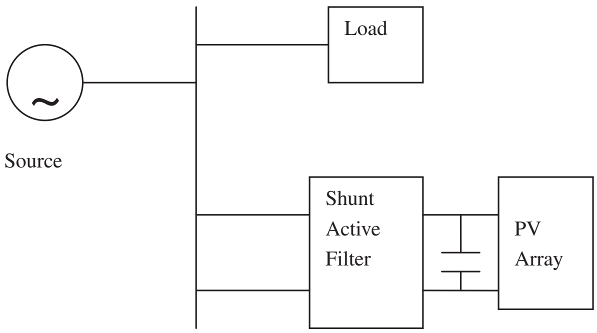

Fig. 1. Configurations of a photovoltaic interactive shunt active power filter system.

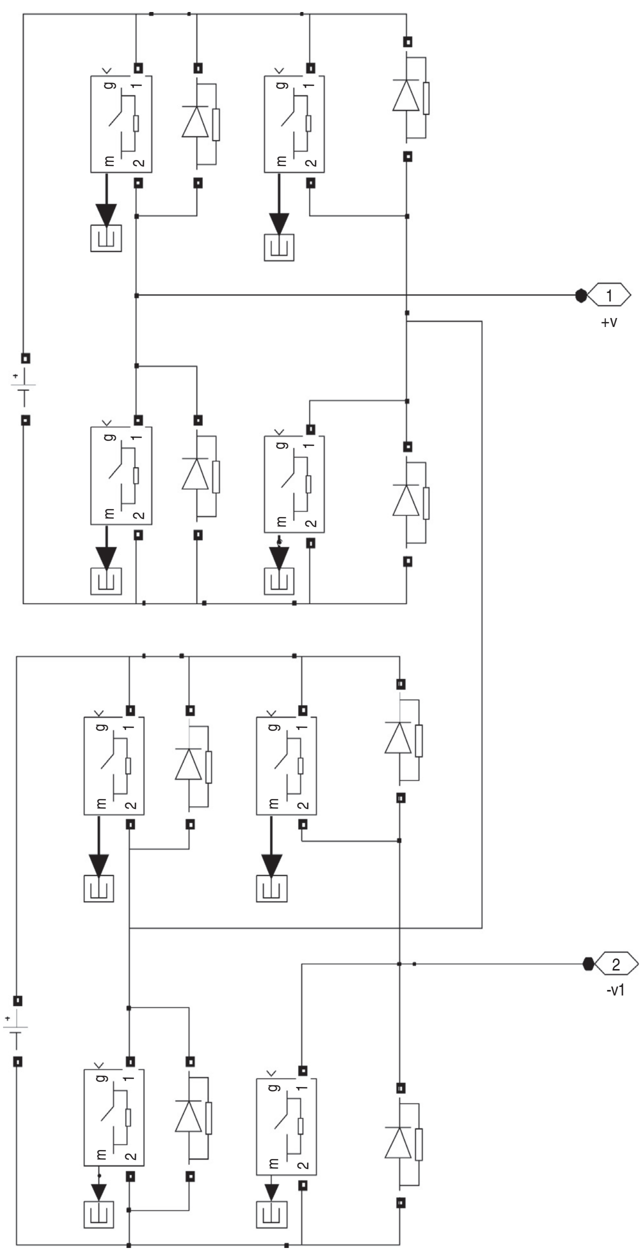

Fig. 2. Topology of single phase cascaded multilevel inverter.

fuzzy PI controller, due to its robustness and no need of mathematical model [17–19]. This work validates an enhanced control strategy of five level cascaded multilevel SAF for the solar system interfaced with the grid.

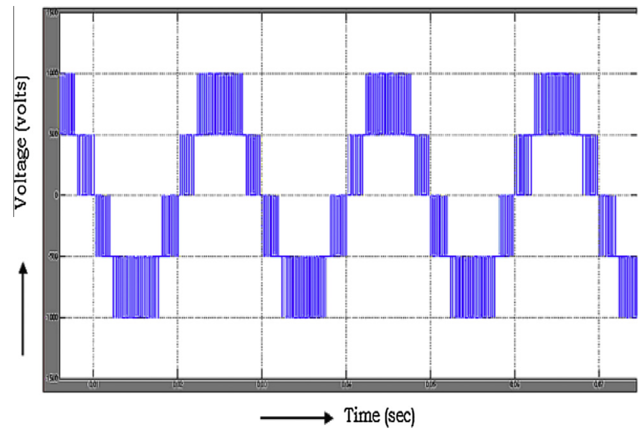

Fig. 3. The output voltage of multilevel inverter.

Principle of the control method

Reference current generation

The reference current has great impact on steady state performance of the SAF. Thus, the reference compensation signals are derived as follows,

The instantaneous current and source voltage is given as

$$i_s(t) = i_1(t) - i_c(t) \tag{1}$$

$$V_s(t) = V_m \sin \omega t \tag{2}$$

When the system is connected with non-linear load, the load current consists of both fundamental and harmonic components which is expressed as

$$\begin{aligned} I_L(t) &= \sum_{n-1}^{\infty} I_n \sin(n\omega t + \phi_n) \\ &= I_1 \sin(n\omega t + \phi_1) + \sum_{n=2}^{\infty} \sin(n\omega t + \phi_n) \end{aligned} \tag{3}$$

Thus, the load power

$$P_L(t) = V_s(t)^* i_l(t) \tag{4}$$

$$\begin{aligned} &= V_m I_1 \sin^2 \omega t^* \cos \phi_1 + V_m I_1 \sin \omega t^* \cos \omega t^* \sin \phi_1 \\ &\quad + V_m \sin \omega t^* \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi n) \end{aligned}$$

$$= P_f(t) + P_r(t) + P_h(t) \tag{5}$$

The real power drawn by the load

$$P_f(t) = V_m I_1 \sin^2 \omega t^* \cos \phi 1 = V_s(t)^* i_s(t) \tag{6}$$

After compensation, the source current will be

$$i_s(t) = P_f(t)/V_s(t) = I_1 \cos \phi_1 \sin \omega t = I_m \sin \omega t \tag{7}$$

where $I_m = I_1 \cos \phi_1$.

The source has to deliver power to compensate the converter switching losses and capacitor leakage besides the real power consumed by the load. The total current contributed by the source

$$I_{sp} = I_{sm} + I_{s1} \tag{8}$$

If the active filter affords the harmonic and reactive power compensation, the source current is sinusoidal and in phase with the source voltage. Thus, the compensation current provided by the active filter

$$i_c(t) = i_L(t) - i_s(t) \tag{9}$$