Simulation Modelling Practice and Theory 71 (2017) 27–44

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Simulation modelling and analysis of modular cascaded multilevel converter based shunt hybrid active power filter for large scale photovoltaic system interconnection

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ARTICLE INFO

Article history:
Received 19 March 2016
Revised 15 October 2016
Accepted 14 November 2016

Keywords:
Harmonics
Modeling
Modular multilevel inverter
Reactive power
PSCAD/EMTDC
Simulation
SHAPF

ABSTRACT

Modular multilevel inverters are promising candidates for next generation of efficient, robust and reliable inverters in large scale photovoltaic system. A modular cascaded multilevel inverter based shunt hybrid active power filter (SHAPF) for three phase grid-connected large scale PV systems is represented in this paper. The main contribution of this paper is to model and control of grid interfaced large scale photovoltaic system with embedded hybrid active power filter functions. In proposed system, the features of hybrid active power filter have been amalgamated in the control circuit of the voltage controlled voltage source inverter interfacing the photovoltaic system to the grid. As a result, the same inverter part of SHAPF is utilized to inject power generated from photovoltaic source to the grid and also to act as hybrid active power filter to compensate harmonics and reactive power demand. With using compensation ability, the grid currents are sinusoidal and in phase with grid voltages. The whole system is modeled in PSCAD/EMTDC. The simulation results are demonstrated to verify the operation and the control system of the proposed system.

1. Introduction

With the development of technology, electric utilities and usage of electric power are increased. The majority part of energy demand is provided by fossil fuels. However, fossil fuels are finite resources and will eventually decrease. Due to this condition, they become too expensive or too environmentally damaging to retrieve. In the recent years, renewable energy in power generation has been emerging as an alternative energy source to mitigate the disadvantages of fossil fuels. Renewable energy sources are widely available on Earth; hence they have attracted much interest in both research and practical applications. Among of these renewable energy, solar energy is much easier to be harvested, converted and delivered to grid by a variety of power converters [1]. There are two main types of PV energy system: grid connected systems and stand-alone systems. The grid connected systems are in parallel with the utility grid and provide PV energy to it. In contrast, standalone systems are connected to the load and electrical applications. Grid connected systems account for a large proportion of installed PV energy systems. As the utilization of PV energy increases, large scale PV generation is being brought to public attention. In the large scale energy system, power quality into the grid, especially harmonics and flicker, impacts on grid system significantly.

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http://dx.doi.org/10.1016/j.simpat.2016.11.003

Nowadays, higher power apparatus have started to be used in large scale PV applications. Many medium voltage systems demand medium voltage and megawatt power level. Connecting only one power semiconductor switch is difficult directly to megawatt power grids. Due to this condition, multilevel power converters are to be used as an alternative solution in medium and high voltage applications. Multilevel converters have the ability to increase the output voltage without rising the voltage rating of switching components. Thus, they are preferred to connect to medium voltage grids without using transformers. Multilevel converters have more advantages than conventional two level converters. Some attractive features are;

- Generate output voltages with very low distortion.
- Reduce the dv/dt stresses.
- Reduce the electromagnetic compatibility problems.
- Generate low common mode voltage.
- Draw input current with low distortion.

Among multilevel converters topologies, cascaded inverters consist of several converters connected in series; thus, the high power and/or high voltage from the combination of the multiple modules would favor this topology in medium and high voltage applications. The modular cascaded H-bridge multilevel inverter is one of the cascaded inverter topologies. The output multilevel voltage waveforms enable the reduction of harmonics in the synthesized current, reducing the size of the needed output filters. The cascaded multilevel inverter also has other advantages such as reduced voltage stresses on the semiconductor switches, as well as having higher efficiency when compared to other converter topologies [2]. Modular multilevel inverters are promising candidates for next generation of efficient, robust and reliable inverters in large scale photovoltaic system. A modular cascaded multilevel inverter based SHAPF for three phase grid-connected large scale PV systems are represented in this paper.

Harmonic distortions can not only increase power losses, but also reduce the lifetime of equipment. In order to reduce the current harmonic pollution, passive filter is one of the traditional solution ineffectively. These filters may cause unwanted resonance conditions. Their other limitation is unable to adapt to the changing conditions in the network and their size. With remarkable process in the speed and capacity of semiconductor switching devices, active filters have been studied and put into practical use, because they have the ability to overcome the disadvantages inherent in passive filters. These types of filters are more effective in harmonic compensation and improve performance [3]. However, active power filters have high initial cost, running cost and required comparatively high power converter ratings. To overcome the aforementioned disadvantages, passive and active filters can be combined into a single device called hybrid active power filters (HAPF). HAPFs [3-6,8–20] effectively smooth the problems of the passive filter and an active power filter solution; hence ensure cost effective harmonic compensation. The passive filter in the system performs basic filtering action at the dominant harmonic frequencies, whereas the active filter part mitigates higher harmonics with precise control methods. This will effectively reduce the overall size and cost of active filtering. In addition, no fundamental voltage is applied to the active part. This results in a great reduction of the voltage rating of the active power filter part [21].

The controller design of SHAPF is a significant and challenging task due to its impact on the performance and stability of the overall system as an active power filter [24]. For this reason, different reference generation and control methods such as pq theory [4-6], fast fourier transform [5], dq theory [7-12], fuzzy controller [13,14], proportional resonant current controller [15] etc. have been applied to SHAPF in the literature. Current controller which is responsible from the producing reference currents is one of the important part of the controller of SHAPF. According to the current control strategy, direct and indirect current controllers can be applied to SHAPF. Direct current controller uses only source currents to compensate harmonics and/or reactive power. Indirect current controller uses both load and filter currents to maintain harmonics and/or reactive power compensation. In literature, indirect current control method is preferred in many of SHAPF studies [7-12, 22,23] and direct current control method is applied and investigated in fewer studies [4,5, 16-19]. In indirect current control, the grid voltage and the impedance of passive filter must be taken into account for fundamental and harmonic frequencies in order to generate proper voltage reference for compensation. This approach can cause complexity in control method. Because of these, instead of using grid voltage and impedance of passive filter, a linear proportional controller is preferred for the calculation of reference voltage by SHAPF studies in literature. However, the linear proportional controller presents moderate performance in the compensation of harmonics. In direct current control, SHAPF can present faster dynamic compensation performance and only current reference is generated with comparing reference current extracted from load current and filter current so grid voltage has no direct effect on control loop. However, the second order impedance characteristic of series connected passive filter causes oscillations in the step response changes of low frequency components so, complex controller methods must be preferred for the control of fundamental frequency components which are used for the dc link control and reactive power compensation.

Furthermore, the reactive power demand of load is taken constant and reactive power compensation requirements are supplied with the constant reactive power capacity of passive filter of SHAPF in the major number of SHAPF studies [4,5, 7-12, 16-19]. However, the reactive power demands of loads show variable reactive power characteristics in the most of industrial applications and SHAPF can be one of the effective solutions for compensation of harmonics and variable reactive demand of industrial loads. The dynamic reactive power compensation is obviously investigated in [4-6]. In [4,5], the adaptive dc link voltage control is performed and the dc link voltage is changed according to the dynamic reactive power compensation requirements. In [4], adaptive dc link voltage control is achieved according to both harmonic currents