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Multifunctional VSC Controlled Solar Photovoltaic System with Active Power Sharing and Power Quality (PQ) Improvement Features

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Abstract

An adaptive PLL-based method and a generalized "dq" are used to extract the dual features from a multifunctional voltage sourced-converter (VSC) controlled solar photovoltaic (SPV) system that is the subject of this paper. These include an improved active power sharing feature that acts as an active harmonic filter (AHF) and is based on the availability of active power on the DC-side collector bus. In comparison to its conventional counterpart, such as synchronous reference frame theory (SRFT), the presented control is computationally less demanding and straightforward to formulate. This work aims to efficiently extract the various ancillary services that the power distribution system's multifunctional VSC provides. Serving the active power demand of the load connected at the point of interconnection (PoI) in the power distribution network is the primary function of any gridconnected inverter (GCI). However, the fourth leg of the multifunctional VSC can also be used as an AHF to adequately supply the zero sequences harmonic component requirement of the unbalanced and nonlinear load, attenuate the rich harmonic content that is present in the source current, and mitigate the load reactive current demand. In addition, the proposed system typically ensures the operation of the unity power factor (UPF). During solar intermittency, an incremental conductance (IC)-based control method is used to optimize and continuously track the maximum power point (MPP). In the MATLAB/Simulink software environment, transient test cases are used to demonstrate the multifunctional VSC's usefulness. A comprehensive set of experimental studies conducted on a prototype created in the laboratory also confirms its practicality

1. Introduction

In a recent year, the growing electricity demand across the globe and increasing carbon emission generated by non-renewable sources have been gaining special attention from the science and engineering society. At the mean time, electric utilities are also concerned about serving the raising needs of energy. Thus, it has now become mandatory to look towards renewable energy source (RES) as a promising substitute to produce green and clean power. Besides this, the development of new/and rapid switching power electronics components, and the evolution in technological advancement in semiconductor technology have played a very crucial role in converting the energy generated by RES into a useful form. The classical converter technology employed in SPV typically systems suffers from poor efficiency ranging from 6 to 7 % and was very expensive in earlier days. However, with continuous evaluation in technological research has brought the efficiency of SPV module from 6-8% to 15-16% .

Moreover, the prices of SPV array module along with converter technology used in it diminishing very moderately. Today, the SPV system is taken into consideration as most optimistic substitutes to fossil fuel-based electricity generating systems, as there is no carbon emission, and no fuel cost involvement. But, it should be pointed out that the technology is still growing and many associated challenges are required to be addressed such as the intermittent nature of RES, high capital cost, and lower SPV module efficiency. Moreover, the application and usage of various nonlinear loads have been grown in the past couple of decades. Consequently, power quality (PQ) problems are also emerging in the power distribution system mainly due to the harmonics introduced by these non-linear power electronics loads, which may pose to a shortfall in reactive current demand of load, power factor degradation, and varying voltage profile problems . Electronics ballast, laptops, battery chargers, adjustable frequency drives (ASD), and printers are considered as major sources of harmonic-rich current in the power distribution system. These current harmonics propagate across the PoI and deteriorate the voltage profile. Subsequently, these harmonics current influence the performance of linear loads adversely, which is not imperative for reliable and efficient power system network. The aforementioned problems can be well addressed byincorporating various functionalities offered by AHF into the control algorithm of the multifunctional VSC.

Needless to say that, the control algorithm plays a very vital role in improving the operation and control of overall solar photovoltaic power conversion system (SPVPCS). The grid connected SPV system proposed in this paper composed of double-stages including intermediate DC/DC boost converter stage, and DC/AC current controlled VSC stage. The primary function of employing boost converter on the SPV side is to harvest the maximal power from the solar array during the varying atmospheric condition. Moreover, the operational performance of VSC can be actively controlled by various algorithms reported in the literature. MPPT techniques and control algorithm have been illustrated in the following part of this section. There have been numerous MPPT methods elucidated in the literature like voltage control, fuzzy logic based control, and short-circuit current etc., although IC and perturb & observe (P&O) are amid the most preferred methods. In this paper, the IC-MPPT technique has been employed, because it offers decent dynamic performance during fluctuations in solar insolation condition. Designing of boost converter along with topologies used in it are illustrated extensively in the scientific literature.

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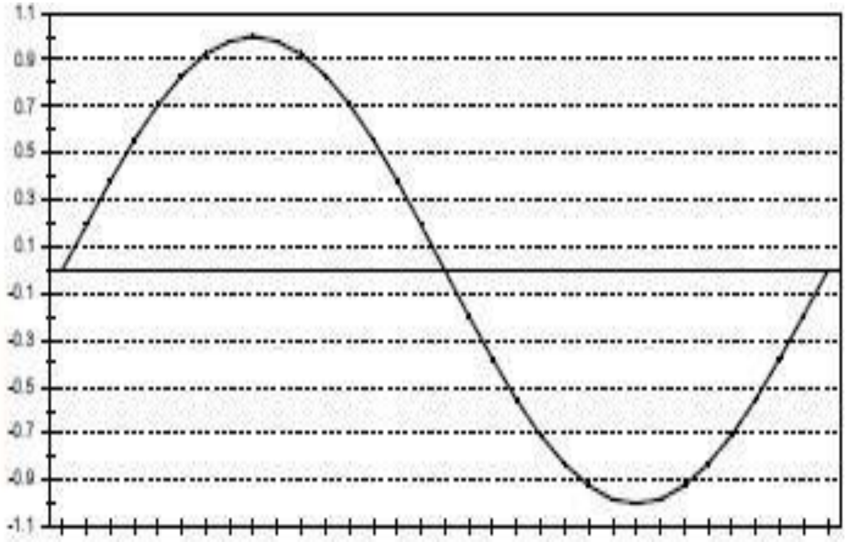

Fig.1 Harmonics

2. Literature Review

The single-tuned notch filter is the most common and economical type of passive filter. The notch filter is connected in shunt with the power distribution system and is series tuned to present low impedance to a particular harmonic current. Thus, harmonic currents are diverted from their normal flow path through the filter. Another popular type of passive filter is the High Pass Filter (HPF). A HPF will allow a large percentage of all harmonics above its corner frequency to pass through. HPF typically takes on one of the three forms, as shown in Fig.2.4.

Although simple and least expensive, the passive filter inherits several shortcomings. The filter components are very bulky because the harmonics that need to be suppressed are usually of the low order. Furthermore the compensation characteristics of these filters are influenced by the source impedance. As such, the filter design is heavily dependent on the power system in which it is connected to. The passive filter is also known to cause resonance, thus affecting the stability of the power distribution systems.

Remarkable progress in power electronics had spurred interest in APF for harmonic distortion mitigation. The basic principle of APF is to utilize power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load. Fig.2.5 shows the components of a typical APF system and their connections. The information regarding the harmonic currents and other system variables are passed to the compensation current / voltage reference signal estimator. The compensation reference signal from the estimator drives the overall system controller

APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APFs performances are independent of the power distribution system properties. On the other hand, APFs have some drawbacks. Active filtering is a relatively

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new technology, practically less than four decades old. There is still a need for further research and development to make this technology well established.. APF can be connected in several power circuit configurations as illustrated in the block diagram shown in fig.2.6. In general, they are divided into three main categories, namely shunt APF, series APF and hybrid APF

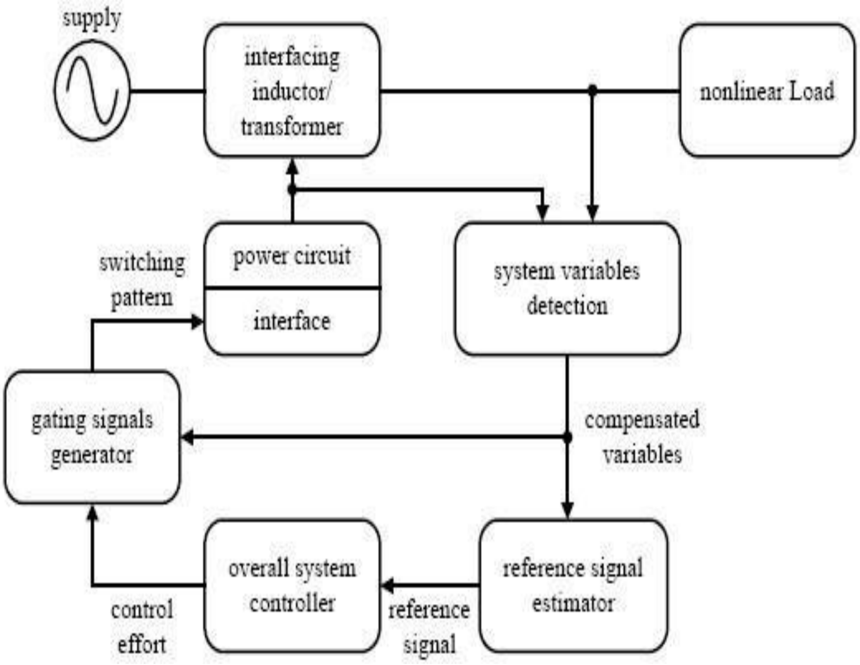

Fig.2 Generalized block diagram for APF

3. Proposed System

In active filtering applications, this is the most common and crucial configuration. Shunt active power filters inject equal but opposite harmonic compensating current to eliminate current harmonics. The shunt active power filter serves as a current source in this instance, injecting the phase-shifted harmonic components produced by the load. The active filter's effect cancels harmonic current components in the load current, keeping the source current sinusoidal and in phase with the appropriate phase-to-neutral voltage.

Any load that is thought to be a harmonic source can be used in accordance with this principle. The active power filter can also compensate for the load power factor with the right control scheme. The active power filter and the non-linear load are regarded as ideal resistors by the power distribution system in this manner. Figure 2.7 depicts the shunt active power filter's compensation property. Due to its well-known topology and simple installation procedure, the voltage source inverter (VSI)-based shunt APF is the most widely used type today. Fig. 2.8 depicts the fundamental components of a standalone active series filter. Between the non-linear load and the utility system, series active power filters primarily perform the functions of voltage regulator and harmonic isolator. The active power filter that is connected in series is better if you want to keep the consumer safe from a bad supply voltage. Compensation of voltage imbalances, voltage distortion, and voltage sags from the AC supply is a particular application for this strategy.

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Because there is no need for energy storage (battery) and the overall rating of the components is smaller, it also represents an economically appealing alternative to low power devices like UPS. The series active power filter can be thought of as a controlled voltage source because it injects a voltage component in series with the supply voltage, compensating for voltage sags and swells on the load side (fig. 1.8). Non-linear loads and coupling transformers must be connected to a parallel LC filter in order for the Series APF to function as a harmonic isolator. Series APFs are less common than their rival, the shunt APF. This is because they have to deal with currents with high loads. When compared to shunt APF, the high capacity of the load currents will result in significant increases in their current rating, particularly on the interfacing transformer's secondary side. The I 2R losses will rise as a result. However, the primary benefit of series APFs over shunt ones is their ability to eliminate voltage harmonics. It gives the load a pure sinusoidal waveform, which is important for devices that are sensitive to voltage (like devices that protect the power system). The series APF is suitable for enhancing the distribution source voltage's quality thanks to this feature.

Analog circuits have historically been the foundation of the majority of APF-developed controllers. Consequently, signal drift is inherent to the APF performance. Hybrid APF configurations offer a solution to the technical limitations of conventional APFs. Typically, they combine passive filters and fundamental APFs. Hybrid APFs, which inherit the advantages of both APFs and passive filters, offer solutions with improved performance that are also cost-effective. This plan aims to simultaneously reduce electromagnetic interference and switching noise. The two most well-known hybrid APFs are depicted in Fig., although other hybrid APFs have also been reported in the literature. 2.9. The hybrid shunt APF's system configuration as depicted in Fig. 2.9(a). Both the passive and shunt APF filter

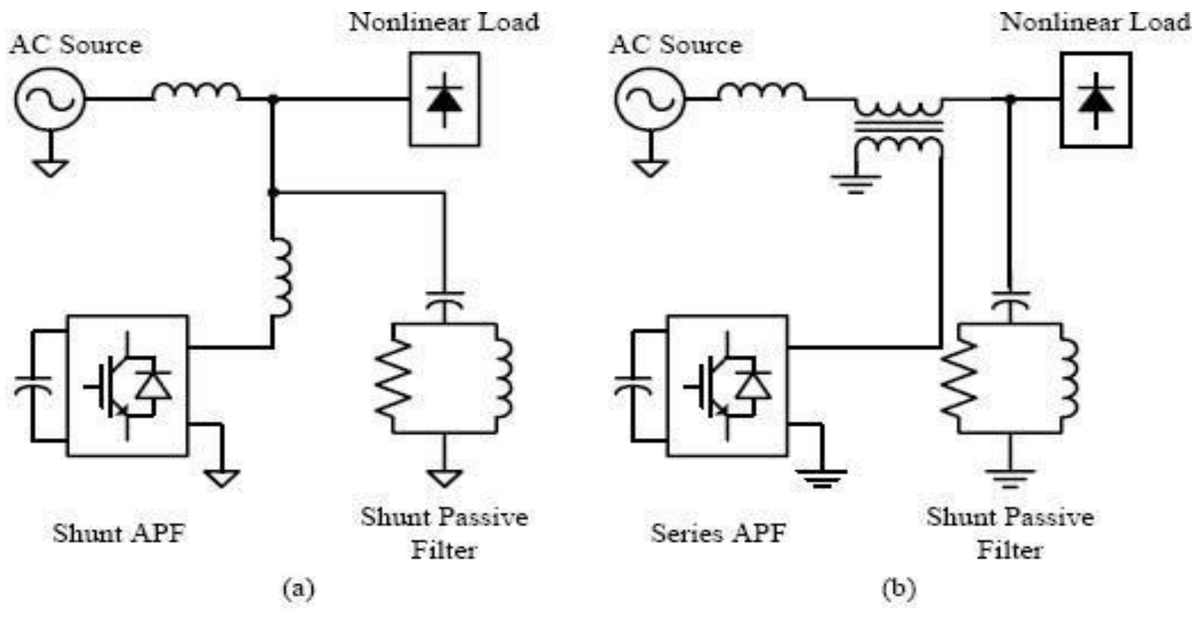

Fig.3 Proposed Method

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4. Conclusion

A generalized „dq" based control approach has been presented in this paper for generating a reference current for 3P4W multifunctional VSC controlled SPVPCS. It has been experimentally demonstrated that the proposed system not only injects the active power into the electric grid but also provides a various PQ solutions in the electric distribution network. The aforementioned multifunctional VSC can be employed to fulfill the following approaches: 1) to suppress the source current harmonics generated by the nonlinear load, 2) to provide the load neutral current demand by the fourth leg of the multifunctional VSC, and

3) to share the active power requirement of load based on the availability of active power at DC-bus terminal. It is evident from the results presented in this paper that this approach actively eliminates the need for supplementary power filtering equipment to enhance the PQ at PoI. The practicality of the proposed approach is verified through both substantial MATLAB/Simulink simulation studies and detailed experimental investigation. Furthermore, the system performance is found to be adequate. It is also demonstrated that the traditional GCI can be effectively utilized as a multifunctional VSC with suitable control technique. It is further noted that the PQ enhancement and active power transfer into the utility grid have been demonstrated extensively under various operating conditions to confirm the performance and control of multifunctional VSC based grid-connected SPVPCS. Besides this, it is shown that the grid currents are maintained to be balanced and sinusoidal at UPF despite varying insolation, current unbalancing, and harmonics. Moreover, the fourth leg of the VSC is adequately employed to mitigate load neutral current locally so that its flow in grid side can be blocked

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