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Modified ICosΦ Controller for Shunt Active Filter Interfacing Renewable Energy Source and Grid

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Abstract

The grid integrated renewable energy sources are becoming a common area of interest for power generation in the recent times. The design and development of efficient interfacing technologies to interconnect renewable energy sources with grid is catching a lot of attention among the researchers these days. The interfacing unit becomes crucial as renewable energy sources when directly connected to grid, can inject harmonic components that may deteriorate the quality of power. This paper proposes a mechanism to use shunt active filter as an interface between renewable energy sources and grid with a modified and efficient control scheme. The shunt active filter with this modified controller controls the real power supplied by the grid (source) in addition to its usual functions such as reactive power compensation, power factor correction and harmonic elimination. The non-linear load is diode bridge rectifier feeding resistive load and the unbalanced load also introduced to verify the controller performance. The simulation of the proposed system under both balanced and unbalanced load conditions have been done and the obtained results prove the effectiveness of using a shunt active filter as the interfacing unit for grid integrated renewable energy system.

Keywords:Shunt Active Filter,Renewable Energy Source, Interfacing unit, balanced and unbalanced loads, Diode bridge rectifier

1. Introduction

Renewable energy sources are becoming the core of power generation schemes in the recent days where

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the traditional energy generation schemes are showing the signs of its end. Often, renewable energy sources are not connected to grid directly. The operational characteristics are requires the use of some interface between the renewable energy source and grid. Certain special requirements need to be satisfied when connecting the renewable energy sources to grid in order to ensure safe and reliable operation. The fault clearing, reclosing and inadvertent islanded operation are major protection related concerns. The detailed survey of power quality problems, measurements, analysis and effects of harmonics have been reported in literature. [1-3].The harmonics have a number of undesirable effects on the distribution system, which cause additional losses, overheating, and overloading in power system equipment [1]. To mitigate the harmonics and improve the quality of power, two commonly used approaches are the passive filters and active filters [4, 5]. The hybrid filters and improved power quality converters are also used as solutions to power quality problems [6- 8].

The different types of interfacing units are used for grid-renewable energy source interconnection as reported in literatures, describes about commonly used topologies such separately connected systems, micro-grids, multi-port converter and custom power devices [9, 10]. The issues such as starting transients, energy conversion efficiency and power quality make the use of custom power interface like shunt active filter and STATCOM as better choice. The shunt active filters as interfacing units is a latest topology reported in [11-12].

In this paper, a three phase shunt active filter with a modified IcosΦ controller is proposed as the interface between a renewable energy source and grid feeding diode bridge rectifier load and unbalanced linear RL load is also introduced between Phase A and Phase C to check the controller performance under unbalanced condition. The shunt active filter which is used as the interfacing unit between renewable energy source and grid is doing normal function such as harmonic elimination, power factor correction and reactive power compensation even under unbalanced condition. In addition to normal active filter functions, there is a control over the real power supplied by the grid (source) with the use of shunt active filter based on modified IcosΦ controller.

2. Three phase shunt active filter as a interface between Renewable energy source and grid

A three phase system supplying a set of non-linear load and unbalanced linear RL load is considered as the test system. Fig. 1 shows the schematic of the system under consideration. A three phase balanced AC source represents the grid and a 7 kVA rated diode bridge rectifier feeding resistive load is considered as the nonlinear load.. An unbalanced linear RL load is added at t=0.5seconds. The power generated by the renewable energy source is injected to grid through the shunt active filter, which is a three phase voltage source inverter. The shunt active filter transfers the power from renewable energy sources as well as does job of harmonic elimination, reactive power compensation and power factor correction by maintaining unity power factor at the source side. The real power supplied by the source is controlled by this shunt active filter with modified IcosΦcontroller. The real power transfer from renewable energy source is regulated by DC-DC converter, which is maintaining the DC link voltage as constant.

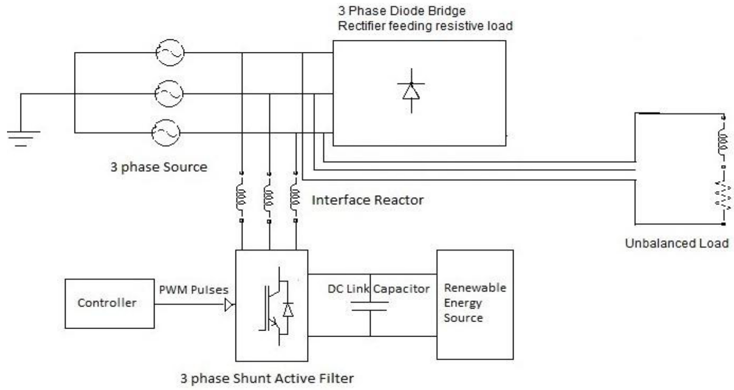

Fig. 1 Schematic of Shunt Active Filter Interfacing for Renewable energy source

3. Modified IcosΦ controller for grid integrated Renewable energy source

The control scheme used to generate the compensation signals forms the main part of active filtering unit. Instantaneous PQ theory [13], synchronous detection algorithm [14], DC bus voltage algorithm [15] and synchronous reference frame theory [16] are some of the widely used three-phase shunt active filtering algorithms. The existing control schemes are still requires fine-tuning to make the computation and the circuit implementations as simple and rugged as possible. A simple and effective control scheme enhances the speed of response and efficiency of the filter. The Icosϕ algorithm is one such a simple current compensation algorithm to compensate harmonics, reactive power and power factor under unbalanced condition [17].

3.1. IcosΦ Control Algorithm

The IcosΦ algorithm is to provide harmonic, reactive power and unbalance compensation in a three phase system with balanced/unbalanced source and any load conditions (i.e) both balanced and unbalanced [17]. It uses minimum computational steps and simple to practically implement in the system conditions like distorted and asymmetrical AC source supplying non-linear unbalanced loads. The current drawn from the source (grid) is highly non-linear and reactive when it is supplying a non-linear load such as diode bridge rectifier, thyristor converter, and AC voltage controller based loads. The algorithm aims at limiting the percentage total harmonic distortion in source current within the IEEE standard limits in addition to achieving unity power factor at the source end. In the IcosΦ algorithm, the desired mains current is consider to be the product of the magnitude of IcosΦ and a unit amplitude sinusoidal in phase with the mains voltage. The mains (grid) is required to supply only the active portion of the load current and the shunt active power filter is expected to provide compensation for the harmonic and reactive portion of the three-phase load current, and also for any imbalance in the three-phase load currents. Hence, only balanced currents will be drawn from the mains which will be purely sinusoidal and in phase with the mains (grid) voltages.

3.2. Modified IcosΦ Control Algorithm

In general shunt active filters are expected to provide current harmonic compensation, reactive power support and imbalance condition. The real power demanded by the loads is met by the source/grid with power factor maintained close to unity.With the renewable energy backup, real power support can also be extended by the shunt active filter under proper control as and when needed. The modified IcosΦ control algorithm is proposed here to achieve additional real power support from renewable energy source using shunt active filter. The grid is required to supply only the fraction of active portion of the load current as determined by the controller. The remaining real power is met by renewable energy source through shunt active filter interface. The main advantage of proposed algorithm is that real power sharing between grid, renewable energy source and load.

The reference compensation currents for the shunt active filter are deduced as the difference between the actual load current and the desired source current in each phase

$$I_{a(comp)} = I_{La} - I_{sa(ref)} ; I_{b(comp)} = I_{Lb} - I_{sb(ref)} ; I_{c(comp)} = I_{Lc} - I_{sc(ref)} \tag{1}$$

where, the desired (reference) source currents in the three phases are given as,

$$I_{sa(\mathrm{ref})} = K\left|\mathrm{I}_{s(\mathrm{ref})}\right| \times \mathrm{U}_a = \mathrm{K}\left|\mathrm{I}_{s(\mathrm{ref})}\right| \sin\omega \mathrm{t}; I_{sb(ref)} = K\left|I_{s(ref)}\right| \times U_b = K\left|I_{s(ref)}\right| \sin(\omega t - 120°);$$

$$I_{sc(ref)} = K\left|I_{s(ref)}\right| \times U_c = K\left|I_{s(ref)}\right| \sin(\omega t + 120°) \tag{2}$$

where K is the load factor which determines how much real power has to be supplied by the source/grid.

Here $\left|\mathrm{I}_{s(\mathrm{ref})}\right|$ defined from the real part of all the three phase currents.

$$\left|I_{s(ref)}\right| = \frac{|I_{La}|+|I_{Lb}|+|I_{Lc}|}{3} = \frac{|I_{La}|\cos\phi_a + |I_{Lb}|\cos\phi_b + |I_{Lc}|\cos\phi_c}{3} \tag{3}$$

$\mathrm{U_a}$, $\mathrm{U_b}$ and $\mathrm{U_c}$ are the unit amplitude templates of the phase to ground source voltages in the three phases respectively.

$$\mathrm{U_a} = 1.\sin\omega \mathrm{t} ; U_b = 1.\sin(\omega t - 120°) ; U_c = 1.\sin(\omega t + 120°) \tag{4}$$

The magnitude of the desired source current $\left|\mathrm{I}_{s(\mathrm{ref})}\right|$ can be expressed as the magnitude of the real component of the fundamental load current in the respective phases .i.e. for phase 'a' it can be written as $\left|\mathrm{I}_{s(\mathrm{ref})}\right| = \left|\mathrm{Re}(\mathrm{I}_{La})\right|$.

A zero crossing detector (ZCD) is used to detect the negative going zero crossing of the corresponding phase voltage. The ZCD has been designed with a tolerance of 5% to ensure that any oscillations around the zero-crossing are taken care of. The phase-shifted fundamental current goes as the "sample" input and the ZCD output pulse goes as the "hold" input to the "sample and hold" circuit whose output is the magnitude $|\mathrm{I}\cos\Phi| = \left|\mathrm{I}_{s(\mathrm{ref})}\right|$. This magnitude is multiplied with unit amplitude sine wave in phase with input voltage and also desired fraction which determines how much real power is supplied by the source. Difference between load current and reference source current gives the reference filter current. This reference filter current and actual filter current are given to a hysteresis controller to get the pulses for the inverter.

4. Modeling and Simulation of Shunt Active Filter Interface for Renewable Energy Source with modified IcosΦ Controller

The simulations of the above described system is carried out in MATLAB Simulink to check the performance of shunt active filter based on modified IcosΦ control algorithm.Three single phase sources are connected in star considered as grid with voltage of 400V, 50Hz. This grid is supplying non-linear load of diode bridge rectifier feeding resistive load and unbalanced linear RL load.

A three phase voltage source inverter (VSI) is considered as shunt active filter. The pulses for the VSI are derived by the controller using modified IcosΦ control algorithm. The shunt active filter parameters are chosen as coupling inductance =9 mH; DC link capacitance = 6mF and voltage across the capacitor =650V.

4.1. Shunt Active Filter with modified IcosΦ Controller as the Interfacing unit

Initially the diode bridge rectifier is switched on and drawing power from source, at t=0.5sec an unbalanced linear RL load is also added with non-linear load. The unbalanced linear RL load having R=50Ω and L=1mH which leads to the total load power consumption as 10KW. The Fig. 2 (a) shows the three phase source/grid current for the test system. From Fig.2 (a), it is clear that after t=0.5sec, the current in phase A and phase C has been increased to some extent and current pattern in phase A and phase C is similar which can be seen clearly in Fig.2.(b).

The shunt active filter used as the interfacing unit for the renewable energy source, grid and load should compensate reactive power and harmonics mitigation thereby maintaining unity power factor at source side. The Fig.2.(b) shows the modified IcosΦ controller performance, which includes the source/grid voltage, load current, reference filter current generated by the controller , actual filter current from the shunt active filter and desired source current respectively for the all three phases. The rich harmonic content in source current is due to presence of non-linear load and unbalanced load. From the Fig.2.(b) one can understand easily the actual filter current from the shunt active filter follows the reference filter current calculated by the modified IcosΦ controller . This implies that the proposed controller is working according to the desired functionalities as discussed earlier.

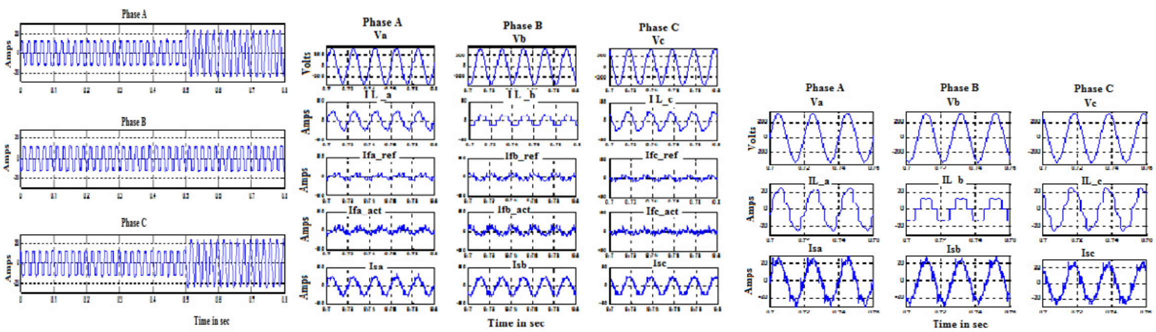

Fig.2. (a) Three phase source current wave forms before compensation (b) Modified IcosΦ controller performance (c) Source voltage and current wave forms before and after compensation

4.2. Modified IcosΦ Controller Performance under unbalanced condition

The Fig.2.(c) shows the proposed controller performance under unbalanced load condition, which includes source voltage and current drawn by the load before compensation and source current after compensation for all the three phases. It is observed that before introducing shunt active filter with modified IcosΦ controller, the current in all the three phases are not same .The current in Phase A and phase C are with diode bridge rectifier with unbalanced linear RL load drawing more current than the phase B and also current pattern different for phase A and phase C . To compensate unbalance and harmonic current, the proposed control algorithm has been generating reference current as shown in Fig.2.(c).The controller is doing the job of harmonic elimination, reactive power compensation and power factor correction by maintaining the source voltage and current in phase and the magnitude in all three phases are equal.

4.3. Power sharing between Renewable energy source and Grid

The Table 2 gives the details of real power sharing between grid/source and renewable energy resource for the above mentioned test system. The simulation has been done based on the various load factor i.e. fraction of real power ,which has to be supplied by the source .From Table.2 it is clear that, depending upon the factor the real power sharing between gird and renewable energy sources has been taking place. The total reactive power required by load has been fully compensated by the filter even under unbalanced condition.

Table2. Power sharing between renewable energy source and grid

L.F	P_L(kW)	Q_L(kVA)	P_S(kW)	Q_S(kVA)	P_{RES} (kW)	Q_{RES}(kVA)
1	10	0.16	11.8	-0.30	-1.8	0.46
0.75	10	0.16	9.2	-0.35	0.8	0.51
0.50	10	0.16	6.7	-0.40	3.3	0.56
0.25	10	0.16	4.1	-0.50	5.9	0.66

LF = Load factor, fraction of real power which is be supplied by the source/grid

When the load factor is 1, the source (grid) supplies entire load power. In addition to this, in all the above cases the source is supplying some extra power to compensate the losses taking place in the interfacing unit (approximately 1.8kW). For different fractions power sharing between gird and renewable energy source is tabulated in Table2, to meet the load of 10kW with load factor .5, the source (grid) should supply only 5 kW and renewable energy source should supply 5kW, where source/grid is supplying 6.7kW to compensate the losses in the interfacing unit.

From all the above results it is observed that a shunt active filter when used as the interfacing unit for renewable energy source and grid achieves all compensation requirements effectively in addition to extending real power sharing of load along with the grid.

5. Conclusions

The proposed modified IcosΦ controller based shunt active filter as an interface between renewable energy sources and grid has been simulated and performance has been analyzed under balanced and unbalanced load conditions. The modified IcosΦ controller has ability to inject the real power from the renewable energy source to grid through the shunt active filter interface and also has the control over real power of source (grid). The proposed controller performing regular shunt active filter as harmonic elimination, reactive power compensation and power factor even under balanced/unbalanced condition.

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