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ORIGINAL RESEARCH ARTICLE

Grid integration of photovoltaic and wind based hybrid distributed generation system with low harmonic injection and power quality improvement using biogeography-based optimization

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This paper investigates the combined operation and performance of the doubly fed induction generator (DFIG) and powerful custom power devices such as dynamic voltage restorer (DVR), static compensator (STATCOM) and unified power quality conditioner (UPQC) with common distributed generation (DG) systems. Improved multilevel inverter based topologies for DVR, STATCOM and UPQC operations using DFIG and PV are proposed in this paper. The proposed technique can efficiently mitigate the power quality problems, for example, voltage sag, swell, flicker, reactive power, voltage interruption, unbalance neutral current, voltage and current harmonics, etc. in the distribution system. The proposed DG connected three phase multilevel converter for photo voltaic (PV) system reduces filtering requirements, increases redundancy and enables transformerless interface with grid. Biogeography-based optimization (BBO) technique is applied in this paper to calculate exact switching angles for the inverter at each modulation index considering low total harmonic distrotion (THD) for the output voltage. The performance of the UPQC mode is compared with both DVR and STATCOM modes. For the proposed topology, the simulation studies with MATLAB are presented which show that the proposed DFIG and PV based UPQC performs significantly better than the DG-DVR and DG-STATCOM combinations.

Introduction

Interconnection and grid integration of distributed generation (DG) based sources has become a widely addressed research topic in the past two decades. Doubly fed induction generator (DFIG) in wind generation scheme and the solar PV based sources are the two most commonly used DGs. Various control strategies for operation and performance of DFIG systems have been well studied in literature [1–3]. The harmonic analysis of DFIG has been covered in [1] for wind energy conversion system. In [2,3], hybrid model of a DFIG is thoroughly studied. Grid harmonics is minimized using optimized coordinated approach in [4] with six-step switching while maintaining stipulated quality of power as recommended in IEEE 519 standard range. In [5], multilevel inverter using particle swarm optimization technique is described. Space vector pulse width modulation technique has been utilized in [6] for the multilevel voltage source inverter with photovoltaic system. Flying capacitor multilevel converter control is proposed in [7] and five level neutral-point clamped inverter is introduced in [8]. Transformer-less series sag compensation with a cascade multilevel inverter is also proposed in [9]. Five level neutral-point clamped inverter is introduced in [10] for dynamic voltage restorer to mitigate the voltage sag. The short circuit in the grid, inrush currents when large machines are switched on the high power and voltage quality problems in the power distribution systems are addressed in [11]. Power quality problems such as sags, swells, flickers, notch, spike, harmonics, transients and reduction of three phase voltage unbalance are studied in the various works regarding static VAr compensators (SVCs) [12], static synchronous compensators (STATCOMs) [13], unified power quality conditioner [14–16] (UPQCs), and custom power devices based on energy storage

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systems, for example, dynamic voltage restorers (DVRs) [17–20]. All these literatures are concentrated on isolated operations in any of the modes, for example, DVR, UPQC, STACOM, etc. Moreover, introduction of renewable sources are not widely used for such compensators.

This paper develops a framework for employing a PV-wind hybrid distributed generation system for DVR, STATCOM or UPQC operation using multilevel converter with optimized switching. The selected harmonic elimination pulse width modulation (SHE-PWM) based multilevel inverter (MLI) switching scheme optimizes the overall injected voltage and current THD in such a way that line harmonics present in the supply also gets reduced. The proposed scheme can inject active power from the hybrid sources while reactive power injection can take place in either of DVR, STATCOM or UPQC operation. The conventional UPQC mode of operation usually does not compensate the voltage interruption alone without energy storage element in the dc-link. But the proposed DG-DFIG-UPQC scheme compensates the voltage interruption in the source with the help of the common shared DC bus between the DFIG rotor side and PV interconnection. In the present approach, biogeography-based optimization (BBO) [21] based SHE-PWM optimization algorithm technique is used to calculate switching angles for the line infacing inverters. Various simulations using MATLAB/Simulink and the corresponding experimental results confirm that the proposed DG-UPQC scheme using hybrid generation performs significantly better than the DG-DVR and DG-STATCOM.

Proposed system configuration

The block diagram of the proposed system considering only wind and PV based hybrid generation and DVR sharing common DC bus is shown in Fig. 1.

In Fig. 1, the DFIG and the PV panels with DC–DC converter are connected in parallel with transformer less DVR interface to microgrid. The DVR can reduce the unbalance in load side voltage, sag, swell, flicker, spike, reactive power unbalance, etc. A multilevel inverter is used as the DVR interface to reduce the harmonic content of the output voltage. The stators of the DFIGs are directly

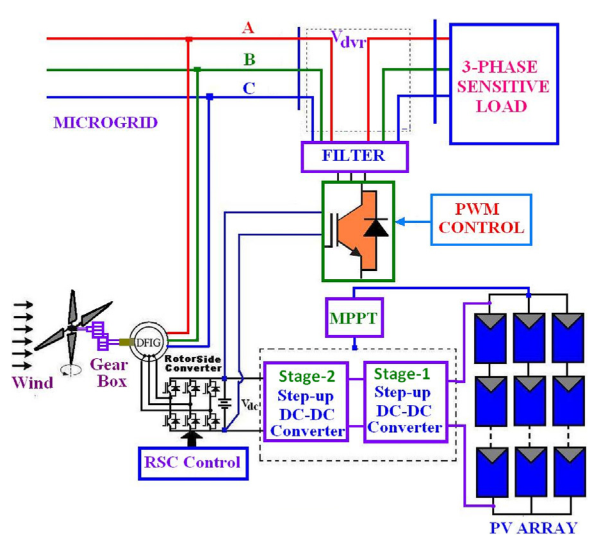

FIG. 1
Proposed transformer less DVR system with PV.

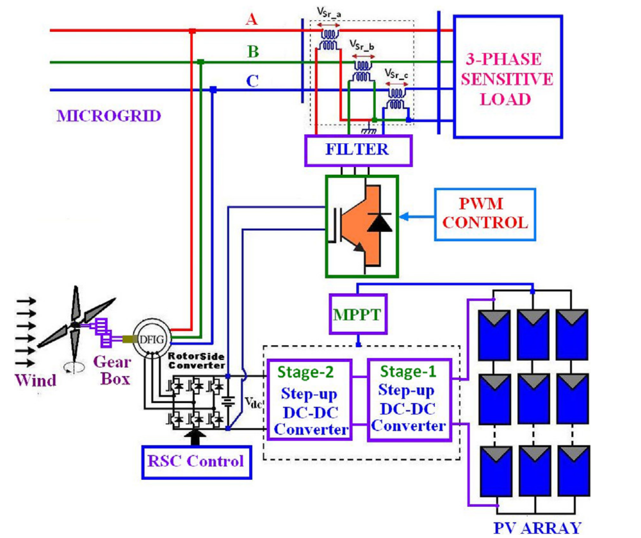

FIG. 2
Proposed transformer connected DVR system with PV.

connected to 50 Hz micro grid. The DFIG is mechanically coupled with a wind turbine because most of the supply is of mechanical power. A battery is provided between the two converters to store the extra energy from the PV panel when the rotor side power demand is less than PV panel output. The same can also act as a dc source in the absence of sunlight to inject the power to the rotor during sub-synchronous operation or store the power coming from the DFIG rotor at super-synchronous speed. Inverters feeding the rotors of the DFIGs, handle high current. Thus the devices will have high current stress both during switching and continuous conduction. Since the conduction current cannot be minimized as it is decided by load, the switching losses should be reduced.

Fig. 2 shows the DVR system is same as Fig. 1 except that the interface is made with the help of series transformer. The schemes in Figs. 1 and 2 are limited to only DVR operation besides active power injection from wind and PV sources. The proposed schemes shown in Figs. 3 and 4 are for improved operation in UPQC mode with reduced injected harmonics. The scheme in Fig. 3 illustrates proposed transformer-less connection while Fig. 4 shows transformer connected PV-UPQC respectively. The SHE-PWM based multilevel inverters are used for interface with grid in both the cases. The transformer less scheme has some important features like lower cost, lower size, free from saturation, neutral current or inrush current related problems, etc. On the other hand, the inverter voltage has to be higher and the output voltage THD can be higher compared to scheme with transformer for same number of switchings. The Micro-grid and the DFIG specifications used for the proposed scheme are given in Table 1.

Existing and proposed switching strategies

The DFIG rotor voltage supplied from inverter is usually a quasi-sine wave to reduce switching losses in the semiconductor devices. Similar is the case for DVR, STATCOM and UPQC inverters. The quasi-sine voltage waveforms generated by these inverters can introduce various odd harmonics of the orders of $6k \pm 1$, $k = 1, 2, 3, \ldots$ to the grid. Elimination of such harmonics through PWM needs higher switching frequencies which can increase