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ScienceDirect

Procedia Technology 21 (2015) 310 – 316

Procedia Technology

SMART GRID Technologies, August 6-8, 2015

A Zig-Zag Transformer and Three-leg VSC based DSTATCOM for a Diesel Generator based Microgrid

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Abstract

The distribution systems are facing severe power quality problems due to the uncontrolled use of different types of linear and non-linear loads such as solid state controllers which will draw harmonics and reactive currents from ac mains. It may lead to poor power quality at ac sources such as sag, swell, notch, flicker, unbalance etc. The installation of the diesel generator set is widely used in practice to feed power to some crucial equipments and in remote areas. DG sets used for these purposes may be loaded with unbalanced, reactive and non-linear loads such as power supplies in telecommunication system and medical equipments. A Zig-Zag Transformer and three-leg VSC based DSTATCOM is used here to compensate the neutral current, harmonic current, reactive power and unbalanced load. The insulated gate bipolar transistor (IGBT) based VSC is supported by a capacitor and is controlled for the compensation required in the load current. The dc bus voltage of the VSC is regulated during varying load conditions. In this paper, a Synchronous Reference Frame (SRF) controlled three-leg voltage source converter (VSC) based DSTATCOM with a Zig-Zag transformer is used for reactive power, harmonics, unbalanced load current and neutral current compensation in grid connected and islanded mode.

Peer-review under responsibility of Amrita School of Engineering, Amrita Vishwa Vidyapeetham University

Keywords: Distribution static compensator (DSTATCOM), neutral current compensation, power quality improvement, Zig-Zag Transformer, Voltage Source Converter (VSC).

1. Introduction

The ac power system has affected the problems regarding reactive power and unbalance from very beginning. It has severely affected with the increased use of power converters as some of these converters not only increase the reactive currents, but also generate the harmonics in the source currents. These power electronic converters are used

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Peer-review under responsibility of Amrita School of Engineering, Amrita Vishwa Vidyapeetham University
doi:10.1016/j.protcy.2015.10.037

in variable frequency ac motor drives, standby inverters, UPS and battery chargers; which generates large harmonics. The current quality problems aggregate under unbalanced load conditions. The installation of diesel engine based electricity generation unit (DG set) is a widely used practice to feed the power in remote areas [1], [2]. The source impedance of the DG sets is quite high. The unbalanced and distorted current may leads to the unbalanced and distorted voltages at point of common coupling (PCC). Harmonics and unbalance load currents flowing through the generator results into torque ripples at the generator shaft. These factors lead to the increased fuel consumption and reduced life of the DG sets. These results to the DG sets to be operated with de rating, which further results into increased cost of the system. Nowadays, small generator units are available with full conversion (inverter-converter) unit to meet necessary power quality norms [3]. Instead of using theses, a DSTATCOM [2] can be used with three phase DG sets to feed unbalanced loads without de rating the DG sets and to have the same power quality norms.
In this paper, a Synchronous Reference Frame (SRF) controlled three-leg voltage source converter (VSC) - DSTATCOM with a Zig-Zag transformer is used in Diesel Generator based Microgrid system for reactive power, harmonics, unbalanced load current and neutral current compensation in a grid connected mode and islanded mode. [4]. A three-leg VSC with a Zig-Zag transformer is reported in literature [7]. The application of Zig-Zag transformer is for compensating the zero-sequence components of load currents. The application of Zig-Zag transformer for reducing neutral current has an advantage due to passive compensation. The Zig-Zag connection is also called the interconnected star connection. This connection has some of the features of the Y and the Δ connections, combining the advantages of both. Therefore the topology of the three leg VSC with a Zig-Zag transformer has shown improved performance reported in paper [5], [6].

2. System Configurations

This paper considers the configuration of the system for a three-phase three-wire DG set connected as a captive power plant along with main three phase source for feeding power to linear and non-linear loads. A 30 KVA DG set is chosen to demonstrate the working of the system with a DSTATCOM. The DSTATCOM consists of an insulated gate bipolar transistor (IGBT)-based three-phase three-leg VSC system. A 7.5 KVA three-phase Zig-Zag transformer is used for neutral current compensation at the point of common coupling (PCC). The linear and non-linear balanced and unbalanced loads are connected at the PCC. The load current is tracked using SRF control algorithm, which is in conjunction with a PWM current controller that provides switching signals for VSC based DSTATCOM. The parameters of Salient pole Synchronous generator are 415V, 30 KVA, 4 pole, 1500 rpm, 50 Hz, X_d = 1.56 pu, X_d ‘ = 0.16 pu, X_d”= 0.12 pu, X_q= 0.78, X_q’= 0.17, X_q”= 0.6, H_s= 0.08. The other crucial parameters are given in Table 1.

Table 1. System Specifications

DG set	A Salient pole Synchronous generator with Deisel engine excitation system	30KVA, 415V, 50Hz,4pole, 1500rpm
Load	Linear	Delta connected R-L load of 37.5KVA at 0.8pf
	Non-Linear	30 KW, diode bridge converter with LC filter at output with L=2mH and C=500μF
Voltage source converter	DC link capacitor C_{dc}=10000μF, AC inductor=3.5mH, Ripple filter: C_r=10μF and R_f=8Ω, fs=20KHz	
Other parameters	AC line voltage:11KV and 50Hz, Line impedance:Ls=3.5mH and Rs=0.01Ω Zig-Zag transformer:7.5KVA, Step down transformer: 11KV/415V	

3. Control Algorithm

The power quality issues in a distributed system can be mitigated by using a DSTATCOM. In this paper, the performance of distribution system under consideration is analysed by three leg DSTATCOM based on Synchronous Reference Frame (SRF) control. The system performance is analysed in MATLAB-SIMULINK model. The single line diagram of the system under consideration is shown in Fig. 1. The three-phase voltage source corresponds to secondary voltage of step-down transformers. An inductor, Ls corresponds to a leakage inductance of a distribution transformer and line inductance. The effective resistance of the distribution transformer and line are the resistor, Rs. The capacitor, C_f and R_f represent ripple capacitor and resistance respectively installed for filtering the high frequency signals of voltage at PCC. The DSTATCOM is installed at the end bus of the distribution line. The installation of the active device is one of the most effective solutions to eliminate harmonics in the distribution line [1].

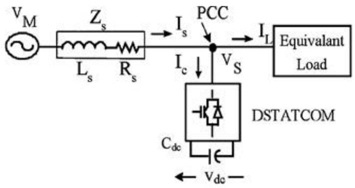

Fig. 1 Single line diagram of DSTATCOM system

The control of DSTATCOM has two parts.

(a) Derivation of reference signals using the required feedback signals.

(b) Generation of the gate signals using PWM current controller by comparing the sensed and reference signals.

The two modes of operation of the DSTATCOM used in this distribution system are

(1) Unity Power factor mode (UPF)

(2) Zero voltage regulation mode (ZVR).

Reference signal estimation

In Synchronous Reference Frame (SRF) theory the sensed load current has to be converted to rotating reference frame using 'sine and cosine' signals, with unity magnitude, generated by a PLL in-phase with the load voltage. Hence the three phase load currents (a-b-c frame) are transformed into two phase stationary global reference (α-β) system, known as Clark's Transformation. This two phase global reference frame is transformed to rotating local reference (d-q-0) frame. This is called Park's transformation. The reference supply current is estimated using the sensed load current and voltage at PCC. The UPF and ZVR strategies of reactive power compensation and its estimations are explained in the following section.

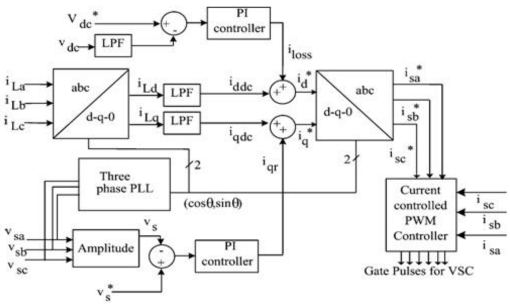

Fig. 2. Control algorithm for the three-leg-VSC-based DSTATCOM in a three phase four-wire system.

Current-controlled PWM for generating gating pulses

In the current controller, the sensed and reference supply currents are compared and a proportional controller is used for amplifying current error in each phase before comparing with a triangular carrier signal to generate the gating signals for six switches in three leg DSTATCOM. Fig. 2 shows the control algorithm for DSTATCOM.

4. MATLAB based modeling of the system

The three-leg DSTATCOM and the Zig-Zag transformer based system for current compensation in a grid connected DG set connected to a stiff voltage source are modeled and simulated using MATLAB. The ripple filter is connected to the DSTATCOM for filtering the ripples in the PCC voltages. The system data is given in Table 1. The control algorithm for DSTATCOM is modeled in MATLAB Simulink (SPS) toolbox. The reference source currents are derived from the sensed PCC voltages (v_{sa}, v_{sb}, v_{sc}), load currents from (i_{La}, i_{Lb}, i_{Lc}), and the dc bus voltage of DSTATCOM (V_{dc}). A pulse width modulated (PWM) current controller is used over the reference and sensed source current to generate gate pulses for the IGBT of DSTATCOM.

5. Simulation Results and Discussions

A. Performance of a Diesel Generator operated in islanded mode, with DSTATCOM compensation.

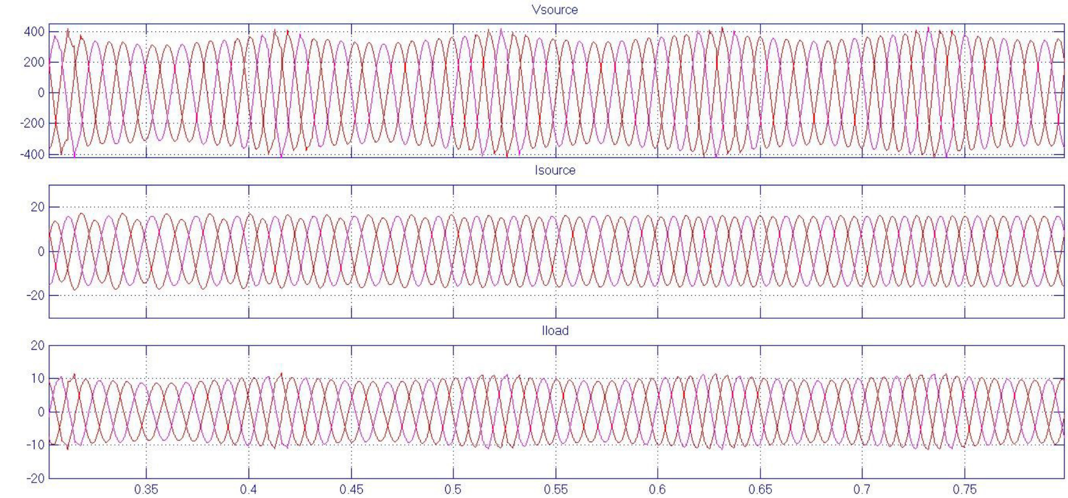

Fig. 3 Diesel Generator operated in islanded mode, with DSTATCOM compensation

B. Performance of a Diesel Generator operated in grid connected mode, without any compensation.

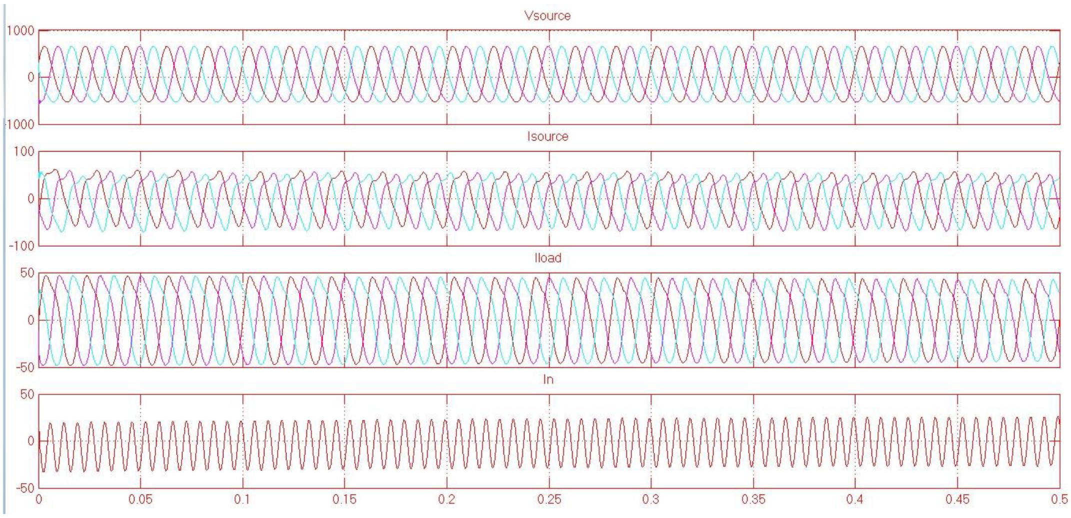

Fig. 4 Diesel Generator operated in grid connected mode, without any compensation

C. Performance of a Diesel Generator operated in grid connected mode, with compensation

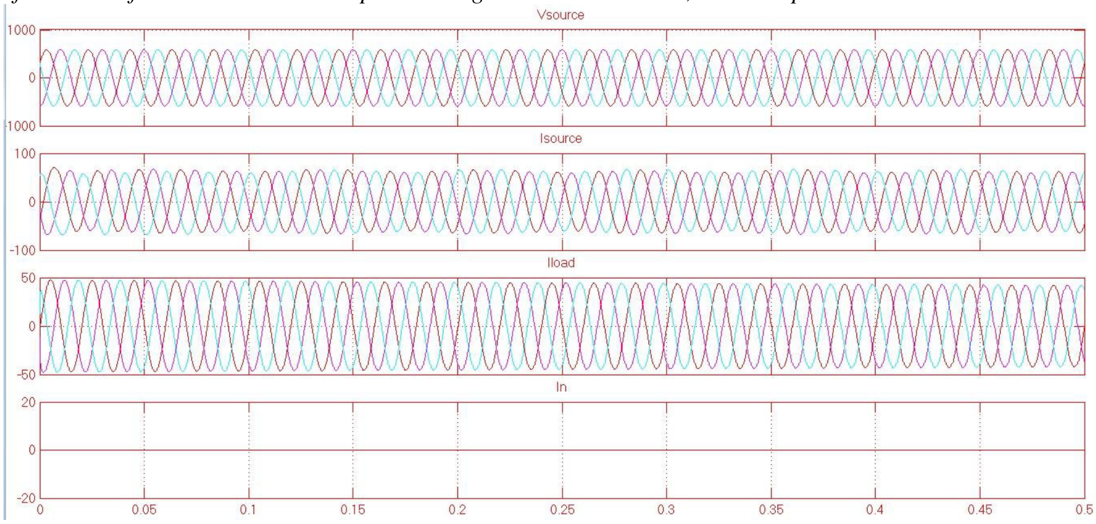

Fig.5 Diesel Generator operated in grid connected mode, with compensation

The performance of a Synchronous Reference Frame (SRF) controlled - DSTATCOM with a Zig-Zag transformer in a grid connected mode and islanded mode is demonstrated. Fig. 3, Fig. 4 and Fig. 5 show the corresponding results of source voltage (V_{source}), source current (I_{source}), load current (I_{load}) and neutral current (I_n).

D. Performance of a Diesel Generator operated in grid connected mode, with unbalanced non-linear load and without any compensation

The performance of the DSTATCOM during the unbalanced load condition is depicted in Fig. 6. At 0.2 s to 0.4 s, three phase load is converted into two phase load. At 0.3 s to 0.4 s, two phase load is converted into single phase load. At 0.4 s, all three phase load is reapplied. It is found that, source current is distorted during unbalanced load and neutral current is increased to the same phase value during the unbalanced load period, because of not providing any voltage and neutral current compensation. The source voltage (V_{source}), source current (I_{source}), PCC voltage (V_{pcc}) and neutral current (I_n) are shown in Fig. 6.

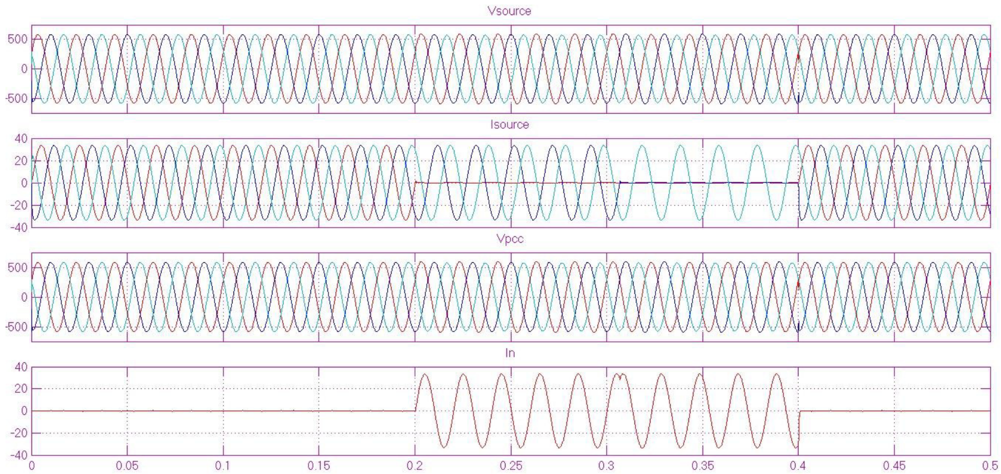

Fig. 6 Diesel Generator operated in grid connected mode, with unbalanced non-linear load and without any compensation

E. Performance of a Three-leg DSTATCOM for a Diesel Generator based micro grid generation system with unbalanced non-linear load condition.

The performance of the DSTATCOM during the unbalanced load condition with DSTATCOM compensation is depicted in Fig. 7. The source voltage (V_{source}), source current (I_{source}), load current (I_a, I_b, I_c) and neutral current (I_n) are shown in Fig. 7. At 0.2 s to 0.4 s, three phase load is converted into two phase load. At 0.3 s to 0.4 s, two phase load is converted into single phase load. At 0.4 s, all three phase load is reapplied. It is found that, source current is compensated even in load current distorted during unbalanced load condition and neutral current is decreased to less than 10% with respect to the value without any compensation during the unbalanced load period.

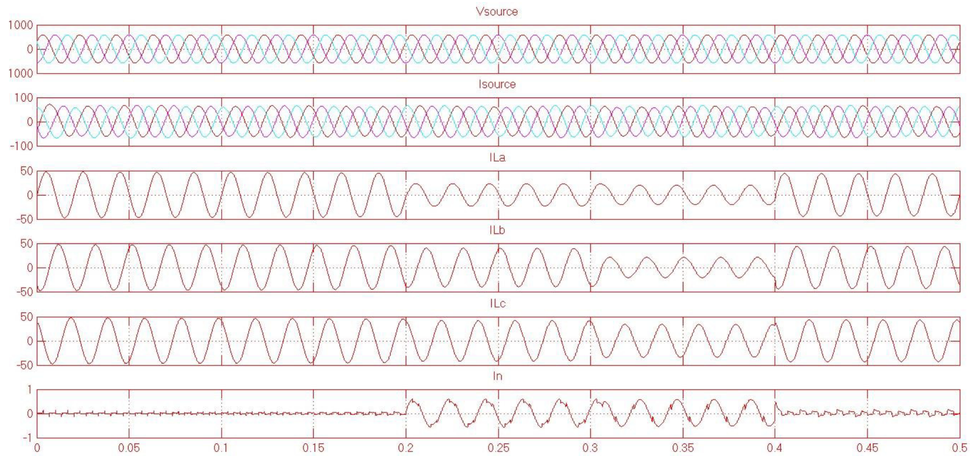

Fig. 7 Diesel Generator based micro grid generation system with unbalanced non-linear load condition.

F. Harmonic spectra of source current (a) without compensation (b) with compensation in islanded mode.

It is found that, without any compensation THD of source current is 51.13% and that of PCC voltage is 3.9%. But with the DSTATCOM compensation it is reduced to 5% in source current and 1.7% in PCC voltage. So the power quality and performance of the system is improved. Table 2 shows the comparison of THD analysis of source current and PCC voltages in Islanded mode and Grid connected mode.

Table 2. Comparison of THD

THD(%)	Islanded Mode		Grid connected Mode	
	Without compensation	With DSTATCOM	Without compensation	With DSTATCOM
Isa	51.14	5.2	21.14	1.7
I_{sb}	51.13	5.1	21.13	1.7
I_{sc}	51.13	5.1	21.14	1.7
V_{ta}	50.0	2.7	4.9	0.4
V_{tb}	50.02	2.7	4.8	0.42
V_{tc}	50.10	2.7	4.8	0.42

6. Conclusion

The proposed Synchronous Reference Frame (SRF) controlled three-leg voltage source converter (VSC) - DSTATCOM with a Zig-Zag transformer is used in a Diesel Generator based Microgrid system. The use of DSTATCOM considerably reduces the harmonics in the source current and the voltages at PCC are improved to a great extent. By using the Zig-Zag transformer, neutral current is compensated and its magnitude is reduced to less than 10% under unbalanced load condition. The cost of installation of DG set with DSTATCOM can be compensated as it leads to less running cost of DG set while feeding a verity of loads.

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