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Load Compensation for Isolated Diesel Generation System

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Abstract

This paper presents the control for reactive power, harmonics and unbalanced load current compensation of a diesel generator using distribution static synchronous compensator (DSTATCOM). The DSTATCOM is achieved using least mean square-based adaptive linear element (Adaline). An Adaline is used to extract balanced positive-sequence real fundamental frequency component of the load current and a proportional–integral (PI) controller is used to maintain a constant voltage at the dc-bus of a voltage-source converter (VSC) working as a DSTATCOM. Switching of VSC is achieved by controlling source currents to follow reference currents using hysteresis-based PWM control. This scheme is simulated under MATLAB environment using Simulink and PSB block-set toolboxes for feeding linear and nonlinear loads. The modeling is performed for a three-phase, three-wire star- connected synchronous generator coupled to a diesel engine, along with the three-leg VSC working as a DSTATCOM. Results are presented to verify the effectiveness of the control of DSTATCOM for the load compensation and an optimal operation of the DG set.

1. Introduction

The diesel engine-based electricity generation unit (DG set) is a widely used practice to feed the power to some crucial equipment in remote areas DG sets used for these purposes are loaded with unbalanced, reactive and nonlinear loads such as power supplies in some telecommunication equipment and medical equipment. The source impedance of the DG set is quite high, and the un- balanced and distorted currents lead to the unbalanced and distorted three-phase voltages at point of common coupling (PCC). Harmonics and unbalanced current flow through the generator result into torque ripples at the generator shaft. All of these factors lead to the increased fuel consumption and reduced life of the DG sets. These forces the DG sets to be operated with derating which results into an increased cost of the system.

This paper addresses the transient studies of electrical networks with embedded, power electronics-based, FACTS and Custom Power (CP) controllers. A considerable percentage of power system studies rely on electromagnetic transient simulations. They provide substantial information relating to the considered basic Static Var Compensator (SVC) with FC-TCR arrangement. The CP controllers include Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR).The paper is organized as follows: the FC-TCR arrangement of SVC is discussed, the theory behind Voltage Source Converter (VSC) – based Controllers namely, D-STATCOM and DVR, the PWM scheme adopted in this paper for D-STATCOM and DVR is described. Then the test cases are presented and the simulation results are discussed and, finally, some conclusive remarks are drawn.

2. Diesel Generator Set

Diesel engine is the prime mover, which drives an alternator to produce electrical energy. In the diesel engine, air is drawn into the cylinder and is compressed to a high ratio (14:1 to 25:1). During this compression, the air is heated to a temperature of 700–900°C. A metered quantity of diesel fuel is then injected into the cylinder, which ignites spontaneously because of the high temperature. Hence, the diesel engine is also known as compression ignition (CI) engine.

A diesel generating set (DGset) should be considered as a system since its successful operation depends on the well-matched performance of the components, namely:

a) The diesel engine and its accessories.
b) The AC Generator.
c) The control systems and switchgear.
d) The foundation and power house civil works.

e) The connected load with its own components like heating, motor drives, lighting etc.

The Fig.2.1 shows the Schematic Diagram Of DGset.

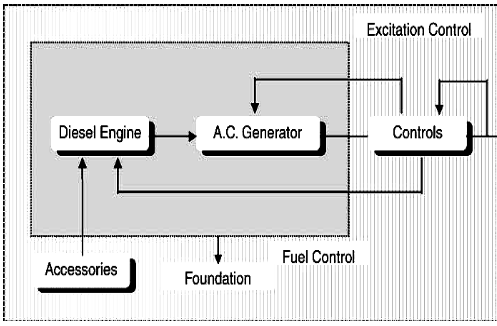

Fig.2.1: Schematic Diagram of DGSet as system

The DGset can be high speed or low speed set. The below table compares the high speed and low speed DG sets. In general High speed is treated as 1500RPM in India.

TABLE2.1: Comparison of High and Low speed DGset

Factor	Slow speed	High Speed
Break Mean Effective Power	Low	High
Weight to Power Ratio	High	Low
Space	High	Low
Type of Use	Continuous	Intermittent
Period between overhauls*	8000 Hours	3200 Hours
Direct Operating Cost	Less	High

* Typical Recommendation from Manufacturer

3. VSC-based Custom Power controllers

A D-STATCOM (Distribution Static Compensator), which consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power.
2. Correction of power factor; and
3. Elimination of current harmonics.

Fig.3.1 Shows the schematic diagram of a D-Statcom. In Fig.3.1 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the voltage source inverter.

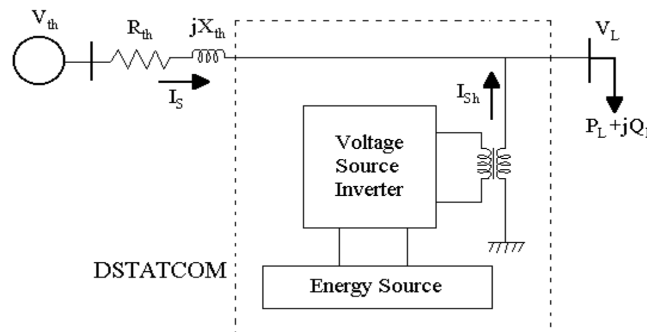

Fig.3.1: diagram of a D-Statcom

The shunt injected current I_{sh} can be written as,

$$I_{sh} = I_L - I_S = I_L - \frac{V_{TH} - V_L}{Z_{Th}}$$

$$I_{sh}\angle\eta = I_L\angle - \theta - \frac{V_{Th}}{Z_{Th}}\angle(\propto - \beta) + \frac{V_L}{Z_{Th}}\angle - \beta$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L I_{sh}^{*}$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with VL, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. The switching frequency is set at 475 Hz.

The Fig3.2 represents the block diagram of proposed D-Statcom controller.

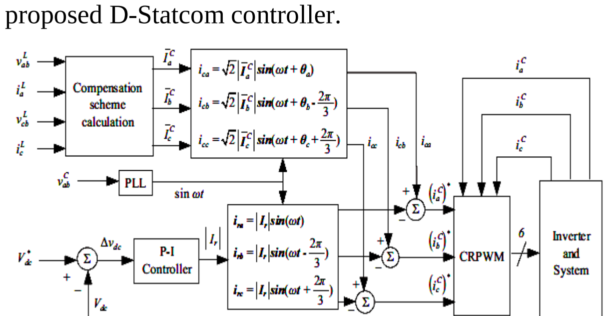

Fig.3.2: The block diagram of proposed D-Statcom controller.

According to the DSTATCOM controller calculates the compensation current commands $\bar{I}_a^C, \bar{I}_b^C, \bar{I}_c^C$ by using line-to-line voltages and line current. The instantaneous compensation currents are obtained with the aid of the synchronous signal sinωt via a PLL circuit. Additionally, the dc-link voltage is maintained by supplying a real part of compensation current | Ir| via a P-I controller, as shown in (Fig.3.2). With the same synchronous signal sinωt, the instantaneous current for active power balance is also yielded. Combining the above two currents generates the needed three-phase current command signals $(i_a^C)^*, (i_b^C)^*, (i_c^C)^*$ for the DSTATCOM. This paper employees a current-regulated PWM (CRPWM) inverter as the power stage of the proposed DSTATCOM. The CRPWM inverter uses the error signals from the comparison results of the reference signals $(i_a^C)^*, (i_b^C)^*, (i_c^C)^*$ and the actual compensation currents i_a^C, i_b^C, i_c^C as the input. This generates the needed compensation current of the DSTATCOM for fast load compensation.

4. System Modelling and Control Algorithm

The modeling of the DG set is performed using a synchronous generator, a speed governor, and the excitation control system. This proposed system is simulated under MATLAB environment using Simulink and PSB Block-set toolboxes. The results for a 30-kVA DG set with the linear load at 0.8 lagging pf and a nonlinear load with different load dynamics and unbalance load conditions are presented to demonstrate the effectiveness of DSTATCOM-DG set system.Fig.4.1 represents the Basic Configuration Of The Dg Set With Dstatcom.

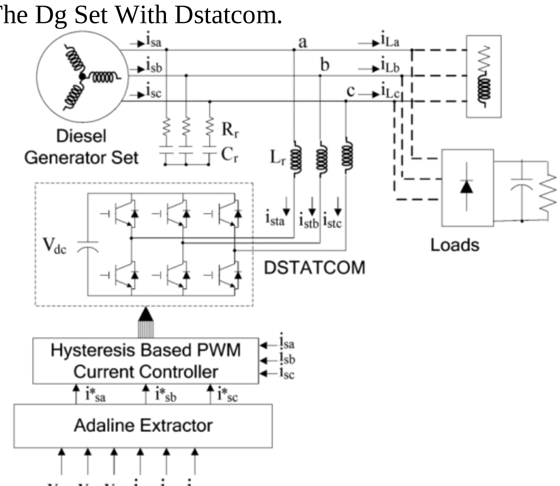

Fig.4.1: Basic Configuration of the Dg Set with Dstatcom.

Fig. 4.1 shows the configuration of the system for a three phase three-wire DG set feeding to variety of loads. A 30 kVA system is chosen to demonstrate the work of the system with the DSTATCOM. The DSTATCOM consists of an insulated gate bipolar transistors-based three-phase three-leg VSC system. The load current is tracked using Adaline-based reference current generator, which in conjunction with the hysteresis-based PWM current controller that provides switching signals for VSC-based DSTATCOM. It controls source currents to follow a set of three-phase reference currents. The parameters of a salient pole synchronous generator are 415 V, 30 kVA, 4 pole, 1500 rpm, 50 Hz, *X*d = 1.56 pu, *X*_ d = 0.15 pu *X*__ d = 0.11 pu, *X*q = 0.78, *X*_ q = 0.17, *X*__ q = 0.6, *H*s = 0.08. The other critical parameters are given in Table 4.1.

TABLE.4.1: critical parameters

Load	Linear	Delta Connected load of 37.5KVA at 0.8pf
	Non – Linear	30KW diode bridge converter with LC filter at output with L=2mH and C = 500Uf
Voltage Source Converter		Dc link Capacitor = 10000UF, AC inductor=3mH, Ripple filter: C = 10UF, R=8ohm and f=20Khz

The operation of this system requires a DG set to supply real power needed to the load and some losses (switching losses of devices used in VSC, losses in the reactor, and dielectric losses of the dc capacitor) in DSTATCOM. Therefore, the reference source current used to decide the switching of the DSTATCOM has two parts. One is real fundamental frequency component of the load current, which is being extracted using Adaline and another component, which corresponds to the losses in the DSTATCOM, are estimated using a PI controller over dc voltage of DSTATCOM.

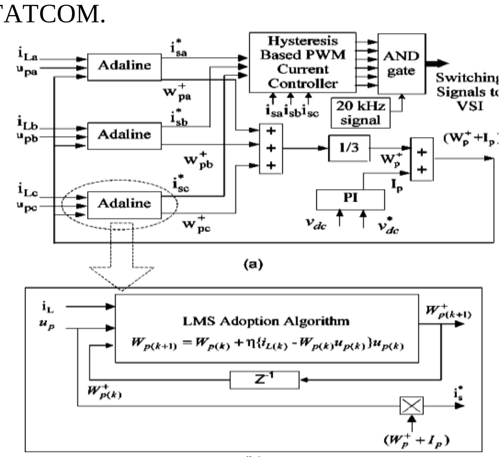

Fig.4.2: (A), (B). Control Block Diagram Of The Reference Current Extraction Scheme

Fig. 4.2(a) shows the control scheme for the implementation of reactive, unbalanced and harmonic currents compensation. The output of the PI controller is added to the weight calculated by the Adaline to maintain the dc-bus voltage of the DSTATCOM.

5. Simulation and test Results

Case1: Linear load without DSTATCOM

The Fig.5.1 represents the Linear Load Compensation of Diesel Engine Generator without Using Dstatcom.

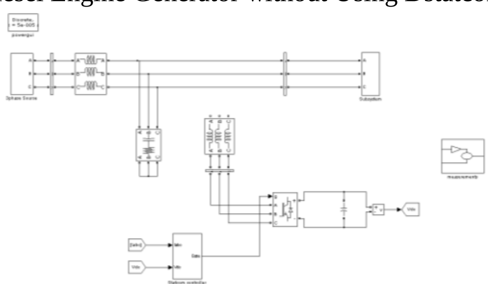

Fig.5.1: The Linear Load Compensation of Diesel Engine Generator without Using Dstatcom

The results were shown below.

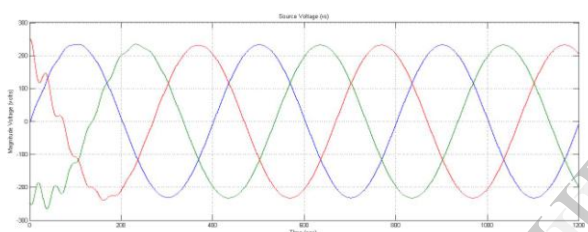

Fig.5.2:Source Voltage

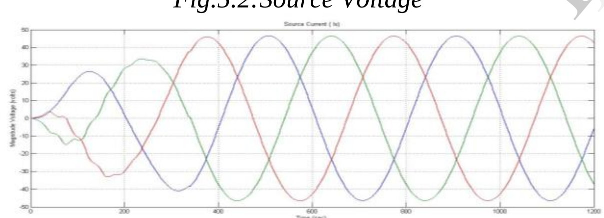

Fig.5.3: Source Current

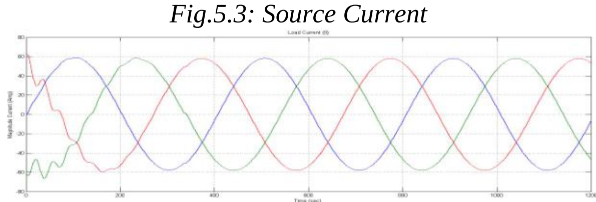

Fig.5.4: Load Current

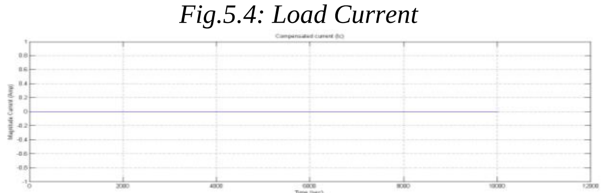

Fig.5.5: Compensated Current

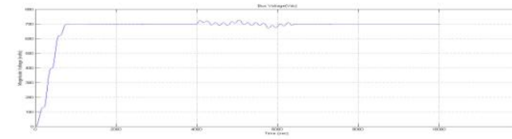

Fig.5.6:Bus Voltage

Case2: Linear load with DSTACOM

The Fig.5.6 represents the Linear Load Compensation of Diesel Engine Generator Using Dstatcom.

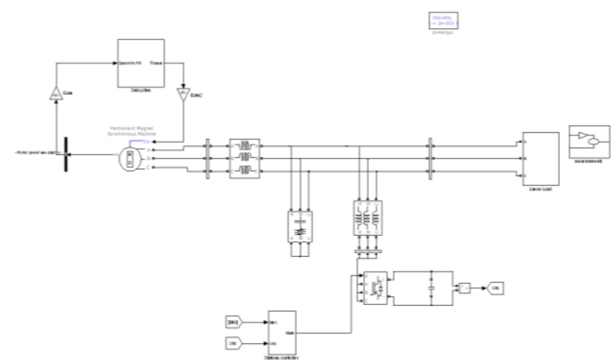

Fig.5.7: The Linear Load Compensation of Diesel Engine Generator Using Dstatcom

The results were shown below.

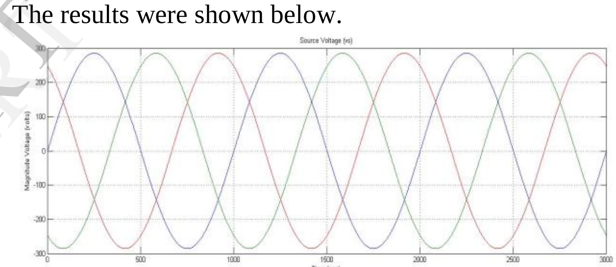

Fig.5.8:Source Voltage

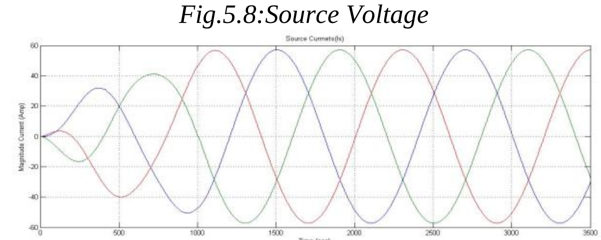

Fig.5.9: Source Current

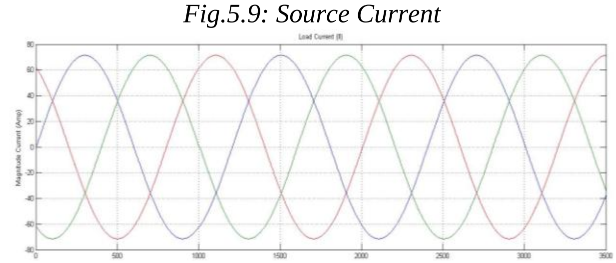

Fig.5.10: Load Current

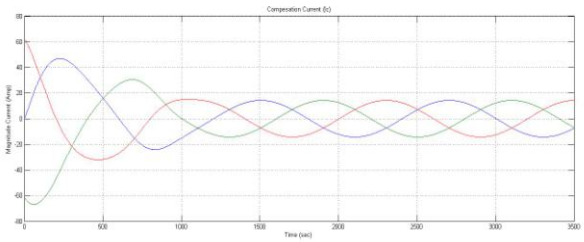

Fig.5.11: Compensated Current

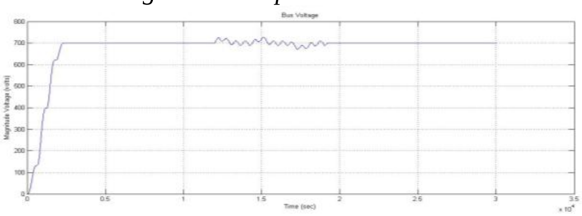

Fig.5.12:Bus Voltage

Case3: Nonlinear load with DSTATCOM

The Fig.5.13 represents the Linear Load Compensation of Diesel Engine Generator Using Dstatcom.

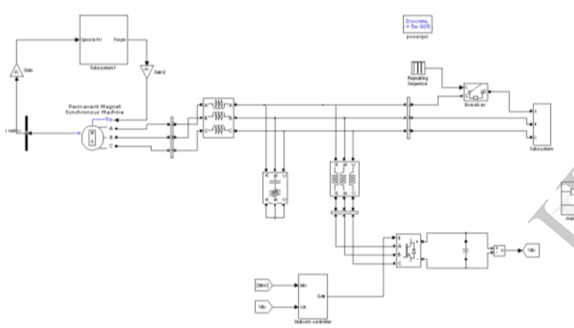

Fig.5.13: NonLinear Load Compensation of Diesel Engine Generator Using Dstatcom.

The results were shown below.

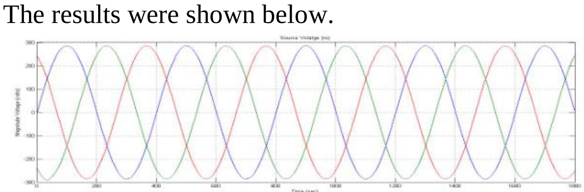

Fig.5.14: Source Voltage

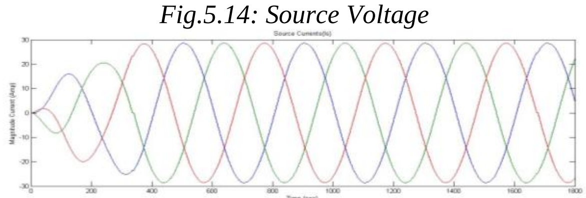

Fig.5.15: Source Current

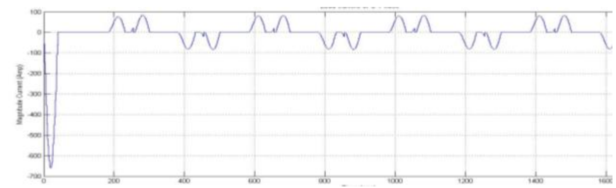

Fig.5.16: Load Current

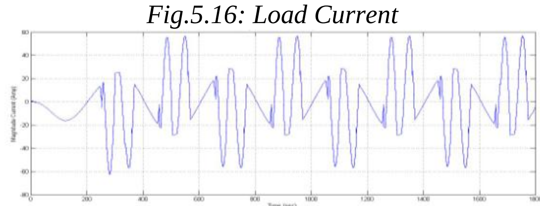

Fig.5.17: Compensated Current

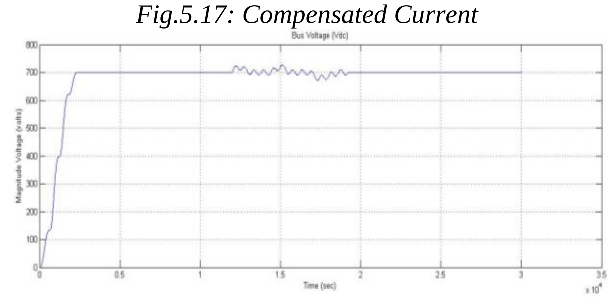

Fig.5.18:Bus Voltage

6. Conclusion

The proposed control algorithm of the DSTATCOM has been found to improve the performance of the isolated DG system. The DSTATOM has compensated the variety of loads on the DG set and it has sinusoidal voltages at PCC and currents with compensated and equivalent linear balanced unity power factor loads. The cost of the installation of DSTATCOM system with the DG set can be compensated as it leads to less initial and running cost of DG set as its ideal operation while feeding variety of loads.

7. Future Work:

Having met the objectives of the paper, some issues arise for future work to be done for the improvements on this paper.

i. To model the wind/diesel system in a longer term period, one-day period, so that the system being modeled can be justified better. However, other software needs to be used since PSCAD/EMTDC is primarily used for transient studies.

ii. A better control technique such as the artificial neuro-network (ANN) can be used to further improve the overall operations.

8. References

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