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D-STATCOM Based Load Compensation for Isolated Generation System

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Abstract-The installation of Diesel Engine based electricity generation unit is widely used in practice to feed the power to some crucial equipment. Diesel Generator (DG) sets used for these purposes are loaded with unbalanced, reactive and non-linear loads such as power supplies in telecommunication equipment and medical equipment. The source impedance of the DG set is quite high and the unbalanced distorted currents lead to the unbalanced and distorted three-phase voltages at the Point of Common Coupling (PCC). All of these factors lead to the increased fuel consumption and reduced life of the DG sets [5]. The DG set is used to supply the load which is non-linear in nature. Due to the non-linear nature of the load, the load gets distorted which will affect the source voltage. To overcome these problems, a D-STATCOM (Distribution Static Compensator) can be used for the reactive power, harmonics and unbalanced load compensation which facilitate, to load the DG set. The D-STATCOM is used to inject the current source at the PCC [1]. The control of D-STATCOM is achieved using Space Vector Pulse Width Modulation (SVPWM) technique. The proposed system is simulatedunder MATLAB environment using Simulink.

Index Terms— Diesel generator, Distribution static compensator, harmonic elimination, load compensation, MATLAB Simulink, Sinusoidal pulse width modulation, Space vector pulse width modulation.

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1 INTRODUCTION

Due to increased power demand, the power generation plays a vital role in power system. The power generation is more than the demand but due to the losses the demand is unable to meet. The losses are due to transmission and distribution. The losses in the distribution side are discussed in this paper. Whenever the supply is given to the load, due to the non-linear nature of the load, the load current gets unbalanced. Due to unbalanced load current, the source gets affected. The DG set is used as a source. The DG set is a three-phase supply with a phase shift of 1200 at each of the phase. The source voltage is a three-phase supply of sinusoidal waveform supplied to the load. The DG set is widely used in practice to feed the power to crucial equipment in remote areas. The DG sets used for these purposes are loaded with unbalanced, reactive and nonlinear loads. These forces the DG sets to be operated with derating, which results into an increased cost of the system.

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Nowadays, small generator units are available with full conversion (inverter-converter) units to meet stringent power quality norms. Instead of using these, a D-STATCOM can be used with a three-phase DG set to feed unbalanced loads without derating the DG set and to have the same cost involved [12].

The performance of the D-STATCOM is very much dependent on the method of deriving reference compensating signals. Instantaneous reactive power theory, modified p-q theory, synchronous reference frame theory, instantaneous id- iq theory, and method for estimation of reference currents by maintaining the voltage of dc link are generally reported in the literature for an estimation of reference currents for D-STATCOM through the extraction of positive-sequence real fundamental current component from the load current. These techniques are based on complex calculations and generally incorporate a set of low-pass filter which results in a delay in the computation of reference currents and therefore leads to slow dynamic response of the D-STATCOM. In this paper, a fast and simple neural network-based control scheme isused to estimate reference source current for control of D-STATCOM [7].

This paper presents D-STATCOM based load compensation for a diesel generator set to enhance its performance. The control of D-STATCOM with capabilities of reactive power, harmonics and unbalanced load compensation is achieved by PWM techniques. Here, the PWM techniques like Sinusoidal Pulse Width Modulation (SPWM) technique and Space Vector Pulse Width Modulation (SVPWM) technique is used to extract positive-sequence fundamental frequency and real component of load current. The dc-bus voltage of voltage source converter (VSC) is supported by a Proportional–Integral (PI) controller which computes current component to compensate losses in D-STATCOM. The life of DG set is enhanced in the absence of unbalanced and harmonic currents. [8].

2 SYSTEM CONFIGURATION OF D-STATCON BASED LOAD COMPENSATION FOR

ISOLATED GENERATION SYSTEM

Fig.1. shows the block diagram for a three-phase three-wire DG set feeding to a variety of loads. A 30 KVA system is chosen to demonstrate the work of system with D-STATCOM. The parameters of a salient pole synchronous generator are 415 V, 30 KVA, 4 pole, 1500 rpm, 50 Hz, Xd= 1.56 pu, X'd = 0.15 pu, X''d= 0.11 pu, Xq =0.78, X'q = 0.17, X''q =0.6, Hs = 0.08.

There are three main types of non-linear loads in power systems. They are

(i) Current source loads,

(ii)Voltage source loads and

(iii)Combination of both above.

The first category of non-linear loads includes the current source (current-fed (or) current-stiff) loads. Traditionally, most non-linear loads have been represented as current source because their current waveforms on AC side are distorted. Example, the phase-controlled thyristor rectifier with a filter inductance on DC side of the rectifier resulting in DC current thyristor rectifiers convert AC voltage source to a DC current source supplying Current Source Inverter (CSI).

The second category of the non-linear load comprises voltage source (voltage fed (or) voltage stiff) loads such as diode rectifier with a capacitive filter at the DC link feeding variable-frequency voltage-source inverter (VSI) based AC motor drives, power supplies with front-end rectifier and capacitive filters installed in computers and other household appliances, battery chargers, etc. These voltage stiffloads draw discontinuous and non-sinusoidal currents resulting in very high THD, low power factor and distortion of AC terminal voltage at the point of common coupling.

The third category of non-linear load is characterized by the combination of current and voltage source loads. They are neither of current source nor of voltage source and may contain the loads of both kinds [5] & [6]. Adjustable Speed Drives is an example of this type.

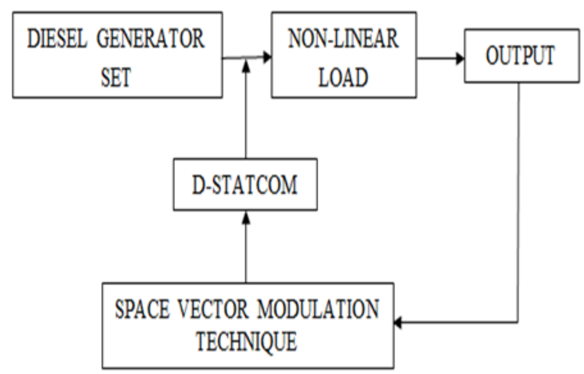

Fig.1. Block Diagram of D-STATCOM based Load compensation for Isolated Generation System.

3 OPERATION OF D-STATCOM

The D-STATCOM consists of an Insulated Gate Bipolar Transistors (IGBT) based three-phase three-leg voltage source converter (VSC) system. It is employed at distribution level or at load side. It also behaves as a shunt active filter. Since the electrical power distribution system is very important to balance the supply and demand of active and reactive power in the electrical power system. In case if the balance is lost, the frequency and voltage excursion may occur which result in collapse of power system.

The main application of D-STATCOM exhibits high speed control of reactive power to provide voltage stabilization in power system. D-STATCOM protect the distribution system from voltage sags, flicker and harmonics caused by reactive current demand. D-STATCOM employs a voltage source converter (VSC) and generates capacitive and inductive reactive power internally. Its control is very fast and has the capability to provide adequate reactive compensation to the system. D-STATCOM can be effectively utilized to regulate the voltage for one large rating motor or for a series of small induction motors starting simultaneously. Induction motor loads draw large starting current (5-6 times) of full rated current and may affect working of sensitive loads [4].

D-STATCOM is a parallel voltage controller consists of a filter, voltage source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer which is shown in fig.1. The voltage source converter provides 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.

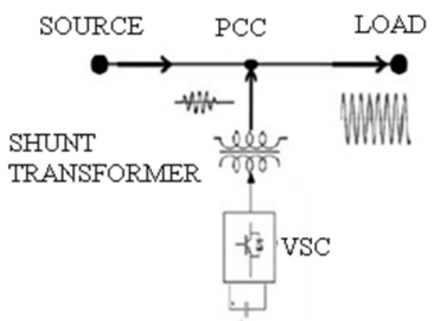

Fig.2 Schematic diagram of D-STATCOM

Suitable adjustment of phase and magnitude of 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,

3. Elimination of current harmonics.

4 CONTROL TECHNIQUES OF D-STATCOM

4.1 PWM based control with voltage measurement

A PWM based control scheme has been proposed that requires only voltage measurements and reactive power measurements are not required. The proposed control system measures only the rms voltage at the load point where reactive power measurements are not required. The VSC switching strategy is based on Sinusoidal PWM technique which offers simplicity and good response. Because distribution network is relatively low power application, PWM methods offers more flexibleoption than the fundamental frequency switching methods favored in FACTS applications. Besides, high switching frequencies can be used to improve the efficiency of converter, without incurring significant switching losses. The simulations carried out shows that D-STATCOM provides excellent voltage regulation capabilities.

4.2 Operation of D-STATCOM in voltage/current control mode

The control of a D-STATCOM can be operated either in the voltage or current control mode.

1. In the voltage control mode, the D-STATCOM can force voltage of distribution bus to sinusoidal waveform.

2. In the current control mode, it can cancel distortion caused by the load, that the current drawn by the compensated load is purely sinusoidal waveform. The proposed algorithm works properly irrespective of unbalance and harmonic distortions in load currents or source voltages (3).

5 CONTROL ALGORITHM

A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply. The most widely used PWM schemes for three-phase voltage source inverters are carrier-based SPWM and SVPWM.

5.1 Sinusoidal Pulse Width Modulation (SPWM) techniques

Sinusoidal Pulse Width Modulation technique is one of the simplest carrier-based modulation methods. SPWM is a familiar technique in the field of Power Electronics where a high frequency triangular carrier signal is compared with a sinusoidal reference signal. The main advantage of the carrier-based SPWM is that the complexity is very low and the dynamic response is very good. The number of pulses per cycle is being decided by the ratio of triangular carrier frequency to that of modulating sinusoidal frequency [10]. Modulation ratio (M_r) is given by the relation,

$$M_r = \frac{Frequency\ of the carrier waveform}{Frequency\ of the\ modulating waveform} \quad (1)$$

Mr is related to harmonic frequency and the harmonics are located at $f = kM_r(f_m)$ where f_m is thefrequency of the modulating signal and k is an integer (1,2,3….n).

Modulation index (MI) is given by the ratio of Amplitude of modulating reference waveform to that of the Amplitude of carrier waveform and is denoted by, MI=Ar/Ac, where Aris the reference amplitude and Ac the carrier amplitude. MI is related to the fundamental (sine wave) output voltage magnitude. If MI is high, then the sine wave output is high and vice versa. When 0 < MI < 1, the linear relationship holds: V_1 = MI Vin, where V_1, Vin is fundamental output voltage and input voltage, respectively [13].

5.2 Space Vector Pulse Width Modulation (SVPWM) techniques

The basic aim of Pulse Width Modulation (PWM) technique is to control output voltage and harmonic reduction. PWM (or) Pulse Duration Modulation (PDM) is commonly used technique for controlling power to inertial electrical devices, made practical by modern Power Electronic switches. In SVPWM, a rotating phase is considered which is obtained by adding all the three voltages. Modulation is accomplished by switching state of an inverter [2] & [14].

The early vectorial representation of three-phase inverters was presented by Park and Kron. But the first use of space vectors was done by Kovacs and Racz, who presented a mathematical treatment and a physical description of the drive transients of machines fed through electronic converters [9].

On the contrary of PWM method which treats the three-phase quantities separately, SVPWM method treats the three modulating signals as a single unit called reference voltage. This reference voltage contains the values of three variable signals. The three-phase inverter is shown in fig.3, could be modeled using the following switching functions [16].

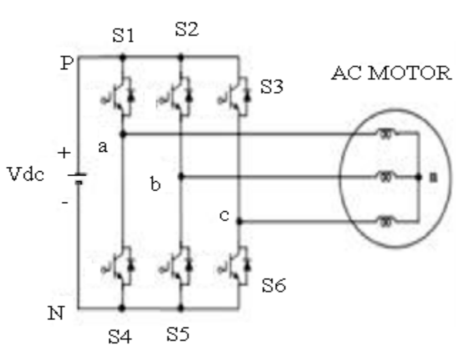

Fig.3 Voltage source three-phase inverter.

There are six switching devices and only three of them are independent as the operation of two power switches of the same leg are complementary. The combination of these three switching states gives out eight possible space voltage vectors. The space vectors forms hexagon with 6 distinct sectors, each spanning 60 degrees in space. At any instant of time, the inverter can produce only one space vector. In space vector PWM a set of three vectors (two active and a zero) can be selected to synthesize the desired voltage in each switching period [9] & [11].

Space vector modulation is a PWM control algorithm for multi-phase AC generation, in which the reference signal is sampled regularly. After each sample, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are selected for appropriate fraction of sampling period in order to synthesize reference signal as average of used vectors. The topology of a three-leg voltage source inverter is the constraint that the input lines must never be shorted and the output current must always be continuous voltage source inverter can assume only eight distinct topologies. Six out of these eight topologies produce a non-zero output voltage and are known as non-zero switching states and the remaining two topologies produce zero output voltage and are known as zero switching states.Output voltages of three-phase inverter depends on switching state of the switches S1 to S6 are the six power transistors that shape output voltage. When an upper switch is turned on indicated as “1” and when the corresponding lower switch is turned off indicated as “0”[6] & [15].

The Space Vector PWM is a control algorithm technique which generates less harmonic distortion in the output voltage (or) current in comparison with the Sinusoidal PWM technique and the Hysteresis-based current control technique [2].

6 SIMULATION AND RESULTS

6.1Introduction

In this section, the simulation results are shown with clear explanation in each graph. Results for the source current waveform, load current waveform and injecting current at the point of common coupling waveforms are given below. In order to rectify the harmonics induced in the system, the simulation investigation is carried out by using MATLAB Simulink.

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6.2 Source current waveform of the load compensation of isolated generation system

Scale
X axis 1 unit=0.5 sec
Y axis 1 unit=10A

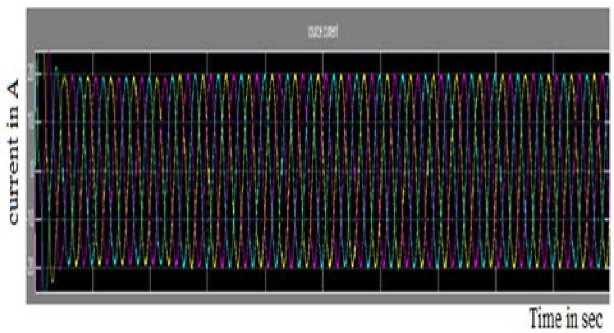

Fig.4.Source current waveform of the load compensation of isolated generation system.

The Fig.4.shows the three-phase source current that is supplied to the load. The source current supplied to the load is of rating 20 A. The corresponding source voltage to the source current is 415 V, 24 KW. The source voltage is a three-phase supply with a phase difference of 1200 each of the phase.

6.3 Load current waveform of the load compensation of isolated generation system

Scale
X axis 1 unit=0.5 sec
Y axis 1 unit= 5 A

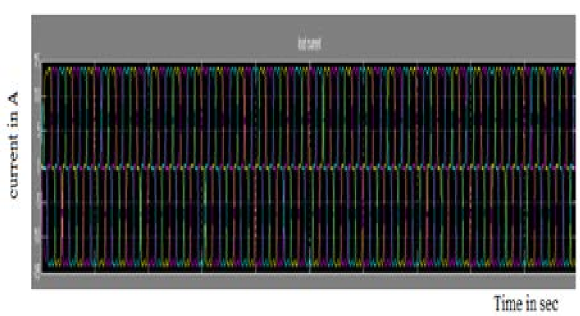

Fig.5.Distorted Load current waveform of the load compensation of isolated generation system.

The Fig.5.shows the distorted load current when the source voltage supplies to load. This distortion is due to non-linear nature of the load. The unbalanced load current is in the order of 15A. Due to this unbalanced load current, the source voltage gets affected. The source impedance is used to prevent the flow of excess current to the source.

6.4 Filter current waveform to be injected at the point of common coupling

Scale
X axis 1 unit=0.5 sec
Y axis 1 unit= 5 A

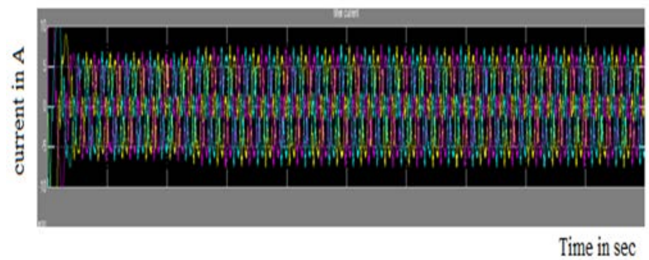

Fig.6.Filter current waveform to be injected at the PCC.

The Fig.6.shows the filter current that is to be injected at the point of common coupling. The filter current is in the order of 5A. The injected current source makes the source voltage to back to original condition.

7 MATLAB SIMULATION

The Fig.4.Fig.5.& Fig.6. shows the MATLAB model of the D-STATCOM-DG set isolated system. The modeling of the DG set is carried out using a star-connected synchronous generator of 30 KVA, controlled by a speed governor and an excitation system. The linear load applied to the generator is at 0.8 pf lagging which is modeled as a delta connection as a series combination of resistance and inductance (R-L) models. The non-linear load is modeled using discrete diodes connected in a bridge with a capacitor filter and a resistive load on a DC bus. The unbalanced condition is realized by disconnecting phase-a from the diode bridge. The simulation is carried out in continuous mode at 1 * 10-6 step size with diode 15s (stiff/NDF) solver.

8 RESULTS AND DISCUSSION

The simulation of D-STATCOM-DG isolated system is carried out with different types of loads i.e. a linear R-L load and a non-linear load i.e. a diode bridge converter load. The load compensation is demonstrated for these types of loads using D-STATCOM system for an isolated DG set. The following observations are made on the basis of obtained simulation results under different system conditions.

8.1 DG Set System Operationsunder Linear Load

A three-phase 18.75 KVA load at 0.8 pf is being connected. After few seconds, the load is increased up to 37.5 KVA at 0.8 pf. The real power supplied by the DG set is 30 KW and the reactive power is supplied by the D-STATCOM. After few seconds, an unbalance is introduced in the load by taking off the load from phase-a. In this case, even though the load current is unbalanced. The source current is balanced. After few seconds, the load is taken out from phase-b, even in this condition the D-STATCOM system is able to balance DG set currents.

8.2 DG Set System Operationsunder Non-Linear Load

The performance of the DG set with D-STATCOM under non-linear loading conditions is carried out. The load on the system is kept 15 KW initially. The load compensation in terms of harmonics mitigation is also being provided by D-STATCOM during this condition. The load is increased to 30 KW after few seconds from the initial time. After few seconds, an unbalance is in the load is observed and the load is reduced to 16.4 KW. After few seconds, phase-a is reconnected again to the diode bridge and the load is reduced to its initial value (15.6 KW). A high value of THD% in the voltage at PCC is due to high source impedance of generator. The improvement in the voltage waveform is achieved using ripple filter employed at the DG set terminals comprising of a capacitance and resistance constituting a high-pass filter. The DG set currents and voltages are observed to be almost sinusoidal and balanced operating at unity power factor [13].

9 CONCLUSION

In this paper, we have studied about the two PWM techniques, SPWM and SVPWM techniques. The SPWM technique used in the system provides a THD level of 2.58 % which is less compared to the IEEE Standards of 519 as 5% of THD.

It has been observed that SVPWM technique has showed superior performances to THD level. The SVPWM technique is a control algorithm in the MATLAB software. The unbalanced load current is given as the feedback to the SVPWM technique in conjunction with D-STATCOM. Furthermore, at high switching frequencies of SVPWM gives better results as compared to SPWM. The SVPWM technique provides a THD level of 2.00% as compared to that of SPWM technique. It is therefore evident that SVPWM achieves a better DC bus utilization compared to SPWM. Thus, based on all obtained results, we concluded that SVPWM technique provides better overall performance and efficiency as compared to SPWM technique.

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