ISOLATED DIESEL GENERATOR INTEGRATED WITH PV-DSTATCOM

D. Suresh[1], S.P.Singh[2]
[1]AssociateProfessor, Department of EEE, VITS, Deshmukhi, Hyderabad
[2]Professor, Department of EEE, IIT-Roorkee, India

Abstract: In this paper, isolated Diesel generator set is integrated with static synchronous compensator (DSTATCOM) for harmonics elimination, reactive power compensation and injection of active power. The control of scheme of DSTATCOM is derived from instantaneous reactive power theory. The dc bus voltage is regulated to constant value with proportional integral (PI) controller of DSTATCOM. The controlling pulses DSTATCOM is carried out with hysteresis controller. The overall system consisting of DG set, DSTATCOM and nonlinear load simulation is carried out with MATLAB environment using Simulink and power system block-set toolboxes. The MATLAB modeling is performed for a synchronous generator coupled to a diesel engine, along with the three-leg VSC working as a PV-DSTATCOM. The simulated responses of PV-DSTATCOM with DG set are presented to verify the effectiveness of the control of PV-DSTATCOM for the compensation harmonics, reactive power and active injection without separate DSTATCOM.

IndexTerms: DSTATCOM, MPPT,harmonics, reactive power.

I. INTRODUCTION

In most of installation the electric power generation is carried out with DG sets to feed the power to some sophisticated equipment in industrial as well as commercial establishments [1], [2], [12]. 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 impedance offered by the DG set is quite high, and the distorted currents produce the voltage drop across the impedance of DG set lead to the reduction and distortion of voltages at point of common coupling (PCC). The torque pulsation is produced in the DG set, which is resulted from the flow of harmonics current. 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. Currently, small diesel generators with improved power quality features integrated with converter-inverter sets are available. The inverter-converter set is integrated to enhance the power quality requirement. Instead of using small generator set to meet power quality requirement, the DSTATCOM can be used with three phase DG set to feed unbalance load. The DSTATCOM functional is to compensate harmonics, reactive power load balancing and can be used for line termination. The small DG set increase the price of the installation and maintenance. With advancement in digital as well as power semiconductor technology, the price of DSTATCOM of an inverter is reduced and can be easily configured to work as PV-DSTATCOM. Additionally, the DSATCOM can compensate harmonics, reactive power and can inject active power from PV array. The integration of PV-DSTATCOM with DG set enable reduction of fuel consumption used for power generation.

To compute reference signal, many control schemes are reported in literature, and some of these are instantaneous reactive power (IRP) theory, instantaneous symmetrical components, synchronous reference frame (SRF) theory, current compensation using dc bus regulation, computation based on per phase basis and scheme based on neural network techniques [4]–[11]. Among these projected control schemes instantaneous reactive power and synchronous reference frame theories are most widely used. This paper present, PV-DSTATCOM is controlled with instantaneous reactive power theory integrated with maximum power point tracking algorithm based on incremental conductance algorithm. The instantaneous reactive power theory with MPPT controlled used for compensation of harmonics and reactive power and tracking of the active power from PV cell. The PV-DSTATCOM integration with DG set enable reduction in fuel consumption of DG set. The performance characteristics of PV-DSTATCOM these controllers are compared. An extensive MATLAB simulation is presented of DSTATCOM. Simulation results demonstrate the effectiveness of these two control algorithms of DSTATCOM for compensation of harmonics and reactive power demand of the nonlinear load.

II. DSTATCOM CONFIGURATION

The DG set integrated with PV-DSTATCOM is shown in Fig.1. The overall system of DSTATCOM consists of diesel generator, DSTATCOM integrated with PV modules and nonlinear load. The DG set is comprised of synchronous generator and internal combustion engine. When nonlinear load is connected to the DG set it induce the harmonics and increase the temperature level of the system. The increase of the temperature in DG set is due to the losses caused by the harmonics and oscillating power. The DSTATCOM is made up of insulated gate bipolar transistor, inductor and capacitor. The DSTATCOM is connected at the point of common coupling to compensate the harmonics induced by nonlinear load. This proposed PV-DSTATCOM also injects the active power harvested from the PV module. The losses caused by harmonics also increase the fuel consumptions and derating of DG set.

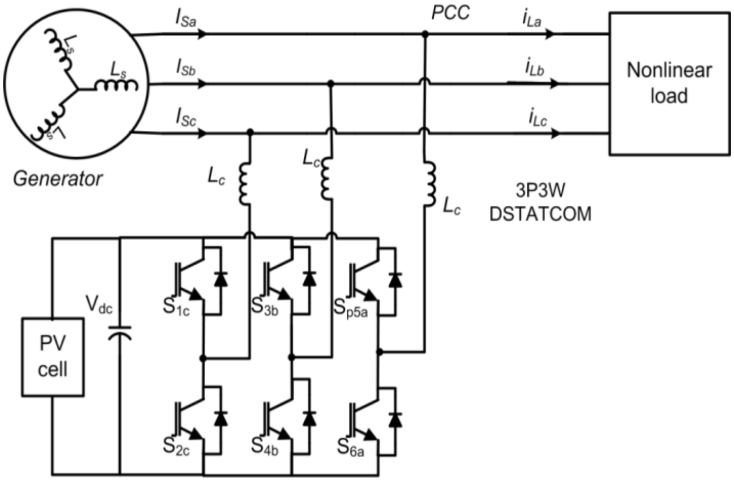

Fig.1.DSTATCOM configuration for DG set integration.

III. CONTROL SCHEME

In literature numbers of control strategies are proposed for efficient extraction of reference current such as synchronous reference frame, power balance, symmetrical component theory and instantaneous reactive power theory etc. [2]. Among these reference current generations instantaneous reference theory (IRP) most efficient and commonly used. In IRP theory, it involves that conversion of the three phase signals into bi-phase and subsequent computation of the active and reactive power. The calculated active and reactive is used for reference generation and transformed back to three phase. These generated reference current fed to the gate pulse generator to track the source current. The dc voltage regulation loop is integrated with maximum power point tracker algorithm. The reference voltage is computed with incremental conductance method for tracking maximum power from the photo voltaic modules. The dc voltage regulation scheme using maximum power point tracker (MPPT) is shown in Fig. 3.

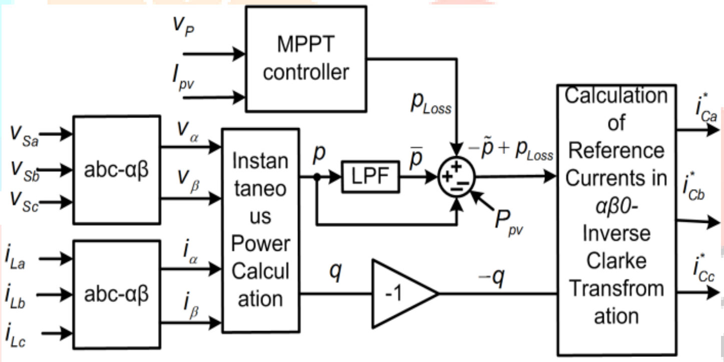

Fig.2. Instantaneous reactive power theory.

IV. DC VOLTAGE REGULATION

The dynamic model of PV cell is shown in Fig. 3 [13]. The N number of modules are connected in series and parallel to obtain the required power level.

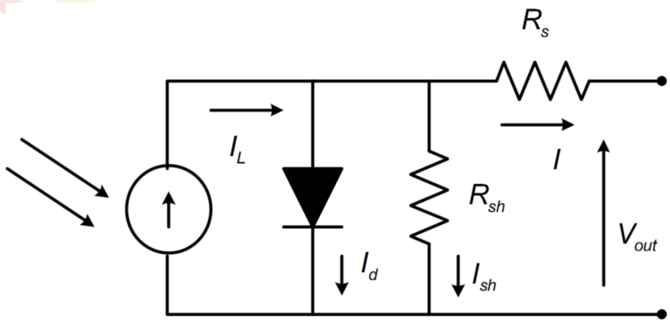

Fig.3. Equivalent circuit of photovoltaic cell.

The current obtain at the output-terminal I is equal to current generated due to solar insolation I_L and is less than the diode-current I_d and theshunt leakage current I_{sh}. Theseries resistance R_s represents the internal resistance, which opposes the flow the current and shunt resistance R_{sh} is inversely proportional to the leakage current. For ideal PVcell, the series loss and shunt losses are negligible. The typical value of series resistance R_s and shunt resistance R_{sh} for 1-in^2 siliconcellis $R_s = 0.05 - 0.10[\Omega]$ and $R_{sh} = 200 - 300\ [\Omega]$. The conversion efficiency of PV depend on R_s, but is independent to any variations in R_{sh}. A small increase in R_s can decrease the PV output significantly.The two most important parameters widely used fordescribing the cell electrical performance are the open-circuitvoltage $V_{oc} = V_{out} + R_s I$ Vobtained when the load currentis zero and the short-circuit current I_{sc}. Ignoringthe small diode and the ground-leakage currents under zeroterminal voltage, the short-circuit current under this conditionis the photocurrent I_L. The PV modules are modeled approximately as a constant current source. The basic equation describing the I-V characteristicof a practical PV cell is

$$I = I_L - I_d - I_{sh} = I_L - I_D\left[e\frac{qV_{oc}}{CkT} - 1\right] - \frac{V_{out} + R_S I}{R_{sh}} \qquad (1)$$

Where I_D is the saturation current, q is the electron charge $\left(1.6\times10^{-19}\,C\right)$, C is the diode emission factor, k is the Boltzmann constant $\left(1.38\times10^{-23}\text{ J/K}\right)$ and T is the temperature.

The PV cell generatesthe maximum power at voltage corresponding to the knee point of the *I-V* curve, as shown in Fig. 3. $V_{\max}$ and $I_{\max}$ are voltage and current at maximum power point, respectively. The DSTATCOM is set to operate at optimal voltage to achieve maximum power by maximum power point tracking algorithm. In this paper, the incremental conductance and integral regulator technique used for tracking the maximum power from the PV modules [6]. This MPPT method is based on the fact that the power slope of the PV is null at MPP point (where $dp/dv = 0$), positive in the left, and negative in the right. In the following equations, *dv* and *di* are obtained by one-sample delayed values V.

$$\frac{dp}{dv} = \frac{d\left(vi\right)}{dv} = i + v\frac{di}{dv} = 0 \qquad (2)$$

$$\frac{dv}{di} = -\frac{i}{v} \qquad (3)$$

$$\begin{cases} \dfrac{dv}{di} > -\dfrac{i}{v} : left \\ \dfrac{dv}{di} < -\dfrac{i}{v} : right \end{cases} \qquad (4)$$

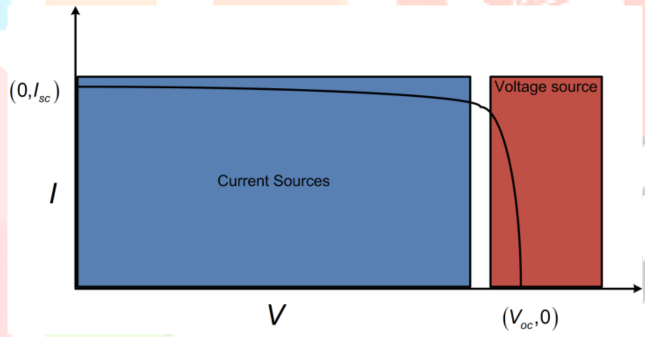

Fig.4. V-I characteristics of PV cell.

The DC voltage regulator with maximum power point tracking algorithm used for estimation of reference voltage is shown in Fig.3. The reference DC voltage is estimated with incremental conductance method and power generated from PV system also estimated for injecting active power from DSTATCOM to grid. The active power injected is carry negative sign, which shows that the DSTATCOM inject active power into the DG set feeding system.

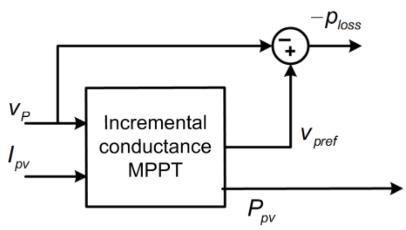

Fig.5

V. Results and Discussions

The simulated waveform of the PV-DSTATCOM under different operating condition is shown in Fig.6, Fig.7 and Fig.8 respectively. The different waveforms of the spectrum can be recognized as source voltage, source current, load current and compensating current and represented as Vsa, Isa, ILa and Ica respectively.

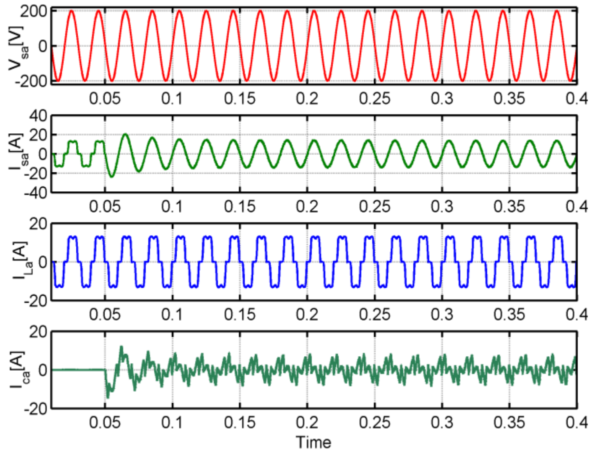

Fig.6. Simulated waveform of DSTATCOM.

When DSTATCOM alone operating without photo voltaic modules connected on its dc side and it is used for compensation of harmonics and reactive power demand of the nonlinear load. Before t=0.05 sec., the source current is consist of integer multiple triplen harmonics current. When DSTATCOM is connected at t=0.05 sec. source current tend to sinusoidal and in synchronous with voltage waveform. The source current total harmonics distortion before compensation is 23.62% and its value after compensation is found to be 2.04%.

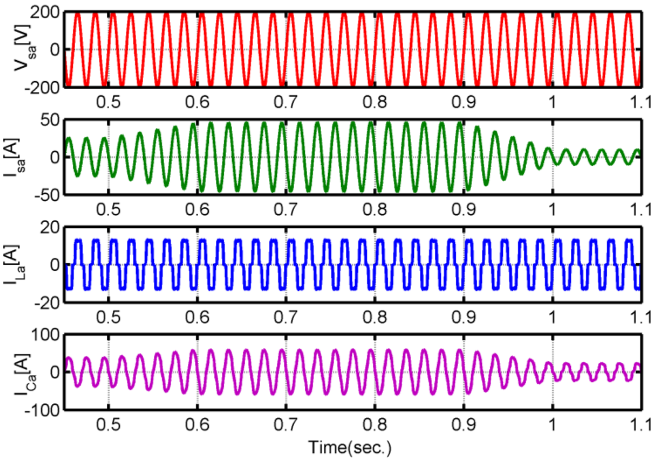

Fig.7. Simulated waveform with MPPT.

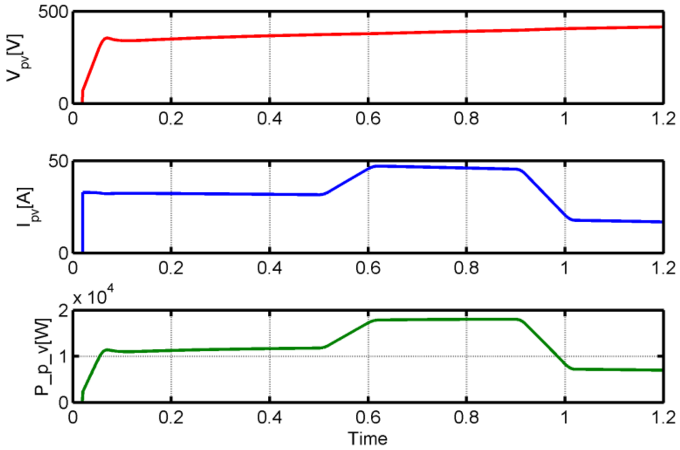

Fig.8.Simulated waveform with power variation.

The simulated response of the PV-DSTATCOM is shown in Fig.7. Before compensation with DSTATCOM source current highly nonlinear and contains harmonics which is result in heating of armature of the synchronous generator. When PV-DSTATCOM start injecting active power harvested from PV module, the source current tends to sinusoidal. The source current is in phase opposition to source voltage, which shows the active power flow from PV-DSTATCOM to the load. As load demand increases on DG set, PV-DSTATCOM compensate the load current demand. This is in turn results in reduction of fuel consumption. And also, DSTATCOM compensate harmonics and balance the current while feeding variety of the load

The power variation with solar insolation is shown in the Fig.8. The different waveform of spectrum identified as PV array voltage, PV array current and active power output of the PV array. With increase in solar insolation, the quantity of output active power also increases. The increase in power output from PV array the quantity of active power injected at point of common coupling also increases. This increase in active power can be observed from the Fig.8, the value of source current gradually increase with increase in compensating current of DSTATCOM. The active power injected from PV-DSTATCOM relieves the loading on the DG set and also compensate the harmonics and reactive power demand of the nonlinear load connected with DG set.

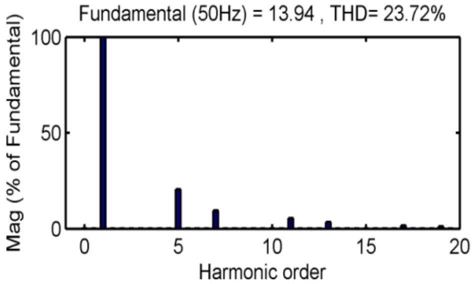

Fig.9. Source current THD without DSTATCOM

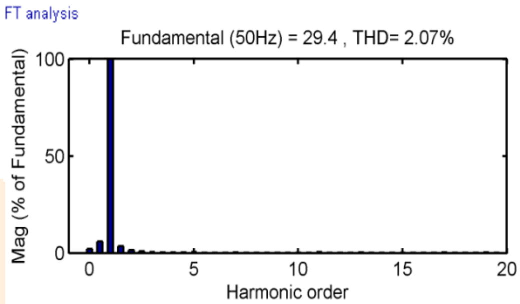

Fig.10. Source current with DSTATCOM compensation.

IV. CONCLUSIONS

In this paper, isolated DG set is integrated with PV DSTATCOM for performance improvement and reduction of fuel consumption. The proposed system compensates the harmonics and reactive power of the nonlinear load. The instantaneous reactive power theory is integrated with maximum power point tracking controller. The incremental conductance method based algorithm is implemented to track maximum power from the PV array. The active power calculated from PV array is used in control scheme to inject active power at point of common coupling. The simulated response of PV-DSTATCOM shows the effective for compensation of harmonics, reactive power and active power injection from PV array.

REFERENCES

[1] IEEE Std 387-1995", *IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations*, 1996.
[2]B. Singh, A. Adya, A. P. Mittal, J. R. P. Gupta, "Performance of DSTATCOM for isolated small alternator feeding non-linear loads", *Proc. Int. Conf. Comput. Appl. Elect. Eng. Recent Adv.*, pp. 211-216, 2005.
[3] B. Singh, K. Al-Haddad and A. Chandra, "A review of active filters for power quality improvement," in *IEEE Tran., on Ind. Electron.*, vol. 46, no. 5, pp. 960-971, Oct 1999.
[4] H. Akagi, E. H. Watanabe, and M. Aredes, *Instantaneous Power Theory and Applications to Power Conditioning*. Hoboken, NJ: Wiley, 2007.
[5] R. S. Herrera, P. Salmeron, and H. Kim, "Instantaneous reactive power theory applied to active power filter compensation: Different approaches, assessment, and experimental results," *IEEE Trans. Ind. Electron.*, vol. 55,no. 1, pp. 184–196, Jan. 2008.
[6] S. Buso, L. Malesani and P. Mattavelli, "Comparison of current control techniques for active filter applications, in *IEEE Transactions on Industrial Electronics*, vol. 45, no. 5, pp. 722-729, Oct 1998.
[7] Po-Tai Cheng, S. Bhattacharya and D. D. Divan, "Line harmonics reduction in high-power systems using square-wave inverters-based dominant harmonic active filter," in *IEEE Transactions on Power Electronics*, vol. 14, no. 2, pp. 265-272, Mar 1999.
[8] P. Verdelho and G. D. Marques, "Four-wire current-regulated PWM voltage converter," in IEEE Transactions on Industrial Electronics, vol. 45, no. 5, pp. 761-770, Oct 1998.
[9] A. Chandra, B. Singh, B. N. Singh and K. Al-Haddad, "An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power-factor correction, and balancing of nonlinear loads," in *IEEE Transactions on Power Electronics,* vol. 15, no. 3, pp. 495-507, May 2000.
[10] B. Singh and J. Solanki, "An Implementation of an Adaptive Control Algorithm for a Three-Phase Shunt Active Filter," in IEEE Transactions on Industrial Electronics, vol. 56, no. 8, pp. 2811-2820, Aug. 2009.
[11] H. Li, Z. Wu and F. Liu, "A Novel Variable Step size Adaptive Harmonic Detecting Algorithm Applied to Active Power Filter," 2006 IEEE International Conference on Industrial Technology, Mumbai, 2006, pp. 574-578.
[12] Bhim Singh, J. Solanki, "Load Compensation for Diesel Generator-Based Isolated Generation System Employing DSTATCOM," *in IEEE Trans., on Indu. Appl.* Vol. 47, No. 1, Jan.-Feb. 2011.
[13] M. G. Villalva, J. R. Gazoli, and E. R. Filho, ``Comprehensive approachto modeling and simulation of photovoltaic arrays," *IEEE Trans. PowerElectron*., vol. 24, no. 5, pp. 11981208, May 2009.