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Power Quality Improvement of PV-diesel-battery hybrid system Using DSTATCOM

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ABSTRACT: This paper presents an control algorithm forisolated solar photo-voltaic (PV)-diesel-battery hybrid system with integrated D-STATCOM. The admittance-based control algorithm is used for load balancing, harmonics elimination, and reactive power compensation under three-phase four-wire linear and nonlinear loads. The PV array is controlled using a maximum power point tracking (MPPT) algorithm to obtain the maximum power under unpredictable operating conditions. The Battery Energy Storage System (BESS) is incorporatedwith diesel engine generator set for the coordinated load management and power flow within the system. Further, the proposed system with the help of D-STATCOM improves the power quality problems and decreases the total harmonic distraction. A four-leg voltage-source converter (VSC) with BESS also provides neutral current compensation. The performance of the proposed standalone hybrid system with integrated D-STATCOM is studied under different loading conditions developed MATLAB/Simulation of the system.

KEYWORDS: Admittance-based control algorithm, battery energy storage system (BESS), diesel generator (DG) set, four-leg voltage-source converter (VSC), D-STATCOM, neutral current compensation, power quality, solar photovoltaic (PV) array, standalone system.

I. INTRODUCTION

At present the power demand is mainly met by the energy from conventional fossil fuels which will be depleted after few years. There is a necessity to conserve the fossil fuel resources for further uses because of increasing energy demand. Due to increased greenhouse gas emissions from the power plants and industries that make use of fossil fuels, the climatic conditions are worsened. This necessitates the use of renewable or alternate energy sources to meet the increasing power demand which are known to cause less pollution. Photovoltaic (PV) cells are semiconductor p-n junction devices produce DC power directly using energy from sunlight. The PV power system operates without noise and requires no maintenance as compared to other renewable energy sources. Since the solar irradiation on earth is intermittent, hybridizing PV system with other source is necessary to provide continuous and reliable supply of electricity.

The solar photovoltaic (PV) power generation hasobtainingextensivesupport and Also used for manyrequirementsfor exampledomestic appliances, stand-alone missions, data communications, hospitals, telecommunication systems, electric aircraft, and solar cars [1]. The application of the PV power generation is for the objectives that it has numerous advantages such as it gives clean power and can be engaged for numerous small-scale applications [2]. Nevertheless, creating an allowance for the hugevariants in the output of PV power, it is overbearing to includein additional power sources similarto a diesel generator (DG) set, fuel cells, battery storage etc. The performance analysis of standalone systems with PV- and DG-based sources is given in [3]. The design and operation of standalone DG-SPV-BES using a peak acknowledgment based control method is shown in [4]. A character triangle function (CTF)-based controltechnique and alsoexamination for four-wire standalone distribution system are presented in [5].

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An enhanced phase-locked loop (PLL)-based control technique is shown in [6], whereas three PLLs are used for extraction of fundamental active and reactive power components of load currents. However, the simulation studies are presented in [4]–[6]. A multiple observer-based control technique for standalone PV-DGbased system is used in [7]. Nevertheless, the authors have given thatinvestigational results, however the control technique in [7] is compound and wantsthe alteration of internal restrictions. Distinct the control technique in [7], the proposed system customs a conductance-based simple control technique. Furthermore, a completeinvestigational study is used to authenticatealtogether the topographies of the system. The proposed system incorporates of a diesel-engine-driven permanent magnet synchronous generator (PMSG), PV array, D-STATCOM and BES. This microgrid is a demonstrative of a typical countryside hospital power supply arrangement which desires to safeguarduninterruptedand constant power supply for 24 × 7 h. Consequently, the PMSG driven by a diesel engine safeguardscontrolled power supply. In order to sanctuary the effectiveness and to reductionofoperation cost, the DG set is made to function at 80–100% of its full capacity [8]. This is for the reason that, under light-load conditions, the efficiency decreases and the maintenance cost withal increases as the DG set is exposed to carbon build up. Typically, to evade these difficulties, the DG is operated by possession a least loading of 80% by betokens of battery charging or the DG is made to turn ON/OFF dependent upon the loading [9]–[11]. However, the turn ON/OFF of the DG set is frequently not suggested as [12], [13].

1) The load mightdifferrecurrently. Therefore, the frequent turn ON/OFF of DG intensifications the mechanical maintenance.

2) The battery life decreases as the discharging current is high for the duration of transient periods.

Besides, the PMSG driven by the diesel engine does not require a separate excitation control. The machine is robust, efficient, brushless construction, and with less maintenance [14]. A battery energy storage system (BESS) is amalgamated to distribute load smoothing in the case of dissimilarities in PV array output potency.

The BESS is deliberated as ideal energy storage for a separate system as cognate to compressed air, super capacitors, fly-wheels, pumped hydro, and superconducting magnetic storage [15]–[17]. The employment of a separate system devised of PV array, DG set, and BESS intends to consummate the following essentialities.

1) To control the point of common coupling (PCC) voltage dependent upon the solar irradiance variations, and load variations and unbalances.

2) There is no obligation for the measurement of load for turn ON/OFF of DG.

3) The power quality of the system is enhanced by dipping the total harmonic distortion (THD) of PCC voltages and DG set currents under IEEE-519 standard.

4) To effectively controlled power flow between source and load.

5) The voltage-source converter (VSC) of BESS offers reactive power compensation and maintains the balanced DG currents. This reduces the vibration of shaft and over-heating of machines.

6) It allows neutral current recompense using four leg VSC.

Currently,the incrementation in the utilization of nonlinear loads such as refrigerators, electronics appliances, medical equipment, computers, etc., has highlighted the concern for power quality in the electrical distribution system. These loads insert harmonics and distort the current and voltage waveforms instigating poor power quality quandaries. The imaginable provision for the mitigation of the potency quality difficulties is with presence of custom power contrivances [18] while meeting the IEEE-519 standard. Three-phase four-wire loads are withal kenned to agonize from the quandary of neutral current due to nonlinearity and unbalance contemporary in the system. This may harvest astronomically immense quantity of neutral current which contains of triplen harmonics. The neutral current may effect overloading of the distribution system and causes extra heat losses, which may be hazardous and poses a solemn peril to the associated equipment. A four-leg VSC is utilized for neutral current emolument in integration to mitigate the current harmonics with other described advantages.

Moreover, the flexible operation of the system be contingent upon employment of the sundry control strategies. Some of the control algorithms that have been pragmatic for controlling are multiloop strategy [20], sliding-mode control [21], P controller-predicated technique [22] and enhanced phase locked technique. The authors are unsuccessful to discuss the potency quality and reactive power emolument. The replication of these controllers to the unbalance and dynamic conditions is slow.

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In this paper, an admittance-predicated control algorithm is applied for the estimation of reference power component of source currents in the PV-DG hybrid system. The admittance of the load is projected utilizing the active and reactive powers of the load. The conductance (GL) and susceptance (BL) are extracted from the prognosticable active power and reactive power of the three-phase four-wire loads, respectively. It is a simple mathematical formulation engendered on sinusoidal Fryze current control. This control approach is predicated on the Lagrange's multiplier method and the fundamental principle of the PQ theory where the computation through the Clarke's conversion is abstracted. Ergo, it distributes an enhancement in the mathematical calculations. Here, the inputs are the load currents (i_{La}, i_{Lb}, i_{Lc}) and load voltages (v_a, v_b, v_c), which are further utilized for the approximation of the active (p) and reactive (q) power components utilizing the formula verbalized in this paper. The oscillating component of potency is eliminated as it is passed through the low-pass filter (LPF) to obtain P_{dc} and Q_{dc}. These are utilized for the approximation of the reference conductance and susceptance, thus giving the value for the reference active and reactive power components. This method enables the abstraction of the fundamental components and compensates independently for the active and reactive powers even when the system includes of harmonics and unbalances at the PCC. The emolument sanctions balanced source currents to be drawn from the network. A D-STATCOM is integrated to the subsisting system to reduce the harmonic further. The controller responds more expeditious beneath the steady-state and dynamic conditions. The control employment is realized utilizing a four-leg VSC with admittance control algorithm.

II. PROPOSED SYSTEM DESIGN AND CONFIGURATION

The standalone system comprises of a PV array along with a boost converter, maximum power point tracking (MPPT) controller, diesel-engine-driven PMSG, a four-leg VSC with BESS, and three-phase four-wire AC loads as shown in Fig. 1. The voltage at the PCC is recuperated by organizing the reactive power through VSC control. Under varying conditions of generation and loads, BESS offers charging during the daytime when the insolation is astronomically immense and the load is less. The battery discharges to compensate for any deficits. The DG set operates while maintaining the system frequency under varying generation and loads. The terminal capacitor provides a constant rated terminal voltage at no load. A four-leg VSC is interfaced along with its dc bus. The ripple filter and interfacing inductors are habituated to eliminate the switching harmonics.

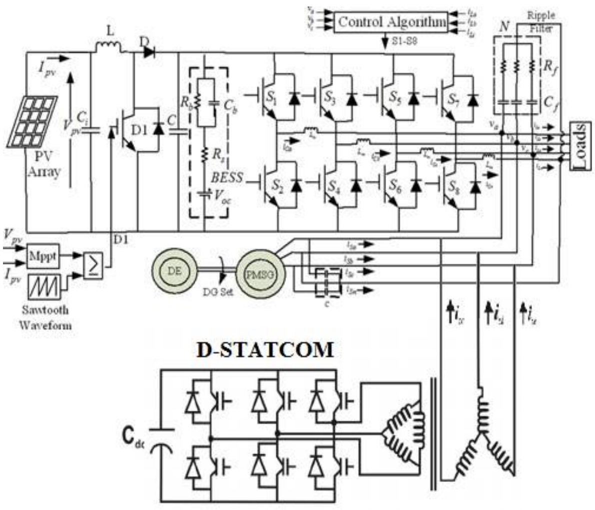

Fig. 1. Schematic diagram of the proposed system.

The considerations required for the cull of sundry elements are discussed as follows and their values are given in the Appendix.

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A. Solar PV Array

The PV array is essentially modeled with the series and parallel modules where insolation and ambient temperature acts as input [26].

The light-engendered current of the PV array depends linearly on the solar irradiation and is additionally influenced by the temperature as shown in Fig. 2. There are ten modules in series resulting in 205 V under open-circuit condition and 100 modules are connected in parallel for 30-A short-circuit current in the PV array. The PV array has been provided with a MPPT controller in order to operate at the maximum power point (MPP) at any given temperature and insolation level. The incremental conductance (IC) algorithm tracks the voltage and current at the maximum power of the solar [27]. This IC method performs good with noise repudiation and less mystification due to system dynamics. The IC method has been used here, which presents the MPP depending upon the slope of the potency curve. The slope of the curve is zero at MPP.

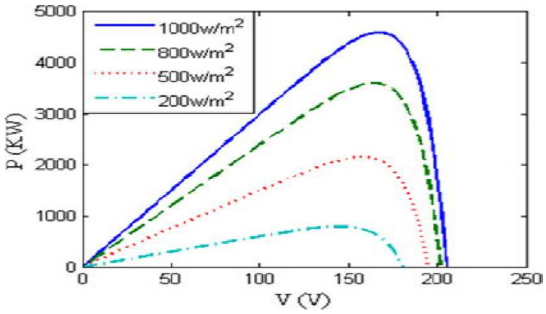

Fig. 2. PV characteristics.

The MPPT controller regulates the control signal of the dc–dc boost converter until the following condition is satisfied:

$$(\partial I/\partial V) = -(I/V). \qquad (1)$$

B. Boost Converter

The design parameters for a boost converter depend upon the current ripple, voltage ripple, and power rating. The boost converter is interfaced with MPPT controller for tracking the maximum puissance.

It is used to boost the voltage to 400 V to feed power to the battery.

The inductor of the boost converter is given as

$$L_b = \frac{V_{in}DT}{\Delta I} = \frac{165 \times 0.5875 \times 1 \times 10^{\wedge -4}}{0.1 \times 27.27} = 3.55\,\text{mH} \approx 4\,\text{mH} \qquad (2)$$

Where*V*inis the input voltage. *D* is the duty cycle, *T* is the time period, and ΔI is the inductor ripple current. The value of ΔI is taken as 10% of the input current. The variation caused by the ripples on the PV power is taken care with the addition of a capacitor (*Ci*) at the input of the boost converter as shown in Fig. 1. This absorbs the ripples and smoothen the power flowwithin the system.

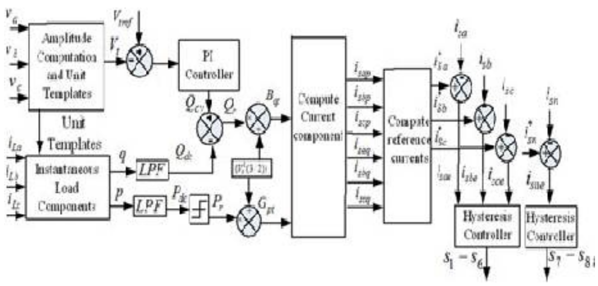

Fig. 3. Admittance-based control algorithm.

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C. Battery Energy Storage System

The battery is connected at the dc link of the VSC. The battery is an energy storage unit, its energy is represented in kilowatt-hour, and a capacitor is used to model the battery unit as shown in Fig. 1. A 2.8-kWh capacity battery rack is used for the energy storage. Therefore, 36 sections of 12 V and 7 Ah are connected in series. The parallel configuration of R_b and C_b describes the charging/discharging stored energy and voltage. The value of resistance R_b = 10 kΩ is large, while R_s= 0.1 W is very small for all practical purposes. The battery operates according to the load variations. In conditions, when the load demand has increased, under those conditions, the power stored in the battery is used, and therefore, the battery starts discharging according to its discharge rate. In the case of reduced load demand, the battery charges from the available PV power once the load demand is satisfied.

D. Ripple Filter

The first-order LPF is tuned at half the switching frequency. It is used to filter the switching ripples of a VSC at PCC. The selected switching frequency is 10 kHz. The switching frequency of 10 kHz is selected, as it would give reduced losses and the size of the components is appropriate according to the selected switching frequency as compared to other value of switching frequency. The value of capacitor is taken as 10 μF. The ripple filter consists of a resistor in series with the capacitor. The value of the resistor is considered to be 5 Ω.

III. STANDALONE HYBRID SYSTEM

D-STATCOM

STATCOM is stand for Static Compensator. It is one of the FACTS family devices. As we know FACTS devices stand for Flexible AC Transmission Systems. It consists of a group of power electronic devices such as IGBT, GTO and transistor. FACTS Devices functioning as same as other power system controllers such as transformer tap changers, phase shifting transformers, passive reactive compensators, and synchronous condensers [26]. To categorize the FACTS Devices, it can be seen by the way they connected to the power systems, either in shunt, series on in shunt-series connection.

Basically a STATCOM is a system that relates closely with power electronic device. One of the power electronic device that be used in STATCOM is voltage source converter (VSC) .Voltage source converter functioning as a source or supplier. It will provide a reactive AC and active AC power to an electrical system. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. Besides that, STATCOM can also be used in wind energy, voltage stabilization, and harmonic filtering. It also may be used for the dynamic compensation of power transmission system, providing voltage support and increased transient stability margins. However, the most common use of STATCOM is for voltage stability [27].

The general arrangement of STATCOM is shown in figure 2.14 .STATCOM system functioning as same as static VAR Compensator (SVC). Both of them provide shunt compensation by using a voltage source converter. The basic principle of operation of STATCOM is generation of a controllable AC voltage source behind a transformer leakage reactance by a voltage source converter connected to a DC capacitor. The voltage difference across the reactance produce active and reactive power exchanges between the STATCOM and power system [26].

A D-STATCOM consists of Voltage Source Converter (VSC), a DC energy storage device, a capacitor, and a coupling transformer to connect the D-STATCOM through it in shunt to the distribution network.

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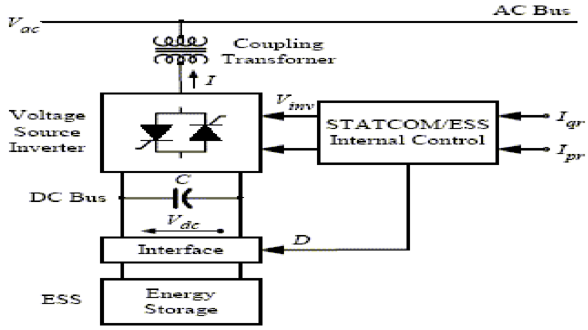

Fig: 2.14 General arrangement of statcom

A. Main Components of (D STATCOM)

D-STATCOM consists of three main components that is Voltage Source Converter (VSC), Energy Storage Circuit, and it Controller system. Each one of this component play an important role to ensure that D-STATCOM can operate wisely without have any problems.

Voltage Source Converter (VSC) is one of the power electronic devices.VSC is the most important component in D-STATCOM and it can generate a sinusoidal voltage waveform with any required magnitude, with any required phase angle and also with any required frequency. Usually VSC is mostly used in Adjustable Speed Drive but it also can be used to mitigate the voltage sags. VSC is used to replace the voltage or to inject the 'missing voltage'. The missing voltage can be defined as the difference between the actual voltage and the nominal voltage [29].

Normally, the converter is based on some kind of energy storage which will get the supply from the DC voltage. This converter is used the switching based on a sinusoidal PWM method. The PWM offers simplicity and good response. The device that used for the switching is an IGBT power electronic device.

Energy Storage Circuit: The purpose of energy storage is to maintain theDC side voltage of VSC. It can be capacitor or DC source, e.g. battery. Traditional STATCOM only has DC capacitor, thus; only reactive power can be injected to the power system by STATCOM, whereas both active and reactive power can be injected to the power system by STATCOM if DC source is used. In energy storage circuit, the DC source was connected in parallel with the DC capacitor. DC source is act as a battery that will supply a power meanwhile the DC capacitor is the main reactive energy storage element. It carries the input ripple current of the converter. To charged the DC capacitor, it could be used either a battery source or it could be recharged by the converter itself [30].

Filter and Control part: As the Pulse-Width Modulation (PWM)technique is used in VSC, the output voltage of VSC has switching ripple, which bring harmonics into the current injected to the power system. These harmonics will affect the voltage quality of the power system. Therefore, a relatively small reactor is installed between VSC and the point of the system which the D-STATCOM is connected, to filter those harmonics in the current. The filter can be L-filter, LC-filter and LCL-filter.

The aim of the controller system is to maintain the constant voltage magnitude at the point where a sensitive load is connected under system disturbances. The control system element can only measured the RMS voltage magnitude that measured at the load point. For the controller system there is no requirements of the reactive power measurements. The input for the controller system is an error signal. This error signal is obtained from the reference signal measured at the terminal voltage and RMS voltage magnitude that measured at the load point. First of all, this error signal will enter to the sequence analyzer blockWhich is functioning to measure the harmonic level in that signal. Then, the PI controller will process this error signal and come out with the output in term of the angle, ∂. This angle can drive the error to zero. Next, this angle will be summed with the phase angle of the supply voltage which is assumed to be 120° to produce the suitable synchronizing signal, required to operate the PWM generator [31]. Then, this angle will be submitted to the PWM signal generator. PWM generator will generate the sinusoidal PWM waveform or signal.

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B. Distribution Static Compensator Configuration

In its most basic form, the STATCOM configuration consist of a two level voltage source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt with ac system, and associated control circuit [28].Figure 2.15 depicts the schematic diagram of the STATCOM. The VSC will convert the DC voltage across the storage device into AC output voltages that are in phase and coupled with the AC system through the reactance of coupling transformer. Since the AC output voltage connected directly with the coupling transformer, the exchange of active and reactive powers can be easily made between the converters and the AC system. The active and reactive power can be exchanged directly by adjusting the phase angle between the converter output voltage and the bus voltage at the point of common coupling.

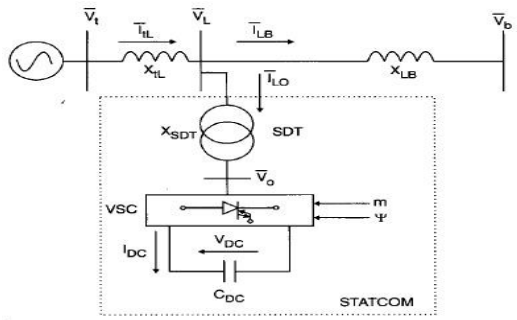

Fig: 2.15 The schematic diagram of a STATCOM

There are many types of FACTS device such as Static VAR Compensator (SVC), Dynamic Voltage Restorer (DVR) and STATCOM itself. To see the advantages of STATCOM, it can be compared with the Static VAR Compensator (SVC). There is a few main advantages of STATCOM over the conventional Static VAR Compensator (SVC) [32]. Firstly, STATCOM has significant size reduction due to reduced number of passive elements. Then, it is also can be able to supply required reactive power even at low voltages. Next, STATCOM is a creator reactive power current output capability at depressed voltages and it is also exhibits faster response and better control stability.

C. Basic Configuration and Function of D-STATCOM

DSTATCOM consist of three main part, namely injection transformer, voltage source inverter (VSI) and PWM generator with specific control scheme. The function of injection transformer is to inject the AC produced from VSI. On the other hand, the VSI is used to convert DC storage to AC while PWM generator is to generate the appropriate gate signal for the switching device in VSI to perform voltage sag mitigation function.

The voltage source inverter (VSI) could convert DC voltage into AC sinusoidal voltage before injection of current back to the power system is done via injection transformer. The total replacement of voltage or insertion of voltage to fill the dipped voltage could be done by implementation of this voltage source converter or specifically named as inverter. A DC energy storage is used to supply the converter with DC voltage, while the electronic switching devices invert DC into the output voltage required.

The most important part of DSTATCOM is its controller. By applying appropriate controller, various power quality disturbances could be solved specifically, includes voltage sag. The main purpose of the control scheme is to keep voltage magnitude fixed at the point where the power system is undergoing voltage sag problem. In modern controller, not only controller for voltage sag compensation, but also some other low-power application use PWM technique instead of Fundamental Frequency Switching (FFS) methods because PWM is more flexible, simple, and good response. Also, PWM techniques could be applied with high switching frequencies so that its efficiency could be maximized and also the switching losses could be drastically reduced.

The controller of the D-STATCOM is designed to conduct the reactive power exchange between the inverter and the system line by modifying the phase angle between the inverter voltage and line voltage. The reactive power output of the D-STATCOM could either be inductive or reactive, depending on the operation mode of D-STATCOM.

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There are three operation modes. When the inverter voltage is same as the system voltage, no reactive power exchange is conducted. When the inverter voltage is larger than the system voltage, the D-STATCOM is having the inductive reactance, the current will be injected from the inverter to the system through the Injection transformer. Consequently, capacitive reactive power is generated by the D-STATCOM. When the inverter voltage is smaller than the system voltage, the D-STATCOM is responding as capacitive reactance, the current will passes through the injection transformer from the system to the inverter. Consequently, the inductive reactive power is absorbed by the D-STATCOM.

D.Operation Modes of A D-STATCOM

1) No load mode

If V_i is equal to V_s, the reactive power is zero and the D-STATCOM does not generate or absorb reactive power.

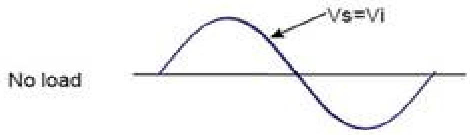

Fig: 2.18 No load mode(V_s-V_i)

2) Capacitive mode

When V_i is greater than V_s, the D-STATCOM shows an inductive reactance connected at its terminal. The current I, flows through the transformer reactance from the DSTATCOM to the ac system, and the device generates capacitive reactive power.

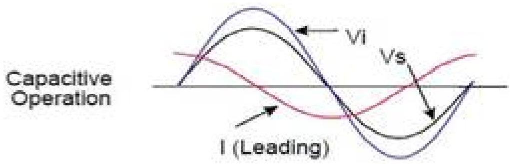

Fig: 2.19 Capacitve mode (V_i>V_s)

3) Inductive mode

If V_s is greater than V_i, the D-STATCOM shows the system as a capacitive reactance. Then the current flows from the ac system to the D-STATCOM, resulting in the device absorbing inductive reactive power.

IV. CONTROL ALGORITHM

The control algorithm extracts the fundamental component of the loads using the admittance control technique. Further, active and reactive power components of the load currents are determined. The proportional integral (PI) control loop produces reactive

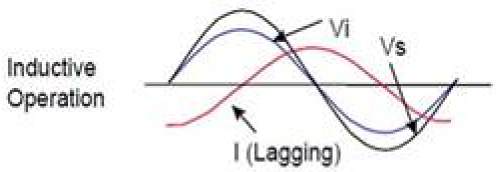

Fig: 2.19 Inductive mode (V_s>V_i)

power (*Q*cv) for voltage control in order to compensate for any changes in reactive power in support to fluctuations in PCC voltages. The reference susceptance (*B*qt) for reactive component of source current is computed by deducting the three phase load reactive power (*Q*dc) from the PI controller output (*Q*cv). The reference conductance (*G*pt) is estimated using the reference load active power (*Pr*). The load active power component is limited to operate the DG set at 80–100% of its full-load capacity with VSC-BESS allowing load leveling. Fig. 3 shows the block diagram of the control technique.

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The evaluation of the control algorithm demonstrates its robustness and relatively faster response. As it is the simple estimation of the active and reactive power components, the quality of computation is increased. Further, while working with the mathematical calculations, there is no delay for obtaining the results and the occurrence of error within the system is also reduced. Therefore, the system performance improves with this control algorithm.

A. Determination of Unit Templates

The amplitude of PCC voltage V_t and phase voltages are employed for the computation of in-phase unit template

$$V_t = \sqrt{\{2 \times (v_a^2 + v_b^2 + v_c^2)/3\}} \quad (3)$$

$$u_a = \frac{v_a}{V_t}, \quad u_b = \frac{v_b}{V_t}, \quad u_c = \frac{v_c}{V_t}. \quad (4)$$

The quadrature unit templates are estimated as

$$w_a = (-u_a + u_c)/\sqrt{3} \quad (5)$$

$$w_b = (3u_a + u_b - u_c)/2\sqrt{3} \quad (6)$$

$$w_c = (-3u_a + u_b - u_c)/2\sqrt{3}. \quad (7)$$

B. Admittance Control Technique

The instantaneous load active power (p) and load reactive power (q) components are computed as follows. The calculated instantaneous components of load power consist of ac and dc components. The dc components are extracted using LPF

$$p = \{v_t(u_a i_{\mathrm{La}} + u_b i_{\mathrm{Lb}} + u_c i_{\mathrm{Lc}})\} = P_{\mathrm{dc}} + P_{\mathrm{ac}} \quad (8)$$

$$q = -\{v_t(w_a i_{\mathrm{La}} + w_b i_{\mathrm{Lb}} + w_c i_{\mathrm{Lc}})\} = Q_{\mathrm{dc}} + Q_{\mathrm{ac}}. \quad (9)$$

The voltage error for the k^{th} instant at PCC is given as

$$V_e(k) = V_{t\mathrm{ref}}(k) - V_t(k) \quad (10)$$

whereV_{tref} (k) is the terminal ac reference voltage amplitude and V_t (k) is the amplitude of three-phase sensed ac voltages at PCC as given in (10).

The PI controller output for maintaining the PCC voltage at the k^{th} sampling instant is given as

$$Q_{\mathrm{cv}}(k) = Q_{\mathrm{cv}}(k-1) + k_{\mathrm{pv}}[V_e(k) - V_e(k-1)] + k_{\mathrm{iv}} V_e(k) \quad (11)$$

wherek_{pv} and k_{iv} denote the proportional and integral gains of the PI controller.

The reference reactive power component (Q_r) is computed from the difference of the PI controller output (Q_{cv}) and the load reactive power component (Q_{dc}) as

$$Q_r = Q_{cv} - Q_{dc}. \quad (12)$$

The active power drawn from the DG set (P_r) is limited to $0.8P_R \leq P_{dc} \leq 1.0P_R$. The reference source active power The reference conductance (G_{pt}) and susceptance (B_{qt}) of the load corresponding to the reference active (P_r) and reactive power (Q_r) components are derived as

$$G_{\mathrm{pt}} = P_r/\{V_t^2(3/2)\} \quad (13)$$

$$B_{\mathrm{qt}} = Q_r/\{V_t^2(3/2)\} \quad (14)$$

$$i_{\mathrm{Sap}} = G_{\mathrm{pt}} V_t u_a, \quad i_{\mathrm{Sbp}} = G_{\mathrm{pt}} V_t u_b, \quad i_{\mathrm{Scp}} = G_{\mathrm{pt}} V_t u_c \quad (15)$$

$$i_{\mathrm{Saq}} = B_{\mathrm{pt}} V_t w_a, \quad i_{\mathrm{Sbq}} = B_{\mathrm{pt}} V_t w_b, \quad i_{\mathrm{Scq}} = B_{\mathrm{pt}} V_t w_c. \quad (16)$$

The total reference source currents (i∗Sa ,i∗S b , i∗S c) are obtained as sum of in-phase and quadrature components of reference source currents of individual phases as

$$i_{\mathrm{Sa}}^* = i_{\mathrm{sap}} + i_{\mathrm{saq}}, \quad i_{\mathrm{Sb}}^* = i_{\mathrm{sbp}} + i_{\mathrm{sbq}}, \quad i_{\mathrm{Sc}}^* = i_{\mathrm{scp}} + i_{\mathrm{scq}}. \quad (17)$$

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C. Neutral Current Compensation

This fourth leg of VSC provides direct control over the source neutral current. The reference neutral current ($i^{*}Sn$) is compared with the sensed source neutral current (i_{Sn}), as shown in Fig. 3. These are used in hysteresis current controller to produce switching signals for four leg of VSC.

V. SIMULATION RESULTS

The response of a standalone system is analyzed undernonlinear load using sim-power system toolbox in MATLAB/ SIMULINK. The performance of the system is observed during line outage in one of the three phases at time t = 1.5 s to 1.56 s, as shown in Fig. 4. It is observed that for a subjected load unbalance in the system, the four-leg VSC has the capability of harmonics elimination as the source currents and the source voltages are maintained constant and neutral current compensation is provided while maintaining a zero source neutral current. The neutral current compensation provided by the four-leg VSC is clearly illustrated with the variations in the load neutral current and VSC neutral current waveforms. The system maintains itsPCC voltage at the desired level. Moreover, it should be noted that even during unbalanced loading, the supply currents are balanced and sinusoidal there by leading to balanced loading on the DG, which in turn results in reduced maintenance and improved efficiency of DG.

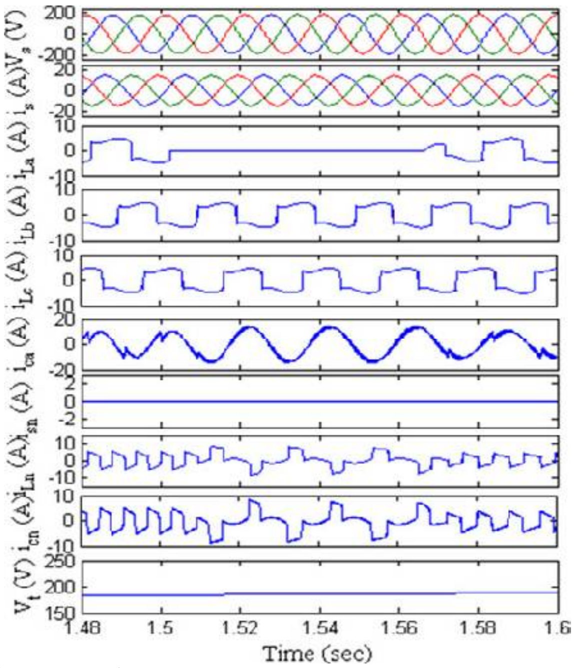

Fig. 4. Performance of the proposed system under unbalance nonlinear load.

VI. CONCLUSION

The admittance-based control technique has been used for a PV-diesel-battery hybrid system with a D-STATCOM for an uninterrupted power supply (UPS) and power quality improvement. The incremental-based MPPT algorithm has carried maximum solar array power under unpredictable conditions of temperature and insolation radiation. The method has been demonstrated to eliminate harmonics, load balancing, and to provide neutral current compensation by incorporating four-leg VSC in the system. The PCC voltage and frequency have been maintained constant. Satisfactory performance of the system has been observed through MATLAB/Simulation results acquired for steady-state and dynamic conditions under both linear/nonlinear loads.

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