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ADMITTANCE BASED CONTROL OF A STANDALONE SOLAR PHOTO-VOLTAIC HYBRID SYSTEM

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ABSTRACT

This paper presents a Standalone Solar Photovoltaic (PV)-diesel-battery hybrid system with new control algorithm. The proposed system deals with the inconsistent energy generation of solar array and also provide quality power. For obtaining maximum power under varying operating conditions maximum power point tracking (MPPT) algorithm is used. The PV array is integrated with a DC-DC boost converter. Diesel generator set along with battery energy storage system (BESS) coordinated for load management and power flow. The admittance based control algorithm is used for Reactive Power Control, Harmonic Mitigation and Load Balancing for balanced and unbalanced loads. A Voltage source converter with BESS provides neutral current compensation. Simpower systems toolbox of MATLAB/SIMULINK is used for analyzing the proposed system under linear and non linear loads.

Index Terms: admittance based control algorithm, bess, dg set, and four-leg vsc, neutral current compensation, power quality, solar photovoltaic array, and standalone system.

I. INTRODUCTION

Most of the remote areas are moving towards renewable energy to meet the need especially due to the lack of roads and infrastructure. Since renewable energy is causing enormous global warming the concern for renewable energy is emerging day by day. It is an alternative for future supply. Among the available resources, energy generation using solar power is gaining wide importance and is used for variety of applications. Like hospitals, electrical vehicles, households, remote missions, air craft's etc [1]. Since solar power is free from pollution it is mostly preferred for small scale applications [2]. But the major drawback is the fluctuation of output power of PV module, this makes compulsory of integrating other power resources like diesel engine (DG) set, battery storage, fuel cells etc. The proposed system consists of PV array and Battery Energy Storage (BES) along with a diesel engine driven Permanent Magnet Synchronous Generator (PMSG). Places like hospitals where uninterrupted power for 24x7 is required especially in rural areas, the proposed micro grid can be employed. DG

set is made to run at 80-100% efficiency to reduce maintenance cost and used to ensure regulated power supply [3]. DG set is run with 80% load because at light load conditions the efficiency of DG set reduces maintenance. Cost increases since DG set is subjected to carbon build up. To keep
loading 80% DG set or battery charging is turn ON/OFF based on loading [4-6], but is not recommended [7-8].

1. Mechanical maintenance increases if repeated turn OFF / ON of DG is done due to frequent load variation.
2. Frequent turn ON / OFF increases discharge currents during transients which reduces battery life.

Separate excitation control is not required for PMSG driven by diesel engine. The machine is less maintenance robot construction with brushless [9]. Since the power output of PV array is varying a BESS is provided for load leveling. For standalone system as compared with compressed air, super capacitors, fly wheels, pumped hydro and superconducting magnetic storage, BESS is Ideal Energy Storage [10-12]. The implementation of a standalone system consisting of PV array, DG set and BESS is used to fulfill the following requirements;

1. Depending upon the solar irradiance, load fluctuations and unbalances, the point of common coupling can be controlled.
2. Standalone system does not measure the load for turn ON/OFF of DG.
3. THD of point of common coupling voltage reduces this improves the power quality.
4. Proposed standalone system effectively controls the power flow between source and load.
5. BESS provided with VSC compensation reactive power.
6. If 4-leg VSC is employed it allows neutral current compensation.

Day to day the usage of non linear loads like computers, electronic appliances, medical equipment, refrigerators etc has been increasing which tends to focus on quality of power. This is due to injection of harmonics in current and voltage waveforms due to Custom Power Devices (CPD's). Three phase wire system also suffer with power quality due to presence of non linear load which also produce 3n harmonics in neutral current. 3n harmonics cause overloading of the system and responsible for overheating of connected equipment. A 4 leg VSC provides current compensation along with harmonic mitigation [14]. Advantage of such system can be more with implementation of various control methodologies. Multi loop strategy [15], Sliding Mode Control [16], P-Controller method [17], Fuzzy Logic Control [18], PLL Control [19] are few. But an author has failed to discuss reactive power compensation and response of controllers during unbalanced condition. Admittance based control algorithm [ ] is proposed in this paper and is used to evaluate reference power component of source currents in PV–DG hybrid system. Using Active and Reactive powers of load is used to estimate the admittance which in turn estimate Conductance ( ) and Susceptance ( ) for 3phase 4- wire loads. Simple mathematical calculations of sinusoidal current control give and . Lagrange's method of multiplier and simple PQ theory concept is used which eliminates computation through clark's transformation and Q of load are estimated by using input load currents (, ,) and voltages (,, ,) using the formulae mentioned in the paper. To obtain constant dc components oscillating components are removed by passing through a low pass filter , used for obtaining and which in turn gives Active and Reactive power components. This method is used to extract fundamental components and compensate P and Q independently even though it has harmonics at point of common

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coupling. This method draws balanced source currents from the source. The controller responds quickly during dynamic and steady state. The control implementation is done with 4-leg VSC. The performance is verified through simulation using MATLAB / SIMULINK.

II. SYSTEM DESIGN AND CONFIGURATION

Fig 1 shows a standalone system consists of PV array along with a boost converter, MPPT controller, diesel engine driven (PMSG) a 4-leg VSC with BESS and a 3 phase 4 wire AC loads. The reactive power control of VSC maintains the voltage constant at point of common coupling. During low load condition BESS gets charged during day time and discharges to compensate any defects. DG set operates with constant frequency under varying generation and loads. The capacitor provides a constant rated terminal voltage on No load. A 4 leg VSC is interfaced and ripples are eliminated using inductor capacitor filters. Taking isolation and ambient temperature as input PV array is modeled with series parallel modules [21].

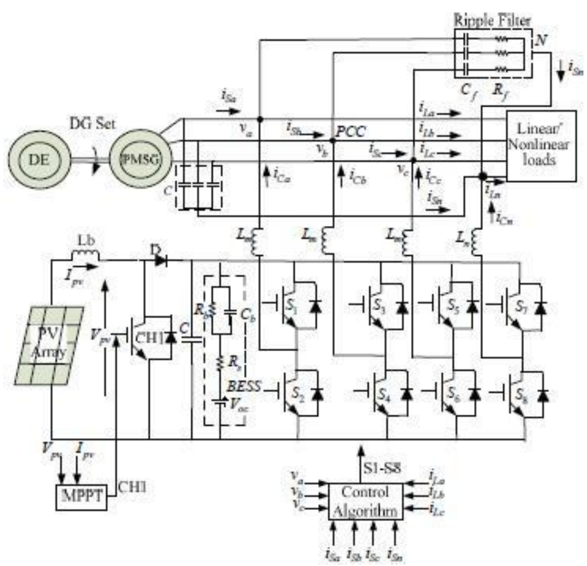


Fig 1.Schematic diagram of the proposed system

2.1 Solar Photovoltaic Array

The current of PV array depends linearly on solar irradiance and also on temperature as shown in [fig

- 10 modules in series produce 205v, 30A short circuit current is produced by 100 modules connected in parallel. For obtaining man power at any given temperature and isolation, PV array is provided with MPPT controller.

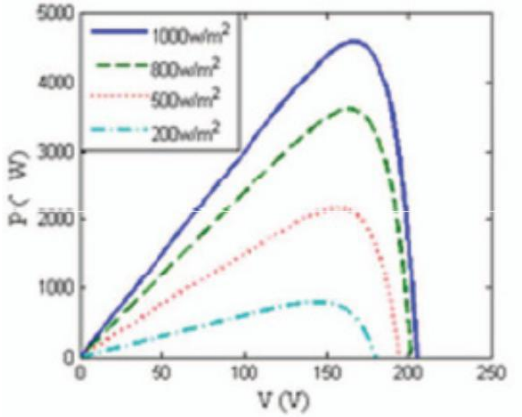


Fig 2.PV Characteristics

The incremental conductance algorithm tracks the voltage and current at maximum power [22]. The flowchart of MPPT is shown in Fig 3. The incremental conductance method performs well under noise and dynamic conditions. Maximum power point is obtained depending upon the slope of the curve. Slope is zero at maximum power point. The DC-DC boost controller output is regulated by MPPT controller until the condition is satisfied.

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

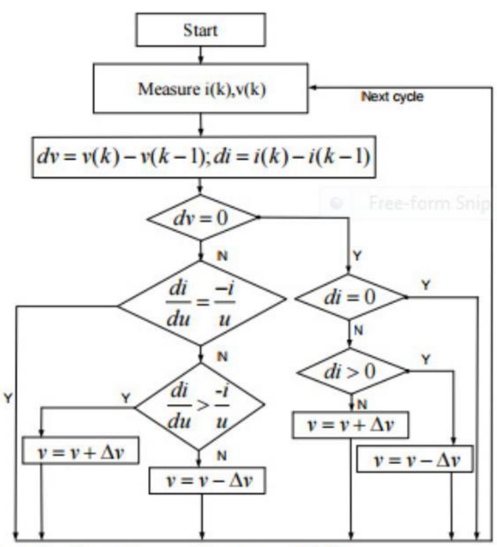


Fig. 3. Flowchart of incremental conductance MPPT

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

2.1 B. Boost Converter

Boost converter is designed based on current ripple, voltage ripple and power rating. The boost converter is interfaced with MPPT to boost the voltage to 400v to feed the battery.The inductor of boost converter is given by

= input voltage D = duty cycle

T = time period

ΔI is the inductor ripple current.

The value of ΔI is taken as 10% of the input current.

2.3. Battery Energy Storage System

Battery is connected at VSC. It is an energy storage unit represented in kilowatt hour (Kwh). Capacitor is used to model the battery shown in fig 1.A 2.8Kwh capacity battery is used for storing energy. 36 sections of 12v, 7Ah are connected in series. And describes Charging / Discharging with =10KΩ and = 0.1 Ω for small applications.

2.4. Ripple Filter

To filter the switching ripples of a VSC at point of common coupling, a first order low pass filter is employed. Filter consists of a capacitor of value 10 KHz and in series with a resistor of 5 Ω

Fig 4.Admittance Based Control Algorithm

The Q axis components are estimated as

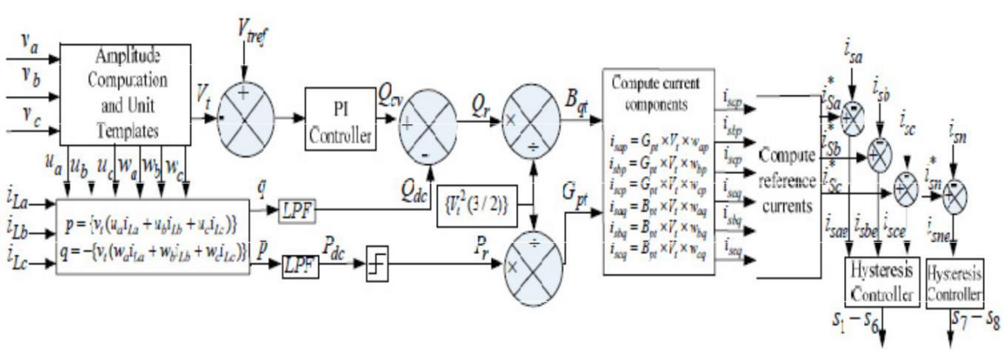
III. CONTROL ALGORITHM

The control algorithm extracts fundamental component of the load using admittance control technique. Further Active and Reactive power components of load power are determined. In order to compensate for any voltage changes at PCC along with Reactive power ( ) Proportional Integral Control Loop is used. The Susceptance ( ) is obtained by the reference reactive power ( ), computed using reactive power Output of PI controller ( ) and the reactive power component () generated using reference load currents. The reference conductance ( ) is generated using reference load active power (*Pr*). Pr is limited to operate DG set at 80 to 100% of its full load capacity and VSC– BESS allows load

3.1. Determination of Unit Templates

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

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



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

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

The phase voltages and the amplitude of voltage at PCC i.e. are used for computation of in phase unit voltages.

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3.2 . Admittance Control Technique

The computation of active power (P) and reactive power (Q) are done as followed. Calculated Active power (P) and Reactive power components (Q) have both AC and DC components. LPF is used to extract the DC components.

The error of voltage at instant at point of common coupling is given as,

$$V_e(k) = V_{tref}(k) - V_t(k) \qquad (10)$$

Where (K) is the terminal reference AC voltage amplitude and (k) is the sensed three phase voltage at PCC (10). At k^{th} sampling time, the PI controller output is used for maintaining the PCC voltage constant and given as,

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

In the above equation the proportional and integral gains of the PI controller are given as

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

! and ! . P controller output ( ) and load reactive power component () the difference of both gives the reference reactive power component) as shown (The active power drawn from the DG set ( ) is limited to 0.8, < <1.0 and ( ) is the rated power output of DG set and is the reference active power. Corresponding to reference active power ( ) and reactive power ( ) the reference conductance ( ) and the susceptance ( ) are derived as,) the reference conductance ( ) and the susceptance ( ) are derived as,

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

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

3.3 Evaluation of Source Reference Currents

The in phase and quadrature components are used to derive the fundamental source currents as shown below,

$$i_{Sap} = G_{pt}V_t u_a ; i_{Sbp} = G_{pt}V_t u_b ; i_{Scp} = G_{pt}V_t u_c \qquad (15)$$

$$i_{Saq} - B_{pt}V_t w_a ; i_{Sbq} - B_{pt}V_t w_b ; i_{Scq} - B_{pt}V_t w_c \qquad (16)$$

The sum of in phase and quadrature components gives the total reference source currents (*, *, *) as shown,

$$i_{Sa}^* = i_{sap} + i_{saq} ; i_{Sb}^* = i_{sbp} + i_{sbq} ; i_{sc}^* = i_{scp} + i_{scq} \qquad (17)$$

The source reference currents (*, *, *) are compared with sensed source currents (, ,) to estimate the errors. Hysteresis current controllers are used to generate the rating signals for IGBT of VSC with error as its input.

3.4. Neutral Current Compensation

The neutral current is controlled by the 4th leg of the Voltage Source Converter. The reference source current ( ) compared with the sensed source current (i_{sn}^{*}) as shown in (fig 4). These are used as input for hysteresis current controller to produce switching signals for 4-leg VSC.

IV. SIMULATION RESULTS

A stand-alone solar PV diesel battery hybrid system feeding 3 phase 4 wire loads have been presented and simulated using MATLAB / SIMULINK with admittance control algorithm where behavior of the system is studied. The 4 leg VSC is used for load leveling during load unbalance alongside by providing the compensation for reactive power and rejecting the harmonics. The system has been shown to maintain the normal condition under steady state and dynamic condition.

4.1. Performance of System under Linear Load

At time t= 1.45 to 1.46s system is subjected to an unbalance as shown in fig 5. The 4-leg VSC is providing the neutral current compensation. The neutral current of source is maintained at zero value. The variation of load neutral current is shown during unbalanced condition. As shown in the results the system re-establishes its nominal condition. As we can see at the point of common coupling voltage is maintain at constant during unbalanced load condition and also it provides reactive power compensation.

4.2. Performance of System under Non Linear Load

When one of the 3 phase is lost at time t=1.5s to 1.56s as shown in figure 6. The performance of system is observed. When it is subjected to unbalanced load in the system. During this 4-leg VSC has the capability of eliminating the harmonics as the source currents and voltages are maintained constant and neutral current compensation is provided by maintaining zero source neutral currents.

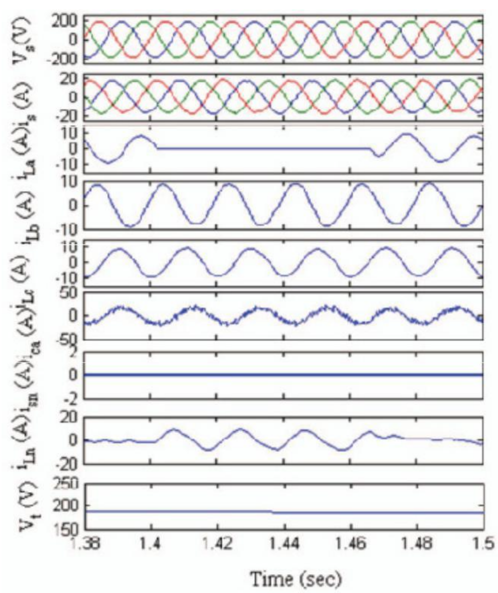

Fig 5. Performance of proposed system under unbalance linear load

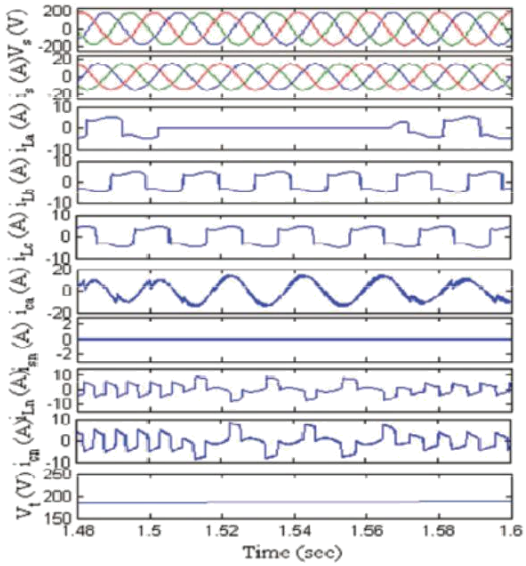

Fig 6. Performance of proposed system under unbalance nonlinear load

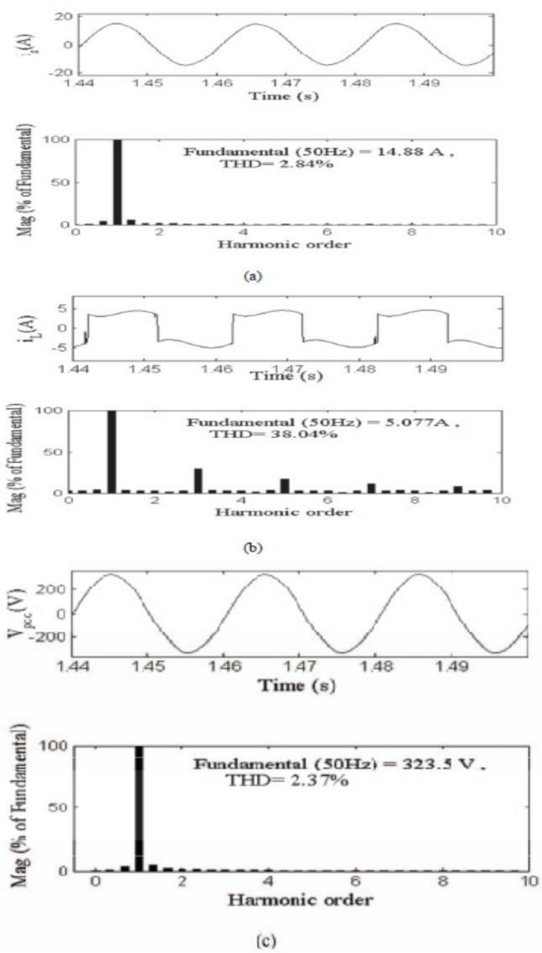

Fig 7. Harmonic spectra of (a) source current, (b) load current and (c) PCC voltage under nonlinear load.

VI.CONCLUSION

The admittance based control algorithm employed for PV-diesel battery hybrid system is used for Uninterrupted Power Supply and Power Quality Improvement. For varying conditions of temperature and isolation radiation, the incremental based MPPT algorithm has delivered maximum solar array power. The above mentioned technique is used for harmonic elimination, load balancing and to provide neutral current compensation by using a 4-leg VSC in the system. The PCC voltage and frequency has been maintained constant. From the above test results, it is concluded that the system is performing satisfactorily under steady state and dynamic conditions under both linear / non linear loads.

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