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A Control Algorithm for a Standalone Solar Photovoltaic (Pv) -Diesel -Battery Hybrid System

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Abstract—*This paper presents a Standalone Solar Photovoltaic (PV)-diesel-battery hybrid system with new control algorithm. For obtaining maximum power under varying operating conditions maximum power point tracking (MPPT) algorithm is used. The battery vitality stockpiling system (BESS) is incorporated with diesel motor generator set for the organized load administration and power stream inside the system The proposed system deals with the intermittent nature of the energy generated by the PV array and it also provides power quality improvement. The PV array is integrated through a dc– dc boost converter and is controlled using a maximum power point tracking algorithm to obtain the maximum power under varying operating conditions. A four-leg voltage-source converter with BESS also provides neutral current compensation. The performance of the proposed standalone hybrid system is designed by using the simulation results.*

Index Terms—Admittance-based control algorithm, battery energy storage system (BESS), diesel generator (DG) set, four-leg voltage-source converter (VSC), neutral current compensation, power quality, solar photovoltaic (PV) array, 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. Among the available renewable energy resources, solar photovoltaic (PV) power generation is gaining wide acceptance, and it is used for various applications such as household appliances, remote missions, data communications, telecommunication systems, hospitals, electric aircraft, and solar cars [1]. The utilization of the PV power generation is for the reason that it has many advantages such as it gives clean power, is portable in nature. However, considering the large fluctuations in the output of PV power, it is imperative to integrate other power sources like a diesel generator (DG) set, battery storage, fuel cells, etc. The performance analysis of standalone systems with PV- and DG-based sources is given in [3]. The proposed system consists of PV array and Battery Energy Storage (BES) along with a diesel engine driven Permanent Magnet Synchronous Generator (PMSG).

The proposed system uses a conductance-based simple control approach. Moreover, a detailed experimental study is used to demonstrate all the features of the system. The proposed system consists of a diesel-engine-driven permanent magnet synchronous generator (PMSG), PVarray, and BES. This microgrid is a representative of a typical rural hospital power the PMSG driven by a diesel engine ensures regulated power supply. In order to maintain the efficiency and to reduce the maintenance cost,

The DG set is made to operate at 80–100% of its full capacity.

1) The load may vary frequently. Therefore, the repeated turn ON/OFF of DG increases the mechanical maintenance.

2) The battery life reduces as the discharging current is high during 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 incorporated to provideload leveling in the case of variations in PV array output power.

The implementation of a standalone system devised of PV array, DG set, and BESS intends to fulfill the following requirements

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

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

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

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

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

PROPOSED SYSTEM

An admittance-based control algorithm [25] is applied for the evaluation of reference power component of source currents in the PV-DG hybrid system. The admittance of the load is estimated using the active and reactive powers of the load. The conductance (GL) and susceptance (BL) are extracted from the estimated active power and reactive power of the three-phase four-wire loads, respectively. It is a simple mathematical formulation based on sinusoidal Fryze current control. This control strategy is based on the

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Volume 05 Issue 12
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Lagrange's multiplier method and the fundamental principle of the PQ theory Fig. 1. Schematic diagram of the proposed system. where the computation through the Clarke's transformation is eliminated. Therefore, it provides an improvement in the mathematical calculations. Here, the inputs are the load currents (iLa, iLb, iLc) and load voltages (va, vb, vc), which are further used for the estimation of the active (p) and reactive (q) power components using the formula mentioned in this paper.

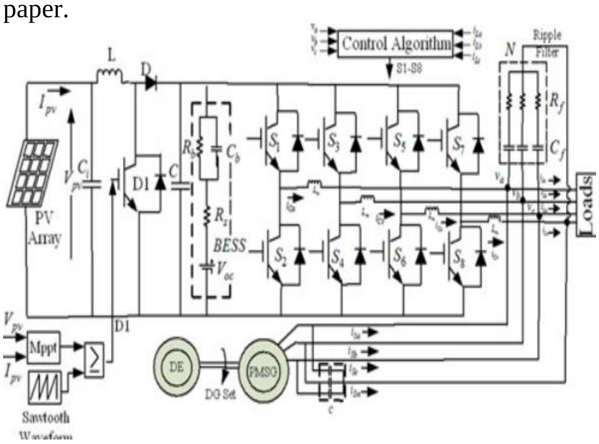

Fig.5.1. Schematic diagram of the proposed system.

The oscillating component of power is eliminated as it is passed through the low-pass filter (LPF) to obtain Pdc and Qdc. These are used for the estimation of the reference conductance and susceptance, thus giving the value for the reference active and reactive power components. The controller responds faster under the steady-state and dynamic conditions.

Construction:

The voltage at the PCC is restored by coordinating the reactive power through VSC control. Under varying conditions of generation and loads, BESS offers charging during the daytime when the insolation is large 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 used to eliminate the switching harmonics.

II. SYSTEM DESIGN AND CONFIGURATION

The standalone system consists 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 restored by coordinating the reactive power through VSC control. Under varying conditions of generation and loads, BESS offers charging during the daytime when the insolation is large 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.

A. Solar PV Array

The PV array is essentially modelled with the series and parallel modules where insolation and ambient temperature acts as

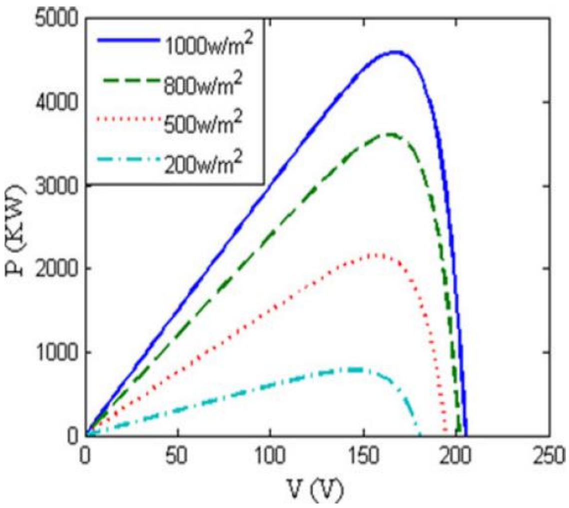

Fig. 2. PV characteristics. input [26].

The light-generated current of the PV array depends linearly on the solar irradiation and is also 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 aMPPT 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 . This IC method performs good with noise rejection and less confusion due to system dynamics. The IC method has been used here, which presents the MPP depending upon the slope of the power curve. The slope of the curve is zero at MPP. The MPPT controller regulates the control signal of the dc–dc boost converter until the following condition is satisfied:

$$\frac{\partial I}{\partial V} = -\left(\frac{I}{V}\right) \qquad (1)$$

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

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Volume 05 Issue 12
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power to the battery. The inductor of the boost converter is given as

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

where Vin is 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 flow within the system.

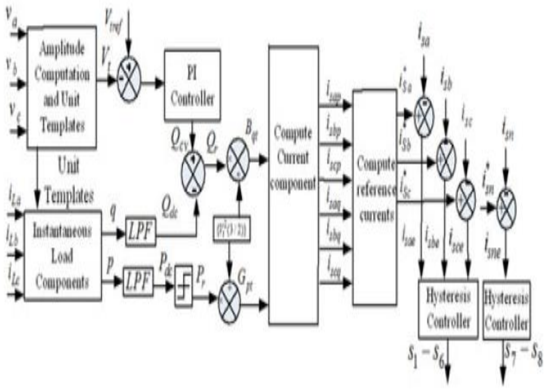


Fig. 3. Admittance-based control algorithm.

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 kilowatthour, 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 Rb and Cb describes the charging/discharging stored energy and voltage. The value of resistance Rb = 10 kΩ is large, while Rs = 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. These selected parameters of the system are given in the Appendix.

III. 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 power (Qcv) for voltage control in order to compensate for any changes in reactive power in support to fluctuations in PCC voltages. The reference susceptance (Bqt) for reactive component of source current is computed by deducting the three phase load reactive power (Qdc) from the PI controller output (Qcv). The reference conductance (Gpt) 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. 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 Vt and phase voltages are employed for the computation of in-phase unit template

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

$$u_a = \frac{v_a}{V_t},$$

$$u_b = \frac{v_b}{V_t}$$

$$u_c = \frac{v_c}{V_t} \quad (3)$$

The quadrature unit templates are estimated as

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

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

$$w_c = (-3u_a + U_B - u_c)/2\sqrt{3} \quad (4)$$

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

$$P = \{V_t(u_a i_{La} + u_b i_{Lb} + u_c i_{Lc})\} = P_{dc} + P_{ac}$$

$$Q = \{-V_t(w_a i_{La} + w_b i_{Lb} + w_c i_{Lc})\} = Q_{dc} + Q_{ac} \quad (5)$$

The voltage error for the kth instant at PCC is given as

$$V_e(k) = V_{tref}(k) - V_t(k) \quad (6)$$

where Vtref (k) is the terminal ac reference voltage amplitude and Vt (k) is the amplitude of three-phase sensed ac voltages at PCC

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 (iSn), as shown in Fig. 3. These are used in hysteresis current controller to produce switching signals for four leg of VSC.

IV. SIMULATION RESULTS

The response of a standalone system is analyzed under nonlinear load using sim-power system. 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. 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.

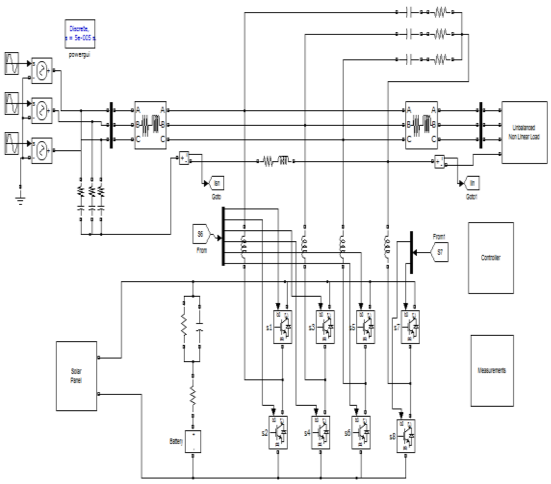


Fig.4.Unbalanced nonlinear load

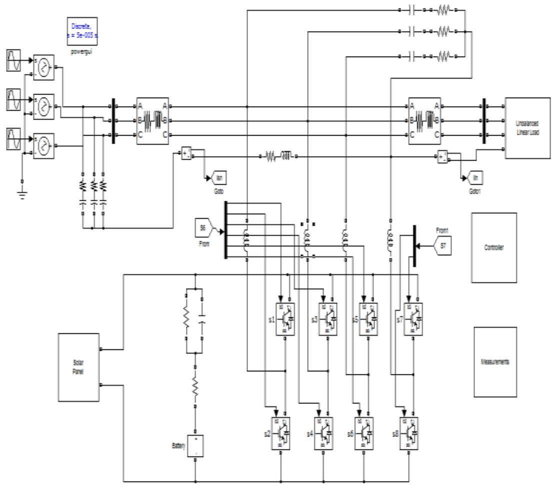
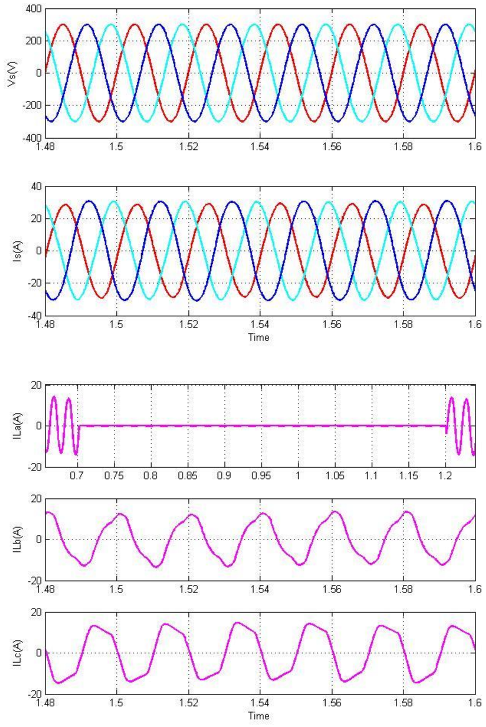


Fig.4.Unbalance linear load



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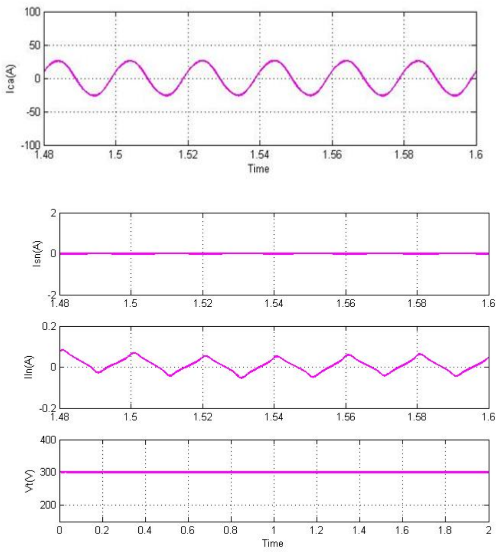
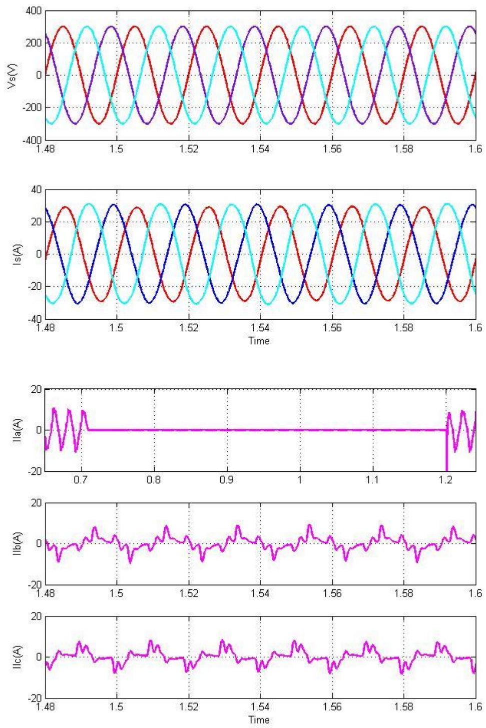


Fig. 5. Performance of the system under unbalance linear load.

The system maintains its PCC 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.



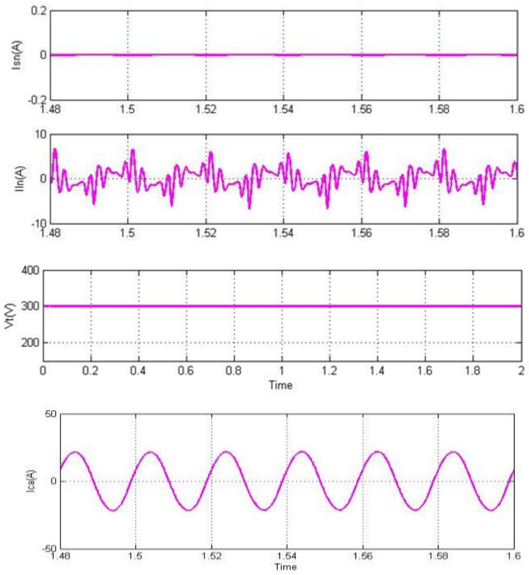


Fig. 6. Performance of the system under unbalance nonlinear load.

CONCLUSION

This paper exhibits a control calculation for isolated sun based photo voltaic (PV) diesel battery hybrid system. The admittance-based control technique has been used for a PV-diesel-battery hybrid system for an uninterrupted power supply and power quality improvement. The incremental-based MPPT algorithm has delivered maximum solar array power under varying conditions of temperature and insolation radiation. The technique has been demonstrated to eliminate harmonics, load balancing, and to provide neutral current compensation by incorporating four-leg VSC in the system. The PCC voltageand frequency have been maintained constant. By using the simulation results we can analyse steady-state and dynamic conditions results under both linear/nonlinear loads.

FUTURE SCOPE

The solar insolation is kept at 1000W/m2 for all these operating conditions.The fixed DC link voltage is kept at 740 V. It can be observed that during under voltage (350 V) the power fed into the grid by a system with adaptive DC link voltage is approximately 6 kW whereas the system using fixed DC link voltage feeds approximately 5.5 kW. Moreover, even under nominal voltage condition (415 V) the system with adaptive DC link voltage feeds more power into the grid. The power fed at 480 V is almost equal as the DC link voltage for both the systems are almost equal.

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