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Power Quality Improvement of PV-Wind-Battery Powered Standalone Hybrid System

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Abstract: Hybrid standalone power supply system's especially operating with renewable energy sources are becoming popular and establishing in many places worldwide. Two major renewable energy sources for electricity generation are solar and wind. Usually Photovoltaic modules (PVMs) are using for producing electricity from solar energy and in the similar way, PMSG based wind power conversion systems are becoming popular for medium power ranges. Therefore, a standalone hybrid system consisting of PVMs, wind, and battery can ensure a reliable power supply to various loads. The combination of these energy sources, along with the battery storage system, offers a flexible and dependable power supply to consumers at all times. This innovative approach involves the implementation of a novel control technique in a microgrid setup to uphold power quality at the PCC. The system integrates devices for maximizing power point to improve energy utilization efficiency. A DC to DC bidirectional circuit connects the battery bank unit (BBU) to the system to efficiently regulate energy. The bidirectional DC to DC circuit controls the dc-link voltage by accurately managing the discharging and charging of the battery. The three-phase inverter is situated between the AC loads and dc-link, designed with a control system that ensures a constant RMS voltage at the PCC, regardless of changes in load and energy sources. MATLAB platform is used to present the results under various case studies in this paper.

Keywords: Power Quality, PV, Wind, Batteries, Standalone Systems.

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1. INTRODUCTION

Electricity is a must in everyone's life in order to satisfy their everyday works. However, many parts of the world continue to lack access to electricity. The best option for distributing power in such remote regions is a standalone microgrid constructed locally [1]. Simultaneously, the globe is being contaminated by hazardous substances emitted from fossil fuels, which are additionally employed in the generation of electrical power. The most cost-effective solution too many of these difficulties is to produce electric power from a hybrid renewable energy systems. Reliable power supply is feasible by combining numerous renewable energy units along with a storage device such as BBU. PVMs and PMSG coupled wind power generation are two important energy conversion strategies for supplying electric energy to remote customers. Furthermore, the power balanced between consumption and production can be maintained by battery bank in any standalone system with the help of a competent energy management system [2-4].

Properly rated BBU can be often employed for energy storage unit in standalone renewable energy operated power supply modules. The battery bank is made up of a number of batteries arranged in series and parallel depending on the requirement of voltage & power rating. Batteries in a standalone system may generally respond quickly to any significant changes. The battery bank must be charged when the generation exceeds the load; otherwise, it must be discharged. Consequently, in order to control the charging and discharging operations of the battery bank due to power imbalances between the load and overall generation, it is necessary to implement a DC-DC bidirectional circuit with an appropriate management system. Individual MPPT: maximum power point tracking circuits can be used with renewable energy sources to optimize their efficiency. Consequently, the wind energy system based on PMSG incorporates a boost converter. In order to develop an economical option, the bidirectional DC to DC circuit connected to the battery is specifically engineered to function as the MPPT circuit for the PV system. This is achieved by merging the MPPT algorithm of the PVMs with the control of the bidirectional DC to DC circuit. Furthermore, in this work, a novel control method for inverter is implemented to produce a constant voltage to operate various loads during unbalanced voltage, hence increasing power quality. Furthermore, the recommended inverter management may modify reactive power needed by the load, which can help to reduce DC-link voltage oscillation. Furthermore, the distribution loads are unbalanced as a result of 1-phase loads are operated at AC bus. Voltages at AC bus will be unbalanced due to flow of unbalanced currents via 1-phase loads at load bus. As a result, the recommended inverter control should keep the AC bus voltage balanced by adjusting the inverter's modulation indices. To sustain power quality in isolated systems, an effective energy management technique should be designed.

2. CONTROL AND CONFIGURATION OF A STANDALONE MICROGRID

Figure 1 displays a hybrid standalone Microgrid that incorporates PV, a wind turbine based on PMSG, a battery, a three-phase converter, and AC loads. A comparable freestanding hybrid microgrid has already been researched by many scholars [8-14]. The researchers presented a microgrid energy management approach [8]. The authors of [9] study controller comparisons. Although the technology is only operable in single phase, the authors of [10] created a greenhouse employing renewable energy units. The authors of [11] built a PV-based standalone system with hardware-in-the-loop. In [12], the researchers provided a detailed account of a DC microgrid designed to generate hydrogen using renewable energy sources. On the other hand, in [13], the authors developed a distinct energy management strategy specifically tailored for a microgrid. The authors [14] give a comparison of several energy management methods for standalone solar, wind, and hydrogen systems. However, references [8-14] are not discussed about the correction of reactive power as well as unbalanced voltages. The following aims are in mind when designing a microgrid based on renewable energy sources in this study.

a) Create an efficient control coordination system for wind, PV, batteries, and loads.
b) In a three-phase system, maintain balanced three-phase voltage at the load bus while flow of unbalanced currents.
c) Create an effective and straight forward energy management system.

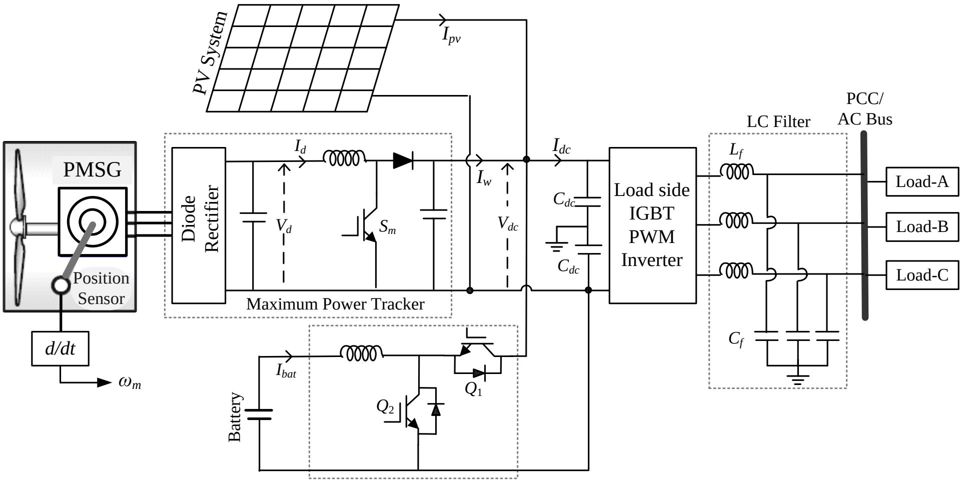

Fig. 1: Microgrid powered by hybrid renewable energy systems.

3. DC VOLTAGE CONTROL SCHEMES

To effectively control the discharging and charging process of the BBU, a DC to DC bidirectional circuit is integrated between the BBU and the dc-link using the suggested control scheme. The main aim to incorporate bidirectional converter is to regulate the voltage at DC-link. The proposed simple control scheme for a bidirectional DC to DC circuit is shown in Fig. 2. The P&O MPPT algorithm is employed to produce the necessary reference voltage command for the dc-link under varying irradiation conditions, enabling the converter to function as a MPPT of PVMs. As a consequence, no extra converter is required for the PVMs to capture the full amount of energy. Based on a lack of dc-link voltage, the PI controller may produce a reference current signal of the battery with its reference signal. This reference current is then compared to the actual BBU current to identify the discharging or charging action, as shown in Fig. 2. The control system of the DC to DC converter considers the State of Charge (SoC) of the BBU to ensure that overcharging and draining of the BBU are prevented. The control logic shown in Fig. 2 is employed to create the converter's needed duty cycle for switching pulses for Q1 and Q2. Adjusting the voltage at the dc-link can accomplish power balance [15-17].

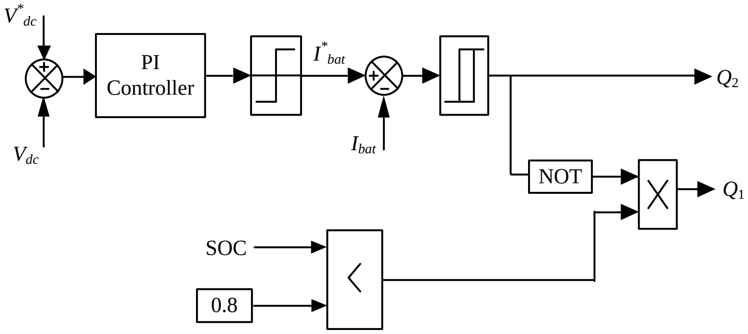

Fig. 2: Control method of the voltage.

4. AC VOLTAGE CONTROL SCHEMES

Due to the fact that most operational loads in residential areas are 1-phases, the majority of loads connected in the distribution system are also 1-phases [17-21]. Therefore, current flowing through each phase is different which creates unbalanced voltages at AC bus due to unbalanced drops at LC-filter. To compensate for imbalanced voltages, adequate inverter management is required for creating counter modulation indexes. Simultaneously, reactive power correction is necessary in order to run reactive power loads linked to an AC bus. The reference value of the RMS voltage on the AC bus is maintained constant in order to achieve this. In order to reduce second frequency oscillations from the DC connection, direct and quadrature axis oscillating component is also incorporated when producing pulses for the inverter. By removing oscillations from the DC connection, you can help to extend the fatigue life of the PMSG shaft. The recommended inverter control approach is depicted in Figure 3. The relevant energy management system is depicted in Figure 4.

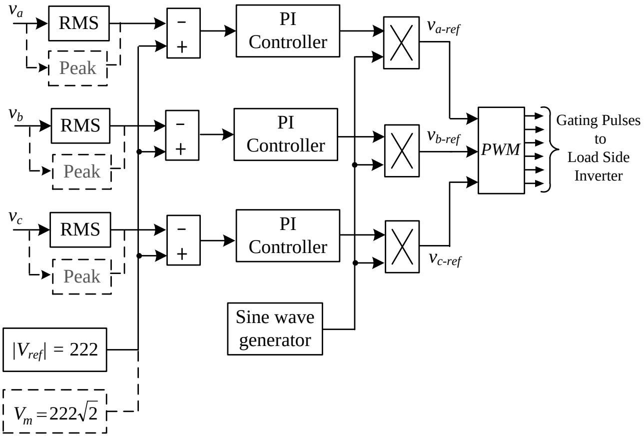

Fig. 3: The inverter's control mechanism is based on the RMS/Peak detection approach.

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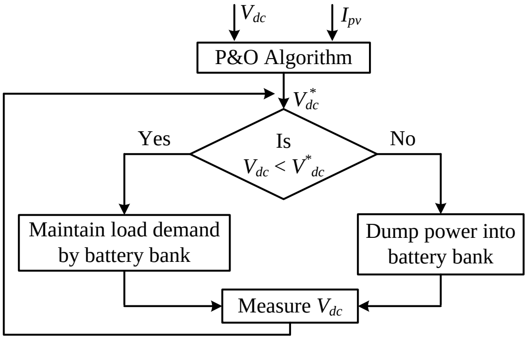


Fig. 4: Energy management algorithm.

5. Results

A single wind model and one PV array are evaluated for optimum visualization on the MATLAB/Simulink platform. The following instances of a hybrid standalone system illustrated in Fig. 1 are analyzed to evaluate controller performance.

Case-1: During the operation of unbalanced currents

The performance of the control methods is evaluated using unbalanced currents running through three phases at load buses, as shown in Fig. 5. The RMS current of each phase are listed below:

Phase-C(i_{lc}) = 8.471A.
Phase-B(i_{lb}) = 9.498A.
Phase-A(i_{la})= 3.518A.

As a result of the unbalanced load flow mentioned earlier, the voltages at the load bus became unbalanced due to variable drops at the filter in the aforementioned unbalanced condition. Nevertheless, the control mechanism implemented in the inverter depicted in Figure 3 has the capability to generate different modulation indexes suitable for each phase. Figure 6 depicts the balanced voltages (line to line) at load bus under this unbalanced load flow. However, for greater clarity, the RMS values of phase voltages, as well as the related modulation indices (MIs) are also shown in Fig. 7.

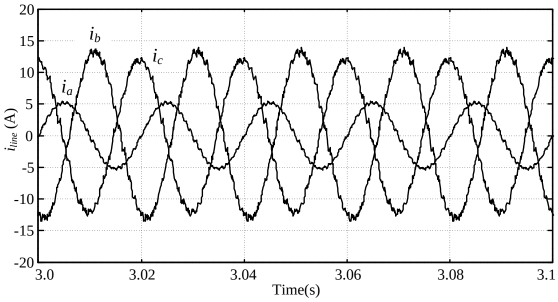


Fig. 5: Unbalanced 3-phase currents at PCC.

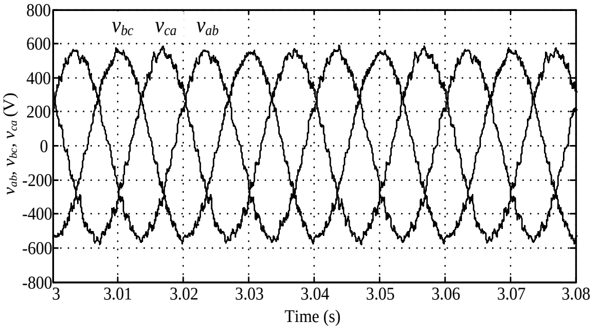


Fig. 6: Instantaneous balanced voltages.

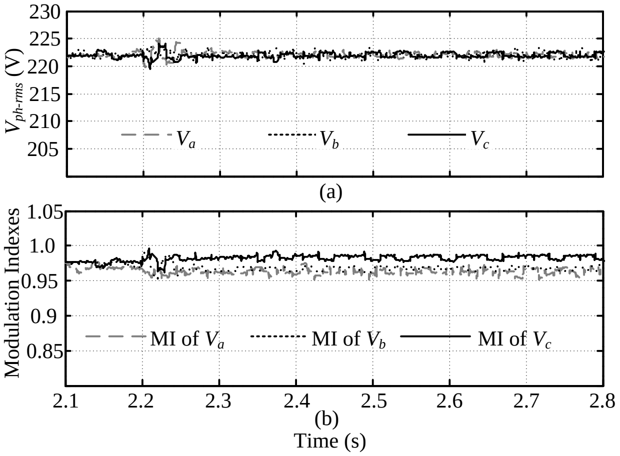


Fig. 7: (a) Voltage (b) MI of inverter legs.

Case-2: Considering meteorological changes

Meteorological changes shown in Fig. 8 are adopted in this case study to evaluate the performance of the proposed control schemes. The changes in speed, irradiance, temperature, and load are considered under various time periods. The precious responses of the line to line RMS voltages at PCC are shown in Fig. 9. This showcases the caliber of electricity supplied to the AC load throughout any alterations. Figures 10 and 11 displays the instantaneous line currents and voltages in addition to the AC voltages at PCC, as the latter may not offer a distinct image.

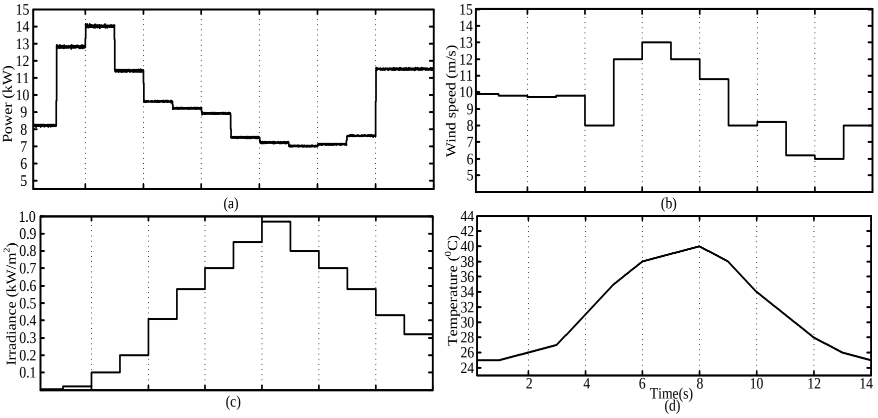


Fig. 8: Changes in (a) power, (b) velocity (c) irradiance, (d) temperature.

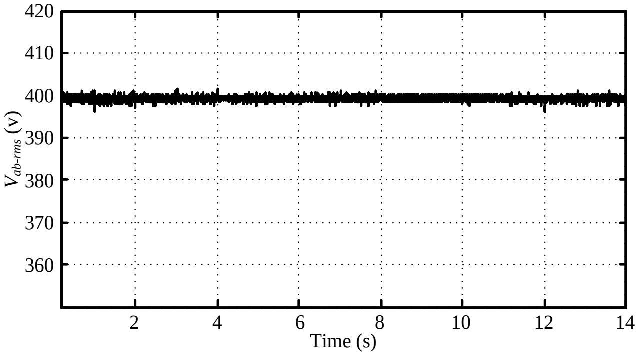


Fig. 9: Voltage (line).

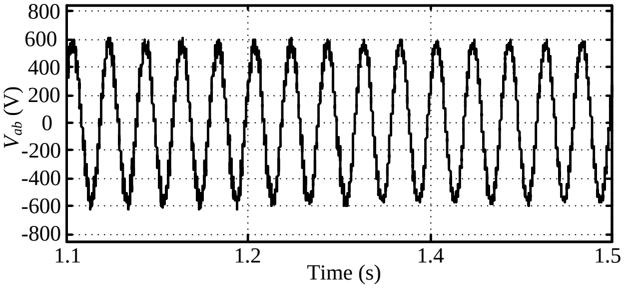


Fig. 10: PCC instantaneous phase-phase voltage.

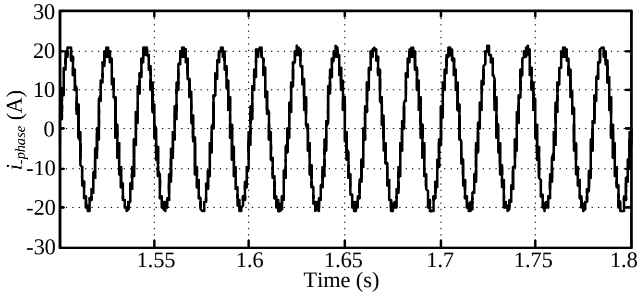


Fig. 11: phase current.

Case-3: *AC bus reactive power correction*

The inverter control method presented in this study has been evaluated for the reactive power needed at the PCC. It is observed that the reactive power demand from the load rises from 9.0 to 17.5kVAR at t= 0.80sec (refer to Fig. 12). This innovative approach aids in offsetting the reactive power required at the load bus.

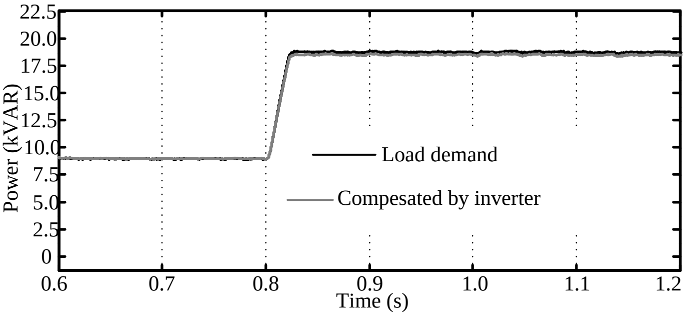
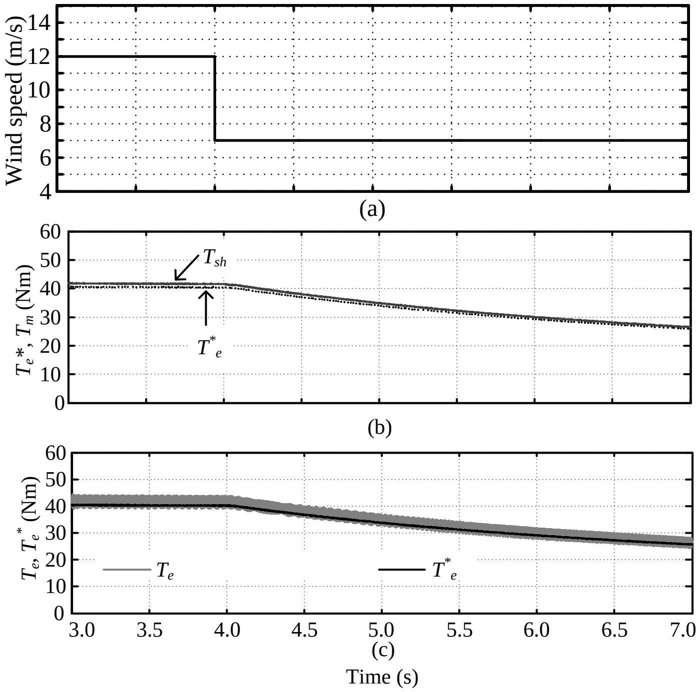


Fig. 12: Operation similar to DSTATCOM (Reactive powers).

Case-4: *Wind and PV MPPT*

The evaluation of the MPPT system for both power units in this case study is conducted by analyzing the changes in wind speed and solar irradiances, as illustrated in Figures 13 and 14. Figure 13(a) displays the fluctuations in wind speed ranging from 12m/s to 7m/s, while Figures 13(b) and (c) depict the corresponding torque of the turbine, enabling the identification of the MPPT process. Based on the examination of Figure 13, it is evident that the wind turbine is functioning at its peak power output.



(a)

(b)

(c)

Fig. 13 Wind turbine (a) speed; (b) shaft torque; (c) generator’s torque.

At t=5.0s, depicted in Fig. 14(a), there is a variation in irradiance from 850W/m2 to 1000. The response of the dc-link voltage in Fig. 14(b) illustrates the tracking of maximum power through PV panels. Figure 14(c) depicts the relevant power graph of two 4.730kW PV units.

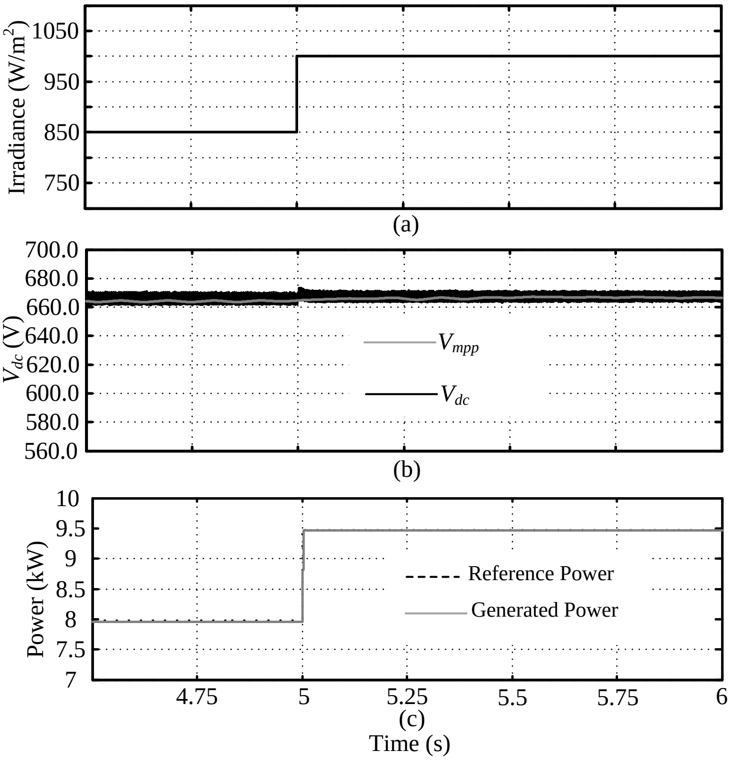


Fig. 14: (a) Change in irradiance, (b) Voltages, (c) Power.

6. CONCLUSION

In this study, a synchronized control strategy is utilized to introduce a streamlined energy management algorithm for microgrid that is supplied by renewable energy sources. The algorithm aims to ensure the provision of high-quality power in various case scenarios. To manage the voltages at both AC and DC busses, PI controllers are utilized in the proposed control techniques. Specifically, the inverter control is designed to maintain balanced voltages on the AC bus, even in the presence of unbalanced loads, and to compensate for reactive power demanded by the load. This study presents the reaction of a microgrid under various situations. Simulink is used to analyze and show the outcomes in various circumstances.

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