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Energy Management System for Sudden Load Varying with PV-Battery & Diesel Generator Hybrid System

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ABSTRACT

Renewable off-grid electricity supply is one alternative that has gained attention, especially with areas lacking a grid system. The aim of this paper is to present an optimal hybrid energy system to meet the electrical demand in a reliable and sustainable manner for an off-grid remote village, Gwakwani, in South Africa. Three off-grid systems have been proposed: (i) Photovoltaic (PV) systems with a diesel generator; (ii) Photovoltaic systems and battery storage; and (iii) Photovoltaic systems with diesel generator and battery storage. For this analysis, different size of photovoltaic panels were tested and the optimal size in each scenario was chosen.

KEYWORDS: *renewable energy; off-grid; hybrid; photovoltaic with battery; photovoltaic with diesel*

I. INTRODUCTION

Now a days the installation of the diesel engine-based electricity generation unit (DG set) is widely used to feed or supply the power to some crucial equipment in remote areas. Normally DG sets used for these purposes or areas are loaded with unbalanced, reactive and nonlinear loads. By using these loads some power quality problems like voltage sag, swell, flickers are occurred. At the point of common coupling the unbalanced and distorted three-phase voltage are occurred due to the unbalanced and distorted currents. Unbalanced currents and harmonics flowing through the generator results in torque ripples at the generator shaft. All of these factors lead to reducing the life of the dg sets, and the DG sets to be operated with derating, which results as an increased cost of the system.

This paper introduces a novel single-stage solar converter called reconfigurable solar converter with diesel generator. The basic concept of the RSC with Diesel Generator is to use a single power conversion system to perform different operation modes such as PV to grid (dc to ac), PV to battery (dc to dc), battery to grid (dc to ac), and battery/PV to grid (dc to ac) for solar PV systems with energy storage. The RSC concept arose from the fact that energy storage integration for utility-scale solar PV systems makes sense if there is an enough gap or a minimal overlap between the PV energy storage and release time. Fig. 1 shows different scenarios for the PVgenerated power time of use. In case (a), the PV energy is always delivered to the grid and there is basically no need of energy storage. However, for cases (b) and (c), the PV energy should be first stored in the battery and then the battery or both battery and PV supply the load. In cases (b) and (c), integration of the battery has the highest value and the RSC provides significant benefit over other integration options when there is the time gap between generation and consumption of power.

II. Distributed Generation System Technologies

A. Photovoltaic System plus Battery Storage

This scenario consists of PV system and battery storage without any conventional electricity sources such as a diesel generator. Different sizes of PV system are tested and the optimal solution selected to compare with other scenarios. The PV will satisfy different purposes at the same time to satisfy the demand and to charge the battery for Evening time or periods with shortage of PV power. In this scenario the total energy supply to village is supplied via PV system either directly from the PV to the load or indirectly from the battery to the load. Technical and economical details of all components including battery and PV inverter are presented in Table 2 below. This scenario has two advantages in comparison with the previous scenario, which are environmental friendliness and being totally self-dependent since there is no need to travel long distances to buy diesel fuel. The autonomous hybrid PV/battery power system considered is a combination of a PV array, battery bank, direct current DC/DC and alternating current AC/DC converter, DC/AC inverter, DC, and AC load as shown in Figure 1.

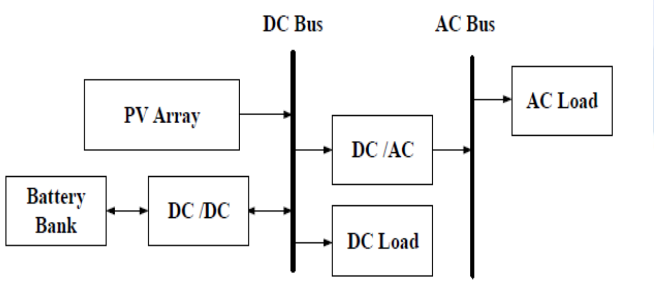

Figure 1. *Block diagram of autonomous hybrid PV/battery storage system.*

B. Photovoltaic System plus Diesel Generator

This scenario consists of a photovoltaic system plus diesel generator, with different PV system sizes tested. These sizes are 1 kW, 0.8 kW, 0.6 kW and 0.4 kW. Then the optimal PV size is compared with the optimal PV size of other scenarios. The PV system supplies the demand during the daytime and any other surplus power is wasted because of the absence of energy storage. Any deficiency in meeting the demand leads to the diesel generator being run, even during the daytime. In this case, the diesel generator has the potential to meet the total demand load due to full rate operation of diesel generator while all PV power production is curtailed or dissipates. Technical and economical details of diesel generator and PV are presented in Table 2 below. The autonomous hybrid PV/diesel power system considered is a combination of a PV array, diesel generator, direct current DC/DC and alternating current AC/DC converter, DC/AC inverter, DC, AC load as shown in Figure 2

C. Photovoltaic system, Diesel Generator plus Battery Storage

This scenario consists of photovoltaic system plus diesel generator and battery storage unit. The autonomous hybrid PV/diesel power system considered is a combination of a PV array, diesel generator, battery storage unit, direct current DC/DC and alternating current AC/DC converter, DC/AC inverter, DC, and AC load as shown in Figure 6. This scenario consists of a photovoltaic system plus diesel generator and battery storage which analyzes the different PV system sizes of 1 kW, 0.8 kW, 0.6 kW and 0.4 kW. The Load Following (LF) dispatch strategy is used as this enables the production of only enough power to meet the primary demand load of (6663 Wh/day) while the generator is in operation. The lower priority objectives such as storage bank and serving the deferrable load are left to the renewable power source. The deficiency in meeting the demand load activates the diesel generator which runs continuously until the storage unit is full (which usually requires an increase in storage unit size)

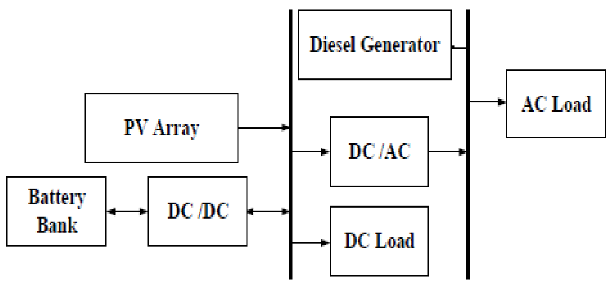

Figure 3. *Block diagram of autonomous hybrid PV/diesel generator system/battery storage.*

III. SYSTEM COMPONENTS

A. Mathematical Modeling of PV Array

A photovoltaic system converts solar energy into electricity. The PV technology uses photovoltaic cells which absorbs photons of light and release electron charges. Several PV cells are connected in series and parallel combination constitutes a PV panel or PV module to produce desired output power. The inverter is used to convert the DC power into AC. The energy extracted from the PV system is one of the reliable natural energy sources because of its eco friendly nature. To achieve the maximum efficiency, it is necessary to extract the maximum power from the PV panels.

The simple equivalent circuit of a PV cell consists of an ideal current source in parallel with an ideal diode is shown in Figure 1.

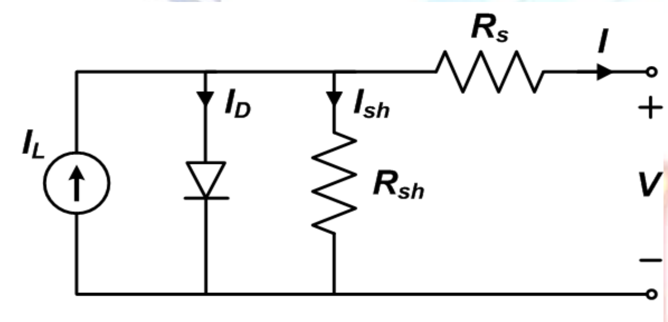

Figure 4 Equivalent model of the PV Cell

The series resistance R_s represents the internal resistance to the current flow. The shunt resistance R_{sh} is inversely related to leakage current to the ground. For an ideal PV cell, $R_s = 0$ (no series loss) and R_{sh} = infinite (no leakage to ground). The typical values of R_S = 0:05 to 0.10Ω and R_{sh} = 200 to 300 Ω. The energy conversion efficiency of PV cell is sensitive to small variations in R_s, but is insensitive to variations in R_{sh}. A small increase in R_s can decrease the PV output significantly.

The process of modeling of solar cell is developed based on the following equations [10], [11]. The output-terminal current I is equal to

$$I = I_L - I_D - I_{sh} \qquad (1)$$

where,

I_L, Light generated current

I_D, Diode Current

I_{sh}, Shunt Leakage current

$$I = I_L - I_{0cell}\left(e^{\frac{q*v}{\alpha*k*T}} - 1\right) \qquad (2)$$

where,

$I_{0,cell}$: Reverse saturation current of the diode[A].

q: Electron charge [1.60217646×10^{-19}c].

k : Boltzmann constant [1.3806503×10^{-23}J/k].

T : Temperature of the p-n junction.

α : Diode identity factor which lies between 1&2 for mono crystaline silicon.

B. Battery

In this study, the lead acid battery model is utilized, which provides good features combined with low cost. The lifetime and efficiency of the battery are set as five years and 85%, respectively.

C. Diesel Generator

Diesel generators are used to meet the peak demand, mainly when there is no output power from the PV system. It is important to note that the Gwakwani residents usually travel long distances of approximately 5 miles to buy fuel which leads to an increase in the fuel price above the normal rates.

IV. SIMULATION RESULTS

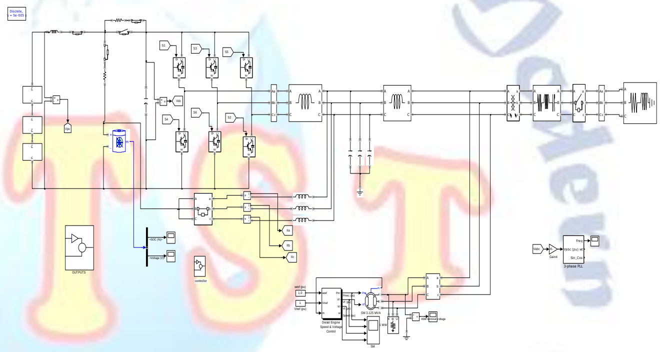

Fig 5: Simulation circuit of proposed circuit

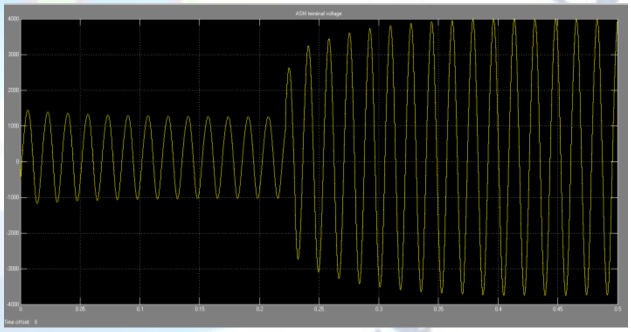

Figure6 : Diesel Generator voltage of proposed circuit

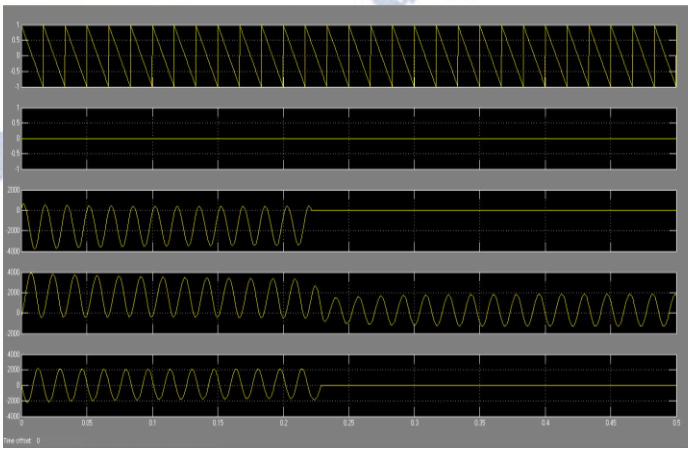

Figure 7 : Phase a,b, and c current waveforms

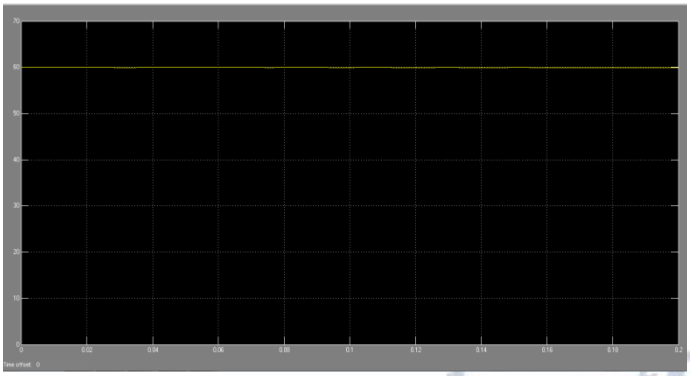

Figure 8: System frequency of Proposed circuit

V. CONCLUSION

Renewable energy-based off-grid rural electrification programs are one of the most effective ways to increase access to energy in remote areas of developing countries. In this paper, three scenarios of off-grid system have been investigated and compared to provide sustainable energy These scenarios are (1) PV-battery system, (2) PV-diesel generator and (3) PV—both diesel generator and battery system. Based on this research analysis both battery and diesel generator systems achieved the same objective function of backing up the PV system at periods of supply shortages. The four different PV sizes used in each model scenario indicated different optimal sizes and this was used as the rallying point for optimization. The optimal size selection satisfied the criteria conditions of: overall system cost, pollution emissions and demand satisfaction.

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