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# DC Voltage Regulation of Solar PV/Wind and Biofuel System Incorporating Battery Storage

Mwaka I. Juma[1,2], Bakari. M.M. Mwinywiwa[1], Consalva J. Msigwa[2] and Aviti T. Mushi[1]

[1]Department of Electrical Engineering, University of Dar es salaam, P.O. Box 3513, Dar es Salaam

[2]Department of Electrical Engineering, Dar es Salaam Institute of Technology, P.O. Box 2958, Dar es Salaam

## ABSTRACT

Tanzania has several places which lack the access to grid. These areas can be powered by utilizing hybrid energy systems (HES) such as solar photovoltaic, wind, and biodiesel. However, such a system produces voltage control challenges at the DC bus due to stochastic nature of those sources, if battery is not coupled. Therefore, this paper first proposes a HES that is coupled to a battery. Secondly, it proposes a control that can regulate the three sources of energy such that the DC bus is maintained at 750 V. Simulation results have shown that a conventional proportional and integral controller can achieve DC bus voltage regulation for the system proposed in this paper regardless of irradiance variation, wind speed variation, or the load variation. This type of energy sources is feasible for use in rural arrears of Tanzania.

***Keywords****: hybrid energy system, biodiesel, DC-DC boost converter, solar photovoltaic*

## 1. Introduction

Tanzania has several rural villages which lack electricity access, despite having huge potential of biomass (Aslam et al., 2021), solar photovoltaic (PV), wind, and other renewable sources. Due to natural intermittency of wind and solar PV, stand-alone systems made from them require energy storage devices or other generation such as diesel to stabilize and supply the loads during their absence. This increases the costs of energy to the end user. The cost of battery storage can be complemented at 20% of total installed capacity of solar PV and biodiesel. Tanzania has a huge potential of biomass that can supplement approximately 87.6% of energy requirements (Aslam et al., 2021). For biomass, the diesel generator can use the biodiesel thus requiring no major engine modification (Nedayali and Shirneshan, 2016). Hybrid Energy System (HES), comprising of various energy resources, can easily sustain the electrical network in remote and rural sites leading to the growth of interest in distributed generators (DGs) (Madaci et al., 2016)). However, this topology introduces problems of increased complexity of the system in comparison with single energy systems (Sharma et al., 2015). The technical challenges of DGs are power quality issues, and control under fluctuating environmental conditions, DC grid voltage regulation, i.e., under autonomous operation mode (Smita et al., 2016). This paper presents a research work focused on integration and control of HES in a microgrid in, an islanded mode to improve voltage regulation through common DC bus. It is more economical to control DC bus instead of AC bus due to the fact that only voltage variable is to be controlled (Juma et al., 2019). Previously DC bus voltage regulation has been done for example by Dileep and Annapurna (2016); Madaci et al. (2016); Sahu et al. (2018); Juma et al. (2019); and Masenge and Mwasilu (2020); still there occurs a dip/swell in the DC bus voltage when input/output changes. This paper proposes a control that addresses this.

## 2. Materials and Methods

Figure 1 displays a HES – solar PV; wind turbine and permanent magnet generator (PMSG) for biodiesel; and battery storage system all integrated into once DC bus and supplying a DC load. The solar PV generates 31.5 kW; and PMSG generates 6 kW. Detailed modeling of solar PV and PMSG are found in (Masenge and Mwasilu, 2020; Kewat et al., 2018; Daniel et al., 2018; Deng et al., 2017; Dileep and Annapurna, 2016). Moreover, the battery storage system is discussed in (Juma et al., 2019).

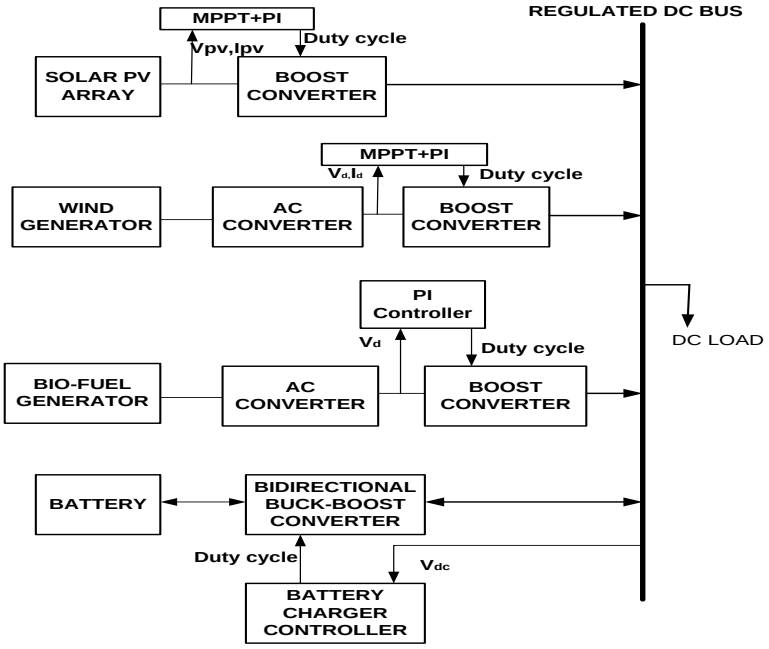



**Figure 1:** Standalone hybrid system

## 3. DC Bus Voltage Regulator

### *A. DC voltage regulation for solar PV/Wind power system*

Figure 1 DC-DC boost converter regulates the DC bus voltage through the maximum power point tracking (MPPT) algorithm and proportional integral (PI) controller (Juma et al., 2019). The input voltage of this converter is either the solar PV or the rectified voltage of the PMSG. The DC bus voltage is regulated at 750 V. The parameters of the PI are designed by Juma et al. (2019) and ELmorshedy et al. (2015).

### *B. DC voltage regulation for Biodiesel generator*

Figure 2 shows the biodiesel generator – PMSG which uses the PI controller to regulate the output voltage of the DC bus through the rectifier, and DC-DC converter, using Equations (1) – (3), where explanations are given next.

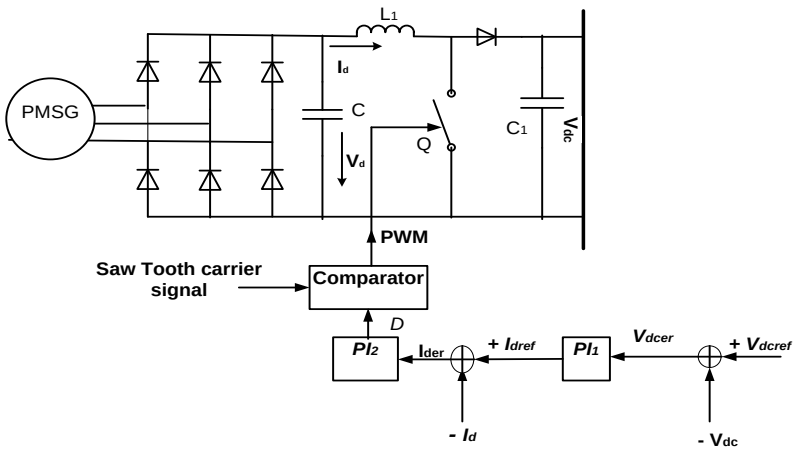



**Figure 2:** DC voltage regulator of biodiesel generator

The reference rectified current $I_{dref}(k)$ is given by (1). Where; $k_{p1}$ and $k_{i1}$ are the gain of the $PI_1$ controller tuned at 0.05 and 25. The duty cycle *D(k)* of the converter is computed by (2) through the $PI_2$ controller, where $k_{p2}$ and $k_{i2}$ are gains tuned at 0.5 and 45 respectively. The current error $I_{der}(k)$ is computed by (3).

$$I_{dref}(k) = I_{dref}(k-1) + k_{p1}[V_{dcref} - V_{dc}(k-1)] + k_{i1}V_{dcref}(k) \quad (1)$$

$$D(k) = D(k-1) + k_{p2}I_{dref}(k-1) + k_{i2}I_{der}(k) \quad (2)$$

$$I_{er}(k) = I_{dref}(k-1) - I_d(k) \quad (3)$$

## 4. Simulation Results and Discussions

**Case 1 Constant load:** Figure 3, the curve on top represents the irradiance variation for 6 s. From 0 s to 1 s the solar is constant at 100 W/m$^2$, then it decreases to 800 W/m$^2$ at 2 s. This irradiance remained constant for 1.5 s, then it increased to 1000 W/m$^2$ at 4.5 s, from then onwards it is constant. At the same time, the wind speed was varying, thus speed of the PMSG varied shown by Figure 3, the curve on bottom. The speed is 150 rad/s from 0 s to 2 s. then it increases to 153 rad/s at 3 s. then it stayed constant for 1.5 s, and started to decrease to reach 150 rad/s at the 6 s mark. With these variation in the irradiance, and the speed, the DC bus voltage is maintained at 750 V, depicted by Figure 4.

**Case 2 Step load increase:** Figure 5 shows two graphs. The graph on the top shows the DC bus voltage, both the reference and the output. The graph on the bottom shows the step increase of load current – from 0 s to 1 s, the load current is 22 A. At this instant, the current jumps to 30 A and remains constant for 1.5 s. Then the load increases to 47 A and stays constant for 1.5 s. From then it increases to 58 A and stays constant till the 6 s mark. While these load currents were changing, the DC bus voltage was regulated at 750 V.

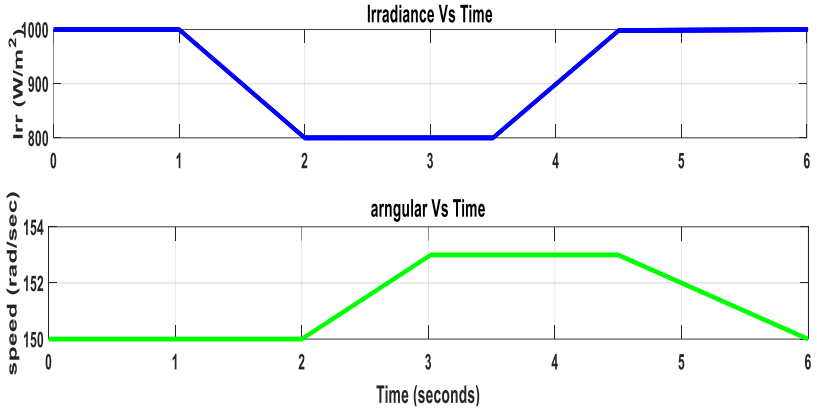



**Figure 3:** Varying solar irradiance and angular speed

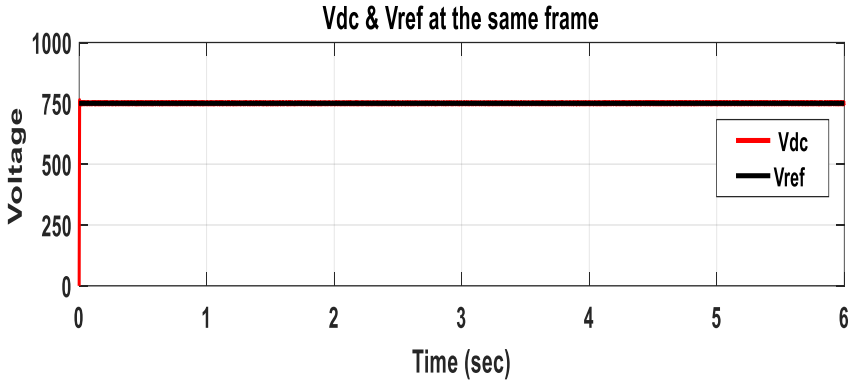



**Figure 4:** DC bus Voltage at constant load

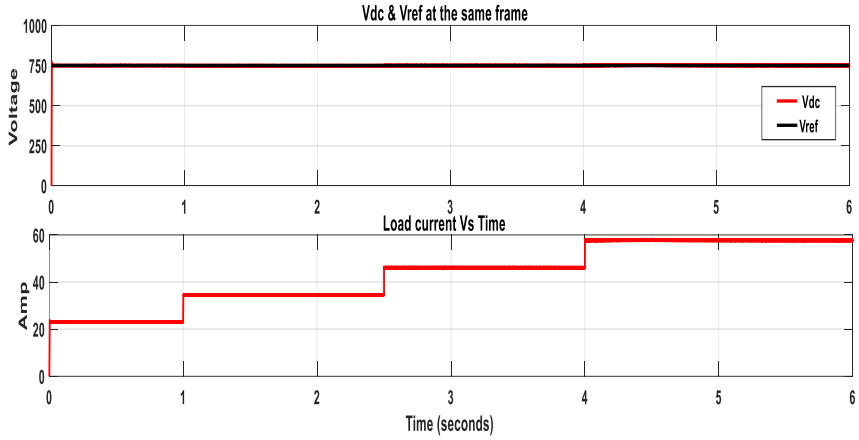



**Figure 5:** DC bus Voltage at constant when step load changes

## 5. Conclusions and Recommendation

This paper has presented HES that comprises of solar PV; wind and PMSG; and biodiesel DG. The simulation results indicated that the proposed control algorithm maintains the voltage of the DC bus at 750 V whether there is irradiance variation, wind speed (therefore PMSG speed) change, or the load change. This work can be expanded to include control of the inverters.

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