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Intelligent Management of the Pumping System for Irrigation of MBAWAANDE Lands in Podor within the NANN-K Project

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Abstract: This article addresses the constraints in exploiting the "MBAWAANDE" lands, particularly the challenges posed by their irrigation system. Currently, the system is powered by a diesel motor pump and a photovoltaic solar system located far apart, leading to inefficiencies and operational difficulties. To mitigate these issues, we propose replacing the motor pump with a generator mounted in parallel with the photovoltaic solar system. This new hybrid configuration, automated by an algorithm, aims to reduce the operational constraints related to distance and minimize diesel consumption, while ensuring continuous and reliable irrigation. The hybrid system integrates the strengths of both power sources, allowing for more flexible and sustainable water pumping. The diesel generator provides backup power during periods of low solar irradiance, ensuring that irrigation needs are met without interruption. Meanwhile, the photovoltaic system takes advantage of renewable energy, reducing dependency on fossil fuels and lowering operational costs. To validate the efficiency and effectiveness of this new configuration, we conducted a simulation using Matlab/Simulink. The results demonstrated that the hybrid system significantly enhances water pumping efficiency with minimal human intervention, ensuring a steady water supply for irrigation. These findings highlight the potential for hybrid systems to improve agricultural practices, especially in remote and resource-constrained areas.

Keywords: Pumping system, Simulink, Photovoltaic solar pumping, Generator, Hybrid configuration

Introduction

The NANN-K project is an ambitious agricultural initiative aimed at exploiting the "MBAWAANDE" lands to ensure food self-sufficiency. The project currently employs two distinct pumping systems: a diesel motor pump and a photovoltaic solar pumping system. However, the distance between these two systems and the operational constraints of using the diesel motor pump present challenges. Therefore, it is imperative to find a more efficient and sustainable pumping solution that eliminates these constraints and ensures continuous irrigation.

Research around the world has explored various pumping systems, assessing their suitability for different regional conditions. Okakwu et al. examined the economic viability of hybrid systems combining photovoltaic (PV), batteries, and diesel generators in Nigeria, highlighting their feasibility (Okakwu, 2023). Dadhich and Shrivastava demonstrated the economic advantages of solar systems over diesel pumps in India (Dadhich, G., & Shrivastava, 2017). Studies by Parajuli et al. in Nepal and Santra et al. in India confirmed the economic benefits of solar pumps for irrigation (Parajuli, 2014; Pande,2016). Alves et al. in Brazil emphasized the long-term profitability of solar pumps despite higher initial costs (Alves,2014), and Shouman et al. highlighted the economic superiority of PV systems in the long run (Shouman, 2016). Ibrahim advocated for the promotion of solar pumps in developing countries, citing their economic, social, and environmental benefits (Ibrahim, 2020).

The novelty of our proposed solution lies in the integration of a generator with a photovoltaic solar system, combined with an automatic switching algorithm to ensure seamless operation. This hybrid system optimizes energy use and minimizes dependency on any single energy source. Unlike previous studies that primarily focused on the economic comparisons of individual systems, our approach emphasizes a practical, real-world application within the context of the NANN-K project. This hybrid configuration addresses the unique challenges of distance and operational constraints encountered in the "MBAWAANDE" lands.

Presentation of the Pumping System Structure

The proposed pumping system combines a generator and an inverter powered by photovoltaic solar panels. When solar energy is available, it is prioritized to power the motor pump through the automatic inverter. When solar energy is insufficient, the generator takes over, ensuring a continuous water supply. This combination offers significant advantages in terms of reliability and energy availability. The schematic diagram below shows the proposed installation, highlighting the placement of the energy management device (automatic inverter) between the generator, the inverter, and the motor pump.

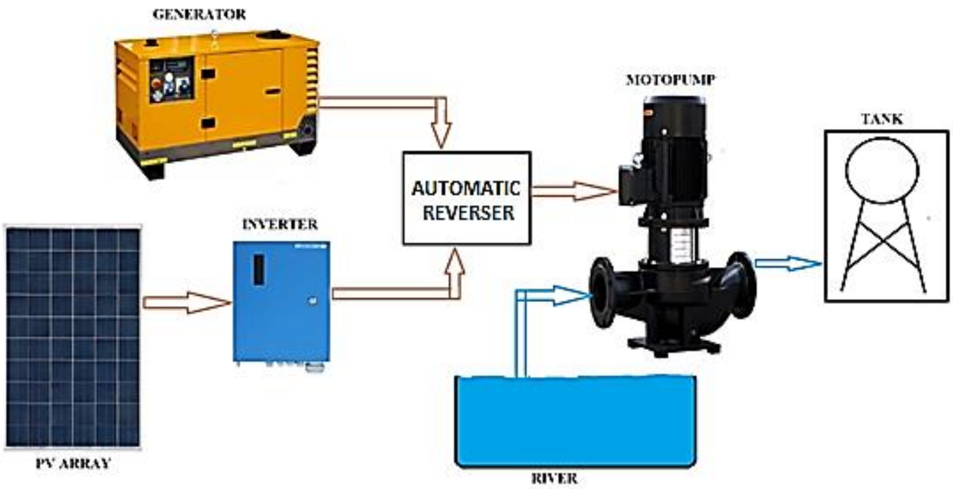

Figure 1. Hybrid pumping system with generator and photovoltaic solar power

This study is based on the exploitation of the "MBAWAANDE" lands in the Podor commune in Senegal. It is related to the NANN-K project and aims for better utilization of these lands by proposing this combination as the best alternative to what is currently on-site.

Modeling of the Essential Components of the System

Modeling of the Boost Converter

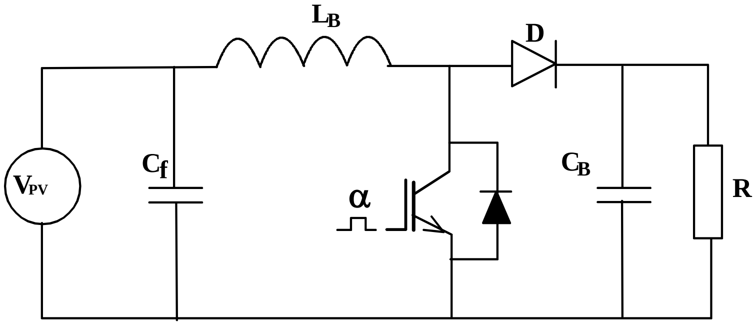

Figure 2. Boost converter structure

A boost converter is used to maintain the voltage within the input range of the inverter with MPPT P&O control. Figure 2 shows the structure of the boost converter, including an ideal IGBT transistor. Similarly, capacitor CB and inductance coil LB are assumed to be perfect.

The voltage transformation ratio of the boost converter is given by (3):

$$M_V = \frac{V_S}{V_{PV}} = \frac{1}{1-D} \quad (1)$$

Where: D is the duty cycle. The values of the inductance L_B and the capacitance C_B are determined in continuous conduction mode according to expressions (2) and (3) as follows:

$$L_B = \frac{(1-D)^2 DR}{2f} \quad (2)$$

$$C_B = \frac{DV_S}{V_r Rf} \quad (3)$$

Where: f is the switching frequency of the transistor, and Vr is the allowable ripple voltage, often estimated at 1% of V_S (Aliane & Zerioul, 2016).

After calculations, the following values are found : L_B = 1.781 mH, Ce = 1000 μF, C_B = 120 μF
In our system, to maintain the power output of the panels at their maximum value under different climatic conditions, a Perturbation and Observation (P&O) MPPT control is used. This control is one of the various techniques used to keep the panels' power at its maximum value. This is achieved by adjusting the duty cycle of the converter. Figure 3 shows the flowchart of the MPPT P&O algorithm.

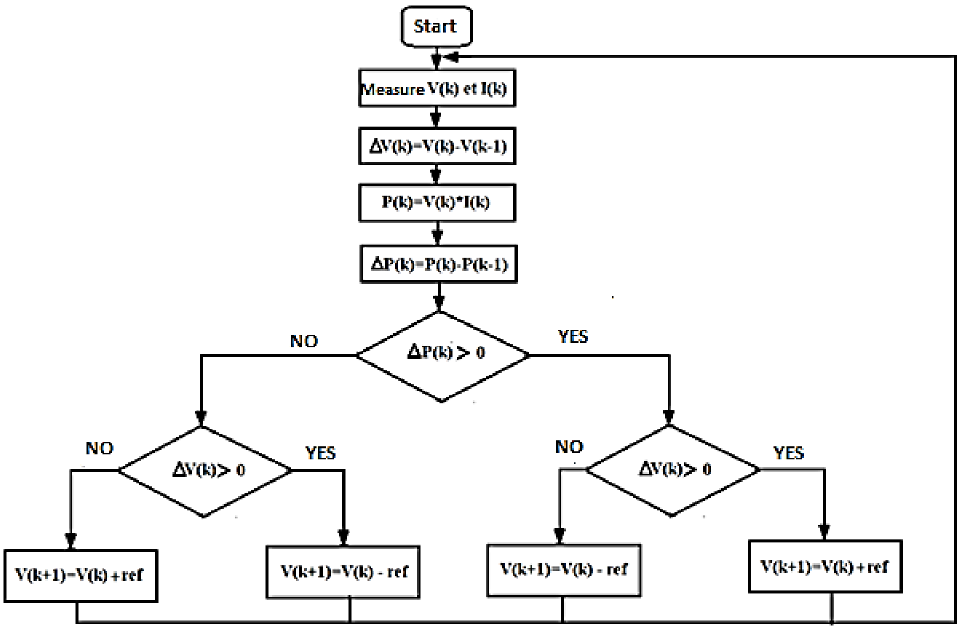

Figure 3. Flowchart of the MPPT P&O algorithm

Automatic Switching Algorithm

This method automates the system by controlling the switching between the photovoltaic solar pumping system and the generator set. This is achieved through an algorithm that allows opening or closing the two circuits. When the irradiation is less than 300 W/m² and the reservoir volume is below its maximum value, the solar circuit is opened and the generator circuit is closed. Conversely, when the irradiation is greater than 300 W/m² and the reservoir volume is below its maximum value, the solar circuit is closed and the generator circuit is opened. However, when the reservoir is full, both circuits are opened. Figure 4 shows the flowchart of the automatic switching algorithm.

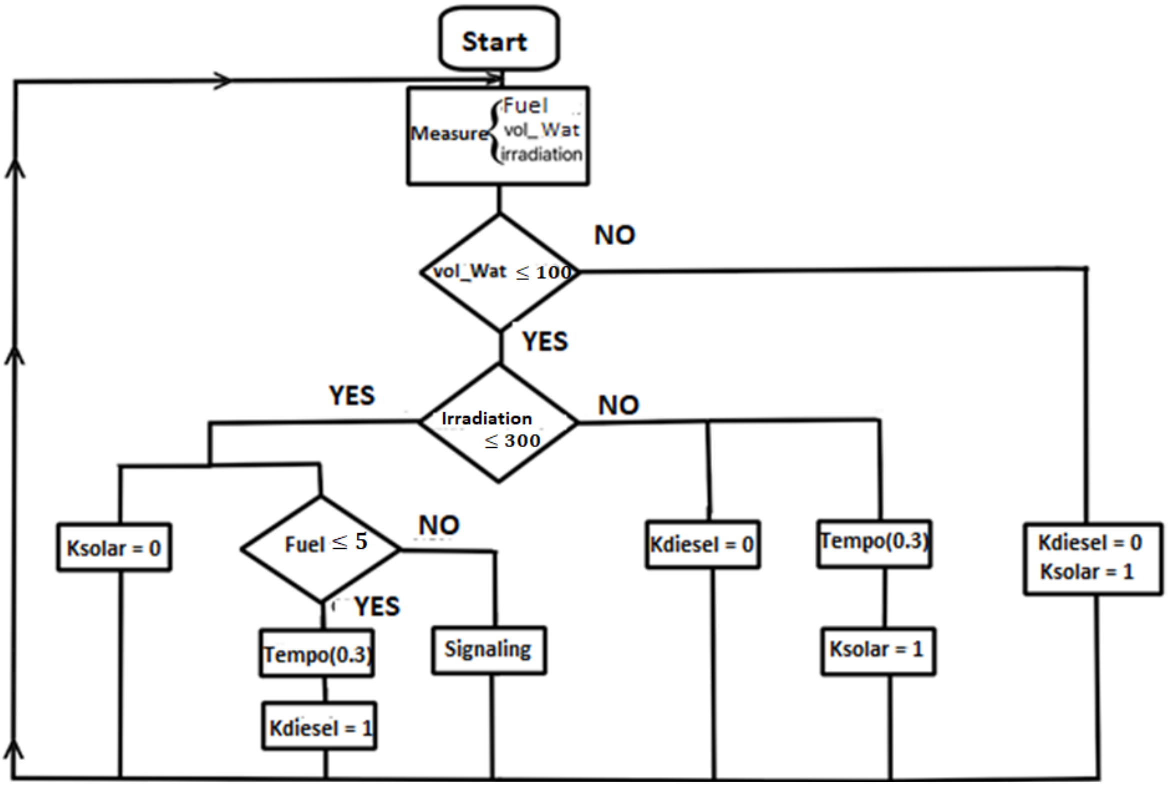

Figure 4. Flowchart of the switch

Results and Discussions

For the simulation in Matlab/Simulink, we used the technical specifications of the equipment installed at the project site. See the tables below. In the context of this simulation in the Simulink environment, the Trinasolar TSM-365DEG14 is used. It's a typical 365W PV module. The module has 72 series of polycrystalline cells connected. The key characteristics are shown in the following table:

Table 1. Characteristics of the solar panel used

Temperature	**T à 25°C**	
Open circuit voltage	V_{OC}	47.1 V
Short circuit current	I_{SC}	9.61 A
Voltage at maximum power	V_{mp}	39.5 V
Current at maximum power	I_{mp}	9.25 A
Maximum power	P_m	365.375 W

An inverter is used to power the asynchronous motor and ensure water pumping across the Senegal River. The input of the inverter corresponds to the voltage provided by the boost converter. In this study, the characteristics of the inverter used are summarized in the following table:

Table 2. The characteristics of the inverter

Input DC	
Umax	850 V DC
Imax	70 A
Output AC	
U	3x380/400/415 V AC 0 à 60 Hz
Pmax	37 kW
Imax	3x65 A

The asynchronous motor converts electrical energy from either the generator or the three-phase inverter into mechanical energy to drive the pump. In this study, the characteristics of the three-phase asynchronous motor used are summarized in the following table.

Table 3. Characteristics of the asynchronous motor of the pump

Designations	Data
Rated power	30 kW
Input voltage	380 V AC
Maximum current	57.6 A
Rotation speed	1470 tr/min
Power factor	0.88
Frequency	50 Hz

The alternator equipped in the generator provides the required power to drive the asynchronous motor of the pump to ensure water pumping. The characteristics of the three-phase alternator used are summarized in the following table.

Table 4. Characteristics of the generator's alternator

Designations	Data
U (Voltage)	400 V
Frequency	50 Hz
Number of phases	3
Delivered current	57.7 A
Active power	32 kW
Apparent power	40 kVA

To validate the hybrid pumping model with automatic switching, a simulation was performed on Matlab/Simulink under temperature conditions of 25°C. The irradiation was initially kept below 300 W/m² to illustrate the operation of the generator set, and then increased above 300 W/m² to simulate solar pumping. Figure 5 shows the structure of the system in Simulink.

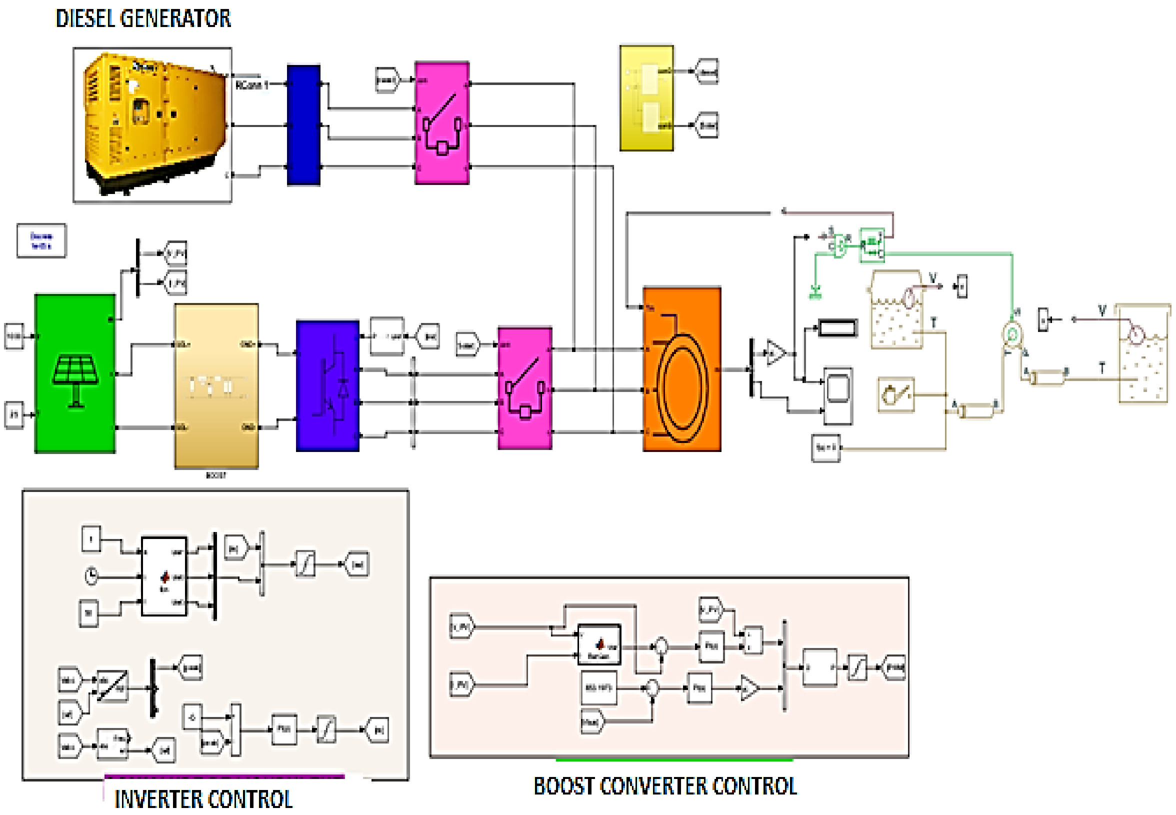

Figure 5. Structure of the solar-generator pumping system in simulink

When irradiation is below 300 W/m² and the reservoir is not full, the automatic inverter switches from solar to generator with a 0.3 s delay, ensuring continuous irrigation. Figure 6 shows the generator-powered water pumping from the river.

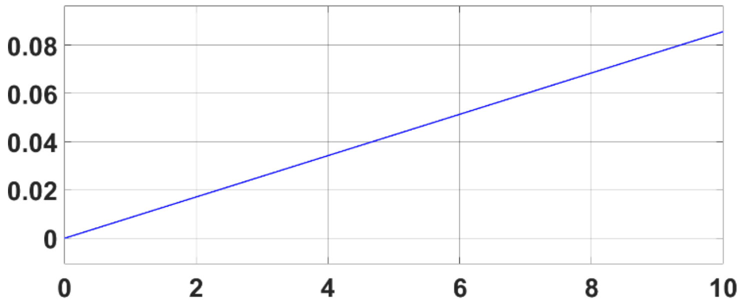

Figure 6. Pumping water from the river by the generator

When powered by the generator, the reservoir fills faster than with solar power for irradiations below 1000 W/m². The automatic inverter effectively manages the switch between systems, ensuring system autonomy and protection. For irradiations above 300 W/m² and when the reservoir is not full, the inverter switches to solar power. Figure 7 shows the solar-powered reservoir filling.

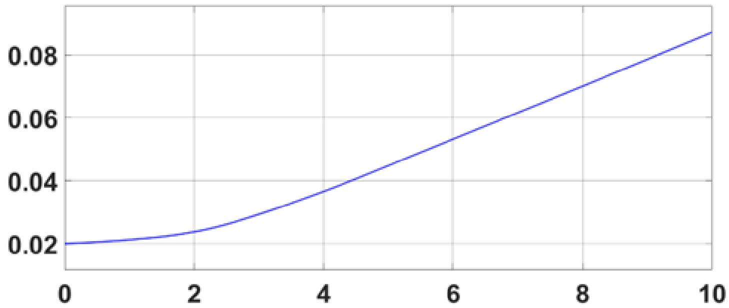

Figure 7. Filling the reservoir with photovoltaic photovoltaic solar power

Figure 8 demonstrates the 0.3s delay during the switch between the generator and the solar system.

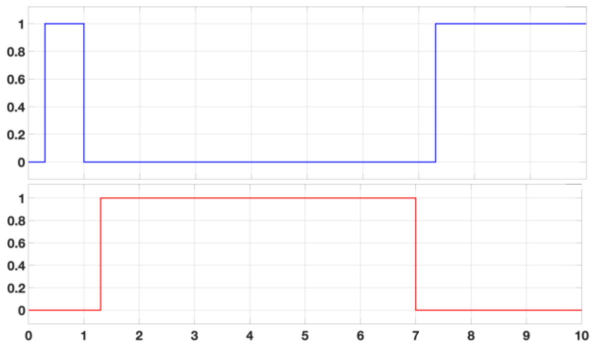

Figure 8. Switching between the generator and the photovoltaic solar system

Conclusion

This article presents a hybrid pumping system combining a photovoltaic solar system and a generator, automated by an algorithm. The Matlab/Simulink simulation demonstrates the system's reliability in ensuring continuous irrigation. Compared to using only a diesel engine pump or a diesel-solar hybrid setup, this solution enhances efficiency and optimizes parallel energy use for additional local applications. This study, part of the NANN-K project in the Podor department, highlights significant economic and operational advantages of our hybrid approach. Furthermore, it emphasizes environmental sustainability by reducing fossil fuel dependency and promoting renewable energy use in agricultural pumping systems. This study underlines the importance of hybrid systems in addressing contemporary challenges in sustainable agriculture and water resource management. To continue this research, integrating energy storage systems to enhance system resilience and conducting field trials to validate the simulation results under real-world conditions would be pertinent. Additionally, a comprehensive economic analysis and environmental impact assessment would provide a better understanding of the long-term benefits of this hybrid configuration.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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