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Research Article

A Grid Connected Fuel Cell System governed by a Series Multi-Cells Inverter utilized Antlions optimization algorithm (ALO).

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Abstract – This paper will employ the Antlion Optimization Algorithm (ALO) for Grid Connection in a multicellular converter linked to the Fuel Cell System. The control methodology implemented involves a rapid inner current control loop governing the grid current, alongside an outer voltage control loop regulating the DC-link voltage.

Keywords- Antlions Optimization Algorithm (ALO), Series Multicells Inverter, Fuel Cells System, Grid.

I. INTRODUCTION

The advancement of renewable energies has become increasingly crucial in the 21st century, given the escalating issue of global warming and environmental degradation. Extensive research has underscored the significance of alternative renewable sources like wind, water, geothermal, and solar energy for electricity generation.

The surge in energy consumption and heightened public awareness of environmental preservation have spurred interest in green energy generation systems, including renewables and fuel cell-based solutions. Furthermore, the ongoing evolution of electricity deregulation and public service restructuring, coupled with limitations on constructing new transmission lines for long-distance electricity transport, has amplified interest in distributed production systems (DG) located near load centers.

Fuel cells serve as portable energy sources in various settings, from remote weather stations and marine vessels to parks, rural areas, electric hybrid vehicles, and small aircraft. They offer compactness, modularity, silence, and environmental friendliness, making them versatile for applications like transportation, auxiliary power units (APU), and stationary or portable power sources.

Fuel cells function as static energy conversion devices, directly transforming fuel chemical energy into electrical energy. They hold promise as a significant DG source due to their high efficiency, minimal emissions, and flexible modular structure. When integrated into electrical networks, fuel cell DG systems must meet stringent operational and performance requirements, necessitating the design of appropriate controllers to optimize their performance characteristics.

Series Multi-Cells Inverters are increasingly integrated into various electrical devices, aiming to convert one electrical energy form to another efficiently. This topology offers advantages such as modular construction and the use of widely available components. However, designing control models for multicellular converters is challenging due to the combination of continuous and discrete variables.

The Antlion Optimization Algorithm (ALO), introduced by Mirjalili and Lewis in 2016, simulates humpback whale hunting behavior to solve optimization problems. Inspired by antlions' predatory strategies, optimal control, and feature selection, ALO aims to overcome limitations like slow convergence and susceptibility to local optima inherent in other swarm intelligence optimization algorithms.

The primary objective of this paper is to apply the Antlion Optimization Algorithm (ALO) to optimize a Grid-connected multicellular converter linked to a fuel cell system. The proposed control strategy encompasses a fast inner current control loop for grid current regulation and an outer voltage control loop for DC-link voltage control. This approach is well-suited to stabilize load variations and enhance converter performance.

II. DC / AC CONVERTER

The DC/AC control stage is facilitated by a three-phase multicellular inverter equipped with two control loops to enhance efficiency. The inverter regulator comprises an internal control loop for DC voltage coupling (VDC), ensuring optimal voltage regulation to facilitate current supply to the DC link. The second loop is an external control loop for forward and quadrature currents (Id, Iq), sourced from the Phase Locked Loop (PLL). Both loops are governed by Fractional Order Proportional Integral Derivative (FOPID) controllers, with their gains adjusted through meta-heuristic techniques such as the Antlion Optimization Algorithm (ALO). This adjustment aims to enhance the dynamic performance of the PV system connected to the grid by optimizing the inverter's performance through modifications to the FOPID controllers' gains for current and voltage regulation. Various meta-heuristic algorithms are explored in subsequent sections for this purpose.

Figure 1 illustrates the schematic of the proposed system. Converter control can be achieved using Pulse Width Modulation (PWM) technique. To implement PWM, two superimposed triangular carriers are employed. Each carrier is associated with one of the two groups of switches controlled complementarily. The positive segment of the carrier determines the switching state of S1, S2, and S3, while the negative segment governs S'1, S'2, and S'3. The primary objective is to regulate the voltages v_(c1) and v_c2 of the capacitors to their respective references E/3 and 2E/3

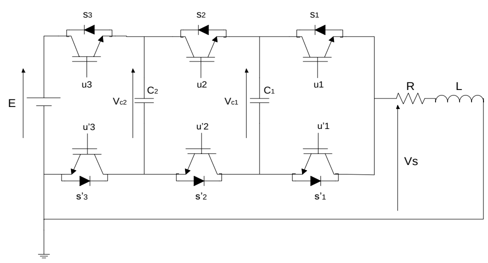

Figure 1. Chopper three cells connected to an RL load

The instantaneous state model of a chopper with three cells is expressed as follows:

$$\begin{cases} \dot{x}_1 = f_1(x,u) = \\ \dot{x}_2 = f_2(x,u) = \\ \dot{x}_3 = f_3(x,u) = \\ y = h(x) = x_3 \end{cases} \quad (1)$$

$(x_1, x_2, x_3)^T = (V_{c1}, V_{c2}, I_{ch})^T$: is the state vector as $x \in \Re^3$

$y = h(x)$: is the measurement vector$y \in \Re$.

(u_1, u_2, u_3) : are controls switches.

$a_1 = a_2 = \frac{1}{C}$, $b_0 = \frac{R}{L}$, $b_1 = \frac{1}{L}$, $\delta_1 = u_2 - u_1$,

$\delta_2 = u_3 - u_2$: are coefficients.

The control scheme for the three- phase inverter is shown in Figure 2.

Figure 3,4 and Figure 5 present the results of simulation for a series multi cells inverter controlled by the PWM technique, the following command sequence is used[15]:

- The voltage source is 1500V, the reference current is 80A.
- The switching frequency $f_{dec} = 20kHz$
- The capacitance of floating sources $C_1 = C_2 = 50\mu F$
- The frequency of the modulant $f_{mod} = 500Hz$

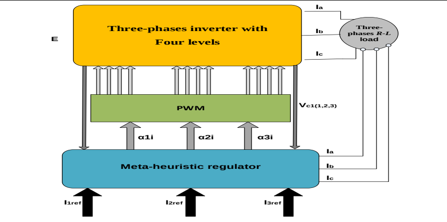

Figure 2. Structure FOPID-ALO control inverter

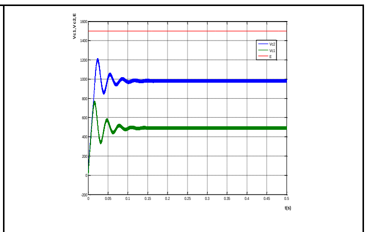

Figure 3. Voltage evolutions V_{C1} ,V_{C2} at the capacitors C1 and C2 terminals.

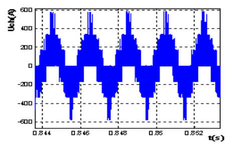

Figure 4. the voltage curve U_{ch} at the terminals of the inverter output)

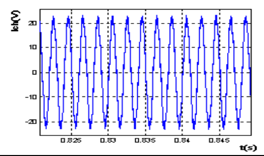

Figure 5. the current curve I_{ch} at the terminals of the inverter output).

Our objective is to regulate the voltages v_{c1} and v_{c2} of capacitors to their references $\frac{E}{3} = \frac{1500}{3} =$ 500V *and* $\frac{2E}{3} = \frac{2\times1500}{3} = 1000V$ as shown in Figure 3 and the load current must reach its reference value $I_{ref} = 80A$ as shown in Figure 5 .

III. MODELLING AND CONTROL STRATEGY OF THE GRID-CONNECTED FUEL CELLS SYSTEM

The inverter is responsible for the following tasks.

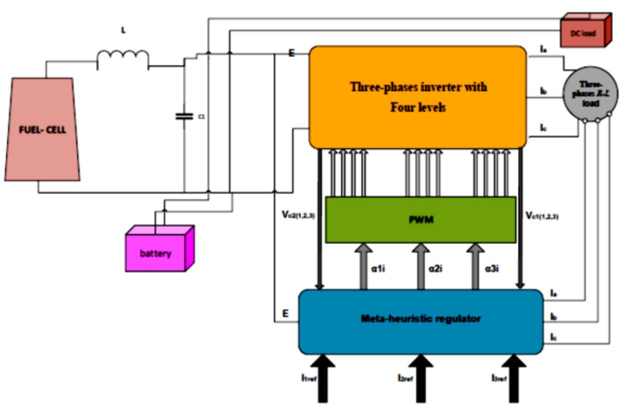

Figure 6. Proposed control structure of three phase grid-connected Fuel cell system.

1. Regulating the active power supplied to the grid.
2. Managing the voltage of the DC link.
3. Ensuring high-quality injection of power.
4. Synchronizing with the grid.

IV. ANTLIONS OPTIMIZATION ALGORITHM (ALO)

The Antlion Optimization Algorithm (ALO) is a stochastic approach inspired by the hunting behavior of antlions (Mirjalili, 2015a). As depicted in Figure 5, the prey, represented by ants, moves randomly across the search space using Eq. (10) (Mirjalili, 2015a). These random movements of the ants are influenced by the traps set by antlions, as described in Eqs. (11) and (12) (Mirjalili, 2015a). Based on the fitness function, ALO employs a roulette wheel mechanism to facilitate antlions in capturing their prey (Dubey et al., 2016; Mirjalili, 2015a; Saxena and Kothari, 2016). Once the ants reach the bottom of the pit, their positions represent the best solutions corresponding to antlion positions, as shown in Eq. (13). Updating antlion positions is iteratively carried out until the termination criterion is met (Mirjalili, 2015a; Mirjalili et al., 2016; Saxena and Kothari, 2016).

$$X_i^t = \frac{(X_i^t - a) * (d_i - c_i^t)}{(d_i^t - a_i)} + c_i$$

$$c_i^t = Antlion_i^t + c^t$$

$$d_i^t = Antlion_i^t + d^t$$

$$Antlion_i^t = Ant_i^t \; iff \; (Ant_i^t) > f(Antlion_i^t)$$

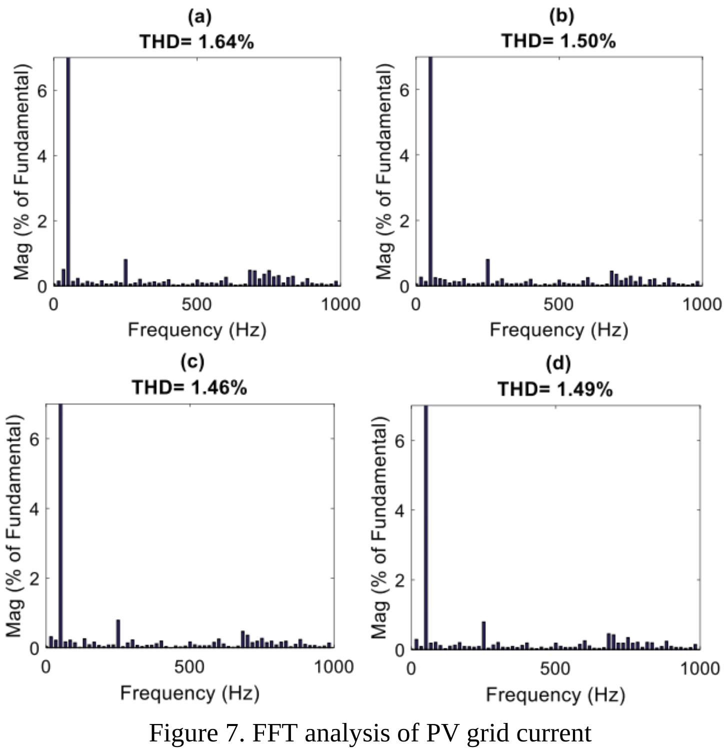

Figure 7. FFT analysis of PV grid current

In this simulation, we will observe varying outcomes when the inverter is coupled with an asynchronous machine. Both PWM control and FOPID-ALO control strategies will be examined.

The simulation begins with a no-load condition, followed by the introduction of a load torque on the asynchronous motor. At t = 1 s, a load torque of l5 N.m is applied. The subsequent figures depict the obtained results accordingly.

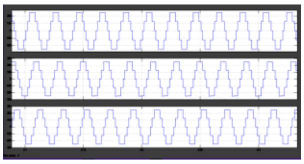

Figure 8. inverter composite voltages (PWM control)

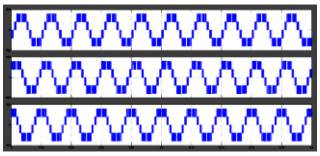

Figure 9. inverter composite voltages (FOPID-ALO control)

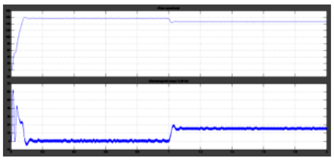

Figure 10. motor speed and electromagnetic torque(PWM control)

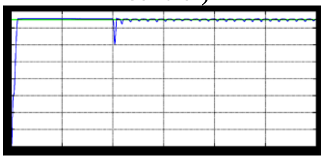

Figure 11. motor speed(FOPID-ALO control)

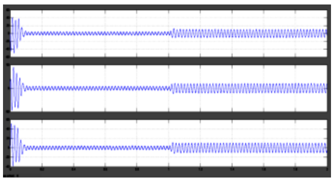

Figure 12. asynchronous motor currents under load(PWM control)

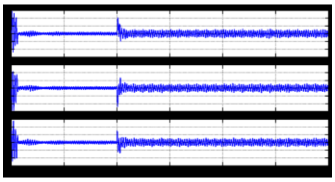

Figure 13. asynchronous motor currents under load(FOPID-ALO control)

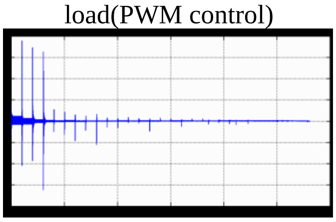

Figure 14. motor electromagnetic torque(PWM control)

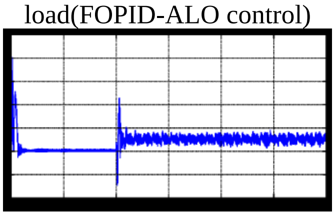

Figure 15. motor electromagnetic torque(FOPID-ALO control)

V. DISCUSSION

In figure 11, at start-up, the speed is slightly higher than the reference, and when the load torque is introduced at t=1s, we see a disturbance rejection that exceeds the acceptable error.

When the FOPID-ALO In figure 12 is applied, the speed is lower than the reference, and the disturbance rejection can be seen at the moment the load torque is applied.

VI. CONCLUSION

This paper's main objective is to apply a fractional-order PID- Antlions optimization algorithm to the multi-levels converter connected to an asynchronous machine. This control scheme is well suited to this type of converter and provides an effective solution for regulating the speed of the asynchronous machine.

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