Evaluation of the Efficiency and Stability of High-Frequency Inverters Under Varying Load Profiles in Photovoltaic Systems

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Abstract—This research undertakes an operational performance analysis of a high-frequency inverter (HFI) within a Solar Power Plant (SPP) system configuration. The investigation prioritizes assessing the effects of pure resistive and mixed resistive-inductive load profiles on its efficiency stability. Experimental findings definitively demonstrate that the HFI inherently maintains superior efficiency stability when operating under purely resistive loads. Conversely, the introduction of varying inductive loads tends to compromise this efficiency stability, inducing significant fluctuations. These results yield crucial recommendations, establishing that HFIs are optimally suited for systems with predominantly resistive loads, thereby contributing to the overall system power efficiency enhancement.

Keywords—High Frequency Inverter, Resistive Load, Inductive Load, Solar Power Plant, Efficiency

I. INTRODUCTION

In 2022, there were 0.21% or around 175 villages in Indonesia that had not been electrified [1]. The use of New Renewable Energy (NRE) can be an appropriate alternative to meet electricity needs. New Renewable Energy (NRE) is energy that can be recovered naturally, and the process is carried out in a sustainable manner [2], [3]. One form of new renewable energy is solar power. The use of solar power can be an economical solution in areas that have high solar potential and limited grid infrastructure [4]. Solar power is utilized in a Solar Power Plant (SPP) that can produce Direct Current (DC) electricity with photovoltaic cells. Solar photovoltaic power is becoming one of the most low-carbon power generation systems. Solar photovoltaic power can address sustainability challenges with the Sustainable Development Goals (SDGs) [5]. Direct current electricity needs to be converted into alternating current electricity using an inverter [6][7]. The main components of the Solar Power Plant (SPP) are photovoltaic solar panels to generate electricity from sunlight, batteries to store energy, and inverters [8][9].

An inverter is an electronic device that converts direct current electricity into alternating current and vice versa. One type of inverter is a high-frequency inverter. A high-frequency inverter is an inverter that produces supraharmonics electromagnetic waves (2 – 150 kHz) [10]. However, when used for daily needs, it has been equalized to 50 Hz. These supraharmonics waves are obtained from the power electronic switching process when converting direct current to alternating current, causing power quality problems [10], [11]. Generally, high-frequency inverters use Metal Oxide Semiconductor Field Effect Transistor (MOSFET) or Insulated Gate Bipolar Transistor (IGBT) [9], [12]. The addition of series capacitors to the inverter can also increase the efficiency of the inverter [13]. While the initial acquisition cost of an HFI tends to be higher compared to its low-frequency counterparts, the compact design provides substantial benefits regarding installation footprint and space utilization. Consequently, rigorous investigation into the efficiency performance of HFIs under actual varying load conditions is paramount for comprehensive system optimization [14].

II. METHODS

This research focuses on high-frequency inverters that can convert Direct Current (DC) electricity into Alternating Current (AC) electricity [14], [15]. This research will examine more deeply the effect of the load on the efficiency of the high-frequency inverter. The resistive load used is a dummy load bank that has a capacity of up to 2 kW, while the inductive load uses several motors. The battery used is LiFePO4. This battery has a long cycle life and is environmentally friendly (non-toxic) [16]. The results of this study are expected to provide a better understanding of high-frequency inverters in 5 kWp capacity Solar Power Plants (SPP).

This research uses a variety of resistive loads from 0 W to 1000 W in the form of a dummy load bank. The inductive load used is a washing machine motor. There are 3 types of washing machine motors used, namely Wash Motor SRD, Wash Motor RMOT, and Tins Motor. The use of resistive loads that are not too high is expected, so that the inverter performance is not too heavy and is included in the safe limit for high-frequency inverters (3000 W). The first test was carried out with resistive load variations without using inductive load variations applied to high-frequency inverters and low-frequency inverters. Second test with resistive load variation and inductive load variation. Mechanical design and wiring application of this research can be seen in Figures 1 and 2.

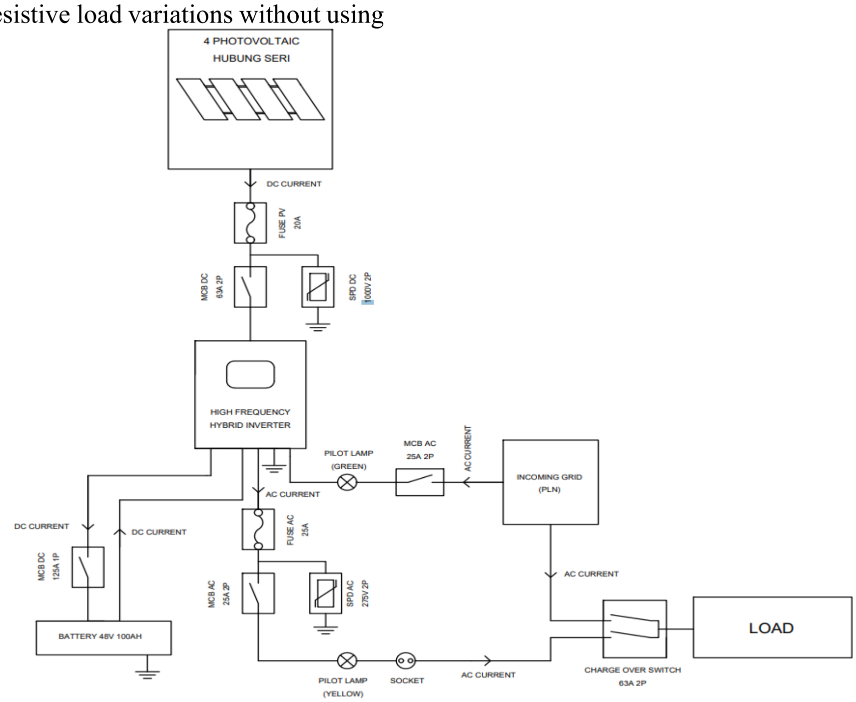

Figure 1. Wiring Design of High-Frequency Inverter

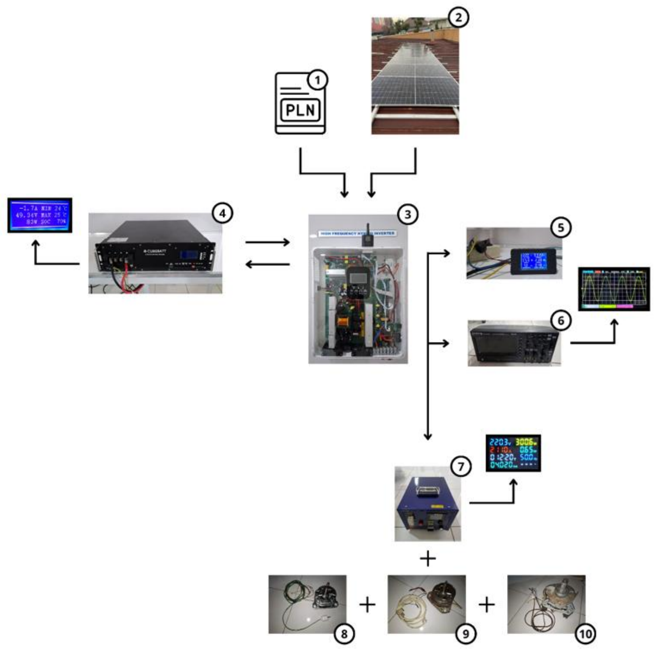

Figure 2. Design Mechanical of High Frequency Inverter

The connected electric current (number 2) can charge the battery (number 5 and number 6) by passing through the Inverter (number 3 and number 4). The inverter can change AC (Alternating Current) electric current into DC (Direct Current) electric current and vice versa. The electric current generated by the solar panel (number 1) is in the form of direct current, which will be stored in the battery until a load is applied. This study uses 2 loads, namely the resistive load and the inductive load. The resistive load uses a load bank (number 9), while the inductive load uses a motor (numbers 10, 11, and 12). When conducting research, data can be seen on the measuring instrument bundle (number 8) and the display on the inverter. The oscilloscope (number 7) is only used to see the output wave on the inverter. The installation of the measuring instrument bundle must be passed by the load so that measurements can be made.

An inverter is an electronic device that can convert direct current electricity into alternating current electricity. This research uses high-frequency inverters (HFI). The inverter used is an off-grid type, but can be connected to the power grid to get alternating current electricity during the rainy season. Specifications and comparison of the two inverters can be seen in Table 1.

Table 1. Specifications of High Frequency Inverter

Parameters	Inverter High Frequency
Rated Power	5 kW
AC Input	220 VAC, 1Φ, 50 Hz
Rated Output	220 VAC, 1Φ, 50 Hz
DC Input	48 V, 115.7 A
Max. PV Charging Current	100 A
Max. PV Input Voltage	500 VDC
Max. Charging Current	100 A
Max. PV Input Power	6000 W
MPPT Tracking Range	120 ~ 450 VDC

The use of loads on high-frequency inverters cannot be 100% of the total input power because it can accelerate the service life. The load bank load used varies from 0 to 1000 kW to maintain the life of the inverter.

The battery used is $LiFePO_4$ (Lithium Iron Phosphate), which has been adjusted to the capacity of the solar panel. This $LiFePO_4$ battery has a cycle life of > 3500.

Table 2. Battery Specifications

Parameters	Battery LiFePO4
Nominal Voltage	48 V
Nominal Capacity	100 Ah
Energy	4,8 kWh
Charge Voltage	54 V ± 1,2 V
Max. Charge Current	50 A
Cell & Method	3,2 V 100 Ah – 15 S1P
Feature	With Digital Display

III. RESULTS AND DISCUSSION

Resistive loads and inductive loads can be connected to the sockets located on inverters. Each inverter has a battery to store its own power reserve. The data taken in this study were obtained on the inverter display, load bank display, and display from the bundling of measuring instruments.

The results of inverter efficiency against resistive loads and inductive loads are shown in Figures 3 to 9.

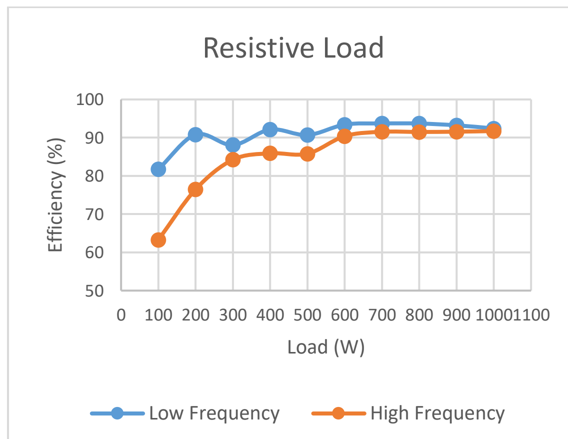

Figure 1. Efficiency with Resistive Load

The HFI demonstrates superior efficiency and stability when operating under purely resistive loads. This stability is directly attributed to the HFI's high switching frequency, which results in a dominant and relatively constant switching loss. Although this frequent switching contributes significantly to the overall power losses, leading to a potentially lower absolute efficiency value compared to inverters with simpler topologies, the consistency of these losses ensures that the efficiency curve remains flat and stable as the resistive load increases. Furthermore, the compact transformer utilized in the HFI, designed for high-frequency operation, experiences significant hysteresis losses and eddy currents. Since these phenomena are also highly predictable and constant at the operating frequency, they further suppress major fluctuations in the measured efficiency.

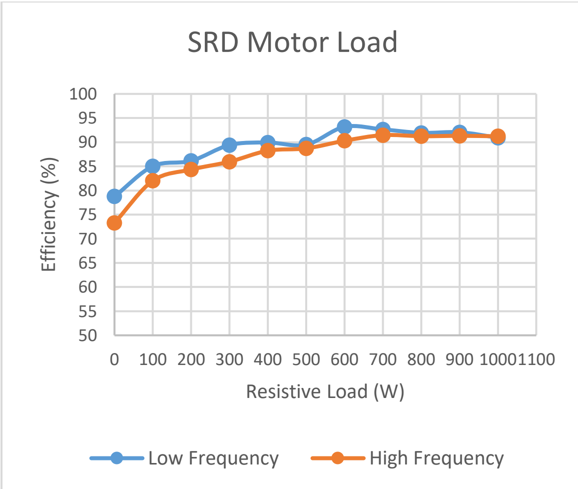

Figure 2. Efficiency with SRD Motor Load

The HFI compact design, which relies on a greater number of sensitive electronic components, renders it inherently susceptible to performance degradation and potential component stress when exposed to dynamic and fluctuating loads, particularly inductive ones. When the HFI is first subjected to an inductive load (e.g., motor), the system experiences a substantial inrush current. The inverter is compelled to undergo a rapid and significant internal adjustment to compensate for this transient demand, which is visually represented by an immediate, sharp fluctuation in the efficiency readings.

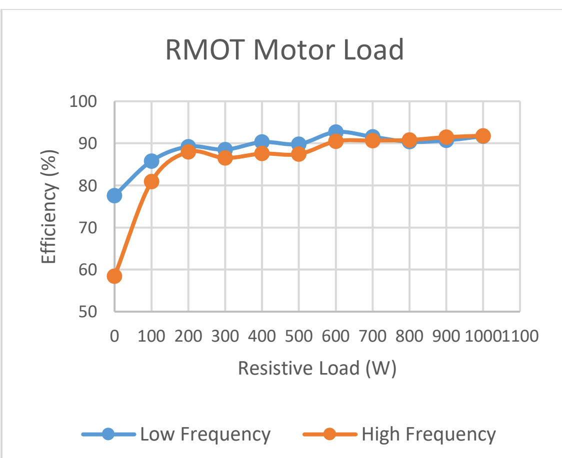

Figure 3. Efficiency with RMOT Motor Load

Despite this initial transient, the efficiency value tends toward greater stability once a high load is established. This subsequent stabilization is observed because the dominant switching loss and transformer-related eddy currents remain constant. Moreover, the increasing demand from the high load elevates the conduction losses within the semiconductor components. This increase in conduction losses, when combined with the constant switching losses, results in only a marginal decrease (depreciation) in the efficiency value, confirming the HFI's stable operational state under sustained high-load conditions.

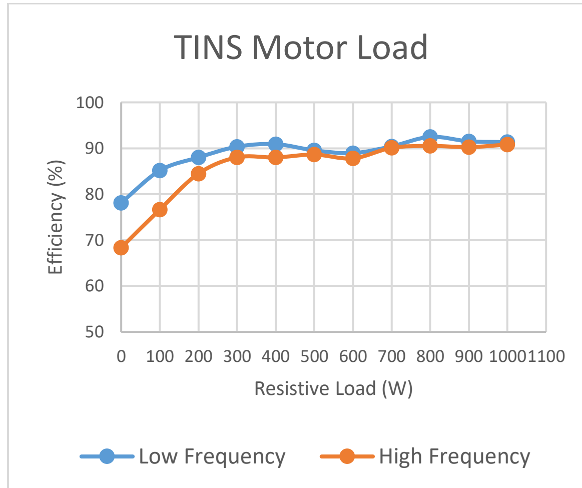

Figure 4. Efficiency with TINS Motor Load

High-frequency inverters use more electronic components, so they are susceptible to damage when given a changing load (fluctuation). When there is an inductive load at the beginning of the use of a high-frequency inverter, the inverter needs to adjust it so as to produce efficiency that rises significantly. However, the efficiency value tends to be more stable when a load is added because the switching loss and eddy current are almost constant. The efficiency of the low-frequency inverter improves after adding load, as the losses remain at high load.

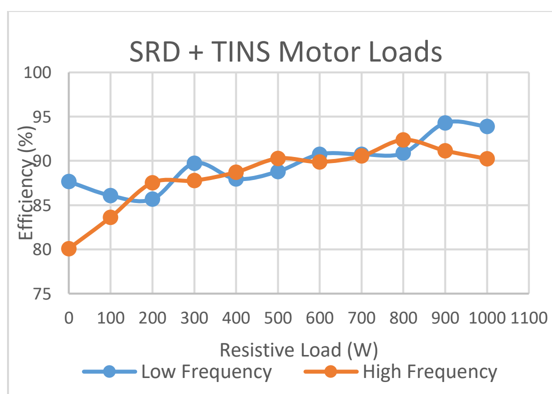

Figure 5. Efficiency with SRD and TINS Motor Loads

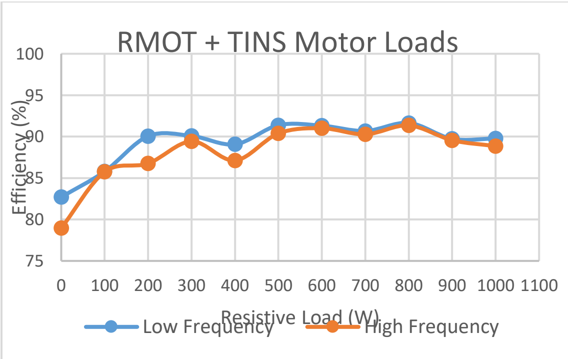

Figure 6. Efficiency with RMOT and TINS Motor Loads

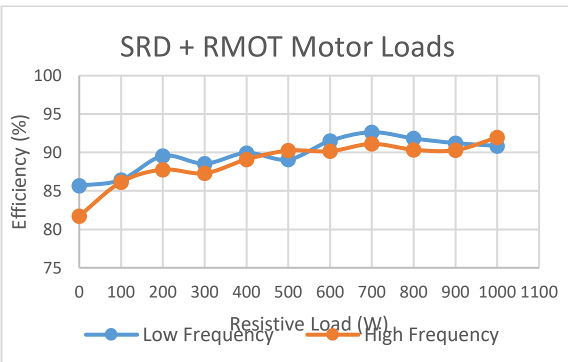

Figure 7. Efficiency with SRD and RMOT Motor Loads

The use of large and variable inductive loads can affect the high-frequency inverter and low-frequency inverter due to the high initial surge that the inverter needs to adjust when fluctuations occur. However, the efficiency values tend to be more stable due to the increase in conduction losses in the semiconductor components, which results in a small decrease at high loads. The efficiency value of the low frequency inverter fluctuates due to copper losses in the transformer and motor windings. The efficiency starts to stabilize at high resistive loads due to fixed loss values.

IV. CONCLUSION

The empirical findings of this study establish that the use of resistive loads in high-frequency inverters yields stable efficiency values. Although the application of combined resistive and inductive load variations can initially induce fluctuating efficiency due to the required adjustment for high initial surge currents, the HFI demonstrates rapid self-correction and a return to relative stability under sustained high-load conditions. Conclusively, the HFI is demonstrated to be optimal for photovoltaic systems where the load profile is predominantly resistive.

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