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Characteristics of an AC/DC Hybrid Converter According to Load Fluctuation

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Abstract *- Due to the increase in the use of renewable energy, there has been a rise in the number of research related to smart or Hybrid converters. So, this work presents the characteristics of a Hybrid converter according to load fluctuation.'Load fluctuation', referring to instability from a fast-changing load or instability from an input source to the converter. The experiment will help to determine the sensitivity of devices suitable for connection to the converter. The aim was achieved through experimentation on a 5kW capacity Hybrid converter with an efficiency of over 90% for both AC and DC input sources. Real-life experimented results suggest that the converter is capable of fast stabilization of instability or fast fluctuation from either the load or an input source.*

Keywords — *DC-DC converter, Dual input/output, Hybrid converter, Smart grid, Smart transformer.*

I. INTRODUCTION

The world, as of now, is characterized by fast development and research. Development is mostly aimed at bettering living standards and easing how things or processes are Carried out, usually with better efficiency and reliability. Electricity is highly required in all domains/ sectors, though it may differ in form or production storage and transmission. In electricity or technology in general, quality of supply is a point of focus [1]. Thanks to some environmental factors such as global warming and also the desire for better energy management, the use of renewable energy sources is on the rapid rise. Most of these renewable energy sources come in DC voltage form and are converted to AC voltage either for step-up/down before transmission or for direct transmission. This conversion is usually done using a power inverter and a power transformer for voltage step up.

A power transformer, which is liable to deterioration due to mechanical and electrical tension, may lead to unwanted situations or failure [3]. Whatever the case may be, this conversion process always incurs some loss which tends to lower the efficiency and reliability at the consumer end, especially for DC loads. This situation is taken care of by using the AC/DC Hybrid converter for low voltage direct current (LVDC) appliances. The idea of a converter with multiple outputs has been around for more than the past 3 decades or so. One of such early designs used a multi-winding transformer and provided multiple isolated DC outputs that had a feedback PWM control for output regulation. But the system becomes unstable with an increase in output power[4]. Afterward, sometime in the late 1970s, other designs aimed at regulating the output voltage had been proposed. One of such was proposed by [5], which used the concept of magnetic coupling to regulate output voltages. The design had two-output with a step up in the voltage and current and was also based on the concept of multi-winding transformers. Later in the 1990s, the limits of the DC-DC converter were pushed to a multi-input by [6], providing a system that could accept multiple sources of different voltages and outputted a single-regulated output. Since there still existed a limitation in control for the prior models, [7] presents a unidirectional three-port topology based on flux additivity. It adds up the produced magnetic flux from the input sources in the magnetic core of the coupled transformer. It implements the phase-shift pulse width modulation (PWM) control technique and can receive power from the input ports individually or simultaneously to supply the load. The phase-shifted PWM control accounts for the output voltage regulation as well as power flow[7]. In recent years, other converter topologies and control algorithms have been proposed, with each one bearing its pros and cons. So, what topology and control technique should be used for a particular converter, is determined by the application area and the requirement. Requirement mostly in terms of sensitivity, power density, robustness, efficiency, cost, and reliability. Many comparative studies have been performed on the hybrid converter and multi-port DC-DC converters to bring out the advantages and disadvantages of each. One such work is Presented in [8] and [9], which focus on the multi-winding-based high-frequency transformers.

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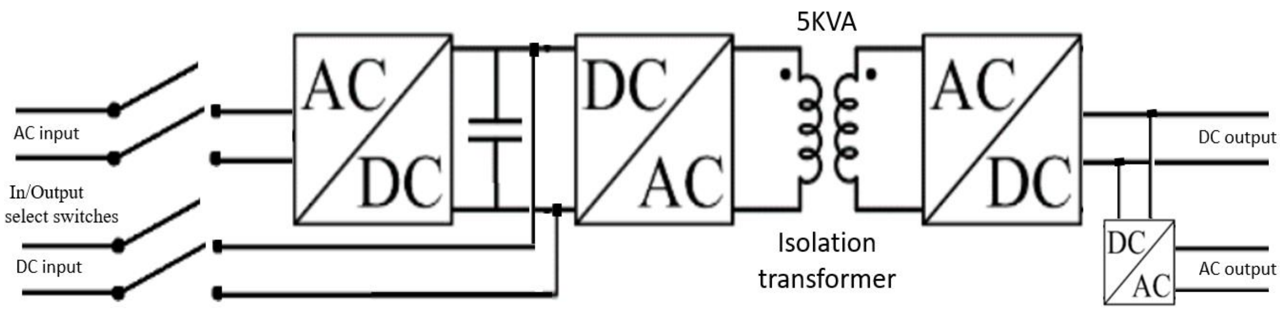


Fig 1. Block diagram of the Hybrid converter

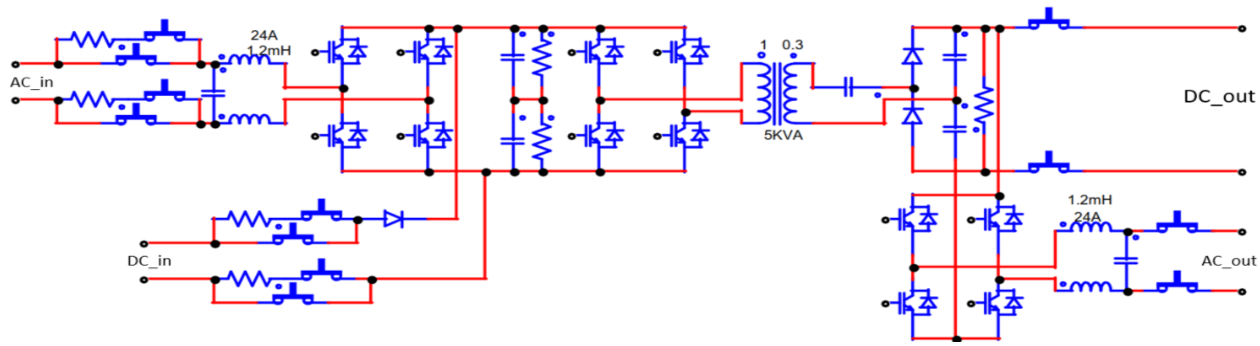


Fig 2. PSIM schematic of the Hybrid converter topology

The converter used for this experiment differs from that of [7] in that; instead of combining input sources in magnetic form (as in [16] and [17]), it combines them in electric form in-between the first and second cell (as indicated in the block diagram of figure 1). The hybrid converter design individually takes as input either an AC or a DC source and simultaneously outputs both AC and DC sources. This experiment is important because Knowledge of a particular converter's reaction to an unstable system (fluctuating load or input source) and the stability requirement of the system in which the converter is to be installed would be great for avoiding unwanted situations. This work provides such knowledge for this particular AC/DC Hybrid converter.

II. MATERIALS AND METHODS

This section describes the hybrid converter used for this experiment, the properties of the converter, other requirements, the experimental setup, and the procedure.

A. *Overview of the Hybrid converter*

The Hybrid converter consists mainly of a transformer that provides galvanic insulation and voltage matching. The transformer is designed to suit the operational frequency of the transformer. The main structure of the converter includes a high-frequency transformer for isolation and other sets of switches at the

Input and output that work as inverters and rectifiers. For problems such as an increase in line voltage caused by the increase in renewable energy sources and harmonics caused by connected operation are limited by conventional transformers. Additional reactive power (static VAR) compensators (capacitors, static VAR compensators, inverters, etc.) are used to complement for limitations. Increasing the number of passives using these devices/components increases the overall system volume, and the problem of increased weight is displayed. The TMS320F28335 Digital Signal Processor (DSP) was used for feedback control and other peripheral control (i.e., the DSP module is the main brain of the whole system). Figure 2 above shows a much better preview of the converter topology in use. The extra switches on the AC line (input and output) account for the drop in efficiency compared to the DC line.

a) Properties of the converter: The properties of the hybrid converter under experimentation are as follow: The converter's target capacity is 5kW with efficiencies greater than 90[%] for both AC and DC input sources. Ratings were confirmed through experimentation, and the results of the experiment are in figures 3 and 4, alongside their corresponding tables of values. The experiment was conducted by establishing two (2) power conversion systems, DC to DC, AC to DC, since this paper focuses only on the DC capabilities (AC intentionally left out). This was done for the development of the converter.

Table 1: DC-DC results

Parameter	Value
Vdc_input	400.849V
Idc_input	13.4347A
P_input	5.3852kW
Vdc_output	380.173V
Idc_output	13.3533A
P_output	5.0766kW
Efficiency	94.27%

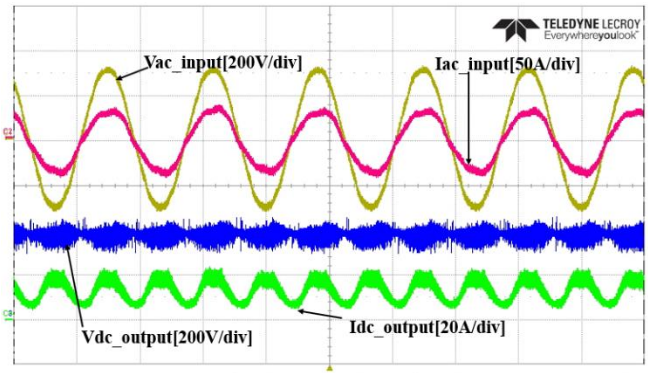


Figure 3. DC-DC waveforms

Table 2: AC-DC results

Parameter	Value
Vac_input	220.78V
Iac_input	24.9233A
P_input	5.468kW
Vdc_output	382.1822V
Idc_output	13.2686A
P_output	5.0698kW
Efficiency	92.718%

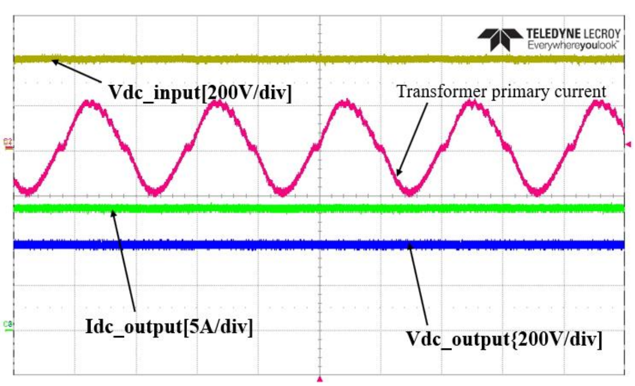


Figure 4. AC-DC waveforms

Firstly, the Hybrid converter was configured as DC to DC to check the performance. Figure 3 and Table 1 show the experiment analysis result for the stated test inputs (voltage, current, and power). It was confirmed that it operates normally with an efficiency of 94.2[%] at a target capacity of 5kW. When configured as an AC to DC and experimented upon with the stated test inputs (voltage, current, and power), it can be seen that normal performance is shown with 92.7[%] efficiency at 5kW, which is the target capacity of the prototype. The results are as shown in figure 4 and its corresponding table 2. From figure 3, it is seen that the converter exhibits zero current switchings (ZCS), which greatly reduces the switching loss and thereby positively impacts the converter's efficiency [13]-[15]. When configured as an AC to DC and experimented upon with the stated test inputs (voltage, current, and power), it can be seen that normal performance is shown with 92.7[%] efficiency at 5kW, which is the target capacity of the prototype. The results are as shown in figure 4 and its corresponding table 2.

B. Requirement

The power converter in use is a low voltage AC-DC-DC/AC Hybrid converter, which takes interchangeably as input both AC and DC sources controlled by a select switch. It outputs AC and DC sources at efficiencies greater than 90[%] simultaneously. A power analyzer, an Oscilloscope, Variable AC and DC power sources, and AC and DC load banks.

a) Experimentation setup: The setup for experimentation was done as displayed in figure 5 below. The figure shows the configuration of the experiment environment to analyze the input/output characteristics such as voltage, current, and power profiles of the prototype and compute the efficiency in each case. The load banks used for this experiment were not included in the setup figure below.

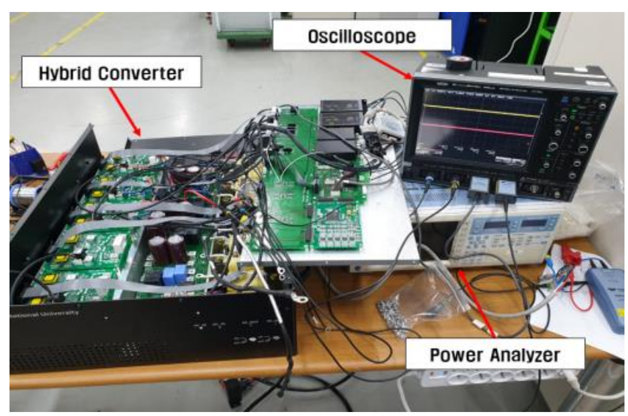


Figure 5. experimentation setup

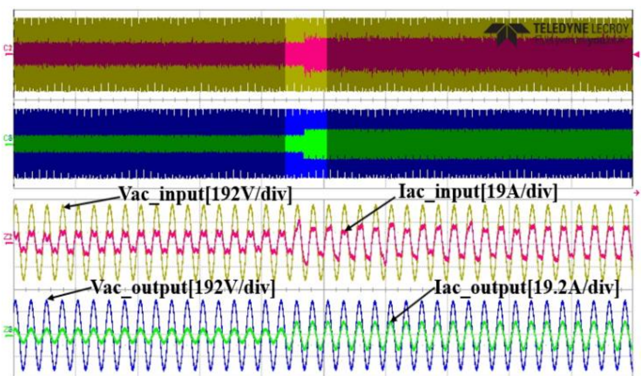
b) Experimentation procedure: After the setup, the experiment proceeded in three ways;

First, Fixed AC input at 220[V] with a sudden change in load (AC and DC).

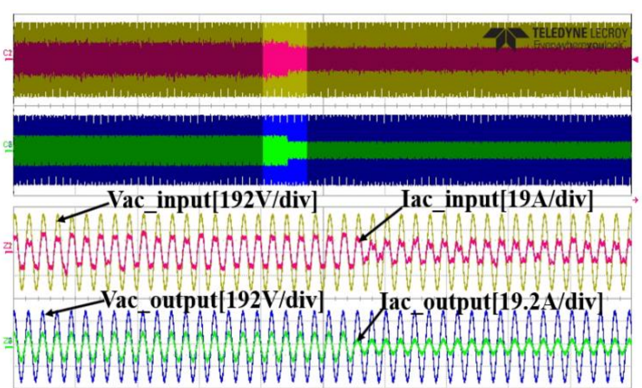
Next, Fixed DC input at 550[V] with a sudden change in load (AC and DC).
Finally, a DC input with sudden change (530[V] → 580[V] → 530[V]) at a fixed DC load of about 1kW.
For each experiment performed, the corresponding voltage and current profiles were recorded from the oscilloscope.

III. RESULTS AND DISCUSSION

Below are the results from the different experiments performed. The different profiles display the voltage and current waveforms, and the discussion of each is given below.
For the first experiment with a fixed AC input of 220[V], the results a displayed in figures 6 and 7.
Figure 6 (a and b) shows the profile for AC load. (a)shows the instance in which the load is increased while (b)denotes a drop in the AC load. For both, a stable and undisturbed output voltage is observed while the current waveforms show a corresponding increase and decrease depending on load fluctuation. Figure 7 (a and b) denote the profile for a DC load. (a) shows the instance in which the load is increased while (b) denotes a drop in the DC load. Just like the case in figure 6 for AC loads, the output voltage is stable.

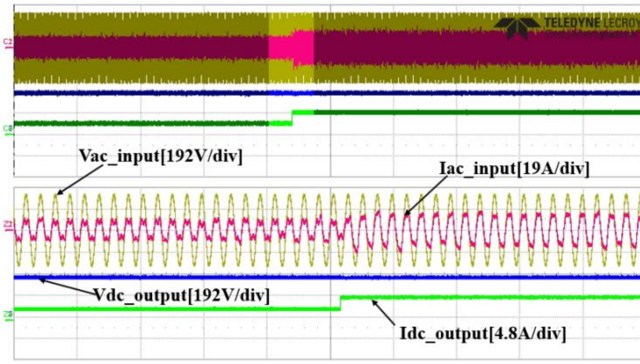


(a)

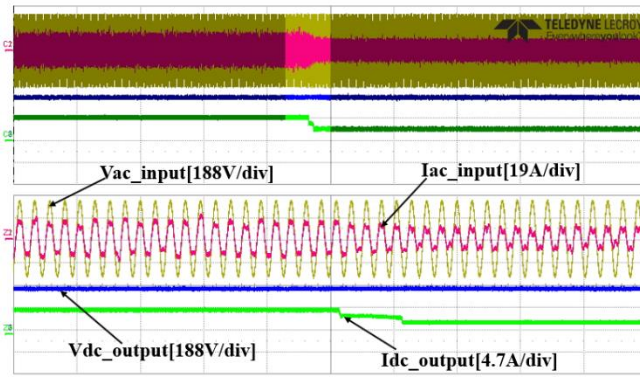


(b)

Figure 6. Fixed AC input, sudden change in AC load (a) 1kW → 2kW (b) 2kW → 1kW

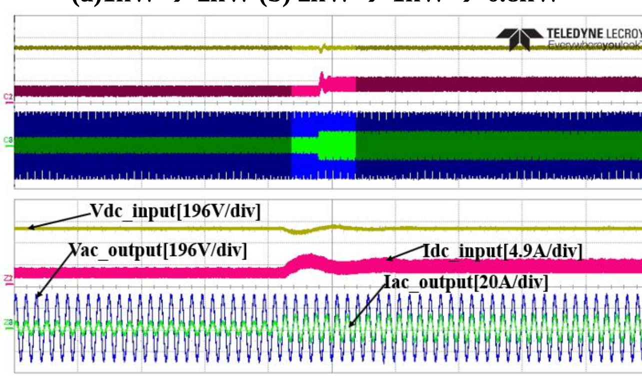


(a)

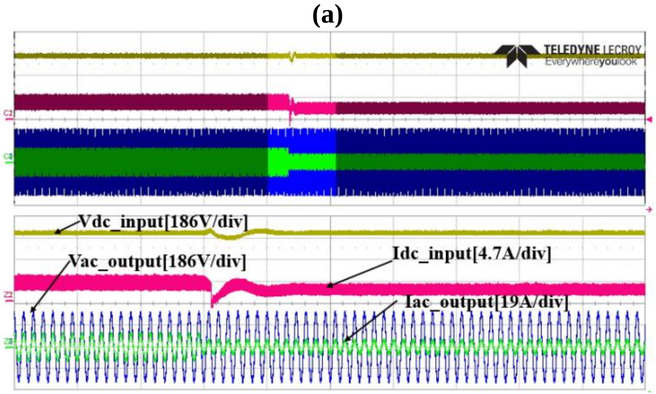


(b)

Figure 7. Fixed AC input, sudden change in DC load (a)1kW → 2kW (b) 2kW → 1kW → 0.8kW

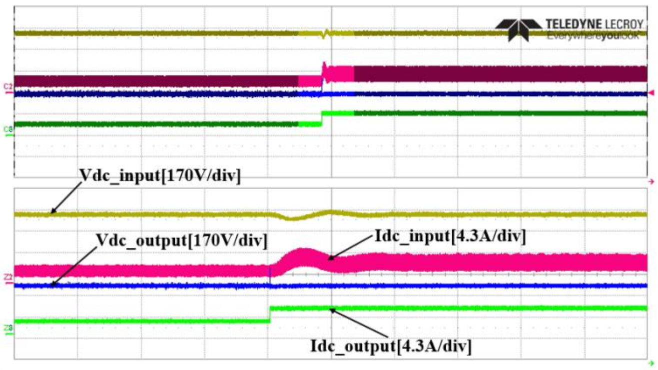


(a)

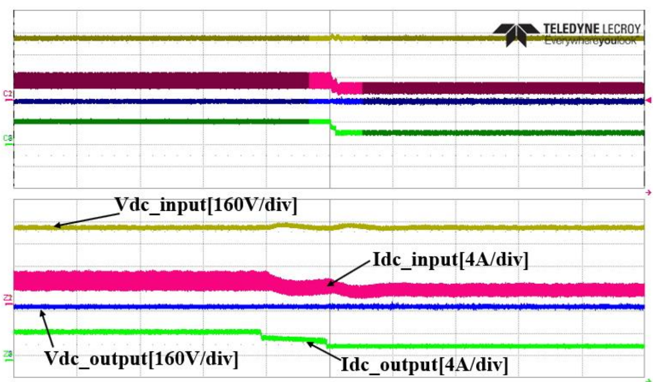


(b)

Figure 8. Fixed DC input, sudden change in AC load (a)1kW → 2kW (b) 2kW → 1kW



(a)



(b)

Figure 9. Fixed DC input, sudden change in DC load (a)1kW → 2kW (b) 2kW → 1kW → 0.8kW

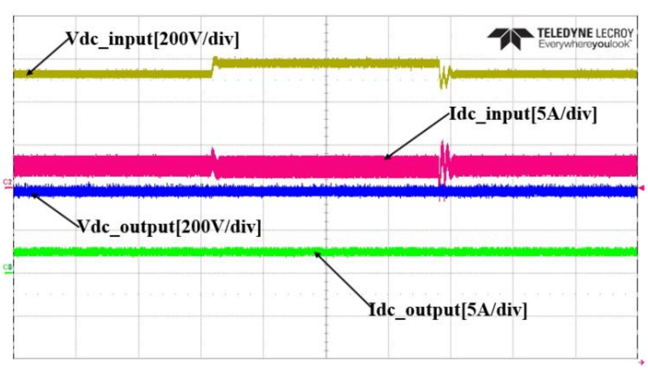


Figure 10. Fixed DC Load of 1kW and changing DC input 530[V] → 580[V] → 530[V]

For the second experiment with a fixed DC input of 550[V], the results are expressed in figures 8 and 9.

Figure 8 shows the waveforms for an AC load when increased (a) and decreased (b). for both instances, and the AC output voltage remains stable while the amplitude of the current waveform is altered with respect to the load change. Figure 9 exhibits the waveforms for the variation of DC loads, both of which a stable output voltage was depicted and the corresponding response of the current according to load variation.

Experimentation on input voltage variation was done only with DC source. And the result was recorded and is displayed in figure 10. It is seen that even with a quick and significant variation in the input source, the output voltage and current profiles remain unchanged.

IV. CONCLUSIONS

This work aimed to present the characteristics of a Hybrid converter according to load fluctuation (an unstable system). The 'unstable system' refers to instability (quick-changing) on the load system or input source(s). The results show that regardless of the area of fluctuation (input source or load), the output voltage (AC and DC source) remains unaffected while the output current changes accordingly. The experiment helps us know how suitable the converter is in terms of use in sensitive situations or devices. So, the experiment was performed in real life instead of the conventional stability calculations and simulations on software for this requirement. Looking through the results from the different experiments performed, the converter can be termed stable, taking into account the response characteristic with respect to a sudden change in a real-life application.

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