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Independent high voltage DC source development for renewable-grid integration interface

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ABSTRACT

Recent advancement in renewable-grid integration research, due to the concern on the environmental impact, leads to extensive study in isolated power converter as their interface. As part of isolation capability in power converter interface, extensive study of magnetic component has been carried out, especially on the design, construction and optimisation to achieve optimal operation. One of the main issue in verifying the analytical power loss model is to have independent HVDC link power source for an experimental validation work. This paper focus on the design and construction of DC link source, to be use in the experimental rig setup. Several DC link source option has been evaluated, and TDK-lambda PF500-360A power supply was selected due to the availability and excellent energy efficiency offered, at better price. External circuit is designed and implemented to achieve desired voltage and current supply characteristic. At the end, the voltage and current of the DC link supply for Dual H-bridges is obtained and shown promising result for experimental rig measurement and data collection work.

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1. INTRODUCTION

Renewable energy and grid integration require several power converter, with or without bidirectional functionality, as an interface between renewable generation, energy storage and grid system [1-6]. One of the main area of interest in renewable-grid integration is the construction and optimisation of magnetic component for power converter [7, 8] which contribute to size and efficiency issue of the system [9-13]. Evaluation and analytical validation work for magnetic component [14-20] study (high frequency transformer) require dual H-bridge DC/DC converter system [21-25].

Therefore, the development of independent HV DC-link source has to be implement and construct, in order to provide the high voltage direct current (DC) to the DC-link side of the dual H-bridge DC/DC converter system as shown in Figure 1. Several choices of after market DC source supply can be used, ranging from variable dc output power supply that is ready to be use, to a fixed dc output voltage power supply which require construction of external circuit in order to operate. In this paper, power supply module, PF500A-360 are selected due to the module availability, inexpensive and within desired specification [26].

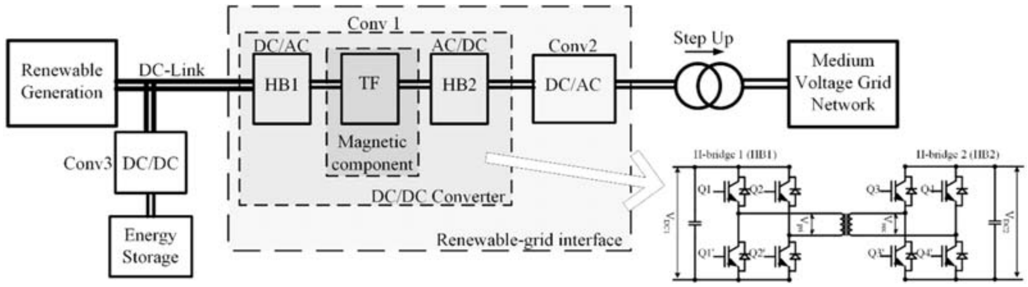


Figure. 1. Renewable system-grid integration interface using power converter

This power module offer easy solution to connect to the H-bridge converter system that has 360Vdc input from AC mains with wide range of inputs, achieved a power factor of 0.95 and able to offer the maximum 750 watt output power at high line inputs, which is capable enough to supply to the H-bridge converter system as on Figure 2.

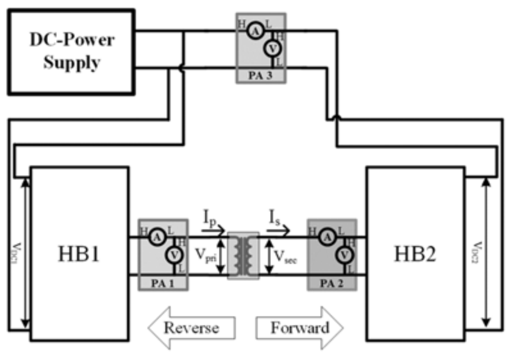


Figure. 2. Intended area of DC source supply that used to provide power for Dual H-bridges power circulation

Other features of this power supply module is thermal protection, inrush limiting circuit, overvoltage protection, maximum of 94% efficiency full load 250Vac supply, as well as complied with EN60950 standard [27]. This project focusing on the construction of High Voltage DC-link power source based on selected module, to facilitate experimental setup mentioned in Figure 2. Next section discussed more detail on the parameters and circuit for this work.

2. EXTERNAL CIRCUIT CONSTRUCTION

For the power supply module to work properly and safely, external circuit and circuit LED indicator have to be build.

2.1. External circuit parameter

This section is the description and the calculation of each external parts of the power supply (shown on Table 1. On the input supply side, three external components have to be added, which is 10A fuse (F1), noise filter, and also input capacitor (C_1) with recommended value of 1uF 250Vac. The function of this C_1 is to provide high frequency noise filter and also reduce unwanted oscillation by placing it closely to the terminal.

Meanwhile, on the output side, capacitor C_2, capacitor C_3, capacitor C_4 and DC fuse F2 value is suggested by power module manufacturer and obtained from application notes [26]. The function of capacitor C_2 and C_3 is used to snub the spike noise from boost inverter and capacitor C_4 is to reduce the common mode circulating current.

Table 1. External circuit parameter

External component			
Input Side		Output Side	
Item	Value	Item	Value
Fuse, F1	10A	Fuse, F2	3A 500 Vdc
C1	1uF, 250V	C2	0.94uF 630V
		C3	0.47uF 630V
		C4	3300pF 400V

2.2. Inrush limiting current and output capacitor

During the DC source operation start-up, one of the main issued faced is high surge current, before its reaching steady state. The instantaneous surge current, drawn by power supply is called inrush current or turn-on current [28-30]. This current can be as high as 20 times steady state current, and can caused damaged to power supply load. Therefore, inrush limiting circuit is required, which consist of resistor that can be calculated as (1)

$$R_{inrush} = \frac{V_{in}\times\sqrt{2}}{I_{inrush}}[\Omega] \tag{1}$$

Where, Rinrush=external resistor value, V_{in} =AC RMS input voltage, and Iinrush=inrush current. On the other hand, output capacitor C_o calculated as below (2) to maintain peak to peak voltage of less than 15 V peak to peak. External output capacitor, C_o, are required to ensure DC-link voltage is constant for line and load change [26, 27, 31]. Mathematical equation to determine the capacitance needed for minimum peak to peak ripple output voltage is (2)

$$C_o \geq \frac{P_{out}}{2\pi f\times V_{p-p}\times V_o\times\eta}[F] \tag{2}$$

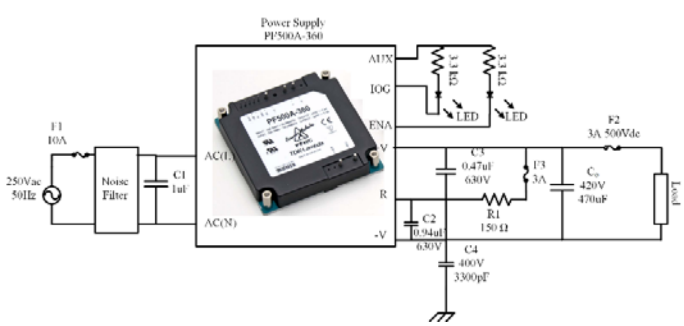
Where, *Co*=Output smoothing capacitor, P_{out} = P_{in} of H-bridge inverter module, f = input frequency, V_{p-p}=output ripple voltage, V_o= rated output voltage of power module, and η=efficiency of power module. Secondly, the output capacitance must also be calculated based on the required holdup time of AC/DC power supply. Formula to determine the capacitance value based on this holdup time shown (3).

$$C_o \geq \frac{2\times(\frac{P_o}{\eta})\times t_{holdup}}{(V_o-\frac{V_{p-p}}{2})^2-V_{min}{}^2}[F] \tag{3}$$

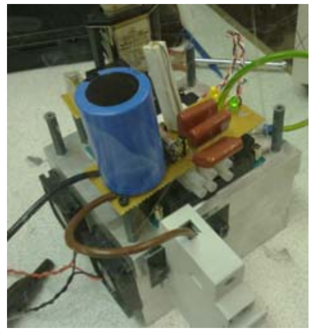
Where, C_o=Output smoothing capacitor, P_o=P_{in} of H-bridge inverter, η=efficiency of the H-bridge inverter, tholdup=holdup time for AC/DC power supply, V_o=rated output voltage, V_{p-p}=output ripple voltage and V_{min} = minimum input voltage of the H-bridge converter.

Figure 3 (a) shows the complete circuit diagram with the component calculated. Once the external circuit is build and connected as on Figure 3 (b), the testing is carried on to the power supply module to obtain and observe the ability of the power supply module to operate as it should.

The operation of power module have several control feature and require several steps before reaching steady state and full controlled mode. One of the feature is overvoltage protection (OVP) mode which detect increase in voltage over its limit of 390V. If output voltage is over 390V, OVP will be trigger and trip, thus, reduce the output voltage to √2 from AC RMS input voltage and output current to zero.



(a)



(b)

Figure 3. (a) The circuit construction of the power supply module, PF500A-360,
(b) Prototype model of high voltage DC source supply

3. TESTING EVALUATION AND RESULT

The constructed power supply module is then applied to the AC input voltage either from auto transformer or 230Vac socket. Initial testing start with less than half load (365Ω) with ac voltage is supplied from auto transformer and the input is increase slowly to the maximum.

3.1. Hot start at full load

After initial testing is successful, the amount of load is then increased to full load (170Ω) to push the DC-link source drawing maximum current on the DC output side.

In Figure 4, the rectifier power supply achieved stability in the operation with the maximum output current of 2.1A (358V/170Ω). Can be observed that this power supply module have a number of step before its entering stability and full controlled mode, power module sequence chart. It is start with the capacitor charging mode using 150Ω an inrush resistance which drawing about 2.37A current.

This process takes approximately 85ms, and once capacitor is charged, system goes into diode rectifier mode where DC output voltage is equal AC peak input voltage. Then, this power supply will enter full controlled mode system at almost 360V voltage. After achieved steady state, can be seen that the input current leveled at 4.5A peak and as resistive load is used, output current will be around (358V/171.7Ω) 2.1A which is maximum current that the system can supply.

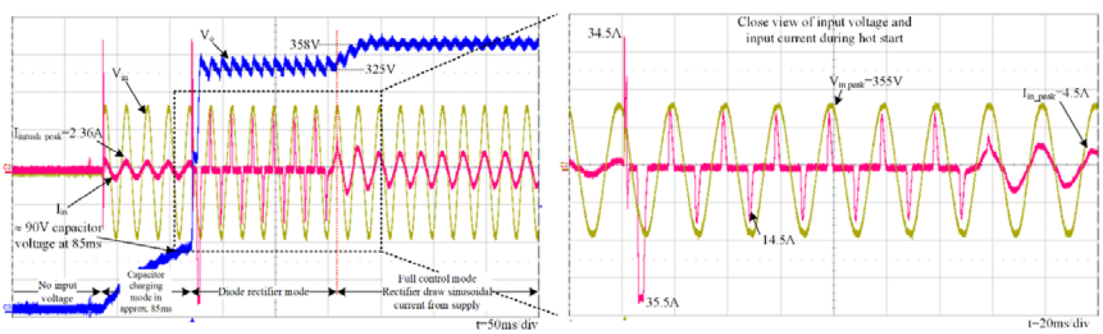


Figure 4. Input AC voltage, input current and output voltage during hot start of power supply with full load

3.2. Hot start with no load

Testing without the load (open circuit at the output) also shows the same steps as in the full load test and the result showed in Figure 5. However, there is no current drawing from the system once system in the full controlled mode. Meanwhile, same result appeared during the capacitor charge mode where the system used an inrush resistance as the load and drawing about 2.35A current. This step is required to make sure the safety of the capacitor, to prevent sudden voltage increased in the capacitor which will caused high current spike.

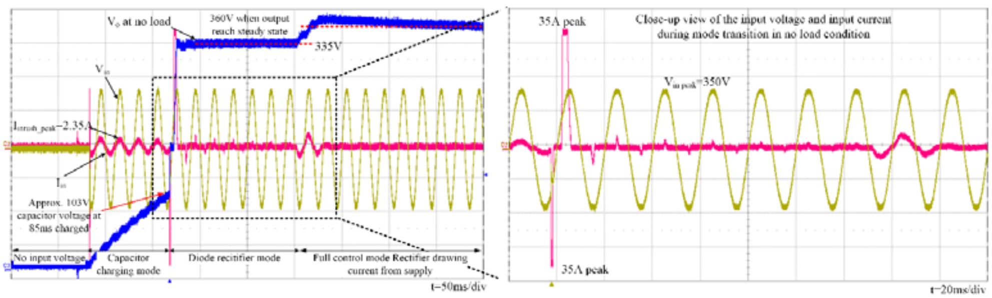


Figure 5. Input AC voltage, input current and output voltage during hot start with no load present

3.3. Operation between full load and no load

Power supply is also run at full voltage and testing both from no load to the full load and full load to no load and the result shown in Figure 6. It is appeared that the power supply behaving properly although there is sudden load is applied to the system. During the operation from no load to the full load, DC output voltage show some voltage dip (about 40V) and taking about 0.4 second to reach the steady state again. However, when removing the load while power supply at full supply, the system taking a longer time to stabilized again (0.6 second). However, both testing shows the ability of the power supply to handle the sudden changed in the load.

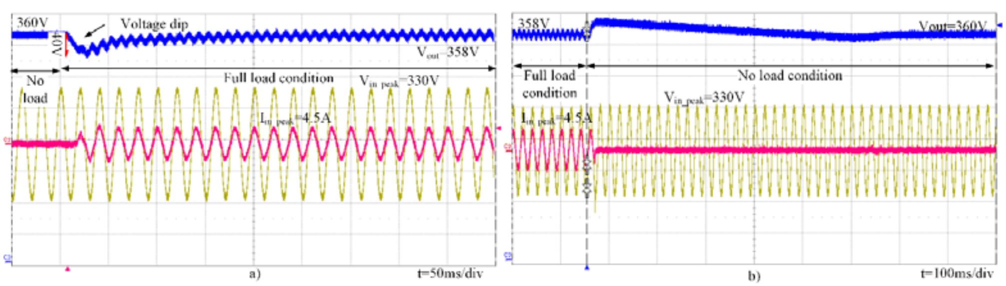


Figure 6. The output voltage, input voltage and input current during sudden load changed at full controlled mode operation.

3.4. Final test with main outlet supply

Finally, startup test using the power socket outlet at both full load operation and also full load to no load operation. The result shows in Figure 7 where the same 4 steps are required before it enter full controlled mode (steady state mode).

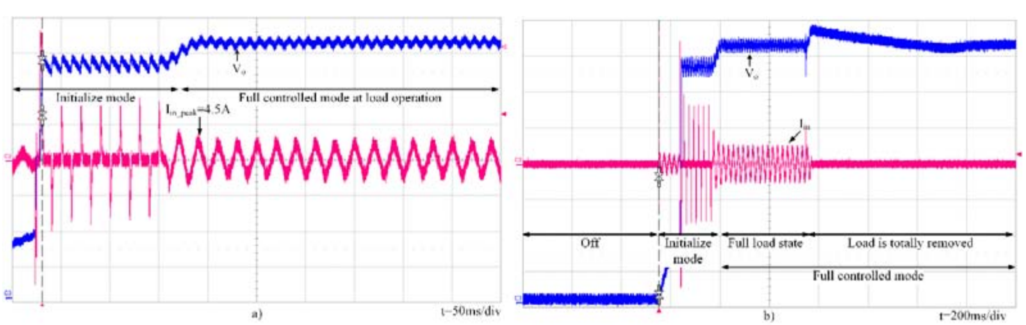


Figure 7. Output voltage and input current of power supply module using 230Vrms socket supply; a) start-up system until steady state is reached, b) start-up system then immediately remove the load.

4. CONCLUSION

As a conclusion, this power supply is properly tested and able to provide high voltage supply the H-Bridge system. However, there is one limitation that needs to be resolved which is high value of the capacitance in the DC-link when this power supply is connected to the H-bridge system. This problem caused the system to draw excessive amount of current and might damage the power supply. One solution is to add the small value of resistance during the startup which is parallel with the DC fuse on the output side. The resistance limit the inrush current during the startup and once the system reach stability, DC fuse can be connected using contactor or some kind of switch. However, this method needs to be properly implemented to make sure the safety of the high voltage power supply operation, used in the experimental setup. In the end, additional validation are require before power supply can be fully implemented to the experimental setup for HF transformer evaluation.

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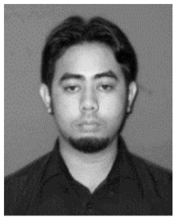

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