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Wind Energy Power System Simulation for a Remote Area Power Supply

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Abstract— This work focuses on the designing and analysis of a wind energy power system for a Remote Area Power Supply (RAPS). The system introduces a three phase ac-ac converter with an isolated high frequency-link for a wind energy conversion system. The galvanic isolation is provided by the HF transformer. The transformer is having the magnetizing inductance which improves power transfer capability. The capacitors are designed on both sides of the transformer to realize ZVS for semiconductor devices and in addition to that it gives passive clamping. The design provides a reduced switch count in order to reduce the losses. The power flow is bi-directional and thus power-flow can be reversed. The operation of the three phase ac-ac converter is explained in eight modes of operation. The performance of the system is analysed using MATLAB/ SIMULINK environment.

Keywords— Wind energy power system, ZVS, HF transformer, Remote Area Power System, RB-IGBT.

I. INTRODUCTION

With the developments in the power electronics, low-cost, high reliability and efficiency converters are available for wind turbine (WT). This paper introduces an isolated zero voltage-switched three phase ac-ac converter with a high-frequency link transformer for low and medium power applications. A small air-gapped high-frequency transformer acts as the key component by providing galvanic isolation as well as transferring power using its magnetizing inductance. Two small capacitors are placed on both sides of the transformer to realize zero-voltage switching for the semiconductor devices in addition to passive clamping [1]. Therefore, the proposed topology is expected to be highly efficient and reliable due to soft switching operation and exclusion of limited lifetime electrolytic capacitors. The basic operation of the converter includes eight modes and is described in detail. Simulation results are provided to verify the performance of the proposed power converter.

II. ZVS ISOLATED HIGH FREQUENCY LINK AC-AC CONVERTER

In this work, the development of soft-switching ac-link converter is presented. The figure shows the proposed wind energy conversion system connected soft-switched HF-link three-phase ac-ac converter with remote area power supply as load.

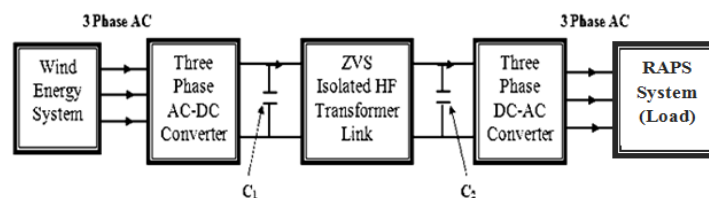


Fig.1 Block Diagram of ZVS Isolated High-Frequency –Link Three AC-AC Converter

A. Energy Delivery to Remote Area Power Supply

Wind turbines are used to generate electricity from the kinetic power of the wind. There are two main kinds of wind generators, those with a vertical axis, and those with a horizontal axis. Wind turbines can be used to generate large amounts of electricity in wind farms both onshore and offshore.

The galvanic isolation is provided by the High-Frequency transformer T_1 . The High-Frequency link of the converter is formed by the magnetizing inductance of the transformer, L_M , and capacitors C_1 and C_2 . These capacitors also act as passive protection and avoid voltage spikes due to the leakage inductances of the transformer when the input or output switches are turned OFF.

The converter employs 12 reverse-blocking insulated-gate bipolar transistors (RB-IGBT). There are two low-pass filters at both sides of the converter to suppress HF harmonics. Power transfer is achieved by the link inductance, L_M , by charging from the input phases and discharging to the output phases. There is no direct power transfer from the input to the output. The link capacitors, C_1 and C_2 , realize partial resonances between the charging and discharging modes to obtain soft-switching operation. A Remote Area Power Supply (RAPS) is, as the name suggests, an electricity supply system often located in a remote area and

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unconnected to a major utility grid. These systems are also known as Stand-Alone Power Systems (SAPS).

III. CIRCUIT CONFIGURATION AND OPERATION PRINCIPLE

The soft-switched HF-link three-phase ac-ac converter is presented. Galvanic isolation is realized by the HF transformer T_1 . The HF link of the converter is formed by the magnetizing inductance of the transformer, L_M , and capacitors C_1 and C_2 . These capacitors also act as passive snubbers and avoid voltage spikes due to the leakage inductances of the transformer when the input or output switches are turned OFF. An airgap may be used in the design of the transformer T_1 to create a proper magnetizing inductance [1].

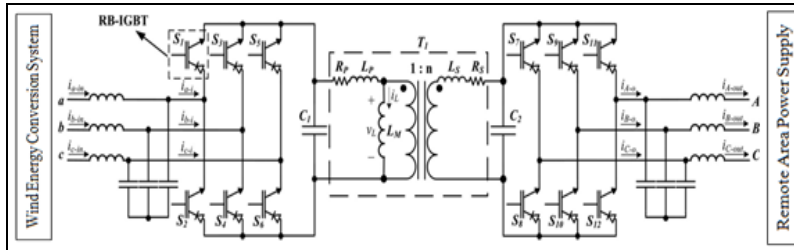


Fig. 2 ZVS isolated HF-Link three-phase ac-ac converter

As the figure shows, the converter employs 12 reverse-blocking insulated-gate bipolar transistors (RB-IGBT). The RB-IGBT has a symmetrical blocking voltage characteristic, which means that it can block both forward and reverse voltage in its off-state. A series combination of a conventional IGBT and a diode can also make a reverse-blocking switch; nonetheless, individual RB-IGBT has the advantage of lower total on-state voltage. Although the converter's switches are unidirectional, the converter can transfer power in both forward and reverse directions conveniently as will be shown later. There are two low-pass filters at both sides of the converter to suppress HF harmonics. It should be noted that if the galvanic isolation is not required, the HF transformer can be easily replaced by an inductor and capacitors, C_1 and C_2 can be merged [1].

Power transfer is achieved by the link inductance, L_M , by charging from the input phases and discharging to the output phases. There is no direct power transfer from the input to the output. The link capacitors, C_1 and C_2 , realize partial resonances between the charging and discharging modes to obtain soft-switching operation [9].

A. RB-IGBT- Reverse Blocking- Insulated Gate Bipolar Junction Transistor

A series combination of a conventional IGBT and a diode can make a reverse-blocking switch. The main difference between the reverse-blocking IGBT and the normal IGBT is that the RB-IGBT is capable of withstanding reverse voltage, i.e. negative collector-emitter voltage. The figure shows the configuration of the RB-IGBT.



Fig.3 RB-IGBT- Reverse-Blocking Insulated Gate Bipolar Transistor

B. Principle of Operation

The proposed resonant HF-link converter is primarily a current-source converter and, as a result, the reference currents of the output phases are necessary in the control scheme. The reference currents of the input phases are also required in this converter's control scheme. The input reference currents can be calculated using the output power and the estimated power loss of the converter. For example, the input reference current of phase a can be given by:

$$i_{a-i.ref}(t) = [\sqrt{2} (P_{out} + P_{loss}) / \sqrt{3} V_{Li}] \sin(\omega t) \quad (1)$$

where V_{Li} is the input line rms voltage, P_{out} is the output active power, and P_{loss} is the estimated power loss of the converter. The input reference currents of phases b and c can be calculated similarly. These reference currents should have the same frequency and phase angle respective to their corresponding input phase voltages to achieve a unity input power factor. The operation of the converter is not highly sensitive to the exact value of the power loss ($P_{out} \gg P_{loss}$); however, to reach an accurate value of the power loss, both the input and output active powers can be measured frequently.

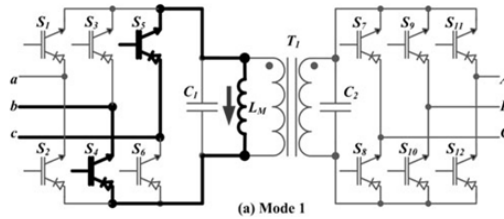
The introduced converter has eight modes of operation in each link cycle. Basically, there are two modes for charging the link inductance from the input phases and two modes for the link inductance to be discharged to the output phases. In addition, there are four resonant modes between these active modes to create soft transition.

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C. Modes of Operation

Mode 1 (Charging)

The HF link is connected to an input phase pair with the highest instantaneous voltage by turning on two proper input-side switches. Therefore, the link inductance, L_M , charges in the positive direction. This mode is allowed to run until the average current of one of the connected input phases meets its instantaneous reference value. The switches are turned OFF afterward. Hence, the connected phase with the smaller instantaneous reference current magnitude meets its reference current in this mode.



(a) Mode 1
Fig. 4 Mode 1

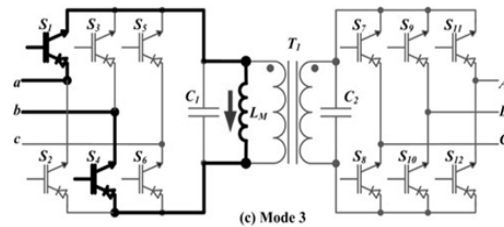
The other connected phase will be linked to the HF link in mode 3 again to meet its reference value accordingly. Owing to the existence of the link capacitors, the link voltage, $v_L(t)$, drops slowly when the mode-1 switches are turned OFF. As a result, the voltages of mode-1 switches increase slowly at their turn-off, which concludes that the switches are turned OFF at almost zero voltage. This zero-voltage turnoff occurs similarly for all the converter's other switches at all line and load conditions.

Mode 2 (Partial Resonance)

The link inductance starts to resonate with its parallel capacitors, and the link voltage starts to drop. This partial resonance continues until the link voltage is equal to the second-highest instantaneous input line-to-line voltage.

Mode 3 (Charging)

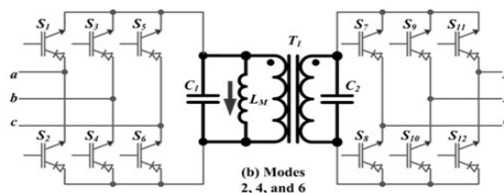
Link is connected to an input phase pair with the second highest instantaneous voltage.



(c) Mode 3
Fig. 5 Mode 3

Mode 4 (Partial Resonance)

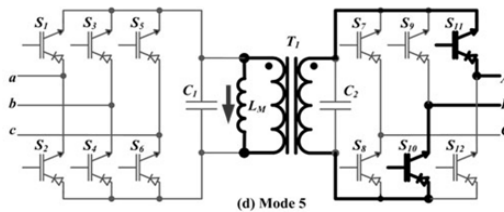
All switches are turned off.



(b) Modes 2, 4, and 6
Fig. 6 Mode 2, 4 and 6

Mode 5 (Discharging)

Link is connected to an output phase pair with the lowest or 2nd-lowest instantaneous reference current difference.



(d) Mode 5
Fig. 7 Mode 5

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Mode 6 (Partial Resonance)

The link components resonate together again until the link voltage equals the reflected voltage of the mode-7 phase pair.

Mode 7 (Discharging)

Link is connected to an output phase pair with the lowest or 2nd-lowest instantaneous reference current difference.

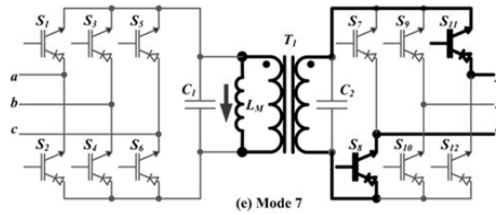


Fig. 8 Mode 7

Mode 8 (Considerable Resonance)

The HF-link components resonate together again. This partial resonance runs until the link voltage becomes equal to the highest instantaneous input line-to-line voltage, and consequently, the converter goes to mode 1 with ZVS.

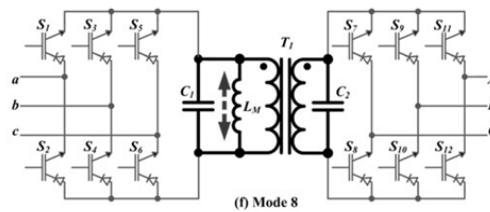


Fig. 9 Mode 8

Thus the design and operational modes of isolated ZVS High-Frequency-link AC-AC converter.

IV. SIMULATION MODELS AND SIMULATION RESULTS

A. Wind Power Generating System

Wind Energy is conversion of kinetic energy (i.e. energy of motion of the wind) into mechanical energy that can be utilized to generate electricity.

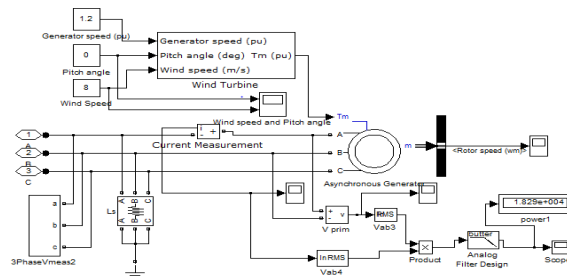


Fig. 10 Wind Energy Power Generating System

B. Simulated Output Waveform from Wind Power System

Simulated Output Voltage Waveform from Asynchronous Generator (SCIG) for Wind Speed = 8m/s

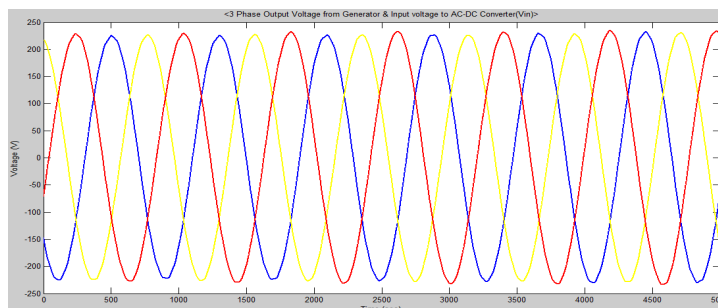


Fig. 11 Waveform: Time(s) vs Three Phase Output Voltage from Asynchronous Generator(V_{in})

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The output from generator is a three phase AC output. The magnitude of the output voltage is 208V AC.

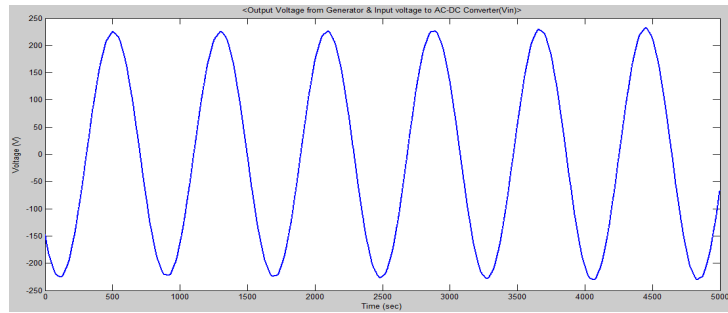


Fig. 12 Waveform: Time(s) vs R Phase Output Voltage from Asynchronous Generator(V_{in})

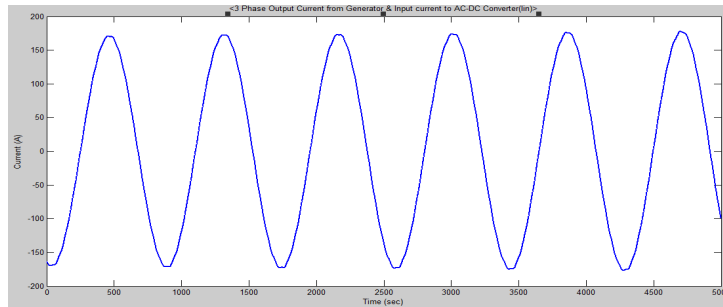


Fig. 13 Waveform: Time(s) vs R Phase Output Current from Asynchronous Generator (I_{in})

The output current from generator is a three phase AC current. The above shown is the current waveform of R phase. The magnitude of the output current is 150A AC.

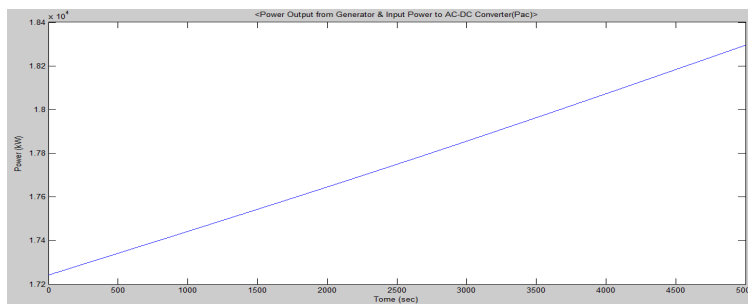


Fig. 14 Waveform: Time(s) vs Power Output from Asynchronous Generator(P_{in})

The magnitude of the output power from the wind power generating system is 18.5kW. Thus the above shown results of voltage, current and power are the generated results from the wind power generating system. The asynchronous generator (Squirrel-Cage Induction Generator) is used for conversion of mechanical to electrical energy.

C. Simulated Model of WECS connected ZVS Isolated HF-link Three-Phase AC-AC Converter

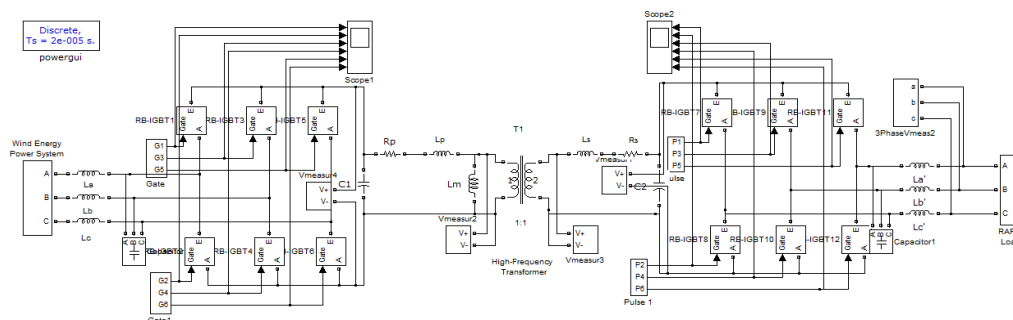


Fig. 15 Simulated Model of over-all system

D. Simulated Output from RB-IGBT Converter and HF-Link Transformer

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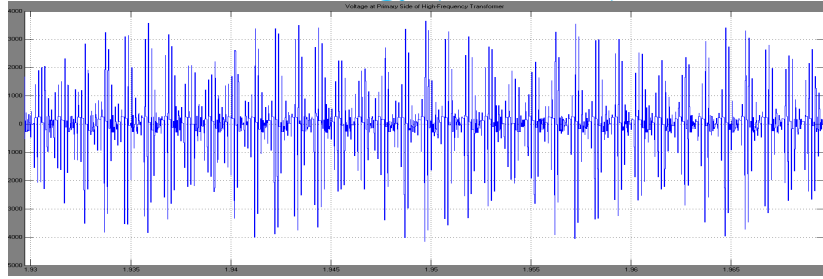


Fig. 16 Waveform: Time(s) vs Output Voltage from RB-IGBT Converter

The voltage output from the reverse blocking –IGBT converter is of magnitude 300V.

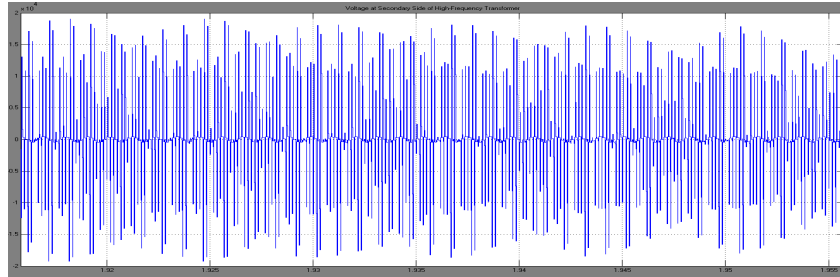


Fig. 17 Waveform: Time(s) vs Output Voltage from HF-link Transformer to RB-IGBT Inverter

The voltage output from the high frequency-link transformer to reverse blocking –IGBT converter is of magnitude 400V. The transformer in the model is a single phase two winding transformer. By assuming the transformer to be ideal, the turns ratio is taken as 1:1.

E. Simulated Output from RB-IGBT Converter and HF-Link Transformer

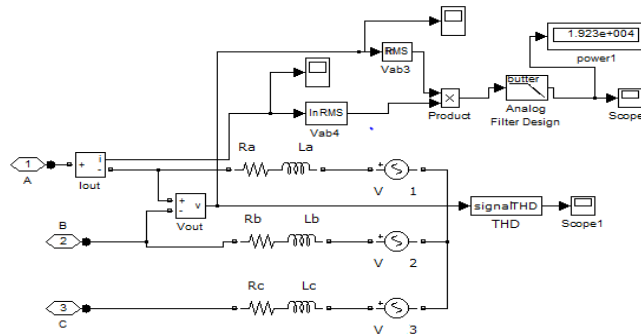


Fig. 18 Simulated Model of the Remote Area Power Supply (RAPS)

F. Simulated Output Waveform from Remote Area Power Supply

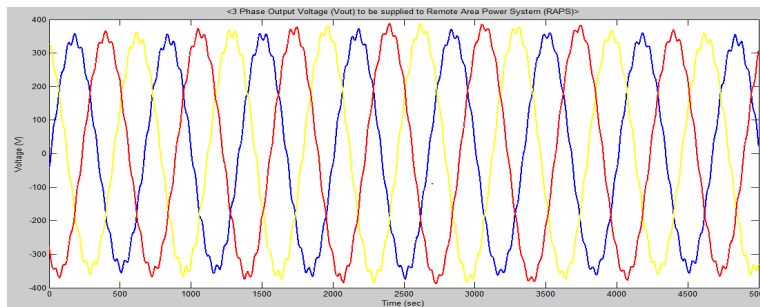


Fig. 19 Waveform: Time(s) vs Three Phase Output Voltage from Remote Area Power Supply acting as Load (V_{out})

The output from Remote Area Power Supply which is acting as Load is a three phase AC output. The magnitude of the output voltage is 380V AC.

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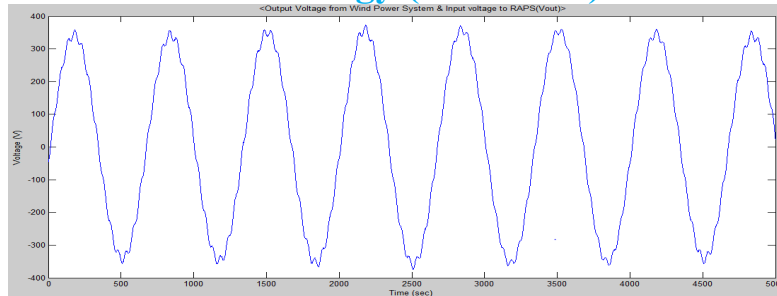


Fig. 20 Waveform: Time(s) vs R Phase Output Voltage from Remote Area Power Supply acting as Load (V_{out})

This RAPS system is employed in areas where the long-term cost of connecting to a utility grid is more expensive than the life-cycle cost of RAPS.

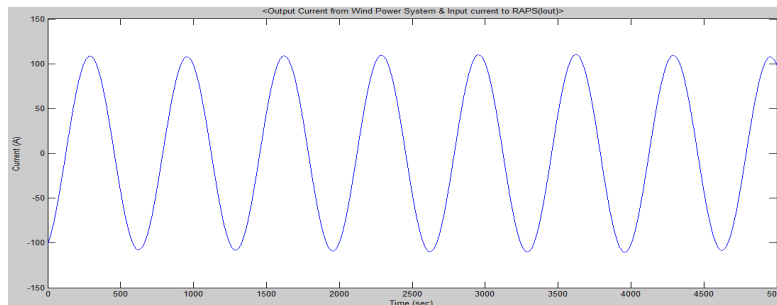


Fig. 21 Waveform: Time(s) vs R Phase Output Current from Remote Area Power Supply (RAPS)

The output current from RAPS is a three phase AC current. The above shown is the current waveform of R phase. The magnitude of the output current is 100A AC.

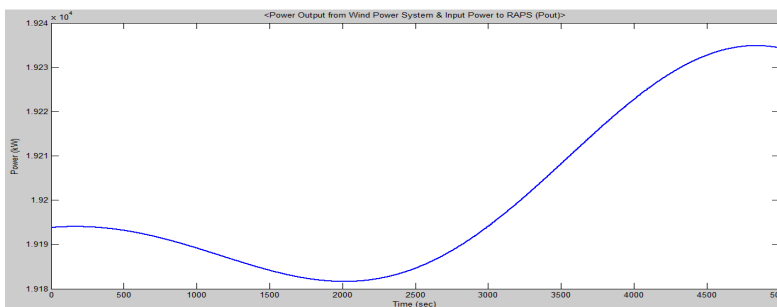


Fig. 22 Waveform: Time(s) vs Power Output from Remote Area Power Supply (RAPS)

The magnitude of the output power from Wind Power Generating System connected ZVS isolated HF-link three-phase ac-ac converter is 19.2kW. Thus the above shown results of voltage, current and power are the generated results from the wind power generating system connected ZVS isolated HF-link three-phase ac-ac converter.

V. CONCLUSION

An isolated HF-link three-phase ac-ac converter with soft-switching operation, a high input power factor, and bidirectional power flow was introduced. Galvanic isolation is realized by a single-phase high frequency transformer, which is considerably smaller than line-frequency isolation transformers. The magnetizing inductance of the air-gapped HF transformer and two small capacitors on both sides of the transformer make the HF link of the converter. The transformer's magnetizing inductance is responsible for power transfer, and the link capacitors help to achieve ZVS as well as passive clamping. The detailed behaviour of the converter was shown and the effectiveness of the proposed power topology was verified by means of the matlab simulation.

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