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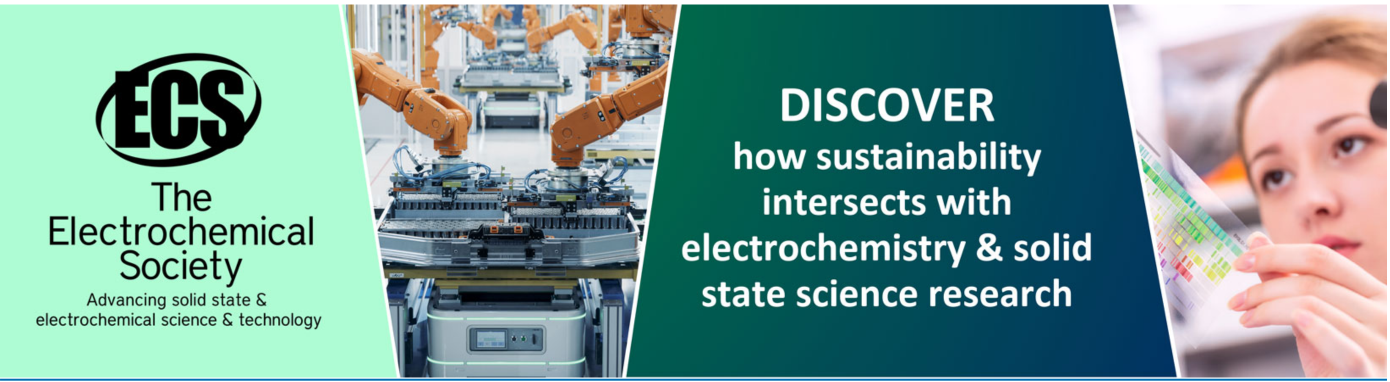

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Design and Simulation of a Portable Copper Tubes Induction Brazing Tool for PV System Application

Hanan Kamil[1], Hamdan F.[2], Fadhil Abbas[2], Isam M. Abdulbaqi[4]

[1, 3] Department of Electrical Engineering, University of Technology, Iraq-Baghdad

[2, 4] Department of Electrical Engineering, Al-Mustansiriayah University, Iraq-Baghdad

eng_hanankamil@yahoo.com

Abstract. This paper presents the design and simulation of a portable induction heating brazing tool. This tool is intended to be very lite, flexible and low price. It is an application of a single-phase Push-Pull as a DC-AC inverter to achieve the high frequency, high voltage suitable for induction heating applications. Two types of power supplies proposed for the welding tool the first is a portable battery, and the second is a photovoltaic panel. The Finite Element Analysis (FEA) applied to study the induction coil design and the welding process using ANSYS programming package, while MATLAB programming package used for simulating the power supply. The achieved results prove the visibility of this tool.

Keywords. Push-Pull Inverter, Induction Heating, Induction Brazing, FEA, ANSYS.

1. Introduction

This work deals with the design and simulation of a portable machine used for brazing copper tubes by induction heating. Since, it is portable then it must fulfill many requirements as a hand tool set, it must be light, small and as low price as possible. These three main restrictions have their effect on the design of this machine. The push-pull idea is considered in this work in order to achieve the following three goals. The first is to convert the DC input to an AC output in single step, the second is to achieve a high output voltage, and the third is to isolate the induction coil circuit to be more saving.

To design the push-pull inverter, the following data about its load must be available:

1. The operating voltage and power.
2. The operating frequency.
3. The expected brazing process time.

In order to prepare these data, the load characteristics of this inverter must be determined. Since the load of this power supply is the induction coil only, then this coil must be designed and its operation during the brazing process has to be analyzed as a preliminary step.

To design an induction coil for such purpose, Maxwell's equations that composed of many partial differential equations must be solved in a three-dimensional model to determine the flux distribution and the eddy currents generated in the copper tube parts under process. This step must be followed by a

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transient thermal analysis to determine the heat distribution due to these eddy currents. Such analyses are known as the electromagnetic-thermal coupled analyses related to the brazing process. Such analyses are adopted to determine the above requirements and to study the brazing process. In order to perform that the Finite Element Method (FEM) adopted to solve these mentioned equations numerically. The FEM solution done using ANSYS R17.0 computer package.

The brazing done normally with the aid of filler material of BCupband BAg type added in the brazing region [1] as shown in Figure (1).

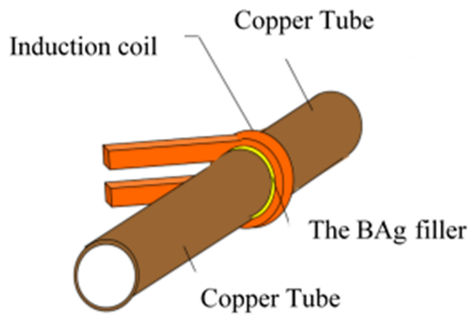


Figure 1. the geometry of the investigated system [1].

The results of the FE model lead to design the proposed push-pull circuit shown in Figure (2) and Figure (3). In this circuit the induction coil is connected in parallel with the resonant capacitor and the tank circuit fed from the push-pull secondary.

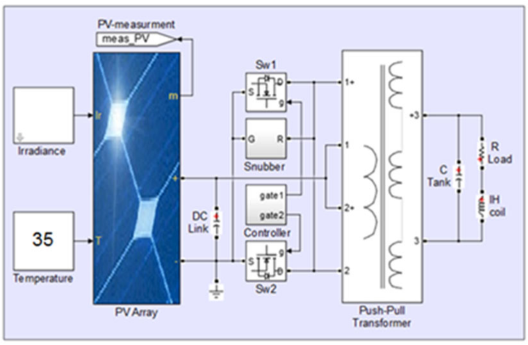


Figure 2. Proposed PV power supply machine.

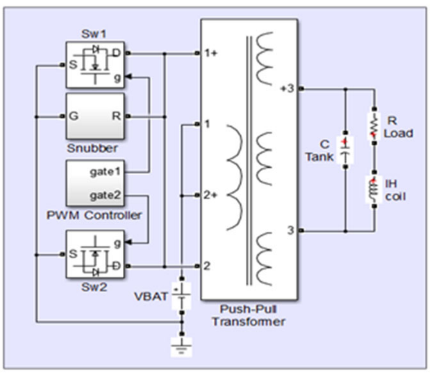


Figure 3. Proposed battery power supply machine.

2. THE INDUCTION COIL DESIGN:

The induction coil composed of one turn only located around the brazing region. The design of such a coil means the determination of the following parameters:

1. The dimensions of the copper tube forming the induction coil itself.
2. The required current passing through it during the brazing period.
3. The required frequency suitable for such brazing process.
4. The time required to perform the brazing process.
5. The equivalent (R-L) circuit of the induction coil

These parameters can be determined by building a 3-D finite element (FE) model for the copper tube to be welded and the induction coil performs the brazing process [3]. This is done using Maxwell's equations to perform the magnetic field distribution and the eddy currents generated in the copper tube parts to be welded. These data are transferred to the associated thermal analysis to calculate the heat distribution in the specimen to be welded due to the flow chart shown in Figure (4) describing this iterative process.

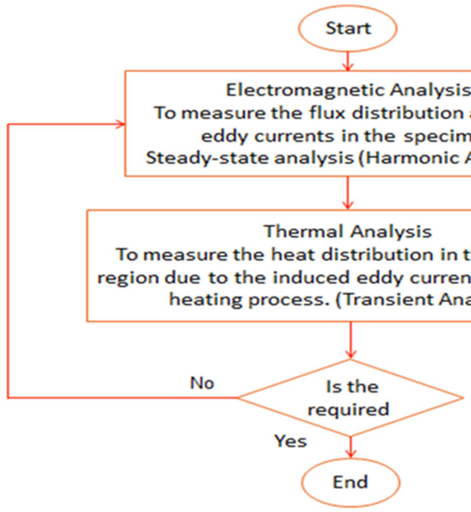
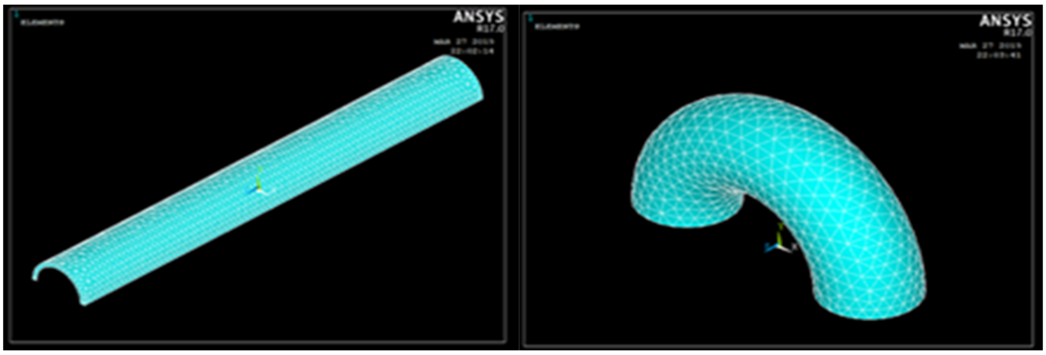


Figure 4. the Flowchart of the Electromagnetic-Thermal Coupled Analysis.

Figure (5-a, b) show half sections of the 3D FE models of the copper tubes to be welded, and the induction coil around it.



(a) The copper tubes mesh. (b) The induction coil mesh.

Figure 5. a, b. 3-D FE model

The coil design process reduces the time, cost and efforts to reach the above suitable parameters using the computer modelling. Figure (6) show the final result of the brazing process by reaching the 602°C in the brazing region during 73s.

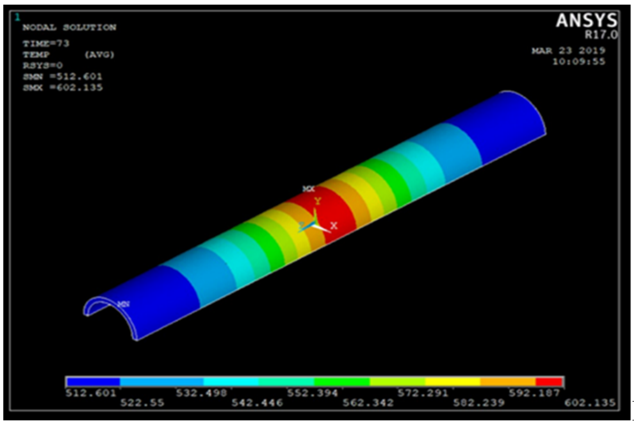


Figure 6. the heat distribution in the specimen.

The FE analysis leads to the truth that the following information must be fulfilled to obtain the brazing process of the copper tube during 73 seconds:

1. The peak value of the coil sinusoidal current (the tank circuit resonant current) must be 1600A.
2. The operating frequency is 50kHz
3. The Coil voltage 355.24V.
4. The secondary current (supplied by the push-pull), 0.36 A
5. The real output power of the push-pull transformer (127.9W).

These data make it easy to estimate the features of the required power supply feeding the tank circuit.

3. DESIGN OF PUSH-PULL TRANSFORMER [2]

Two power supplies are proposed for this work, the first source is PV module have the following parameters, Table-1 shows the simulation parameters of (1SOltech1STH-215-P) module that it is used in the MATLABL/Simulink.

Table 1. Simulation parameters of PV module

Maximum Power (W)	213.15W
Open Circuit Voltage (V)	36.3V
Short-Circuit Current I_{sc} (A)	7.84A
Voltage at maximum power point V_{mp} (V)	29V
Current at maximum power point I_{mp} (A)	7.35A

The available portable battery is 24V, 50Ah, and then it can be considered as the second DC power supply for the push-pull inverter.

Due to the high switching frequency consideration, the core material was chosen to be ferrite. The specification of ferrite core type 0P43515EC is shown in Figure (7) [5]. The specifications and the equivalent circuit parameters of the push-pull transformer are determined due to [4] as shown in Table-2, and its winding distribution is shown in Figure (8). The push-pull transformer equivalent circuit is shown in Figure (9).

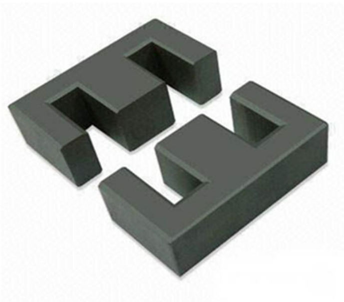


Figure 7. The E-E core of the push-pull transformer.

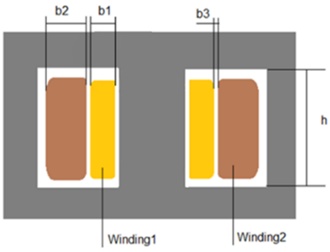


Figure 8. Geometrical distribution of transformer windings.

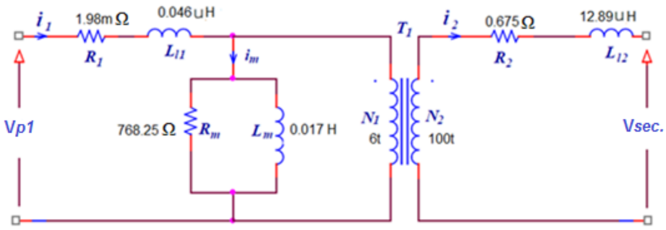


Figure 9. the equivalent circuit of the Push-pull transformer.

The following data represents the designed push-pull transformer as shown in Table-2.

Table 2.

Effective magnetic circuit length (l_e)	6.93cm
Mean length of turn(MLT)	4.0cm
Core area(A_c)	0.87cm^2
Window area (W_a)	1.568cm^2
Turns ratio	20
Primary leakage inductance (L_{l1})	0.0464 µH
Secondary leakage inductance (L_{l2})	12.89 µH
Magnetizing inductance (L_m)	0.017H
Primary resistance (R_1)	1.98 mΩ
Secondary resistance (R_2)	0.675Ω
Core loss resistance (R_m)	768.25 Ω
Efficiency	0.85
Frequency	50kHz
Input voltage (V_{BAT})	24 V DC
Secondary voltage	355.24V
Output power	127.9W

4. PORTABLE BATTERY SIMULATION RESULTS

The MATLAB Simulink used to apply the circuit shown in Figure (3), as represented in Figure (10). This circuit supplied by a 24V battery, while the control circuit feeding a 50 kHz pulses to the gate switches 1 and 2. Figures (10-18) represent the push-pull input voltage, current, output voltage, current, and the coil current waveforms respectively. These results improve the validity of implementing such a portable, light weight, cheap and simple brazing machine.

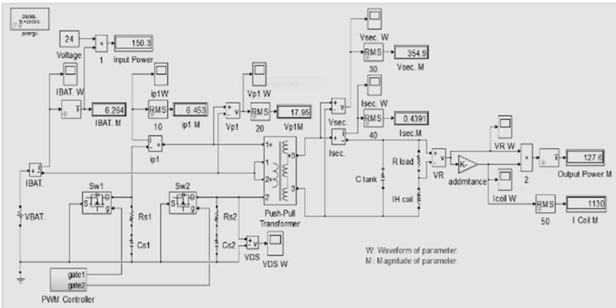


Figure 10. Machine simulation diagram for battery power supply

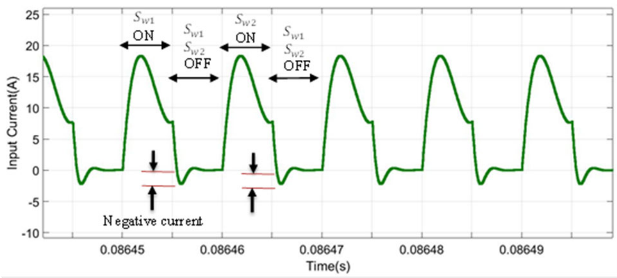


Figure 11. Input current waveform.

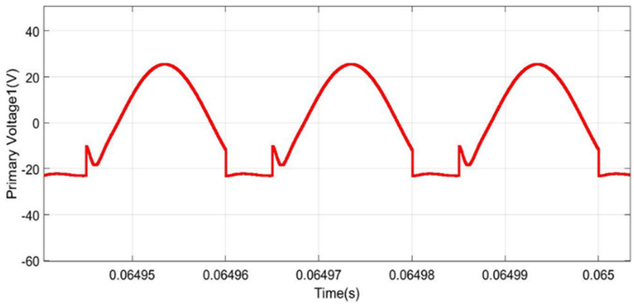


Figure 12. the Push-Pull transformer primary voltage.

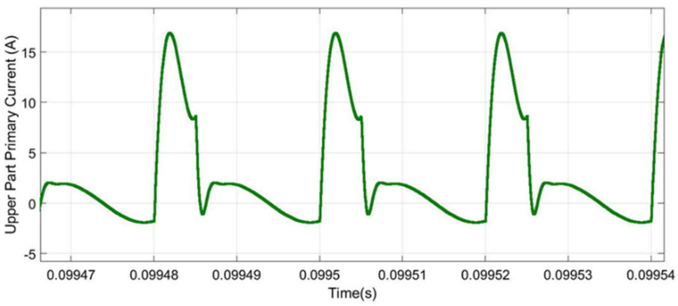


Figure 13. the Push-Pull transformer primary current.

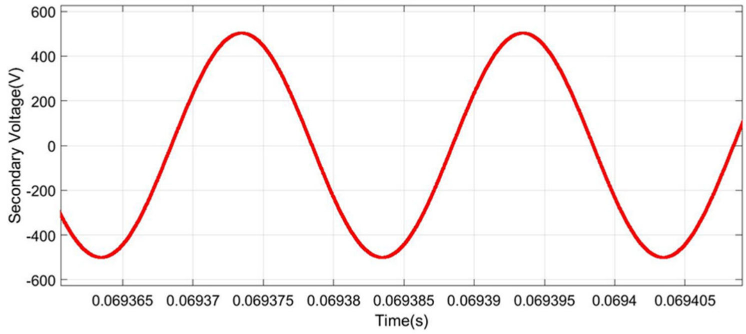


Figure 14. the secondary voltage of the Push-Pull transformer.

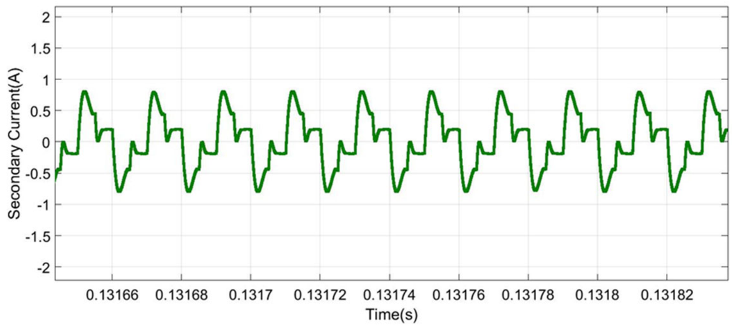


Figure 15. the secondary current of the Push-Pull transformer.

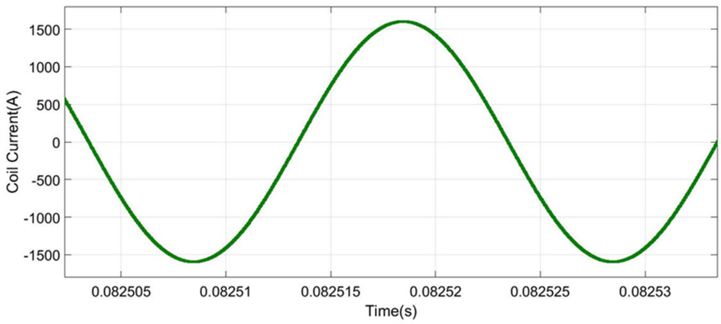


Figure 16. the simulation results of the IH coil current waveform.

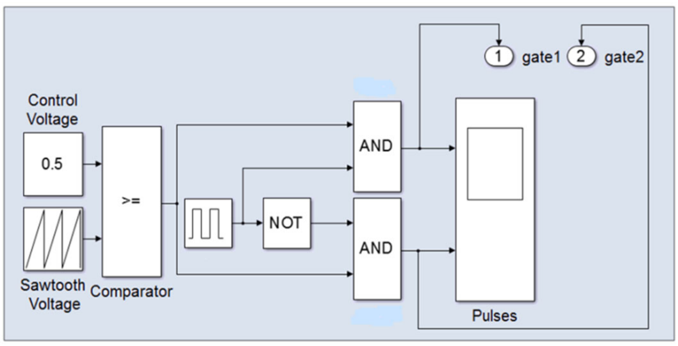


Figure 17. Simulink construction of a gate driver circuit

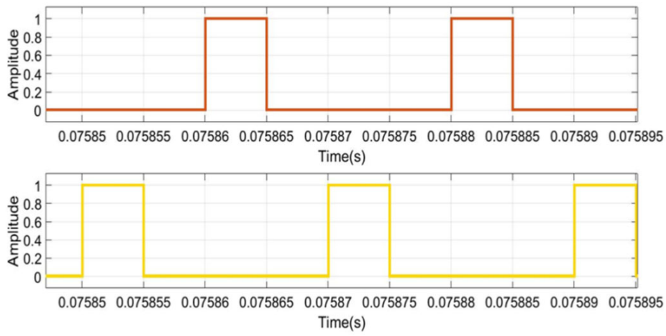


Figure 18. PWM Simulation waveform.

5. PHOTOVOLTIC MODULE SIMULATION RESULTS

The MATLAB Simulink used to apply the circuit shown in Figure (2), as represented in Figure (19). This circuit supplied by a 213.15W PV module, while the control circuit feeding a 50 kHz pulses to the gate switches 1 and 2. Figures (19-27) represent the push-pull input voltage, current, output voltage, current, and the coil current waveforms respectively. These results improve the validity of implementing such a portable, light weight, cheap and simple brazing machine.

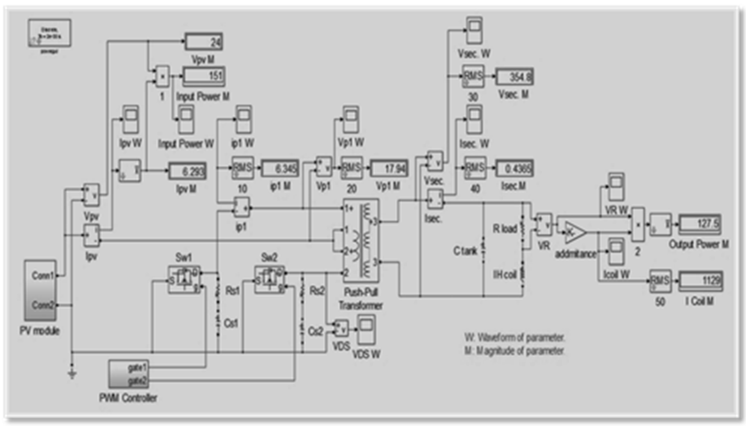


Figure 19. Machine simulation diagram for PV module Power supply.

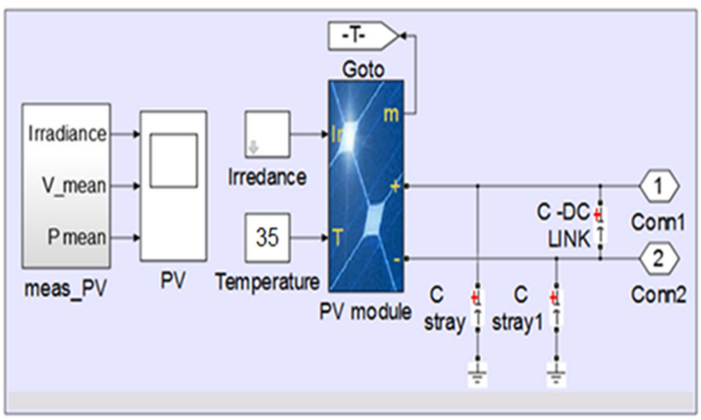


Figure 20. presents the PV module circuit.

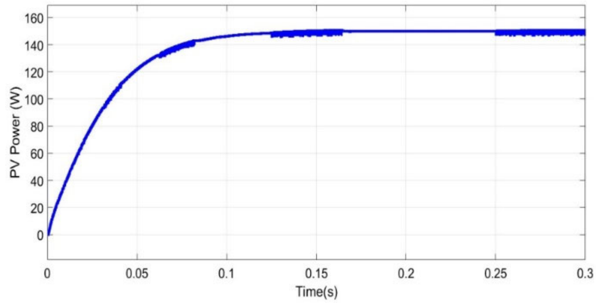


Figure 21. Input Power to Inverter Circuit.

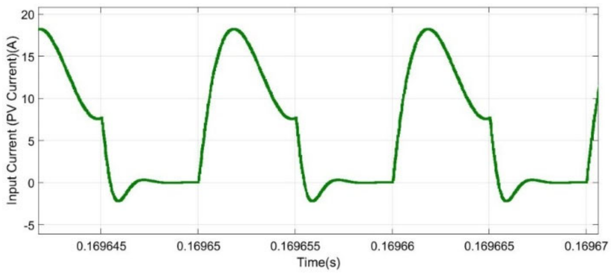


Figure 22. Input current waveform.

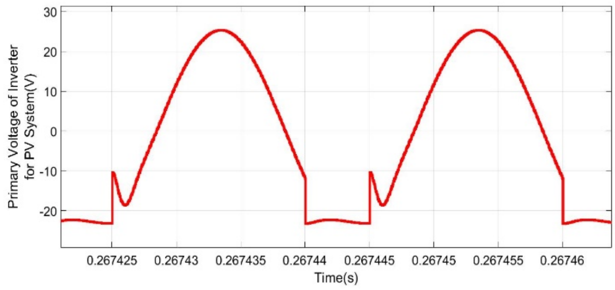


Figure 23. the Push-Pull inverter primary voltage.

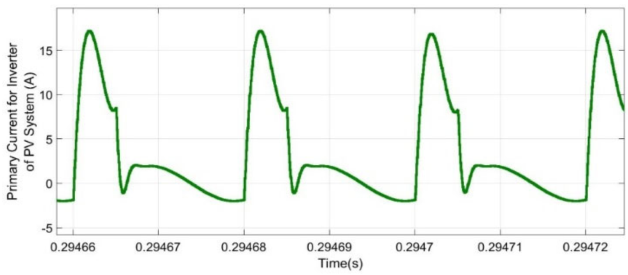


Figure 24. the Push-Pull inverter primary current.

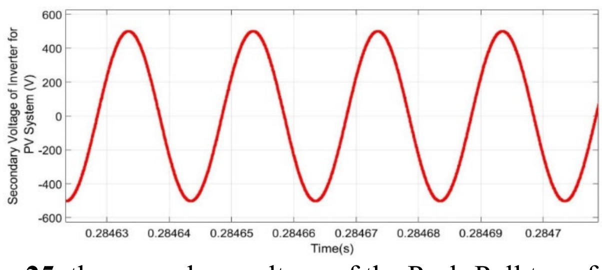


Figure 25. the secondary voltage of the Push-Pull transformer.

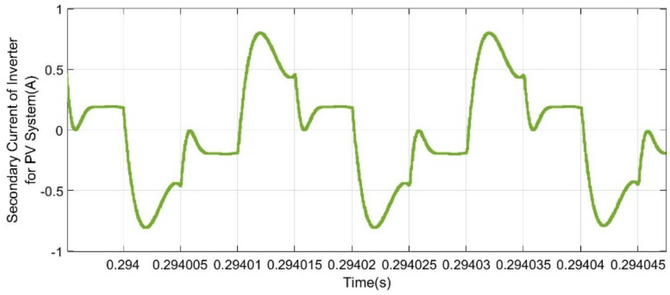


Figure 26. the secondary current of the Push-Pull inverter.

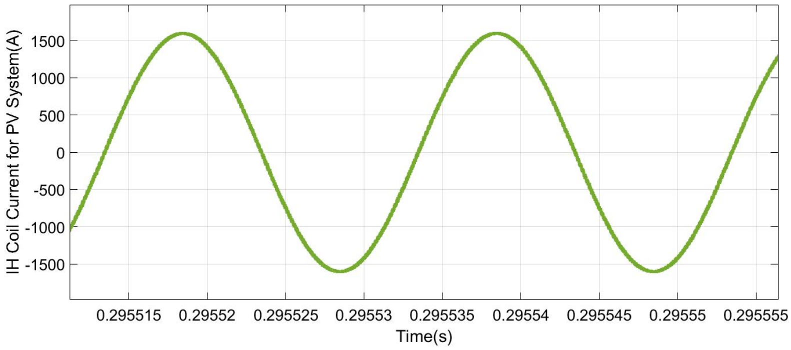


Figure 27. the simulation results of the IH coil current waveform.

For the similar control circuit schematic diagram and PWM pulses mentioned in Figures (17,18)

6. CONCLUSIONS

The analysis done in this work lead to conclude that the ability of building such portable machine. The tank resonant circuit is very effective in performing the required reactive current for such purpose. The high-quality factor of the tank circuit eliminates the need to use the Maximum Power Point Tracker (MPPT) with the PV panel. It is clear that the practical implementation of this portable machine will show different results in that the effects of the connection resistances will appear and this will lead to reduce the quality factor of the tank circuit. This will lead to a slight deviation in the design requirements to match these differences.

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