# Experimental Implementation of a Two Output Series Resonant Inverter Using Arduino

M. HELAIMI, R. TALEB, D. BENYOUCEF, M. R. FELLAGUE, A. ZAGGAOUI
Laboratoire de Génie Electrique et Energies Renouvelables, Université Hassiba Benbouali, Hay Salem, route nationale N° 19, 02000 Chlef, Algérie.
email: halimi1976@yahoo.fr

*Abstract*— **Simulation and experimental studies of two output series resonant inverter with Asymmetrical Duty Cycle (ADC) control are presented in this work. The prototype has been implemented using 06 MOSFET transistors with 06 antiparallel diodes as switches. The inverter is designed to supply two resonant loads. Simulation and experimental results of the output waveforms of the proposed inverter for RLC load are given. Good agreement was obtained between simulation and laboratory experiments.**

***Keywords—A two output series resonant inverter, ADC control, Simulation, Exprimental, MOSFET***

## I. INTRODUCTION

Nowdays, resonant inverters are used in a number of industrial applications including surface hardening, melting, brazing and induction cooking. These inverters are employed to achieve ZVS or ZCS operation by employing the resonant circuit. Depending on a high power density and improved reliability, the full-bridge series resonant inverter based on IGBT's or MOSFET's is the most used topology [1].

In order to improve the conversion efficiency, different control strategies have been proposed including [1]: Asymmetrical duty-cycle (ADC) control, phase-shift control and asymmetrical voltage-cancellation (AVC) control.

In some applications, two inverters are used to supply two resonant loads simultaneously and independently. This technique requires two bridges of eight static switches. If the number of loads is increased, then it will make more the construction cost and take more power consumption [2]-[5].

This paper presents analysis, simulation and experimental implementation of a two output series resonant inverter with Asymmetrical Duty Cycle (ADC) control strategies using Arduino. This system is designed to reduce the number of switches from 4-leg to 3-leg converter.

This paper is organized as follows: the proposed resonant inverter configuration and mathematical analysis of the system is given in Section 2. The main steps of experimental implementation of the proposed inverter are given in Section 3. Section 4 is reserved to present some practical and simulation results. Finally, Section 5 concludes this paper.

## II. PROPOSED INVERTER

This Section describes the simplified topology of the proposed H-bridge two output series resonant inverter [2]-[5]. This configuration includes a DC power supply $V_i$ and six MOSFET switches T1~T6 with external freewheeling diodes D1~D6. The oscillating circuit given in Figure 1 is composed of series combination of $R_i$, $L_i$ and $C_i$.

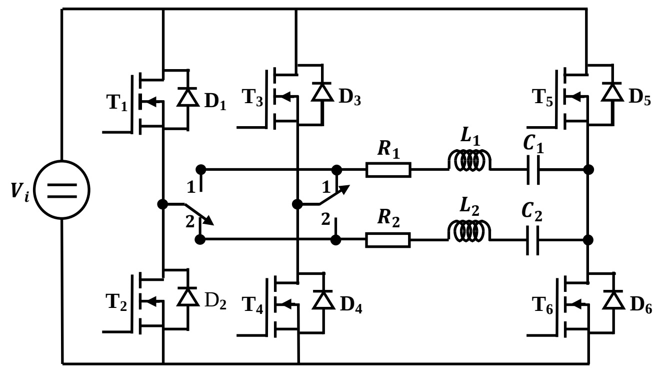


Fig. 1. A two output series resonant inverter

The converter is operated above the natural frequency of the loads given by:

$$\omega_{0i} = \sqrt{\frac{1}{L_i . C_i}}, i = 1,2 \quad (1)$$

According to the switch ON-OFF conditions the typical waveform of the applied voltage $u_{ab}(t)$ is given in Figure 2 [1]:

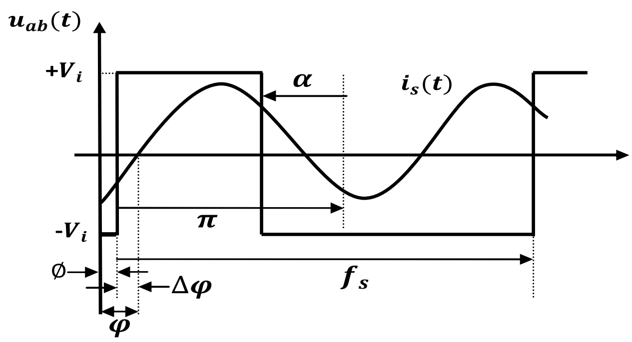


Fig. 2. Asymmetrical duty cycle control

In order to simplify the analysis, the following assumptions are considered:
The switches T1~T6 and the transformer are ideal.
The converter loses are negligible.

The first harmonic of the applied voltage is given by:

$$U = \frac{V_i}{\pi}.\sqrt{10 + 6.\sin\alpha} \quad (2)$$

The phase of the fundamental frequency of the applied voltage $\theta$ is expressed as:

$$\theta = tan^{-1}\left(\frac{\sin\alpha}{3+\cos\alpha}\right) \quad (3)$$

The input impedance can be expressed by:

$$Z_i = \sqrt{R_i^2 + (L_i.\omega_{si} - \frac{1}{C_i.\omega_{si}})^2}, i = 1,2 \quad (4)$$

where $\omega_{s1}$ and $\omega_{s1}$ are the operating angular frequency of the inverter.

The current $I_1$ and $I_2$ are defined as:

$$I_i = \frac{U}{Z_i}, i = 1,2 \quad (5)$$

Active powers provided by the inverters can be derived as:

$$P_i = R_i.I_i^2, i = 1,2 \quad (6)$$

The differential nonlinear equations that describe the circuit can be written as [2]:

$$\begin{bmatrix} L & 0 \\ 0 & C \end{bmatrix}.\begin{bmatrix} \dot{i} \\ \dot{v}_c \end{bmatrix} = \begin{bmatrix} -R & -I \\ -I & 0 \end{bmatrix}.\begin{bmatrix} i \\ v_c \end{bmatrix} + \begin{bmatrix} f_j \\ 0 \end{bmatrix}.V_i \quad (7)$$

where:

$$i = \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$

$$v_c = \begin{bmatrix} v_{c1} \\ v_{c2} \end{bmatrix}$$

$R$, $L$ and $C$ are diagonal matrices given by:

$$R = \begin{bmatrix} R_1 & 0 \\ 0 & R_2 \end{bmatrix}$$

$$L = \begin{bmatrix} L_1 & 0 \\ 0 & L_2 \end{bmatrix}$$

$$C = \begin{bmatrix} C_1 & 0 \\ 0 & C_2 \end{bmatrix}$$

$f_j$ is a vector which describes the connections between the network component and the input voltage. This vector can take the following values: 1 (forward connection), -1 (reversed connection).

## III. Practical Implementation

This Section describes the necessary steps of implementation of the two output series resonant inverter. The system consists of three parts: the power circuit, the control circuit and the oscillating loads. The power circuit is composed of a DC voltage source and 03 arms. Each arm is composed of 02 electronic switches based on electronic MOSFET. Figure 6 shows the schema of one electronic switch:

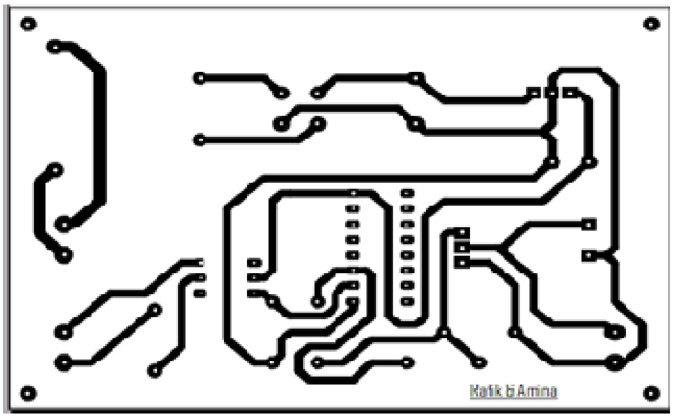

Fig. 3. Schema of one electronic switch

The practical realization of this switch requires appropriate choice of basic electronic components that accomplish the requested function. The following figure (Figure 4) shows the basic prototype switch used in this application.

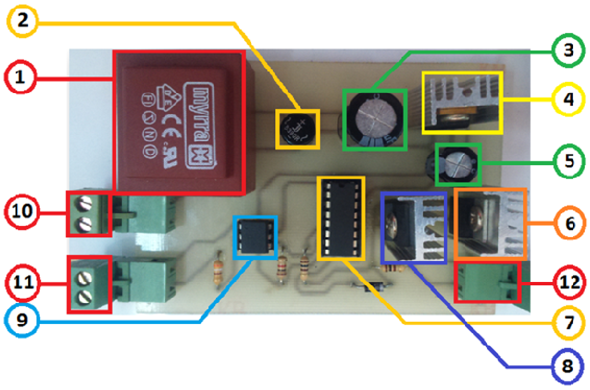


Fig. 4. Experimental prototype of one switch

The realized prototype is composed of:
1-Transformer $220/12v$, 2-Rectifier, 3-Capacity, 4- Regulator 7815, 5- Capacity, 6- Diode RHRP 1540, 7- CD 4050, 8- MOSFET K 2645, 9- Opto.4N25, 10- Terminal $220v$, 11- Terminal $5v$, 12-Terminal.

A laboratory prototype of the proposed inverter is shown in Figure 9. This module ensures the transfer and conversion of power between the source and load.

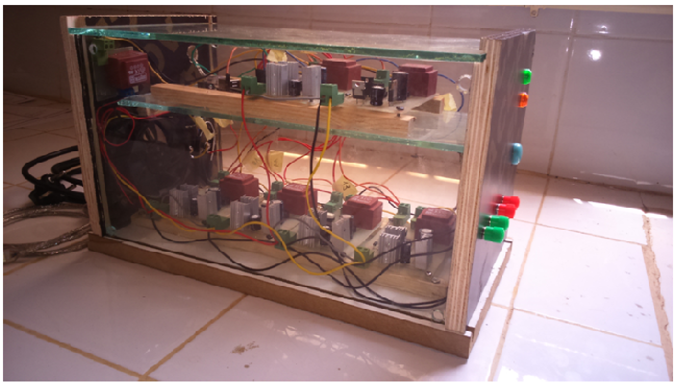

Fig. 5. A two output series resonant inverter prototype

For the control circuit, Arduino will produce a PWM signal pulse train with varying duty cycle of the switch in the range of 0 % to 100 %. Practically, duty cycle for proposed inverter is only in the range of 0 % to 75 %. This is due to instability of inverter. The implemented program is written in C Language. This program is divided into three parts: Declaration of variables, initialization and configuration of inputs/outputs, execution of the main program

Figure 3 shows a part of the main program used to control the switches of the proposed inverter:

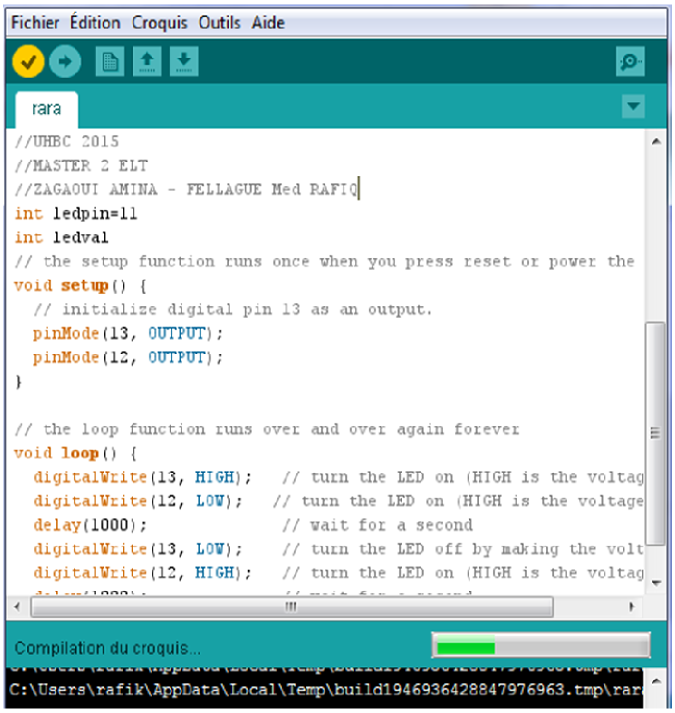


Fig. 6. The implemented program

The oscillating load used in this application consists of three blocks: R, L and C. Each block consists of a series of values as shown in Figure 6:

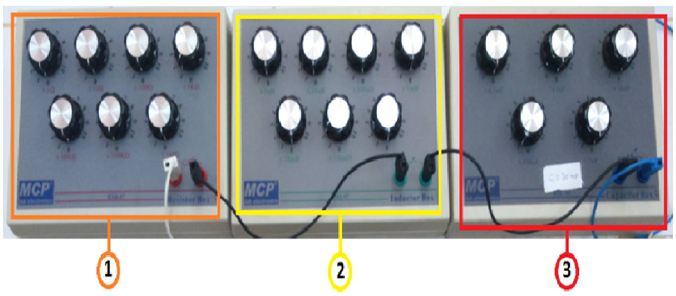


Fig. 7: Series resonant load
1-Resistance, 2-inductance, 3.-Capacity

## IV. Practical Implementation

Proposed inverter configuration with ADC control technique is simulated and experimentally verified using the parameters shown in Table 1. The proposed inverter is designed and operated at switching frequency of 1.14 kHz.

TABLE I. SIMULATION PARAMETERS

| *Item* | *Symbol* | *Value* | *Unit* |
|---|---|---|---|
| Resistance | $R_1, R_2$ | 1; 2 | $[k\Omega]$ |
| Inductance | $L_1, L_2$ | 0.2 | $[H]$ |
| Capacity | $C_1, C_2$ | 100 | $[nF]$ |
| Phase angle | $\alpha$ | 90; 180; 270 | $[°]$ |
| Input voltage | $V_i$ | 5 | $[v]$ |

The experimental results associated with the simulation ones are presented in Figure 8, 9, 10 and 11. These results show the dynamic response of $u(t)$, $u_R(t)$, $u_L(t)$ and $u_c(t)$ as well as $\alpha = 180°$.

The comparison of results obtained in simulation and implementation shows good agreement, which confirms the validity of the analysis and implementation of the system. Both $u_R(t)$ and $u_C(t)$ can be pure sine waveforms around or above switching frequency.

## V. Conclusion

This paper presents analysis, simulation and experimental implementation of a two output series resonant inverter. The conversion of the energy is provided by three arms containing six electronic switches. The control of these switches is ensured by Arduino. The prototype developed in the laboratory is tested for different situations. The obtained results are compared with those obtained from a numerical simulation. The existing agreement between results confirmed the mathematical analysis of the proposed inverter and the performance of the realized prototype.

## References

[1] J. M. Burdio, L. A. Barragan, F. Monterde, D. Navarro, and J. Acero, "Asymmetrical voltage-cancellation control for full-bridge series resonant inverters," IEEE Trans. Power Electron., vol. 19, no. 2, pp. 461-469, 2004.

[2] Pattanapong Kongsakorn and Anuwat Jangwanitlert, “ A two-output high frequency series resonant induction Heater”, IEEE international conference on Electrical Engineering/ Electronics, Computer, Telecommunications & Information technology, pp 842-845, 2010.

[3] S. Jaanaa Rubavathy and P.Murugesan, “Simulation and verification of a multi output series resonant inverter fed induction heater system”, IEEE International Conference on Power Electronics, Drives and Energy Systems, December16-19, 2012, Bengaluru, India.

[4] S. H. Hosseini, A. Yazdenpanah Goharrizi and E. Karimi, “ A Multi output Series-resonant inverter with Asymmetric voltage cancellation control for induction heating cooking appliances”, CES/ IEEE 5th International conference on Power Electronics & Motion control, vol.3, pp 1-6, 2006.

[5] Jose M. Burdio, Fernando Monterde, Jose R. Garcia, Luis A. Barragan, Abelardo Martinez, “ A two output series-resonant inverter for induction heating cooking appliances”, IEEE transaction on Power Electronics, vol.20, N° 4, pp 815-822, July 2005.

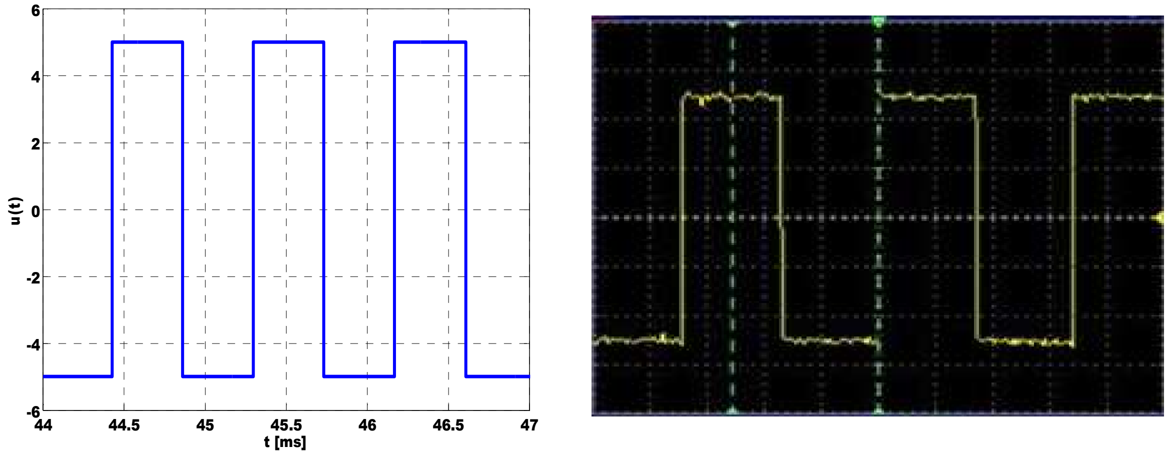


Fig. 8: Simulated and experimental waveforms of $u(t)$ at $1.14kHz$
with $\alpha = 180°,\ 2v/div$

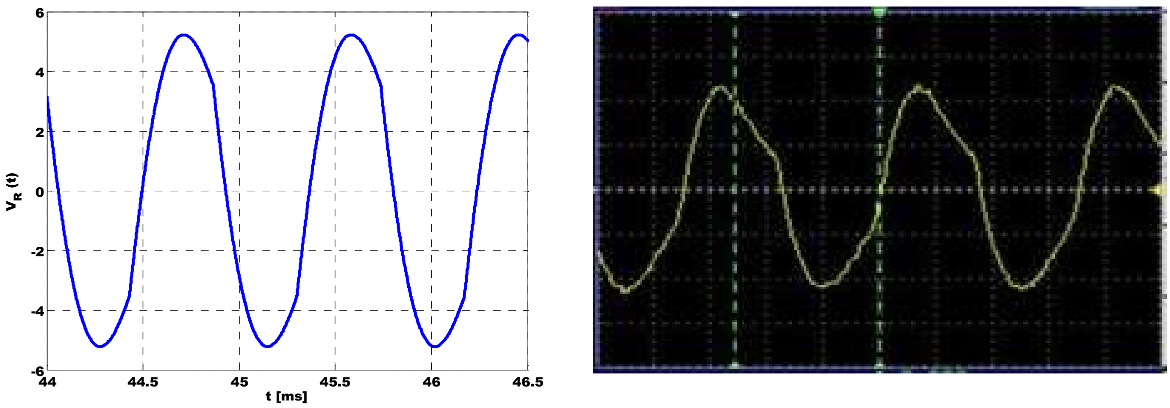


Fig. 9: Simulated and experimental waveforms of $u_R(t)$ at $1.14kHz$
with $\alpha = 180°,\ 2v/div$

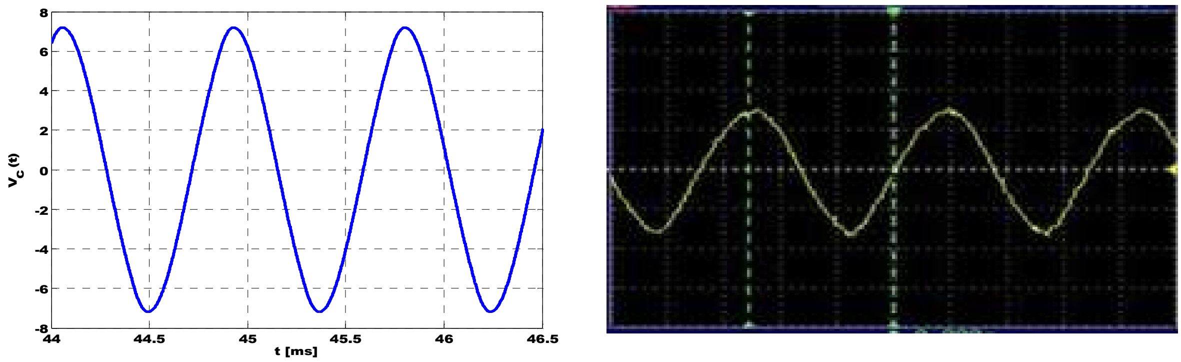


Fig. 10: Simulated and experimental waveforms of $u_C(t)$ at $1.14kHz$
with $\alpha = 180°,\ 5v/div$

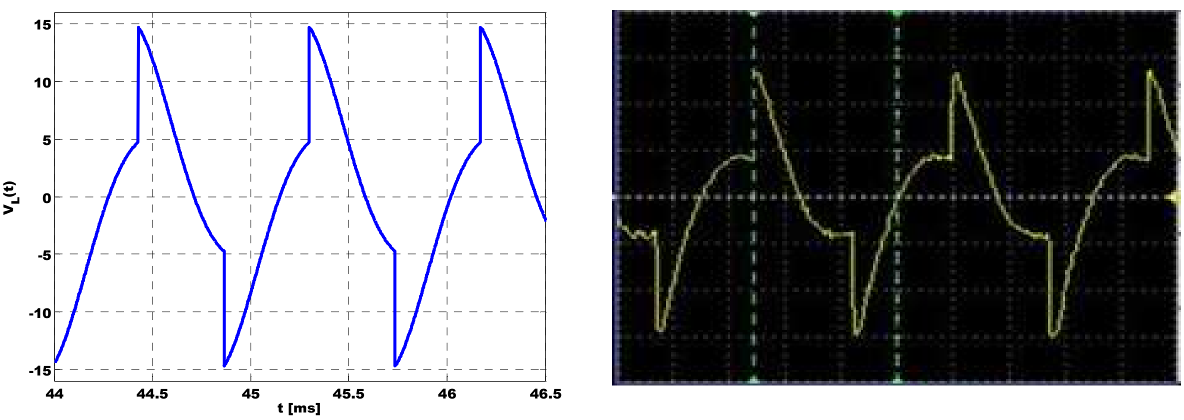


Fig. 11: Simulated and experimental waveforms of $u_L(t)$ at $1.14kHz$
with $\alpha = 180°,\ 5v/div$