

# Current fed inverter application as a controllable DC load

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**Abstract** – High precision electronic DC loads are necessary for testing the characteristics of switching power supplies, DC power sources such as photovoltaics, fuel cells. Variable electronic loads can be controlled from a remote computer for testing equipment in remote areas and other specific research & development or educational purposes. Electronic loads can also be used in distant control of the test equipment. This paper presents an application of a current fed inverter as controllable DC load. The studied topology is a parallel full bridge inverter with thyristors. The control loop is based on a PI regulator and is realized by variable switching frequency and constant duty ratio.

**Keywords** – Power electronic, Controllable DC load, Current fed inverter, Energy recycling

## I. INTRODUCTION

Electronic DC loads have a range of applications in applied engineering and R&D, which include testing of power supplies and DC power sources such as fuel cells and PV generators (fig.1). They are also used for testing steady-state or transient characteristics of generators, including also student laboratory assignments.

The main requirements for DC loads are [1-6]:

- Compact volume and weight
- Wide range of control of the load input impedance
- Precision in the control of current and power drawn from the DC source
- Scalability - parallel connection of several loads for increasing input power range

The simplest usual way of testing batteries, obtaining their polarization curves or photovoltaic generator I-V curves is through series connection of variable resistors. But this is impractical for a powers superior than few hundred watts because it is related with high losses and doesn't provide the necessary precision, because of the resistance temperature dependence and the absence of a current control loop [1-3]. Also the large volume of such equipment can be considered another disadvantage.

Another relatively simple method is the use of a MOSFET transistor and an operational amplifier as a variable load (fig.1) [4]: the resistance between drain and source is modulated through the gate-source voltage. The MOSFET in this method operates in three operation modes (cut-off, active and ohmic region). As a result, most of the power delivered by the source has to be dissipated by the transistor, which limits its application to a relatively low power.

For the convenience of broader power range and better input current accuracy, PWM switching circuits have been studied and tested in the recent years [2-5]. Subject of most of the studies and researches on this subject are DC-DC converters application as electronic load. Different topologies are examined: the Buck converter is not applicable for this purpose, because of the discontinuous input current [3]. The most often used topology is the Boost converter (fig.2). This is mainly because the circuit sizing methodology for Sepic or Ćuk converters is more complex than the Boost and in general they do not possess considerable advantages in this particular application, compared to the boost converter circuit. By the use of an electronic converter, the power is dissipated in the load resistance and in the switching elements (fig.2).

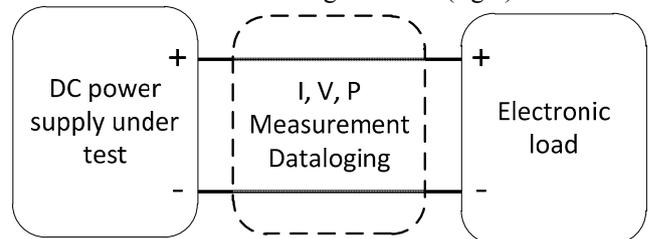


Fig. 1. Test bench for DC power sources

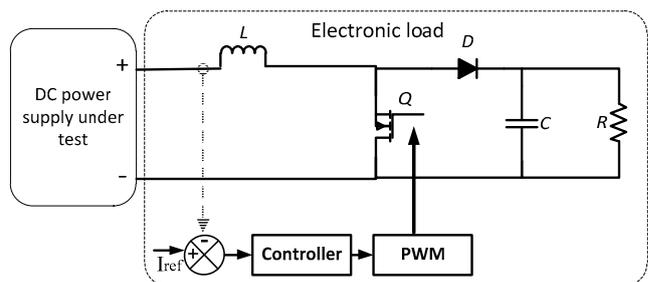


Fig. 2. Boost chopper as electronic load

For testing DC and three-phase AC sources with power greater than several kW energy recycling devices have been developed (fig.3) [3-5]. These consist of a DC chopper (or rectifier when testing AC generators) and a grid-connected single- or three-phase inverter. This configuration raises the maximum power that the load can consume as most of the power drawn from the source is injected to the grid. In this way the energy is “recycled”, instead of being dissipated in heat sinks. This allows testing of sources with rated power up to hundreds of kilowatts.

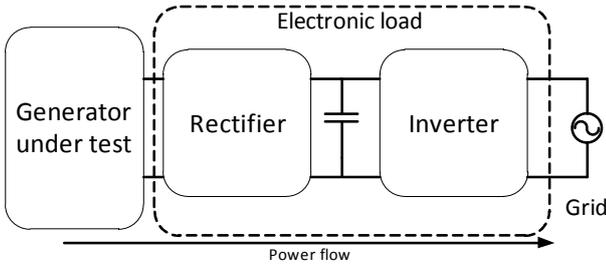


Fig. 3. Testing power sources by energy recycling

## II. CURRENT FED INVERTER APPLICATION AS ELECTRONIC LOAD

In this paper a current fed bridge inverter circuit (fig.4) is used as a controllable DC load. The characteristics required for this appliance are enumerated in table 1. The switching devices are thyristors, but bipolar or MOSFET transistors can be used as well. The inverter equivalent circuit is presented on fig. 5. The current drawn from the source can be considered constant and with zero ripple if the inductance  $L_d$  is high enough. The values of the RC branch are constant. If the duty ratio is also fixed, then the current drawn from the source is a function of the switching frequency  $f$ . In other words, the circuit equivalent impedance is proportional to the switching period  $T$ .

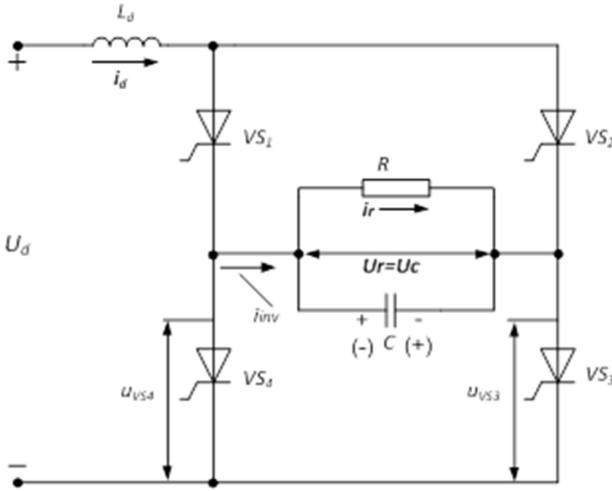


Fig. 4. Current fed inverter circuit

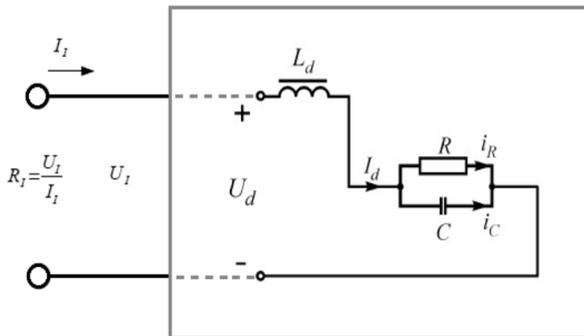


Fig. 5. Equivalent circuit

The circuit analysis is performed under the following adoptions:

- The DC source under study is idealized
- The switching devices, thyristors in this study, are idealized (the voltage drop by conduction is zero).
- The resistance of the input inductor is zero.

These adoptions do not add a considerable loss of precision in the results [6]. The duty ratio of the inverter is 0,5. The value of the input current is controlled by variation of the switching frequency. The circuit operates with switching frequencies in range from 1000 to 19500 Hz to achieve the required range of equivalent impedance. The requirement for the current control loop is a resolution of 500mA or less and the ripple less than 150-200 mA.

TABLE 1. CHARACTERISTICS OF THE DC LOAD

Input voltage range	3÷25 V
Equivalent impedance range	1÷200 $\Omega$
Dissipated power range	0÷525 W
Switching frequency range	1000 ÷20000 Hz

## III. CIRCUIT ANALYSIS

The inverter equivalent circuit can be represented as an idealized current source connected in series to a parallel RC load. The equation describing the circuit is [6-8]:

$$I_d = \frac{u_c}{R} + C \frac{du_c}{dt} \Rightarrow \frac{du_c}{dt} + \frac{1}{RC} u_c - \frac{I_d}{C} = 0 \quad (1)$$

Where  $I_d$  is the current drawn from the source,  $U_c$  is the capacitor voltage,  $R$  and  $C$  are the capacitance and the resistance of the RC branch.  $U_c$  is expressed with the following equation:

$$u_c(t) = I_d R \left( 1 + A e^{-\frac{t}{RC}} \right) \quad (2)$$

The value of the constant  $A$  can be found, from the periodic capacitor voltage in both switching states:

$$u_c \left( t = -\frac{T}{4} \right) = -u_c \left( t = \frac{T}{4} \right) \quad (3)$$

This can be rewritten as:

$$I_d R \left( 1 + A e^{\frac{T}{4RC}} \right) = -I_d R \left( 1 + A e^{-\frac{T}{4RC}} \right) \quad (4)$$

Then the integration constant  $A$  is equal to:

$$A = -\frac{e^{\frac{T}{4RC}} + e^{-\frac{T}{4RC}}}{2} = -\frac{1}{\cosh\left(\frac{T}{4RC}\right)} \quad (5)$$

The switching period  $T$  is expressed from the switching frequency  $f$  and taking into account that the capacitor voltage  $U_c$  is equal to the voltage  $U_r$  is obtained the expression of the inverter input current  $I_d$ :

The current drawn from the DC source is:

$$I_d = \frac{U_d}{R \left( 1 - 4fRC \tanh\left(\frac{1}{4fRC}\right) \right)} \quad (6)$$

The relation of the voltage applied on the load at the inverter output and the DC source voltage  $U_d$  is:

$$u_R(t) = \frac{U_d}{1 - \frac{4}{k} \tanh\left(\frac{k}{4}\right)} \left( 1 - \frac{e^{-k\frac{t}{T}}}{\cosh\left(\frac{k}{4}\right)} \right) \quad (7)$$

Where  $k$  is the load coefficient, whose value is a function of switching frequency and the impedance of the RC branch:

$$k = \frac{1}{fRC} \quad (8)$$

The ratio of the equivalent input and output resistance of the studied circuit is expressed by:

$$\frac{R_i}{R_T} = 1 - \frac{4}{k} \tanh\left(\frac{k}{4}\right) \quad (9)$$

The relation between the DC source voltage ( $U_d$ ) and the voltage across the RC load at the inverter output ( $U_r$ ) is:

$$\frac{U_r}{U_d} = \frac{1}{\sqrt{1 - \frac{4}{k} \tanh\left(\frac{k}{4}\right)}} \quad (10)$$

The circuit parameters are calculated once for  $F_{min}=1000$  Hz the equivalent impedance of the circuit equals  $200 \Omega$ . After that, the maximum switching frequency is found by solving the equation for circuit equivalent impedance  $1 \Omega$ . The maximum frequency is 19346 Hz. Most of the modern thyristors are capable of operating with switching frequency up to 20 kHz.

For the input inductor  $L_d$  is chosen a value of 250mH in order to minimize the ripple current. In theory larger values of this inductance are better, but they tend to add inertia in the system response to profound changes in current reference.

The turn-off time required for restoring the thyristor valve properties should to be considered: on fig. 6 is plotted the relative turn off time  $t_q/T$  expressed in P.U. of the switching period  $T$ . Its value for this circuit at the maximum frequency of 19346 Hz is 0,24T or 12,43  $\mu$ s.

The maximum instantaneous bias voltage applied on the switches also has to be taken into account in order to avoid malfunctions. It is equal to the maximum instantaneous value of the load capacitor  $U_c$ . The capacitor voltage has a peak in the switching instants:  $t=0$ ,  $t=T/2$ ,  $t=T$  etc. The maximum DC source voltage of 25V and the maximal switching frequency are replaced in equation (7) and the value obtained is  $U_{VSmax} = -997$  V.

TABLE 2. SPECIFICATION OF THE CIRCUIT ELEMENTS

$R$	510 $\Omega$
$C$	330 nF
$L_d$	250 mH
Requirements for the switching thyristors:	
$t_q$	$\leq 12 \mu$ s
$U_{VSmax}$	$\geq 1000$ V

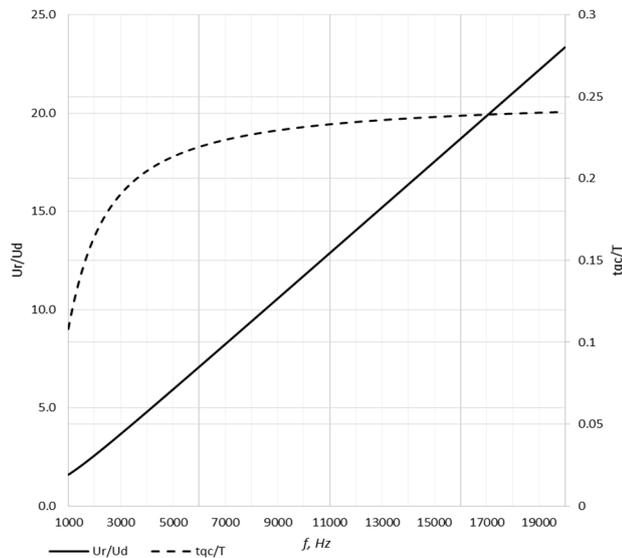


Fig. 6. Frequency analysis of  $t_q/T$  and  $U_r/U_d$  of the inverter circuit.

#### IV. SYSTEM MODEL AND SIMULATION RESULTS

The system is modeled and simulated in MATLAB/Simulink environment (fig.7). The inverter is modeled by its switching equations [6-9]. A signal controlled oscillator drives rectangular pulses for gate signals of the switching thyristors. The switching frequency is controlled by PI regulator with current feedback loop, the integral constants  $K_p$  and  $K_i$  are tuned according to the Ziegler-Nichols method [7-9]. On fig. 8 and fig. 9 respectively are presented the test current reference signal  $I_{dref}$  and as result the current  $I_d$  drawn from the DC source. The system is following correctly the current reference ramp. Fig. 10 presents a more detailed view on the input current ripple. The bias voltage of one of the switching thyristors is shown on fig.11. It is in the boundaries determined by the circuit analysis.

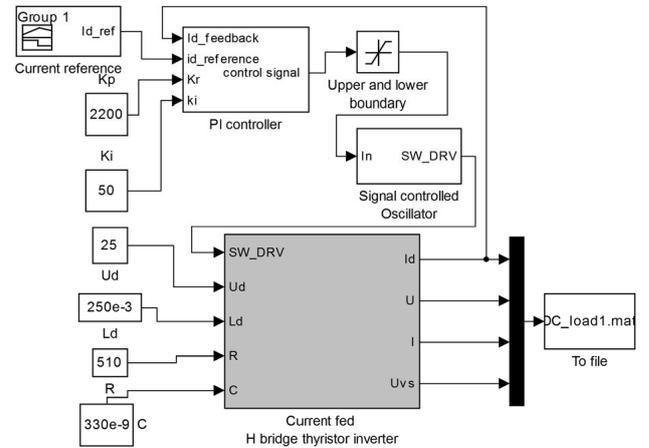


Fig. 7. MATLAB/Simulink model diagram

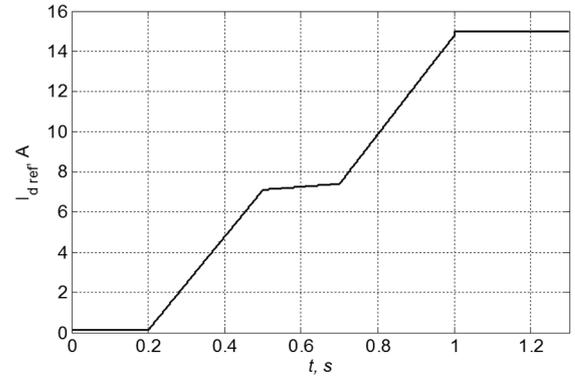


Fig. 8. Reference signal for the DC current  $I_{dref}$  (A)

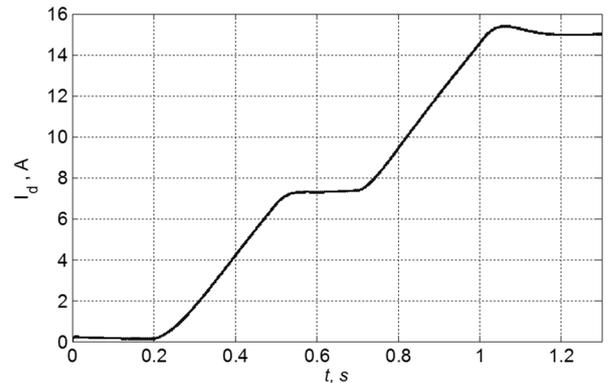


Fig. 9. Current drawn from the source  $I_d$  (A)

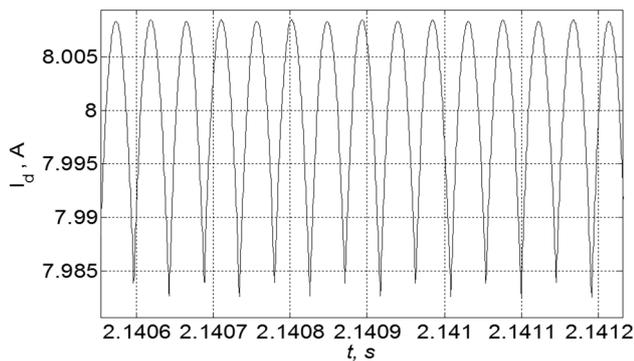


Fig. 10.  $I_d$  current ripple (A)

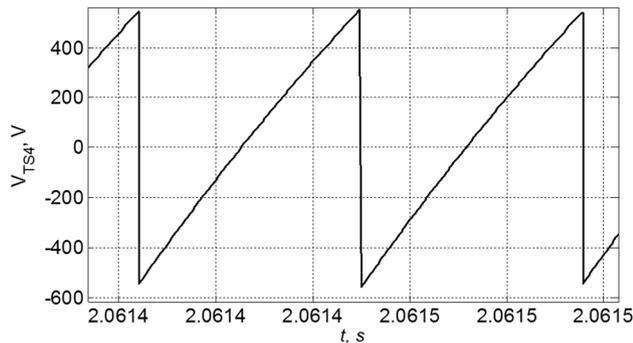


Fig. 11. Bias voltage on the thyristors:  $V_{TS4}$ , V

## V. CONCLUSION

A current fed inverter application as controllable DC load is presented in this paper. The circuit synthesis and equations are presented and the elements are calculated to obtain the required characteristics: input voltage of up to 25V, load equivalent impedance from 1 to 200  $\Omega$  and switching frequency less than 20 kHz which allows the use of thyristors as switching elements. The inverter operates with constant duty ratio and variable switching frequency controlled by a closed current loop. The required characteristics of the switching thyristors: restoration time  $t_{qc}$  and maximum bias voltage  $V_{TS}$  are considered.

The MATLAB/Simulink system model is based on the inverter switching equations. Simulation results demonstrate correct system operation under step changes in the current reference, although the PI controller gives some overshoot. The voltage drop on the switching elements is in the specified range and the thyristor restoration time is as expected. The so synthesized inverter circuit is fully operational and a prototype circuit board can be created for a real test.

In future works advanced control methods, such as Fuzzy Logic, Model predictive control etc. can be experimented for a more robust, rapid and precise system control [10], [11].

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