Entre Ciencia e Ingeniería, ISSN 1909-8367
Año 7 No. 13 - Primer Semestre de 2013, página 9 - 13

Design of a Simple Electronic Load Controlled with Configurable Load Profile[1]

Diseño de una Carga Electrónica Simple Controlada por un Pérfil de Carga Configurada

A. F. Restrepo, J. A. Rusca, E. Franco
Recibido Enero 30 de 2013 – Aceptado Mayo 30 de 2013

***Abstract* - This article presents the design and implementation of an electronic load controlled of low power (60 W), which is normally used to validate the electrical specifications from different power supplies, evaluating the static and dynamic response of the system under test. The power circuit and analog control is specified. Furthermore, the system implemented allows the generation of different load profiles using a low cost microcontroller to generate the load values in different time. Finally, the validation of the electronic load controlled for a load profile is presented.**

***Key Words* - Electronic Load Controlled, Load profile, MOSFET, Microcontroller, Validation.**

***Resumen* - En este artículo se presenta el diseño e implementación de una carga electrónica controlada de baja potencia (60 W), estas son usadas normalmente para validar las especificaciones eléctricas de diferentes fuentes de potencia, evaluando el comportamiento estático y dinámico del sistema bajo prueba. Se especifica el circuito de potencia y control análogo. Además, el sistema implementado permite la generación de diferentes perfiles de carga usando un microcontrolador de bajo costo para generar los diferentes valores de carga en el tiempo. Finalmente, se presenta la validación de la carga electrónica controlada para un perfil de carga.**

Palabras clave - Carga electrónica controlada, Perfil de carga, MOSFET, Microcontrolador, Validación.

[1] Producto derivado del proyecto de investigación "Ambiente espacialmente restringido con campo magnético uniforme de baja magnitud y frecuencia, y compensación del campo geomagnético para estudios sobre sistemas biológicos", desarrollado por el grupo de investigación en Control Industrial, vinculado a la Facultad de Ingeniería de la Universidad del Valle.

Introduction

In most researches on power sources is necessary to use a test system to evaluate the dynamic and static performance of a particular system. Currently there are different modules of electronic loads [1, 2], with different operating ranges [3-5] and with a high cost, for this reason the implementation of an electronic load controlled low-power (60 W maximum) is proposed, which also allows programming of different load profiles using an ATmega16 microcontroller [6].

The electronic load controlled operation basically consists of a MOSFET transistor in the ohmic region [7, 8], this allows for a time varying load, which can be related as a voltage controlled (gate-source voltage) current source (drain current). Furthermore, an overcurrent protection circuit adjustable is implemented by limiting the operating range of the current load.

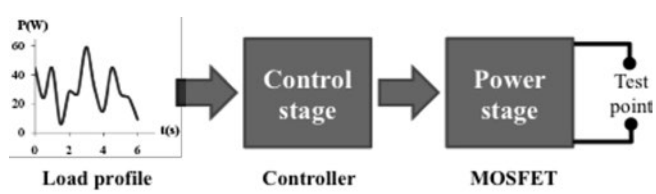


Fig. 1. General system structure

Finally, validation of the electronic load controlled is performed by applying a defined load profile to a source of DC. The possibility offered by the system of having a variable load [9] either linear or nonlinear in time, is one of the most interesting aspects raised in this article.

II. System Description

The general system structure of the electronic load controlled can be seen in Fig. 1, the system basically consists of three stages, the generation stage of the load profile, the control stage and the power stage.

Table I
Specifications of The IRFP32N50K MOSFET.

Parameter	Variable	Value
Drain-Source voltage (to V_{GS} = 0 V)	V_{DSS}	500 V
Gate-Source voltage	V_{GS}	+ 30 V
Drain current	I_D	32 A
Threshold voltage	V_{th}	3 V – 5 V

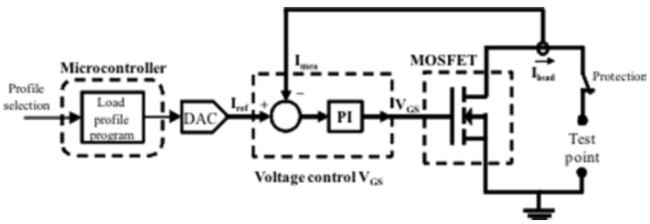


Fig. 2. Power and control diagram of the electronic load controlled.

The generation stage of load profile allows to program a sequence of load values in a controlled manner over time, this stage consists of a ATMega16 microcontroller and a D/A converter which is responsible for providing the reference signal to the controller. The control stage is responsible for maintaining a load current controlled that depends on the supplied reference signal, this control action is performed on the signal voltage V_{GS} of the power MOSFET.

Finally the power stage consists of the operation of a MOSFET transistor in the ohmic region, this mode of transistor operation allows variation of drain current (I_D) as a result of varying the voltage between gate and source (V_{GS}). In Fig. 2 shows a bit more detailed diagram of the electronic load controlled for each of its stages, differentiating the power and control diagram. Below it is a brief description of each stage of the system.

A MOSFET Power stage.

For the implementation of the power circuit is used a power MOSFET reference IRFP32N50K (International Rectifier) [10], N-channel enhancement-mode, its main characteristics are summarized in TABLE I. This device is the basis of the electronic load, due to their technical characteristics; its operation in the ohmic region can be used as a resistance controlled by voltage, taking into account the equivalent circuit of the MOSFET [11].

An important parameter to consider when operating the MOSFET in the ohmic region is the threshold voltage ($V_{GS(ON)}$ or V_{th}), according to data of TABLE I, it presents a range of 3 V and 5 V, which reveals a wide range to find the potential value of V_{th}; in Fig. 3 the manufacturer shows the characteristics for the different curves of the device used. Because of this wide range to determine the threshold voltage, it is best to find this voltage experimentally by adjusting the operating parameters and varying the V_{GS} voltage until generate a drain-source current (I_{DS}).

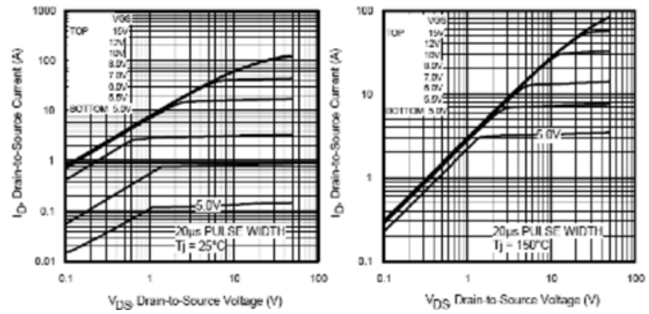


Fig. 3. Typical output characteristics of the IRFP32N50K MOSFET.

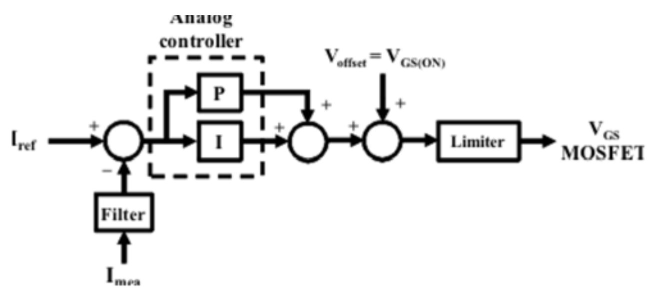


Fig. 4. PI controller diagram of the electronic load controlled.

Initially tests were performed in open loop (without feedback of the measured current) for a behavioral response of the device by applying a voltage between gate and source to find experimentally the V_{th}. The value found of the threshold voltage is $\mathbf{V_{th} = 4{,}6\ V}$, where it begins to circulate the I_{DS} current of approximately 20 mA.

The search of the threshold voltage allowed observing a typical problem of instability by the open loop configuration, since during the test showed a rise in the I_{DS} current generated by the phenomenon of self-heating due to the positive temperature coefficient of the device. For this reason is necessary the feedback system via a control loop as shown in Fig. 4, the controller is designed with a PI action implemented with operational amplifiers and the feedback system by means of current measurement I_{DS} (I_{mea}). The diagram shows that the signal voltage V_{GS} is the sum of measured signal and an offset voltage signal, this offset is adjusted to a value close to V_{th} of the MOSFET.

B Control stage.

After performing open loop tests is defined the controller type to be implemented with the goal of eliminating the steady-state error and obtain a fast system response to a change in the desired reference signal.

The proposed solution uses a PI analog structure (see Fig. 4) to ensure a null steady-state error [12], where initially the feedback voltage signal coming from the LEM HX-10P current sensor and is sent to an operational amplifier (LF353) configured in differential mode, this operation is performed between the reference voltage V_{ref} (proportional to I_{ref}) and the feedback voltage (proportional to I_{mea}), the difference between these voltages generates the error signal that is carried to the PI controller, this error signal is carried to a variable gain amplifier greater than or equal to one to apply the proportional action, and parallel the integral action converging the two actions in an adder implemented with operational amplifiers, finally making the sum of the control action and the offset value (V_{th}).

Thereafter this control signal is carried to an operational amplifier configured as a voltage limiter which includes an additional protection to the electronic load, with the aim of limiting the maximum voltage value applied to the MOSFET in the event that the controller enters a state of instability or present a failure.

The controller keeps track between a desired reference voltage and the sensor voltage, the reference voltage is adjusted in such a manner that retains the same scale of the sensor voltage signal of 400 mV/A [13]. Finally, the relationship between the reference voltage and output current of the electronic load controlled as shown in equation (1) is obtained:

$$I_{load} = 2{,}5 * V_{ref} \tag{1}$$

Where:
V_{ref}: Voltage value proportional to Iref.

Moreover, the circuit overcurrent protection (see Fig. 5) is implemented with two integrated circuits, the LM393 voltage comparator and the LM358 operational amplifier configured as a voltage follower, also used a 2N5064 SCR and a HG4138 relay supporting up to 15 A in their contacts. This protection seeks to interrupt the path of the current through the MOSFET drain terminal bringing it to zero value, allowing the positive terminal of the source or the test circuit can be isolated from the load.

When the measured current exceeds the reference value, the comparator generates a voltage that enables SCR, energizing the coil and allowing the relay activation to produce the opening of a normally-closed (NC) contact; this connects the positive terminal of the circuit under test and the drain terminal of the MOSFET transistor. The opening of this contact (NC) interrupts the power consumption doing zero the drain - source current (I_{DS} = 0 A), this condition is maintained due to the interlocking of the SCR. Therefore, it is necessary to unlocking the SCR to enable again the operation of the electronic load controlled.

C. Load profiles.

One of the most important characteristic of the electronic load is its behavior as a voltage controlled current source, considering this, a system which allows the programming of different reference voltage values over time is implemented in order to set different load profiles.

The system is implemented by means of an ATMega16 microcontroller and a DAC0808 digital/analog converter as shows in the Fig. 2. The reference voltage value of the electronic load is represented in the microcontroller as a digital data corresponding to an analog value between 0 V and 5 V [14]. However, it should ensure a reference voltage between 0 V and 2 V, corresponding to the maximum digital value 0x66H.

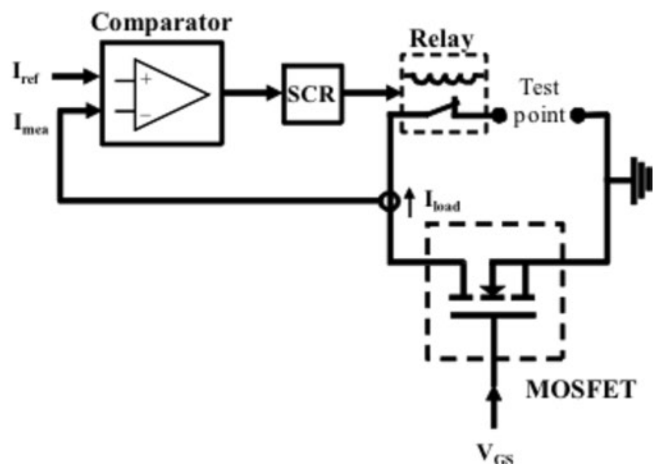


Fig. 5. Protection circuit of the electronic load controlled.

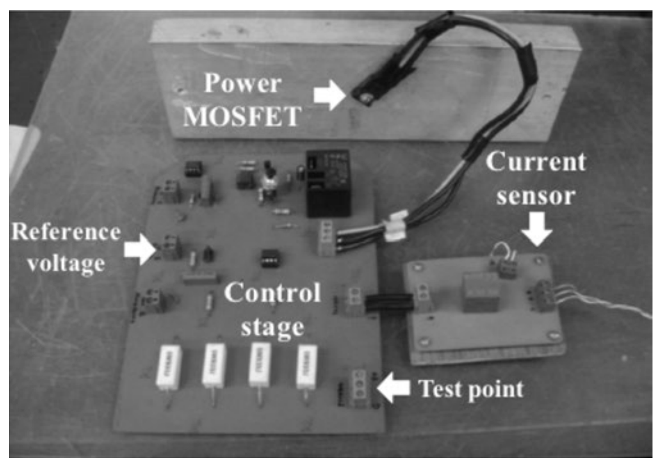
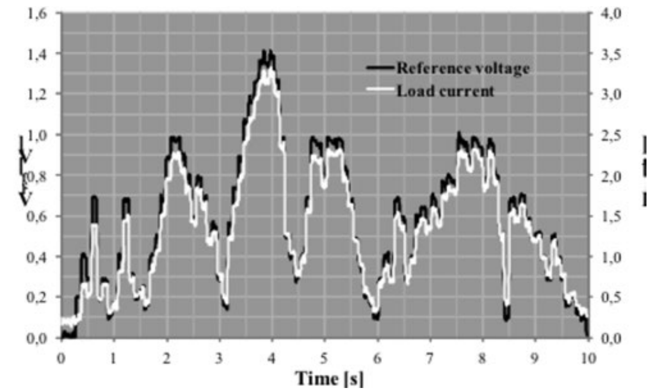


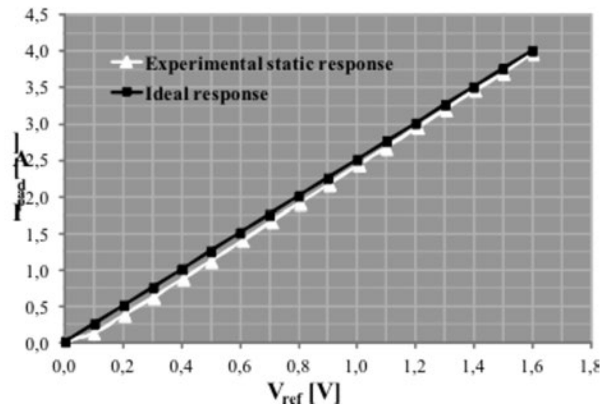
Fig. 6. Hardware implementation of the electronic load controlled.

Different values of reference voltage for a defined load profile are represented in digital data that are stored in a vector in the main program of the microcontroller, program execution consists basically to write the different digital values stored on the C port of the microcontroller to a fixed sampling period.

The hardware implementation of the proposed system shown in Fig. 6, which can identify the control stage, the power MOSFET, the current sensor as well as the reference voltage and test point.



(a)



(b)

Fig. 7. Response of the electronic load controlled.
(a) To variation of Vref. (b) To a defined load profile.

III. Results Electronic Load Controlled

For the validation process partial tests are performed for electronic load controlled using a DC power source. The source was set at an operation voltage of 12 V, obtaining the results shown in Fig. 7, which shows the response of the load current between 0,0 A and 4,0 A to variations of the reference voltage between 0,0 V and 1,6 V respectively.

TABLE II
ELECTRICAL CHARACTERISTICS OF THE ELECTRONIC LOAD CONTROLLED.

Parameter	Value
Operation voltage	12 $V_{(DC)}$
Output current range	0,1 A – 5,0 A
Maximum power	60 W
Reference voltage	0 V – 2 V
Current sensor (hall effect)	LEM HX 10-P

The static response curve of the electronic load to variations in the reference voltage (see Fig. 7 (a)) shows a good correlation between results obtained experimentally and ideally expected data; one can observe a significant offset error for low values of current that decreases as current increases. From the results it gets a maximum error of 52% for V_{ref} = 0,1 V and a minimum error of 1% for V_{ref} = 1,6 V. This offset error for low current values is associated with the offset error of the LEM HX 10-P current sensor which according to the manufacturer is 40 mV [13]; this offset voltage of the sensor affects significantly the low-current measurements.

Fig. 7 (b) shows the dynamic response of the electronic load to a defined load profile by the reference voltage signal, the results show a good tracking of the waveform of the output current with respect to the reference voltage signal. Moreover, one can see the small offset error mentioned above along the entire curve.

Finally with all the above considerations, in TABLE II summarizes the electrical characteristics of the electronic load controlled.

IV. Conclusions

The electronic load controlled was implemented with a low-cost electronics, simple in hardware and software components, converting the system in an alternative of great application for research purposes, allowing experiment with pilot testing of various systems that meet the power under which it was designed the electronic load, ensuring the protection of the system under test and evaluate system performance in critical operating conditions.

The electronic load controlled supports the programming of different load profiles, i.e. which can generate load variations over time, depending on the required specifications. This feature allows the electronic load is used in experimental tests to obtain the static and dynamic response of a power system, for example in low power systems, such as DC sources, dynamical systems, DC-DC converters, among other applications.

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Andrés F. Restrepo was born in Palmira, Colombia, in 1985. He received the Engineering degree in Electronic Engineering, the Master degree in Automatic from Universidad del Valle, Cali, Colombia, in 2010 and 2013 respectively, and is currently a Ph.D. student in Electrical and Electronic Engineering in the same institution. His current research interests are the control systems and the applications of magnetic fields on biological systems, specifically the generation and control of uniform magnetic field with geomagnetic field compensation.

Jorge A. Rusca was born in Jamundí, Colombia, in 1982. He received the Engineering degree in Electronic Engineering from Universidad del Valle, Cali, Colombia, in 2010, and is currently a postgraduate student in industrial automation in the same institution. His current research interest is on industrial control applications, instrumentation and modeling to control applications, more exactly in the production of fuel alcohol from sugar cane juice and electric cogeneration.

Edinson Franco was born in Cali, Colombia, in 1964. He received the Engineering degree in Electrical Engineering, the Master degree in Automatic and the Engineering Doctor degree from Universidad del Valle, Cali, Colombia, in 1991, 1994 and 2007, respectively. He is working as full time professor in the same University, where he is a professor and researcher of the Postgraduate Program on Electrical and Electronic Engineering. His current research interests are technology control applications and education to control.