

AN OVER-CURRENT PROTECTION OF POWER MODULES USING IGBT

**Mincho Rumenov Zhivkov, Georgi Bogomilov Georgiev,
Vencislav Cekov Valchev**

Department of Electronic Engineering and Microelectronics, Technical University of Varna,
Studentska Str. 1, 9000 Varna, Bulgaria, phone: +359 52 383 266, e-mail: m.zhivkov@ieee.org

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An important feature of power electronic converters is the presence of fast and reliable protection. The use of such protection is compulsory in experimental equipment for development of power converters (so called test platforms). This paper presents a solution chosen by the authors for the over-current protection of a test platform (about 6kW in full bridge configuration and frequency range from 20kHz to 400kHz). The proposed circuit provides fast over-current detecting, slow current shut down and possibility for manual or automatic restart.

Recommendations are given about circuit dimensioning as well as simulated results and conclusions are presented.

1. INTRODUCTION

The high frequency operating power modules (above 100kHz) employ MOSFETs as power switches since the IGBTs are frequency limited. However, the de-saturation of the IGBT can be used for short circuit and over-current protection of MOSFET based power stages [1], (see Fig.1a).

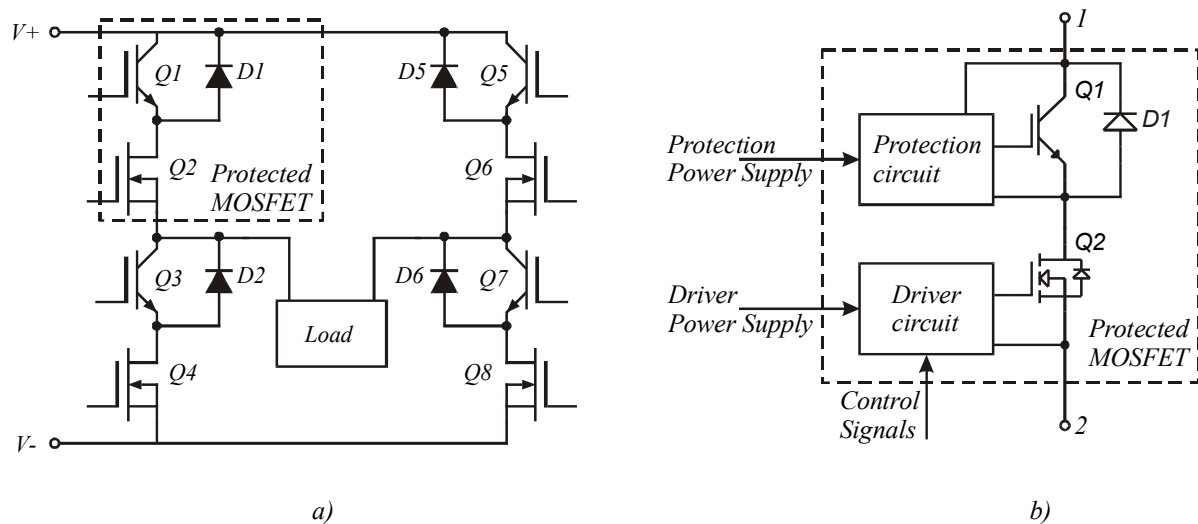


Fig.1 The over-current protection using an IGBT as current sensing device

The basic concept of such solution is illustrated in Fig.1b. The IGBT is in on-state during the turn-on and turn-off transitions of the MOSFET, i.e. during the normal operation of the converter. The load current (between nodes 1 and 2) is measured by monitoring the collector-emitter voltage (V_{CE}) of the IGBT. If V_{CE} exceeds a chosen value, the IGBT turns off and stops the current through the MOSFET.

Hereafter, we briefly explain the IGBT short circuit behavior, the over-current protection approach and shut down requirements, which the protection must cover.

1.1 IGBT short circuit behavior

If the IGBT turns on into a short circuit or short circuit occurs when the IGBT is turned on [2,3,6], the collector-emitter voltage rises rapidly with the load current causing excessive power dissipation. This abnormal presence of high V_{CE} when the IGBT is supposed to be on is often called *de-saturation*. The IGBT short circuit withstand time varies up to few microseconds depending on the applied gate voltage. The short circuit condition can be detected by monitoring the V_{CE} and reacting at some voltage threshold (about 7V typically).

1.2 Over-current protection (current limiting) approach

To provide not only short circuit protection but also current limiting [2,3], the V_{CE} threshold must be chosen from the V_{CE} - I_C characteristics, given in the IGBT data sheet, depending on the current of protection action, gate voltage and device temperature.

The over-current condition is set if:

- The instantaneous collector-emitter voltage exceeds the chosen V_{CE} threshold.
- Gate-emitter voltage is greater than gate-emitter threshold voltage.
- This state lasts more than 2 μ s (typically).

1.3 Shut down requirements

When the IGBT is rapidly turned off, trapped energy in the circuit stray inductance is dissipated in the device, causing a voltage overshoot across it [4,5,6]. The magnitude of this transient voltage is proportional to the amount of stray inductance and the rate of fall of turn-off current. The worst situation occurs at short circuit where the rapidly turn-off of the IGBT produces di/dt s which can reach a few thousands A/ μ s. Shutting off such high currents too quickly is potentially detrimental to the device. The voltage transients at IGBT turn-off can be significantly reduced by slowing the turn-off gate voltage signal.

2. THE PROPOSED OVER-CURRENT PROTECTION

The functional diagram of the proposed over-current detecting circuit and the key waveforms for arbitrary load current are given in Fig.2a and Fig.2b. The protection consists of current sensing IGBT (Q1), voltage comparator (U1), delay circuit (I_C , C_{delay} , Q2), comparator with hysteresis (U2) and driver circuit (U3). The restart is provided by transistor Q3. The $+V_{CC}$ usually is in the range of 12÷15V. The $-V_{CC}$ (normally -5V) is used to ensure sufficient noise immunity and to avoid spurious turn-on of the IGBT due to high dv/dt s. All voltages are given with respect to the ground.

2.1 Principle of operation

Let's assume that the transistor Q3 is turned-off, driver output is high, the IGBT is in on-state and the load current flows between nodes 1 and 2. A high voltage fast recovery diode (D1) is connected to the IGBT collector to monitor the collector-

emitter voltage. The (+) input of the comparator (U1) is pulled down by D1 to the V_{CE} . The (-) input of the comparator is supplied with a chosen threshold value ($V_{protect,th}$), at which the protection acts. When the (+) input voltage ($V_{CE}' = V_{CE} + V_{F,D1}$) exceeds $V_{protect,th}$, see instant t_0 in Fig.2b, the capacitor C_{delay} starts to charge linearly introducing a short delay before protection action. If V_{CE}' falls below $V_{protect,th}$, before V_{Cdelay} reaches the protection turn-off voltage threshold ($V_{turn off,th}$), the capacitor C_{delay} is quickly discharged through D2 and Q2, see instant t_1 in Fig.2b. If V_{Cdelay} exceeds the $V_{turn off,th}$, at instant t_3 , the comparator (U2) sets the gate driver output in low state and the IGBT turns-off at instant t_4 . The resistor R4 slows the IGBT turn-off transition. The diode D1 becomes reverse biased.

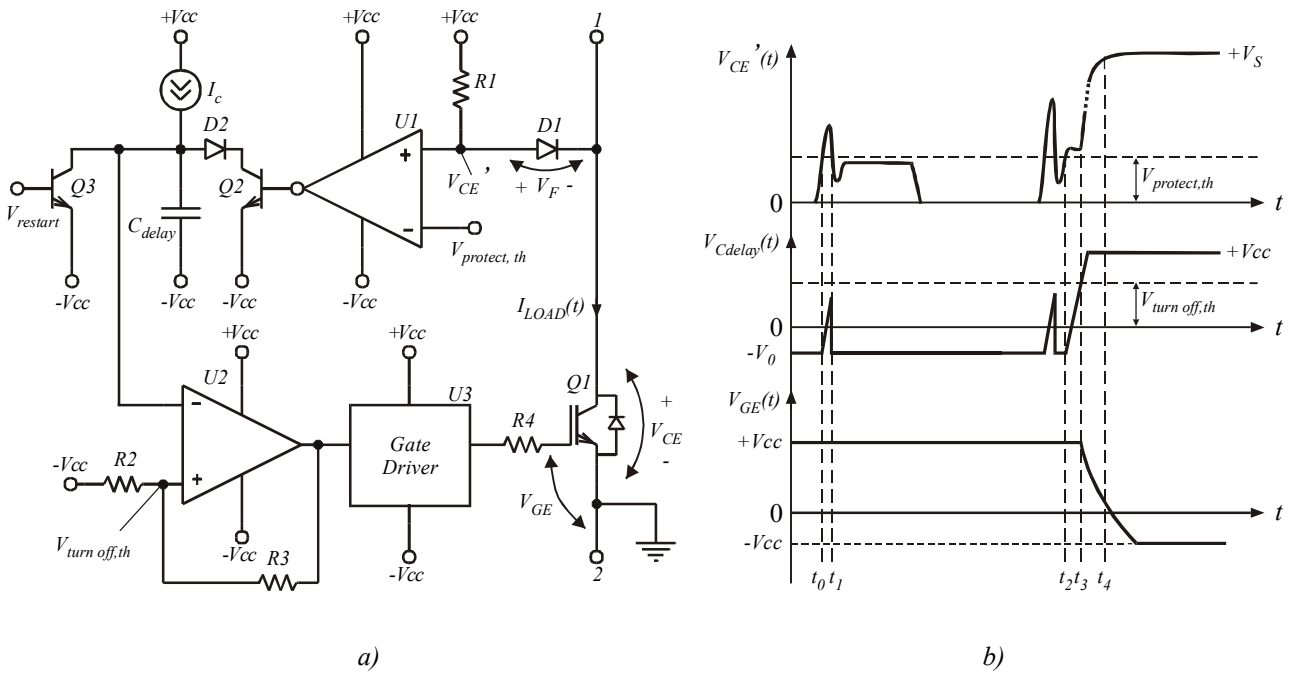


Fig.2 a)-Functional diagram of the proposed protection and b)-key waveforms for arbitrary load current

It should be mentioned that once the protection is activated it remains in this state until the power stage supply ($+V_s$) is not removed and the transistor Q3 is not turned-on. Note that while the transistor Q3 is turned-on, the protection does not function properly but the IGBT is in on-state. For that reason, the restart pulse duration ($V_{restart}$) must be less than 500ns.

A delay must be provided after the comparator output (U1) to avoid erroneous actions of the protection due to turn-on and turn-off transitions of the MOSFET or parasitic disturbances. The delay time (t_{DELAY}) must conform to the withstand capabilities of the MOSFET as well as it is limited by the IGBT short circuit withstand time.

The delay time can be defined:

$$t_{DELAY} = t_{SC} - t_{TURN-OFF} - t_{PR} \quad (1),$$

where:

t_{SC} is the IGBT short circuit withstand time (normally $5 \div 10 \mu s$);

$t_{TURN-OFF}$ is the IGBT turn-off time;

t_{PR} is the total prolongation time of protection circuit.

The delay time usually is in the range of $1,5 \div 2 \mu s$.

The turn-off voltage threshold, at which the protection acts, can be calculated:

$$V_{turn\ off, th} = \frac{I_c}{C_{delay}} t_{DELAY} + V_0 = \frac{I_c}{C_{delay}} t_{DELAY} + (V_{F,D2} + V_{CE,Q2}) \quad (2),$$

where:

I_c is constant charge current;

V_0 is the initial voltage at which the capacitor starts to charge.

2.2 The simulated set-up

The simulated set-up is given in Fig.3. A more realistic circuit in comparison with that, shown in Fig.2a, is simulated. The circuit provides fast over-current detecting, slow current shut down, delay time, LED indication and possibility for manual or automatic restart.

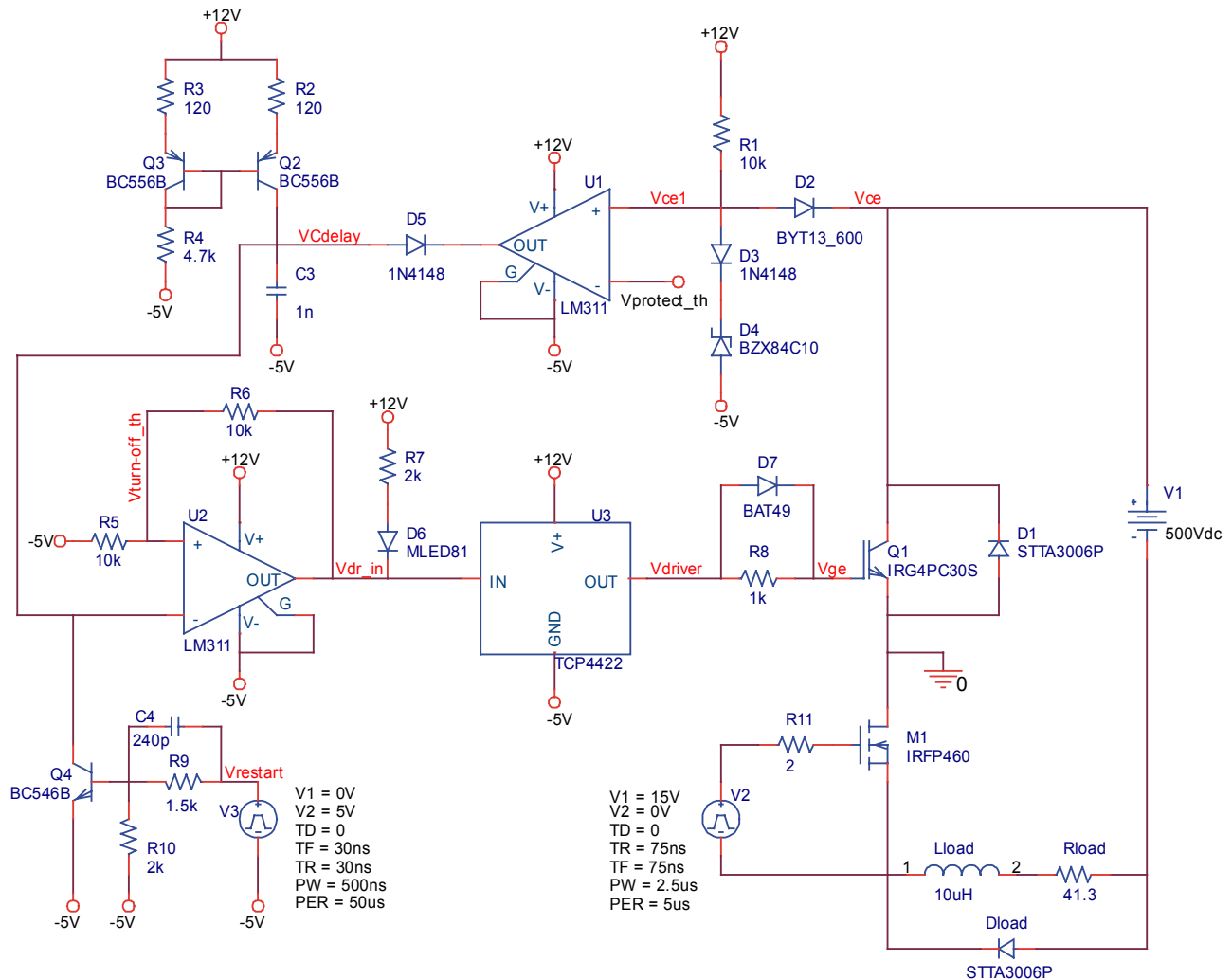


Fig.3 The simulated set-up

To reduce the conduction losses, a low voltage drop IGBT has been chosen (IRG4PC30S has $V_{CE(on) typ.} = 1,4V$). The protection is tuned to act at 12A instantaneous current (500V maximum).

3. SIMULATED RESULTS

To verify the operation of the proposed protection, simulation results are obtained. In this section we present results using the PSpice A/D simulator.

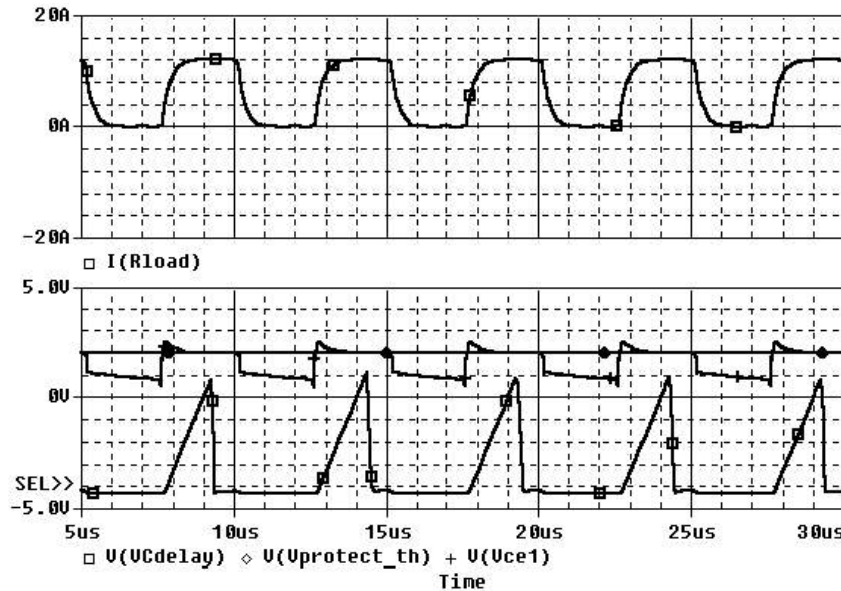


Fig.4 The protection waveforms during normal operation

($I_{load}=12A$; $V_{DC}=500V$; $f=200kHz$; $R_{load}=41,4 \Omega$; $L_{load}=10\mu H$; $V_{protect,th}=2.01V$)

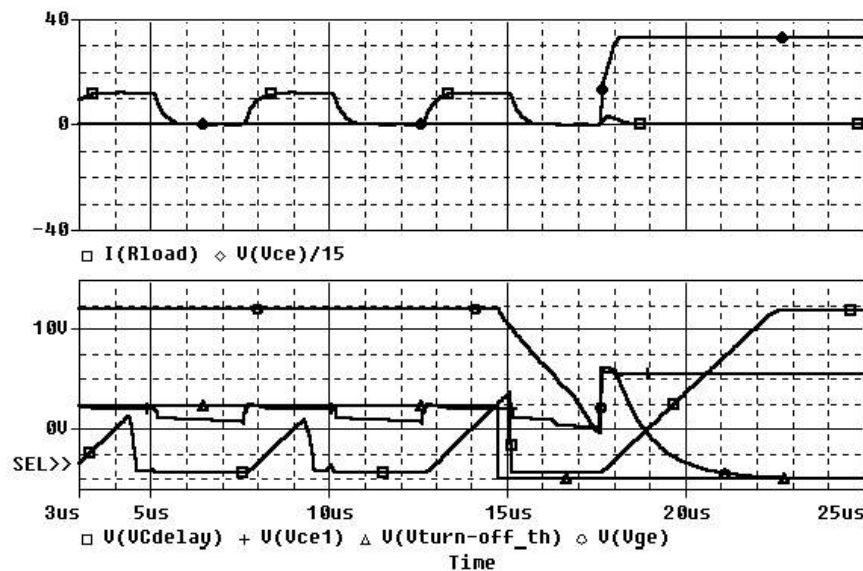


Fig.5 The protection waveforms during over-current event

($V_{DC}=500V$; $f=200kHz$; $R_{load}=41,2\Omega$; $L_{load}=10\mu H$; $V_{protect,th}=2.01V$; $t_{delay}=2\mu s$)

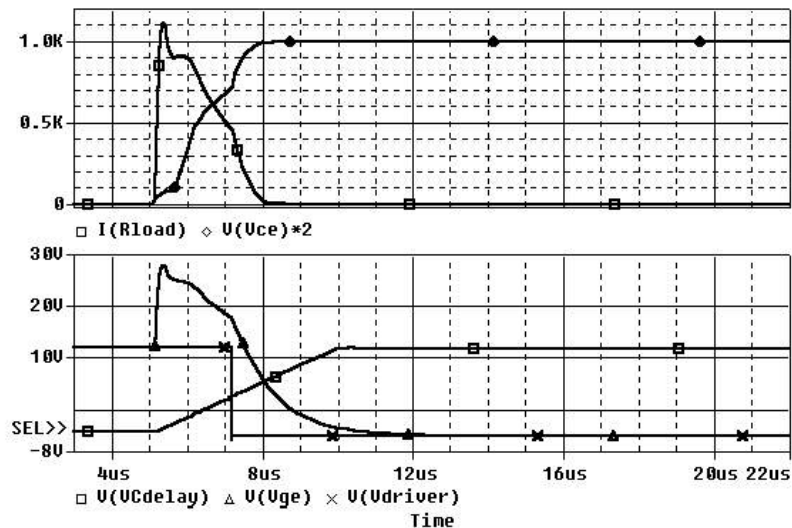


Fig.6 The protection waveforms at short circuit

($V_{DC}=500V$; $R_{load}=0,1\Omega^*$; $L_{load}=40nH^*$; $V_{protect,th}=2.01V$; $t_{delay}=2\mu s$)

* R_{load} and L_{load} represent the ohmic resistance and the stray inductance of the PCB at short circuit simulation.

4. CONCLUSION

A fast and reliable 12A over-current protection is presented and simulated in this paper. An IGBT is used for current sensing. The protection is intended for test platform (about 6kW in full bridge configuration and frequency range from 20kHz to 400kHz). The features of the proposed protection allow its wide application in different types of power electronic converters. The circuit provides fast current measuring, slow current shut down, delay time, LED indication and possibility for manual or automatic restart. The advantages of the proposed protection are:

- The used IGBT can be slow and inexpensive.
- The IGBT exhibits lower parasitic inductance in comparison with current sense transformers.
- The protection acts even if control signals fail.

5. REFERENCES

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