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Modeling and Simulation of an Improved Microcontroller Based Desaturation Current Protection

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Abstract – **This paper presents modeling and simulation of an improved microcontroller based desaturation current protection. Improved features include: cost effectiveness, flexibility and fast response times. The current protection utilizes undervoltage lockout features of modern integrated drivers – providing a reliable activation directly at the power electronic side of the converter. The presented model and simulation allows fast and straightforward design, as well as reduced time for testing and debugging when developing devices that operate under different conditions with different components.**

Keywords – **electronic current protection, IGBT driver, undervoltage lockout**

I. Introduction

Many modern electrical and electronic devices are based on, or in some parts include power electronic blocks. Those blocks predominantly operate based on switched mode energy conversion, where specialized electronic switches control the flow of the electric current. Most of those switches are semiconductor components, such as: IGBT and MOSFET. To operate correctly, within their designated power electronics circuits, those switches need various interfacing circuits, such as: drivers, current protections, measurement topologies, etc. Those interfacing circuits are often required to function under conditions that may include: high currents and voltages, high insulation voltages (if galvanic separation is required), high frequencies, high reliability.

This paper considers those factors and suggests studies dedicated on a specialized driving circuit that includes an improved microcontroller based desaturation current protection. Desaturation current protections are a cost effective solution applicable mainly to IGBT devices, where the current is registered indirectly by measuring the collector-emitter voltage drop (V_{CE}) on the transistor. Various solutions of desaturation protections exist, where different advantages and disadvantages are present [1, 2].

As a preceding research an improved desaturation protection was suggested by the authors – figure 1. The presented circuit utilizes the undervoltage lockout (ULVO) features of an integrated driver with galvanic separation. When overcurrent occurs and the protection activates, the supply voltage of the driver is pulled down and therefore the UVLO activates, consequently the output of the driver goes to a low level – effectively turning off the transistor and limiting its current. This protection was experimentally verified. Detailed description and study can be found at [3].

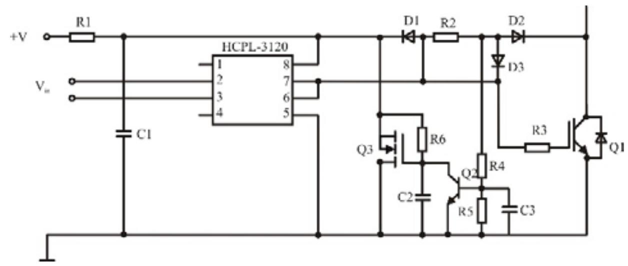

Fig. 1. Desaturation current protection

A disadvantage of the presented protection was the difficult set-up of its components in correspondence with the desired mode of operation. This was improved on, by developing a modified circuit that includes a microcontroller - figure 2 – detailed explanation and verification is presented at [4]. The microcontroller unit allows to set-up the protection parameters in the program code, thus providing easier adjustment of component values. However debugging when various conditions and parameters were involved was an issue. In order to improve this the current paper suggest a specialized model and simulation procedure that allows to test, debug and set the parameters of the current protection's components.

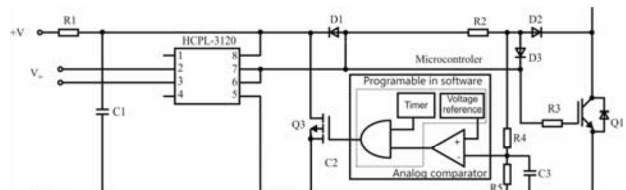

Fig. 2. Microcontroller based desaturation current protection

II. Modeling

A block diagram of the complete developed model is presented at figure 3. The model consists of three main blocks:

• Driving block – figure 4 – represents the driver and the circuitry required to pull down the supply voltage and activate the protection. More specifically: 1) is the totem pole topology that drives the IGBTs [6]. The parameters of the totem pole circuit can be set so they can reflect the properties – sink and source current and transient parameters – of the driver to be implemented; 2) is the control logic of the driver. The control logic includes the interface that drives and enables the totem pole; 3) is the

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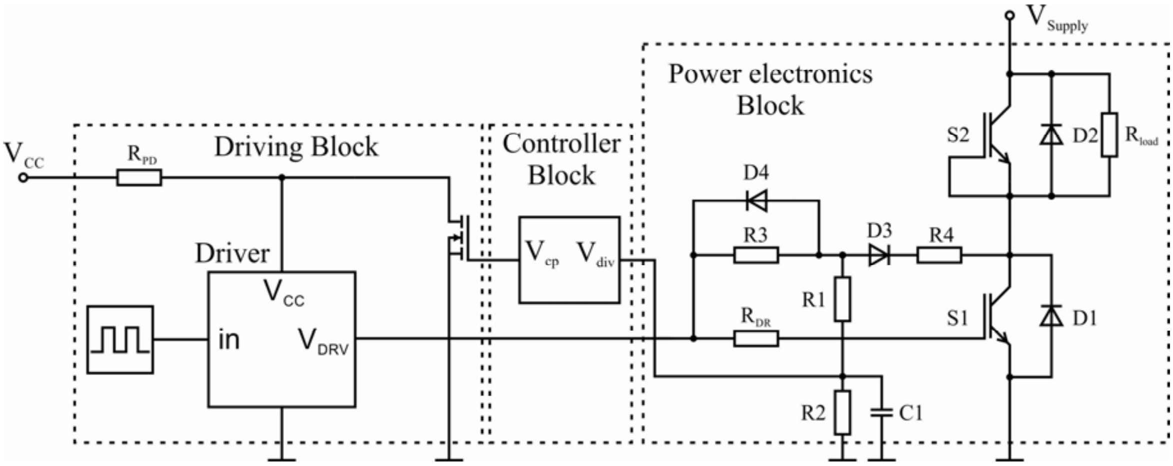

Fig. 3. Block diagram of the suggested model

UVLO block modeled as a comparator with hysteresis; 4) is the logical signal that controls the circuit – in the case with the presented simulations, this signal is with frequency of 40kHz and a duty ratio of 0,25; 5) is the pull down resistor that limits the supply current when the protection is tripped; 6) is the electronic switch that pulls down the voltage on the driver – the MOSFET is model based on [5,6].

• Power electronics block – this blocks represents the circuitry of the protected transistor as well as the components that sense the current – figure 5. The block includes: the device under test (D.U.T.) S1 modeled using

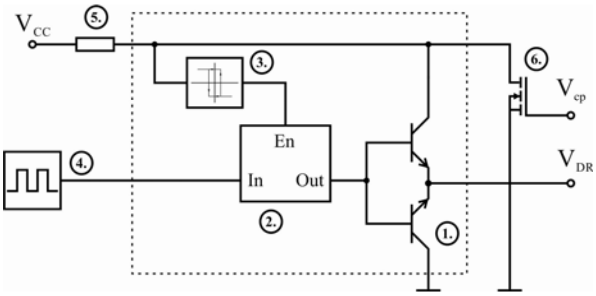

Fig. 4. Equivalent circuit of the driving block

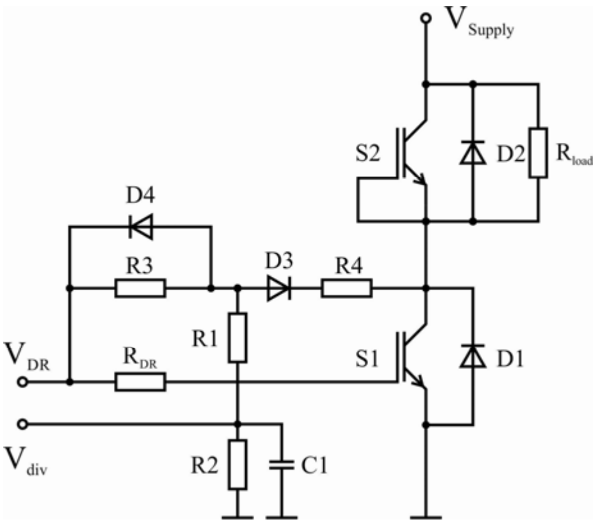

Fig. 5. Equivalent circuit of the power electronics block

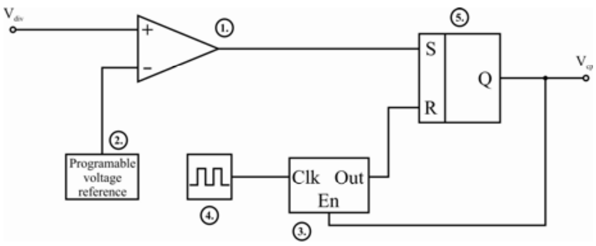

Fig. 6. Equivalent circuit of the controller block

[5], as well as an additional IGBT – S2 that allows to take into account effects of the reverse recovery of diodes (modeled based on [7,8]); the load of the circuit R_{load} that in order to test the protection can be switched for different values during simulation; voltage sensing components – D3 (modeled based on [7,8]) and R4; a voltage diver R1 and R2; filter capacitor C1; enabling link to the driving signal – R3; driving resistor - R_{DR}; protection diode D4 – that transfers charges (mainly from the parasitic capacitance of D3) that could trip the protection during turn-off transients of the D.U.T.

• Controller block – figure 6 – this is the block that controls the protection. All the components included are part of the microcontroller that is used in the protection. In this way the selected microcontroller include: 1) an integrated comparator (for the model developed using [7]), 2) a programmable reference voltage source; 3) a timer – in the case of the simulations it was concluded that a 16 bit timer could be sufficient for most cases; 4) a clock source, not necessary to be a clock source additional to the one of the microcontroller - in the conducted studies and implementations an 8MHz clock source was used. All those components are common to many of the modern microcontrollers. Additionally for the model a 5) RS trigger was required - in the practically implemented systems this component was realized in software. In order for the model to be accurate, specific delays that can occur during execution of the instructions were included.

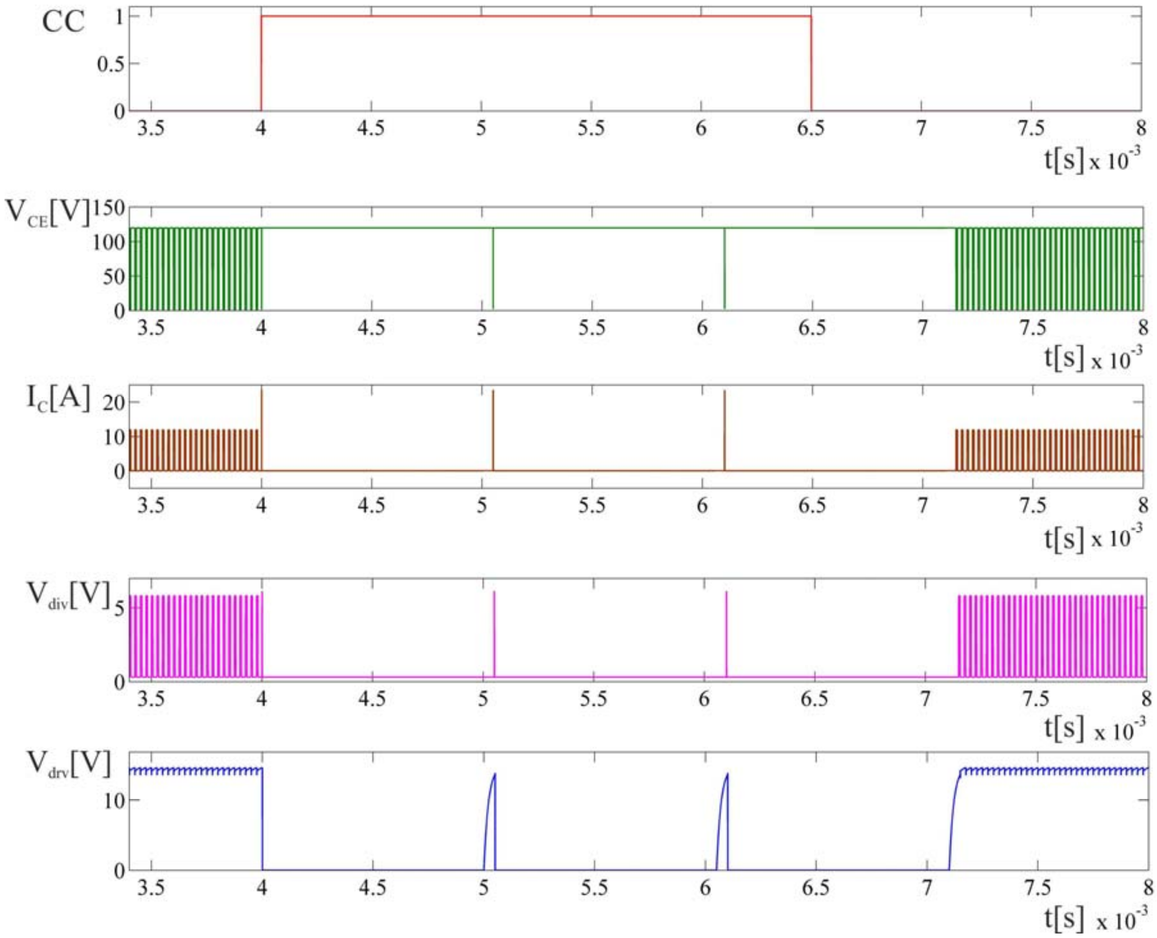

Fig. 7. Consolidated simulation results

III. SIMULATION RESULTS

The presented model was developed in a software for computer calculations and simulations – MATLAB, Simulink. For initial tests of the model and its verification an IGBT with parameters presented in table 1 was selected.

TABLE 1. PARAMETERS OF THE SELECTED D.U.T.

Group of parameters	Parameter	Value
Power Ratings	Maximum voltage	1350V
	Average current	20A
On-state parameters	resistance/ voltage drop	1.9V
On-state parameters	Forward voltage drop	1,8V

The selected component is the same used in preceding researches [3] and [4] where experimental results from the protection are present.

Consolidated results from the simulation are presented at figure 7. On the figure: CC is a signal for current commutation – logical 0 of this signal represents a load resistor R_{load} (10Ω), while a logical 1 represents a load resistor with value $R_{load}/2$ (5Ω); V_{CE} is the voltage drop on the transistor (supply voltage for the simulation is 120V); I_C is the collector current through the transistor - the protection is programmed to be tripped at 15A; V_{div} is the output voltage of the voltage diver (figure 5 – R1, R2); V_{drv} is the power supply of the driver.

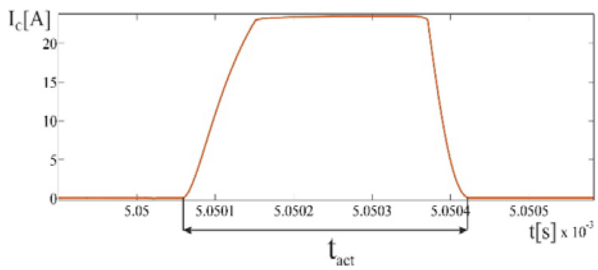

Fig. 8. Activation time for the protection

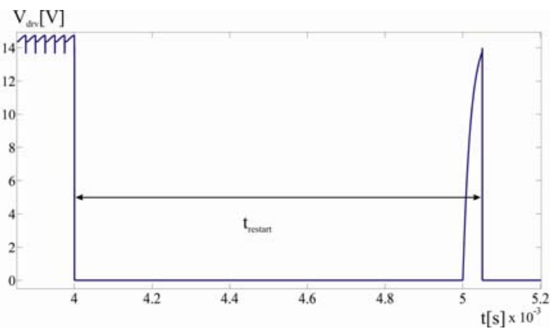

Fig. 9. Restart time for the protection

From the presented results it can be seen that the protection is operational and performs as specified. Those consolidated results were compared and are close to the experimental ones presented in [3] and [4] – this gives a basis for the model verification.

In addition figures 8 and 9 present the time required to activate and consequently restart the protection. The activation time of the protection t_{act} for the given case is 50ns, while the time for automatic restart is 1.1ms where 1ms is the time set as a programmable delay in the controller timer a 0.1ms is the time required to restore power to the driver. In the case with the given results, several restarts occur.

IV. Model Implementation and Design Assistance Graphical Interface

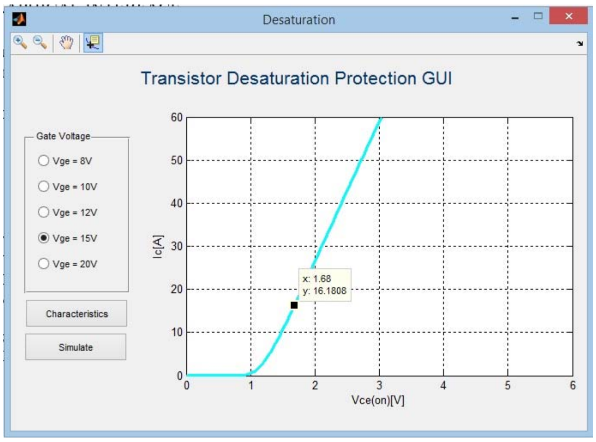

Fig. 10. Suggested GUI

In order to better implement the model and its simulation results into the design process of the suggested current protection, a specialized graphical user interface (GUI) was developed. The main window of the graphical interface is presented at figure 10. The GUI allow users to preload volt ampere characteristics of IGBTs, on which bases a tripping current and corresponding voltage of the collector emitter of the D.U.T. can be set. The GUI program can then calculate and set parameters in the model and proceed to simulate and test. Users can later check if the topology satisfies their requirements and correct and optimize the parameters of the circuit through series of simulations.

Several designs were tested using GUI and the model, where different analysis were carried out. Test circuits were implemented. Experimental results were consistent with those obtained through the model.

IV. Conclusions

A model of a specialized desaturation current protection based of microcontroller is presented. The model is completely described and characterized. Using the model in computer based simulation results that provide evidence of its functionality were obtained. The results allow the user to determine various parameters related to the work of the suggested protection. Those parameters can then be successfully implemented in design. This is done using specially developed GUI presented in the paper.

Design tests were carried out using the model, where results were compared with experiments done in previous publications. Simulation and experimental results show consistency.

Main advantages of the suggested current protection include: fast response times, compatibility with existing drivers with integrated ULVO, low component count including a microcontroller and an electronic switch, low overall cost.

Acknowledgements

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