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Silicon Carbide Controlled Current Limiter, Current Limitation Strategies, Foreseen Applications and Benefits.

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Abstract--The expansion of electricity networks (distribution of energy, telecommunication), strongly contributed to increase the risks of appearance of defects, such as surge or overload. This multiplicity and complexity of electric networks, the need to have reliable systems favoured the development of serial protection devices. Fuse solution allows an efficient and total protection but requires to replace an element in case of failure. Therefore, other solutions have been investigated.

Complex systems have been developed, all based on serial compensation, such as supra-conductor material, GTO MOV combination ...

Indeed, because of the strong energy appearance during a short circuit, it is necessary to limit and to dissipate the energy of the short circuit, under high bias. This constraint leads to a feasibility study of a current limiter in 4H silicon carbide (4H-SiC).

A VJFET structure was retained focusing on a nominal current of $I_N = 1$ A and a nominal voltage of $V_N = 690$ V. The device was optimised, taking into account SiC excellent physical properties. The VJFET was designed checking the trade-off between a low on-resistance value, high voltage capability and the highest gate transconductance value. A first batch of component was made, validating the bi-directional limitation function in both current and voltage mode, ($V_{MAX} = 970$ V). The efficiency of the protection was validated, demonstrating the capacity of a component to react very quickly ($t < 1$ μ s). Using such a device is very suitable in several applications (protection against short circuit, transient over current...) as it will allow to reduce transient phenomena and thus increase the efficiency and lifetime of the whole system.

Keywords : *silicon carbide device, fault current limiter, serial protection, 2D finite element simulation, DC motor torque control*

I. INTRODUCTION

Serial compensation can be done by the adjunction in the electrical circuit of an equivalent variable resistor that can be supra-conductor material, or Gate Turn Off (GTO) Metal Oxide Varistor (MOV) combination. Numerous strategy can be :

1 compensation with supraconductive effect temperature dependence [1],

2 adding resistances in serial to reduce the current and mechanical switch [2],

3 polymer based devices also named "Positive Temperature Coefficient (PTC) composite" [3],

4 specific semiconductor current limiters [4], [5].

Focusing on first system, high cost of such components constrain the utilization to power plant distribution an no effective commercial systems are available [6].

Concerning the second point, although name "static disjunction", good performances can be expected from this kind of system and some of them are actually used. They required high energy capacity resistance and GTO devices. Main difficulty consist in driving switch to react very quickly to a short circuit [2].

Third kind of current limiter is related to lower power application (low voltage and low current) [7]. Current limitation is based on the variation of the serial resistance while temperature rise-up by a modification of the crystalline structure of the composite. The composition change can be due either to self heating or to external temperature variation. Therefore, such devices can react to a short-circuit (current rise up lead to self heating and resistance rise-up) or can prevent effect of temperature rise-up during a battery charging cycle for example [8]. Their advantage is the low cost while theirs drawbacks are time need to restore original structure and time to react to a new electrical default.

Up to now, few specific semiconductor current limiters exist and are limited to very low voltage or current applications. Highest capabilities of Current Regulative Diode (CRD) for example are $I_N = 5 \text{ mA}$, $V_{\max} = 120 \text{ V}$ [9]. Few patents describe other solution such as an IGBT based-on structure [5]. The main problems of actual current limiting devices are the maximal operating temperature of silicon and its voltage capabilities.

“Fig. 1” presents temperature and voltage limitations for both silicon and silicon carbide current limiters.

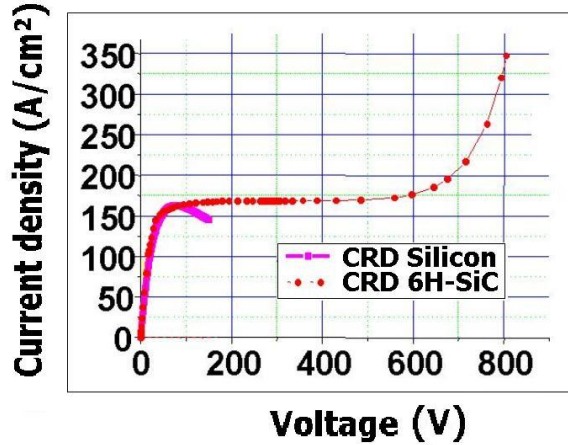


Figure 1. Comparison between Si and SiC CRD.

The silicon CRD can not reach (due to thermal runaway) 200 V while the SiC-CRD overpasses 600 V. It underlines the high voltage and current capabilities of SiC devices. Indeed, because of the strong energy appearance during a short circuit, it is necessary to limit and to dissipate the energy of the short circuit, under high bias. These constraints lead to a feasibility study of a current limiter in 4H silicon carbide.

II. VJFET BASE CURRENT LIMITER

A VJFET structure (“Fig. 2”) was retained with the following foreseen characteristics of a nominal current of $I_N = 1 \text{ A}$ and a nominal voltage of $V_N = 690 \text{ V}$.

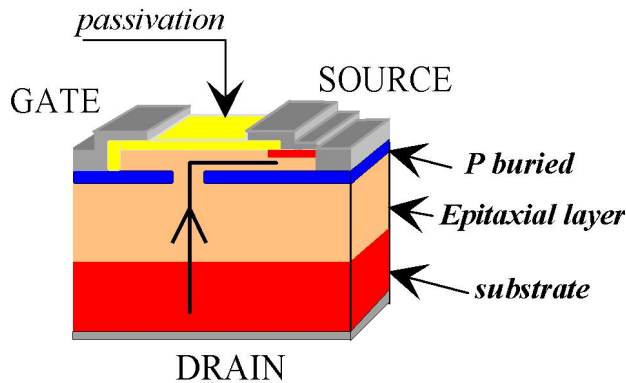


Figure 2. Three terminals fault current limiter device structure.

In normal mode (static state), current flows from drain to source using the path between p-buried layers (gate and source). When a default appears in the protected circuit, high voltage is applied on the drain. PN junction is thus reverse biased, pinching the channel and limiting the current flow. The device was optimised, taking into account foreseen characteristics and SiC peculiarities. The VJFET was designed checking the trade-off between a low on-resistance value, high voltage capability and a as good as possible gate transconductance value. The optimisation of device parameters was made using a finite elements solver (ISE tcad software). “Fig. 3” presents the evolution of an optimal term depending on channel length (L) and gate to source distance (W).

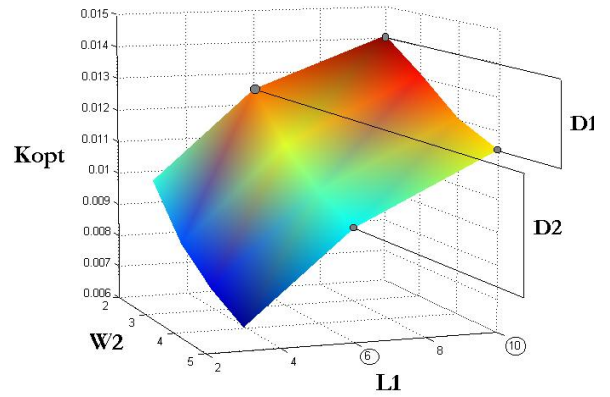


Figure 3. Optimal terms channel length “L” and p-type buried layers distance “W” determined by finite element simulations

III. SERIAL PROTECTION DEMONSTRATION

A first batch of component was made, validating the bi-directional limitation function in both current and voltage mode, ($V_{\max} = 970 \text{ V}$). The efficiency of the protection was validated, demonstrating the capacity of a component to react in very short time ($t_r < 1 \mu\text{s}$) (“Fig. 4”), while plugged in a real electrical system (“Fig. 5”).

An additional inductance plugged in serial with the current limiter was used to check over-voltage appearing in the circuit. A 10 time higher inductor value only implies a 3.6 time higher over-voltage. This measure clearly demonstrates both over-current and over-voltage reduction using a silicon carbide current limiter. Furthermore, no significant change of the response time was measured (less than $1 \mu\text{s}$).

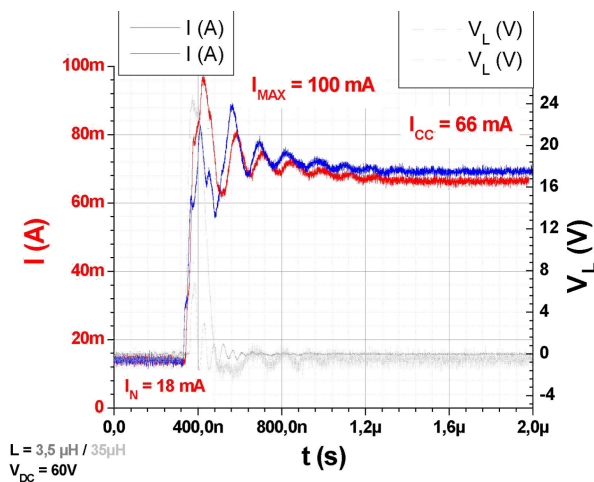


Figure 4. Experimental short circuit waveforms of the current limiter.

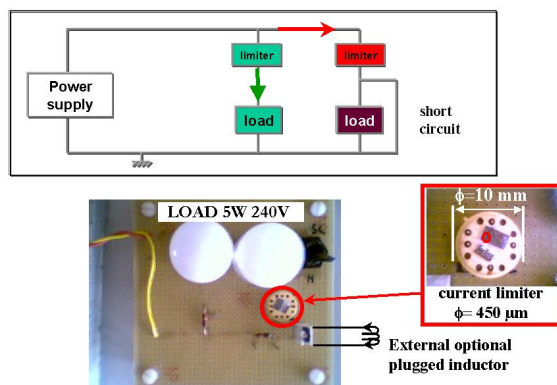


Figure 5. Description of the electrical circuit used to perform switching tests

Using such a device is very suitable in several applications such as short circuit protection, transient over current reduction, power supply factor correction.

III. FORESEEN APPLICATION

Another appropriate use is electrical motor starting phase, allowing soft torque at start up without sensitive modifications of the dynamic behaviour of a continuous current motor. Simulations were carried out using Matlab© to check the effect of the adjunction of a serial current limiter within the electrical system on the dynamic behaviour of the motor.

Models of a continuous current motor coupled with a model of the current limiter (resistor dependent on current) were used in a Simulink description of the system

A - MATLAB MODEL DESCRIPTION

A Simulink description of a DC motor is presented in “Fig. 6”.

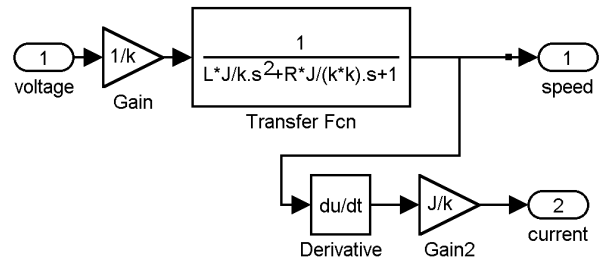


Figure 6. Simulink block describing the transfer function of a DC motor.

In order to avoid any numerical instability (due to the derivative block) during transient simulations, two different models were implemented and compute in parallel. The first one concern the case of no current-saturation “Fig. 7”.

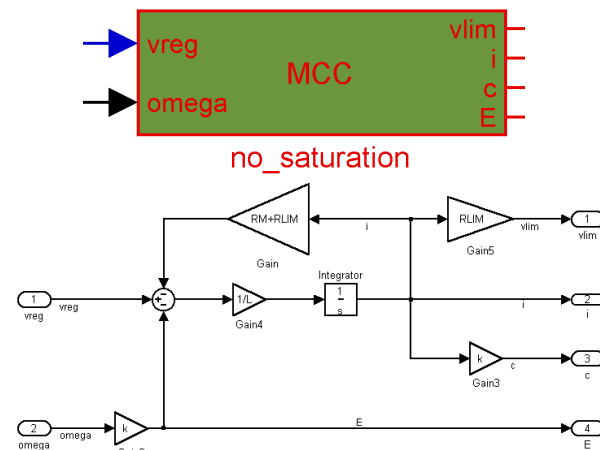


Figure 7. Simulink block describing the transfer function of a DC motor in non current-saturation mode.

The other one is used while current-saturation occurs (“Fig. 8”).

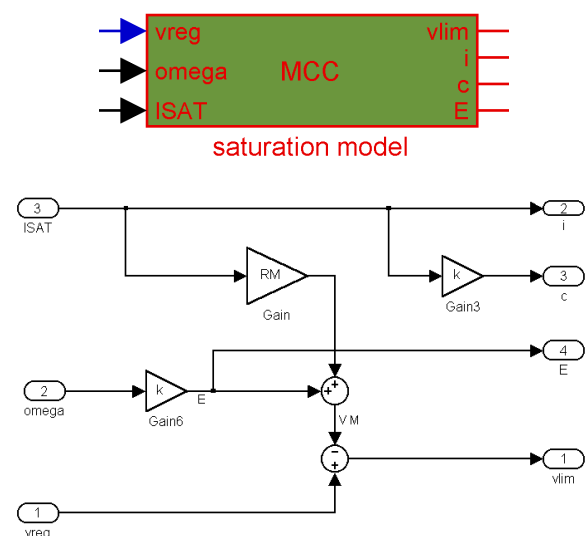


Figure 8. Simulink block describing the transfer function of a DC motor in current-saturation mode.

Both models were computed in parallel. The torque output of each model is used as a synchronisation signal whereas the current is used to switch the main output between saturated and not saturated model outputs.

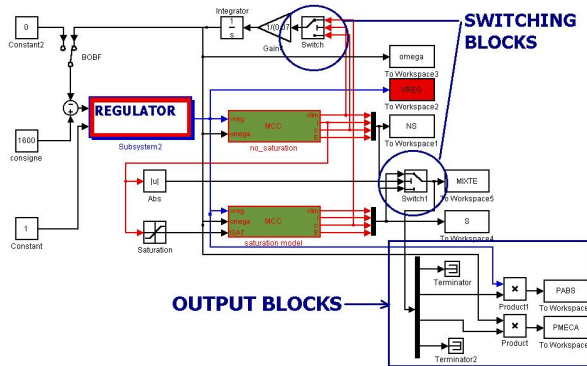


Figure 9. Simulink block describing the whole system.

A suitable utilisation of such a model can be the determination of the most appropriate current limiting device (in terms of current ratings and maximal mechanical power) with respect to dynamic performance.

B - MATLAB MODEL APPLICATION

As shown in “Fig. 10” and “Fig. 11”, simulations permits to estimate both the response time and the maximal transient mechanical power for given speed reference and current limitation values. From this can be extracted optimal parameters of a current limiter considering given speed requirements, dynamics and mechanical limitations.

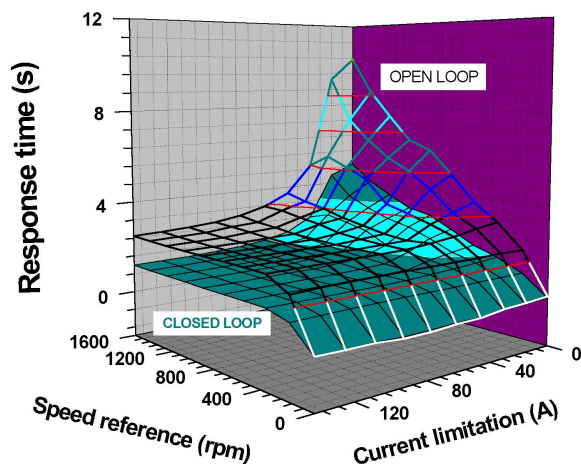


Figure 10. Response time of a DC motor to a speed reference versus current limitation.

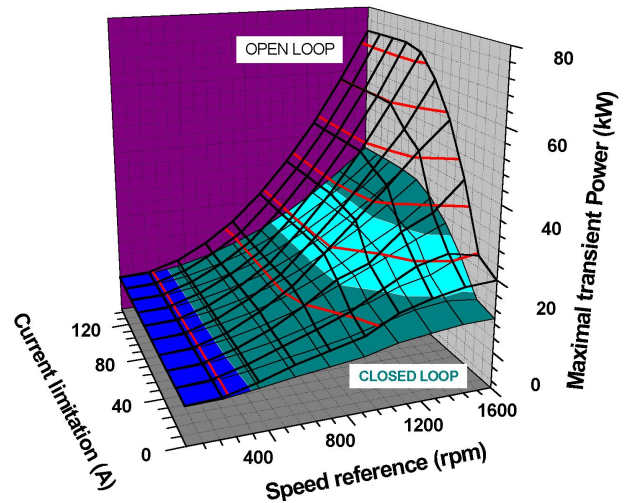


Figure 11. Maximal transient power during starting phase of a DC motor for given speed reference and current limitation values

Using previous model, the speed evolution was compared for two different reference speeds (250 rpm and at $t=9$ s, 1600 rpm). The maximum current set in both case was 480 A. In the first case no over-current was observed. For an highest speed reference (1600 rpm) an over-current appears. Using a current limiter didn't change the speed stabilisation time, but limits considerably the maximum transient power as illustrated in (“Fig. 12”).

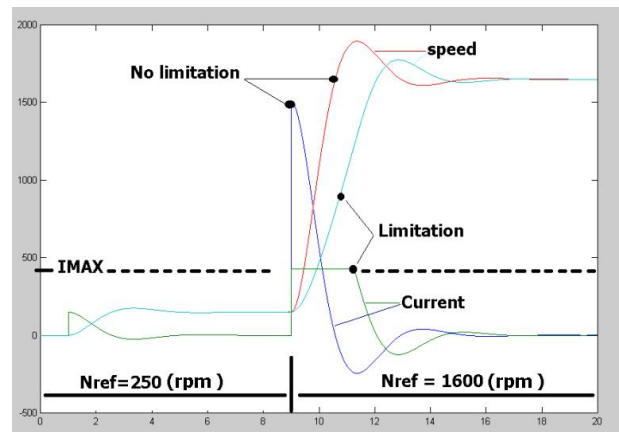


Figure 12. Transient evolution of speed for two given speed reference and a fixed current limitation value (480A).

III. CONCLUSION

Adding in serial such a device in application will allow to reduce transient phenomena, such as over-current reduction during starting phase and thereby over-torque limitation. This will allows an increase of the efficiency and life time of the whole system, without the need of a complex electronic driver (as the current limiter acts without control board).

The possibility of integration of an internal current control system as been demonstrated [10] and is the next challenge to get a smart controlled current limiter. Further modelling and experimental validation will be made to illustrate such a benefit.

IV. REFERENCES

- [1] S. Sugimoto, J. Kida et al , "Principle and characteristics of a Fault Current Limiter with Series Compensation", IEEE-Transactions-on-Power-Delivery. vol.11, no.2; April 1996; p. 842-7
- [2] G. De Palma, « Etude et Réalisation d'un Disjoncteur Statique Limiteur pour Réseau alternatif 660V/100A », in french, Th. Doct, Lyon, Inst. Nat. Sc. Appl., 1992, 124 p
- [3] A. Chiste, D. Kladar, Eaton's Cutler-Hammer, "Electronic Systems Protection via Advanced Surge Protective Devices", Proc. IAS02, Pittsburg, Etats-Unis, 13-18 Octobre 2002, 4 p.
- [4] S.M. Sze, "Physics of Semiconductor Devices", 2nd ed., New York : J. Wiley and Sons, 1981, 868 p.
- [5] J.L Sanchez, Ph. Leturcq, et al "Design and fabrication of a new high voltage current limiting device for serial protection applications", Proc. 8th International Symposium on Power Semiconductor Devices and ICs, ISPSD'96, IEEE, (Hawai USA), 1996, p. 201-205
- [6] W. Paul, ABB Corp, "Analysis of a passive superconducting fault current limiter", Applied Superconductivity, IEEE Spectrum p.49-54 Vol.35, Issue 5 ISSN:0018-9235 May 1998
- [7] Raychem Corp. « Circuit protection databook », 1998. Available from the web site : <http://www.circuitprotection.com>
- [8] F. Owen, " Battery protection. Low temperature polymer positive temperature coefficient device provides added insurance", PCIM-Power-Electronic-Systems. vol.25, no.3; March 1999; p.55, 57-8.
- [9] SEMITEC Corp. "Current Regulative Diode", available from Internet web-site : <http://www.semitec.co.jp/english/indexe.htm>
- [10] D. Tournier, P. Godignon, J. Montserrat, D. Planson, J.P. Chante, F. Sarrus, "Compatibility of VJFET Technology to MESFET Fabrication and its Interest to System Integration : Fabrication of 6H and 4H-SiC 110V Lateral MESFET", 2002, Materials science forum. 389, p. 1403 (4 pages), Trans. Tech. Publications.