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Performance Investigation of Dynamic Characteristics of Power Semiconductor Diodes

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Introduction

Current tendencies in the field of power semiconductor devices are characterized by increasing efficiency (reducing losses) and power density (decreasing volume). This results in contradictory tendencies because increase of power density is achieved by increasing the switching frequency, which results in increase of commutation losses. Main influence on amount of commutation losses has character of commutation process, whereby nowadays soft – switching techniques are being enforced (ZVS – Zero – Voltage Switching, ZCS – Zero – Current Switching). Losses generated during soft – switching processes are several fold lower than during hard switching mode, in which component part is being switched when instant values of current and voltage are nonzero. It have to be said that almost today, the hard-switching is still the most used commutation process due to its simplicity and ability to be used in every topology without any additional circuit.

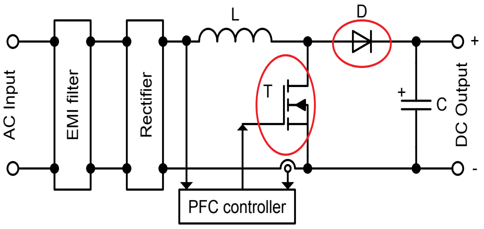

Fig. 1. BOOST type of PFC circuit

Significant part of total losses using hard-switching commutation mode of power semiconductor system is in most of practical applications of power electronics caused by diode's turn – off process. The goal of every power semiconductor system design is approach to the highest efficiency with respect to maximum output power. However different practical applications require utilization of different circuit topology, in which projection and selection of proper components are performing the most important challenge at gaining of optimal power. Almost all the Switched – Mode Power Supplies (SMPS) are nowadays being developed in cooperation with a power factor control input stage (Fig.1) in order to meet the international regulatory standards for harmonic content. The negative feedbacks of such technical improvement are additional switching losses that are generated during commutation process of mentioned boost diode and power transistor. Therefore this system needs perfect specification of suitable components for given application (boost diode, MOSFET or IGBT transistor) that is by reason of optimization of output power and also financial costs [1].

In next chapters, analysis of diode reverse recovery effect, and its negative feedback minimization in various performance levels is described.

Reverse recovery of diode

The negative feedbacks of reverse recovery effect lie in switching losses rising of power transistor. Commutation process between diode and transistor of PFC circuit shown on Fig. 1 has following waveforms (Fig. 2). Generation of transistor's turn – on losses is in this case caused by time – duration of diode's reverse recovery.

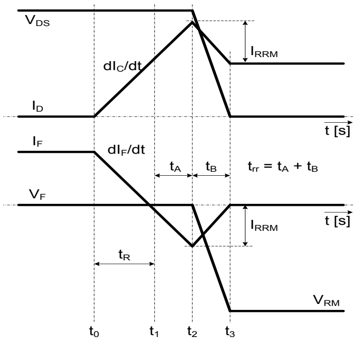

Fig. 2. Commutation process between transistor and diode

From figure is clear to say, that effect of reverse recovery has negative influence on turn – on process of power transistor in form of higher switching losses that are generated during interval:

$$t_{on}= t_R + t_{rr}\ ;\ where\ trr = t_A + t_B, \qquad (1)$$

where for the power loss calculation is valid next equation:

$$\begin{cases} P_{on} = \dfrac{1}{T} W_{on}, \\ W_{on} = \int i_P(t) \cdot u_P(t) \cdot dt, \end{cases} \qquad (2)$$

here T – time-period of computed action; iP – time function of device's current; uP – time function of device's voltage.

Most of data that are available from oscilloscope for calculation are in discrete form, so then it is necessary to use equations in discrete version (3), instead of (2) [2]

$$W_{on} = \sum_{n=T_{Z1}}^{T_{Z2}} I_P[n] \cdot U_P[n] \cdot \Delta T, \qquad (3)$$

here TZ1 – sequence of sample at the begin of process (turn–on/off, stabilized conductivity/non-conductivity of device); TZ2 – is sequence of sample at the end of process (turn–on/off, stabilize conductivity/non-conductivity of device); IP[n] – i-sample of current through device; UP[n] – i-sample of device's voltage; ΔT – sampling time.

Thereby it is possible to calculate the element of energy which is being absorbed by transistor during time - interval ton= tR + trr. Consequently there is need to use an equation to determine the value of total losses

$$P_{on} = \frac{1}{T} W_{on}. \qquad (4)$$

From mentioned above results that selection of suitable diode could perfectly eliminate almost all of the turn - on losses without usage of soft – commutation.

Experimental results

However the limiting factor of diode selection further remains parameters of power circuit (voltage, current) as well as switching frequency. For that purpose we've made a set of experimental measurements, which are closely described in [21]. These measurements have been made as set of parametric measurements with variations of voltage, current and frequency. Every measurement has been done with 25°C of device temperature. It deals SBD diodes based on SiC substrate (SDT06S60) HyperFast (STTH506), Turbo2Fast (STTH5R06) and FastRecovery (BYT12) silicon based diodes.

Fig. 3 shows graphic interpretation of energy that is absorbed by transistor during its transistor turn - on process in dependence on switching frequency. It can be seen that most of this energy is generated at very low value of switching frequency especially in the case of HyperFast diode structure. With the use of various diode structures almost similar amount of absorbed energy has been produced with increase of switching frequency. Excessive abnormality occurs only in the case of BYT12.

Table 1. Types of investigated diode's

	$I_{F(AV)}$ [A]	V_{RRM} [V]	$I_{RM(typ)}$ [A]	$V_{F(max)}$ [V]	$t_{rr(max)}$ [ns]
SDT06S60	6	600	n.a	1,7	n.a
STTH506	5	600	3,6	1,95	12
STTH5R06	5	600	5,0	1,8	40
BYT12	12	1000	9,0	1,9	155

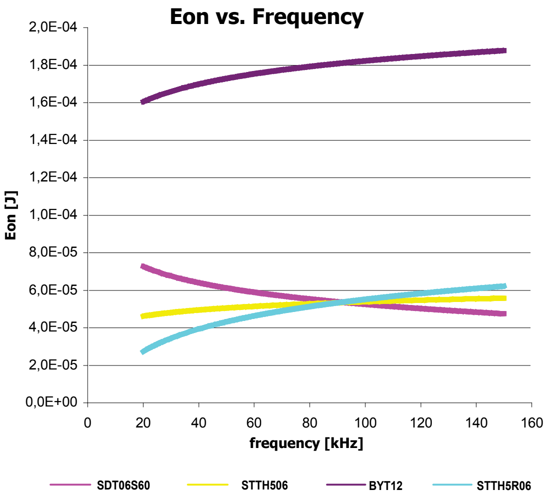

Fig. 3. Dependence of absorbed energy during transistor's turn - on process against switching frequency (fsw = var., U = 300V, I = 5A, L = 500μH)

The measurement's result proves considerable dependence of turn-on losses on switching frequency. Statement that with increase of switching frequency will increase the generation of switching losses is generally valid [5]. But measurement shows that by influence of different diode's structure the situation should be critical at low frequencies too.

Table 2. Turn-on loses vs. frequency

300V / 4A	**P [W]**				
Frequency [kHz]	20	50	75	100	150
SDT06S60	1,44	2,6	3,8	5,5	7,16
STTH506	0,96	3,2	3,8	5,6	8,36
STTH5R06	0,56	2,1	3,9	5,4	9,25
BYT12	3,2	8,5	13,8	17,9	28,48

From mentioned above is clear, that in practical application where switching frequency will be lower than 50kHz, the usage of SBD diode is totally undesirable. More preferable is to use cheaper variant namely one of HyperFast diodes (STTH5R06, BYT12).

Selecting most extreme power loading (600V, 6A), we have made new comparison of dynamic characteristic of examined diodes almost at critical 150°C to see how SiC can perfectly withstand extreme conditions almost at high frequencies (100kHz), in which Si diodes are becoming unsuitable.

Fig. 4–7 show waveforms of diode voltages and currents during turn-off process. Each figure shows measurement at 25°C and 150°C.

As we can, see diodes based on Si structure are showing significant increase of t_{rr} and I_{RM} when temperature is raising what will result in higher turn-off losses. Dynamic parameters at 150°C of SBD SiC diode are surprisingly better (t_{rr} = 17ns) than during measurement at 25°C (t_{rr} = 20ns). This fact confirms statement that diodes based on SiC technology have better dynamic abilities at higher temperatures (thermal resistibility up to 600°C).

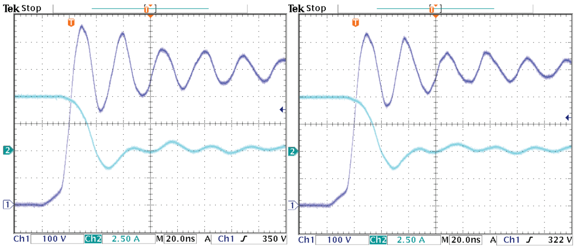

Fig. 4. Turn-off process of SiC diode SDT06S60 (Chip temperature 25°C – left150°C – right)

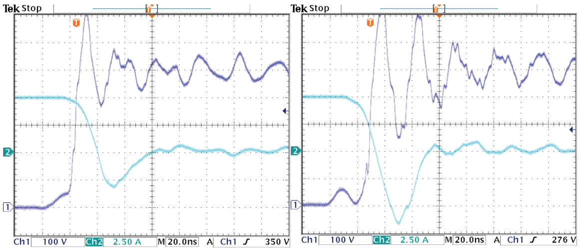

Fig. 5. Turn-off process of Si diode STTH5R06 (Chip temperature 25°C – left;150°C – right)

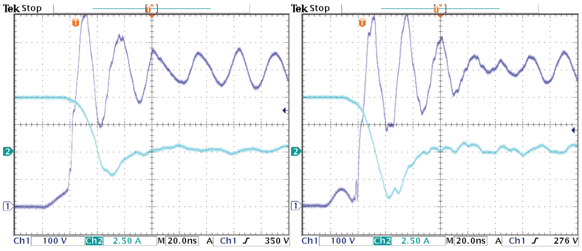

Fig. 6. Turn-off process of Si diode STTH506 (Chip temperature 25°C – left;150°C – right)

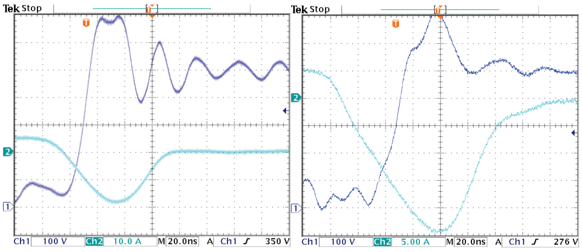

Fig. 7. Turn-off process of Si diode BYT12 (Chip temperature 25°C – left;150°C – right)

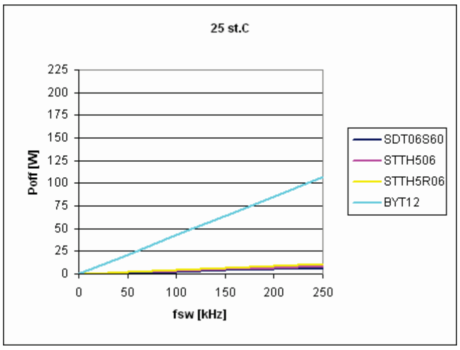

Fig. 8. Power losses for selected diodes at 25°C

Detailed evaluation of measurements oriented for number interpretation is shown on next graphs. The dependency of power losses on switching frequency up to 250 kHz is shown on these graphs. It is clear to say that usage of SBD SiC diodes is advantageous in application with extreme conditions where energy efficiency is necessary.

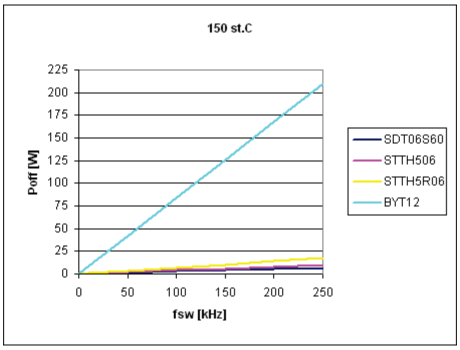

Fig. 9. Power losses for selected diodes at 150°C

Conclusions

The parametrical measurements have demonstrated massive influence of various diode structures on generation of power loss during turn - off process. From first measurements that have been done at 25°C [21], results show that diodes based on SiC technology are not the best solution for every application, almost when they are price non-competitive to standard diodes, whereby there exists Si based diodes which shows very good dynamic abilities and therefore low power loss generation.

New measurements made at 150°C are showing huge differences in behaviour between each types. Surprisingly, SBD SiC are showing even better performance as during measurement with 25°C. This is caused due to innovative technology in manufacture of power semiconductor diodes. Therefore we can simply say that this structures are very perspective in applications, where extreme condition withstanding will be necessary.

From above discussion and experiments which have been made is clear to say that one technology is not suited for all applications even through the name diode sounds very simple. For the best performance, one has to choose the right diode.

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Utilization of SiC SBD diodes in DC-DC converter applications is discussed. First reverse recovery effect of various diodes’ structures and its elimination is being described. Experimental measurements have been done and consequently data were converted into continuous form for graphic interpretation in dependence on switching frequency, supply voltage and load current. Accordingly, the utilization of new progressive materials of power SBD diodes on SiC technology is being described, whereby measurements were done also at higher (150°C) temperatures. This measurements show key differences in dynamic characteristic between each diodes and therefore proper selection of diode and optimization of power supply should be done. It is concerned SiC SBD diode structures versus Si UltraFast and HyperFast diodes rated for 600V. Ill. 9, bibl. 22 (in English; summaries in English, Russian and Lithuanian).

П. Шпаник, Р. Шул, М. Фривалдски, П. Дргона, Ю. Кандрач. Исследование эффективности динамических характеристик силовых полупроводниковых диодов // Электроника и электротехника. – Каунас: Технология, 2010. – № 3(99). – C. 3–6.

Обсуждается использование диодов SiC SBD в конвертерах DC-DC. Описывается обратный эффект восстановления структуры различных диодов и его элиминация. Проведены экспериментальные измерения. Данные были преобразованы в непрерывную форму для графической интерпретации в зависимости для частоты переключения, напряжения и тока нагрузки. Описывается использование новых материалов силовых SBD диодов на технологии SiC, когда измерения проводились при более высоких (150 °C) температурах. Это измерения показывают основные различия в динамических характеристик диодов и, следовательно, как правильного выбрать диода и оптимизировать его питание. Ил. 9, библ. 22 (на английском языке; рефераты на английском, русском и литовском яз.).

P. Špánik, R. Šul, M. Frívaldský, P. Drgoňa, J. Kandráč. Galingų puslaidininkinių diodų dinaminių charakteristikų efektyvumo tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 3(99). – P. 3–6.

Aptariama, kaip SiC SBD diodai gali būti naudojami DC-DC keitikliuose. Aprašomas atvirkštinis įvairių diodų struktūros atsikūrimo reiškinys ir jo pašalinimo būdai. Atlikti eksperimentiniai matavimai, o gautiems duomenims suteikta nepertraukiama forma, kad juos būtų galima interpretuoti grafiškai, atsižvelgiant į komutavimo dažnį, maitinimo įtampą ir apkrovos srovę. Aprašomas naujų medžiagų naudojimas galingiems SBD diodams gaminti taikant SiC technologiją. Matavimai taip pat atlikti esant aukštesnėms (150 °C) temperatūroms. Šie matavimai rodo esminius diodų dinaminių charakteristikų skirtumus ir kaip reiktų tinkamai parinkti diodą ir optimizuoti jo maitinimo šaltinį. Il. 9, bibl. 22 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).