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V-I Curve Based Condition Monitoring System for Power Devices

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***Abstract*— According to gaining importance of power electronics systems in the society, reliability issues of power semiconductor devices are the constrains on availability of the system operations. Regular interval based maintenance for higher availability, on the other hand, increases operation cost since the lifetime of power devices have a large deviation with production lots or conditions which they are used. Condition based maintenance (CBM) of power semiconductor devices will be a promising solution for both the availability and cost of power electronics system maintenance. In this study, a high signal resolution condition monitoring system board has been demonstrated. The system monitors real time V-I curve for both switching device and diode with case temperature and the data is stored on board memory and can be monitored on-line. The board was mounted on the gate driver board being supplied power from the gate driver board and demonstrated on a commercial 60kVA inverter.**

Keywords—V-I curve; Condition minitoring; Power devices; IGBT; power Diode; Condition based maintenance (CBM)

I. INTRODUCTION

Power semiconductor devices are reliability critical components in power electronics systems with high heat generation density and high electric field in the chip and package. The lifetimes of the devices have large deviation under operation, assembling, production conditions and environment the system is used. Thus, regular interval base maintenance to reduce the down time sometimes cause the increase in maintenance cost with unnecessary replacement of good components. Condition based maintenance (CBM) solves the problem for higher availability and system failure and unnecessary maintenance will be prevented.

CBM approach requires [1],

--Select indicator of component degradation,

--Set threshold for the indicator to detect that the component is approaching to failure.

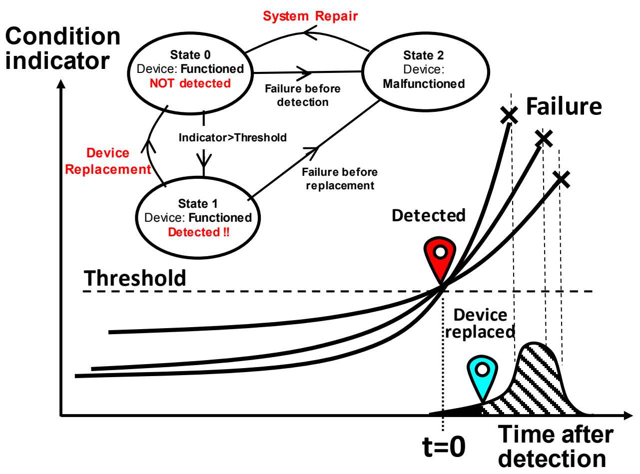


Fig. 1 Condition based maintenance (CBM) for power semiconductor devices.

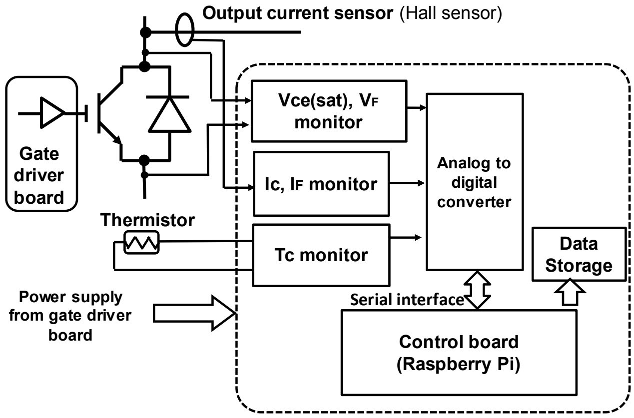


Fig. 2. Schematic of proposed condition monitoring system for power devices (IGBT) with V-I curve applied for three-phase inverter system.

The selected indicator is required to detect the degradation state accurately with sufficient remaining time to failure. If the indicator is not properly selected, or monitoring system is not sufficiently accurate, the component may cause system down without detection (State 0 to 2 in Fig. 1) or system down before maintenance (State 1 to 2 in Fig. 1) with too short time to replace component before failure occurs.

In reported researches, several indicators are selected for power semiconductor condition monitoring [2], such as voltage or current change rate during switching [3, 4], induced voltage between Kelvin and power emitter terminals [5]. Vce(sat) has

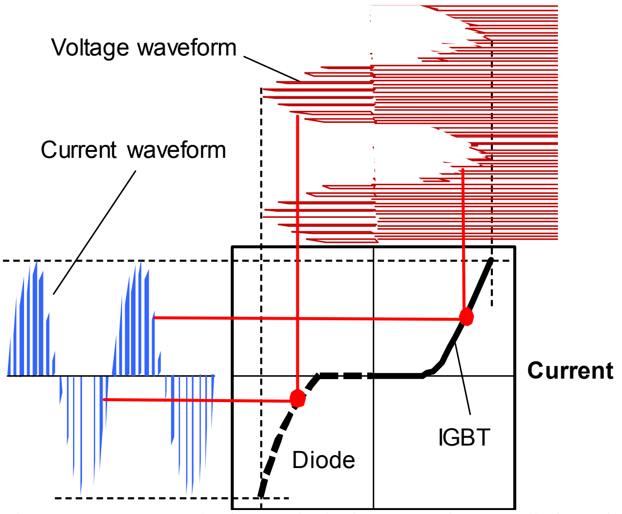


Fig. 3. V-I curve monitoring method of IGBT and power diode under continuous oscillation.

been commonly selected as the indicator for detecting bond wire lift and solder layer degradation ([6-8]), since the degradation directly increases Vce(sat) [9]. Since the increase of the voltage is as small as 50mV to 100mV range for degradation state, the condition monitoring system is required to have sufficient accuracy.

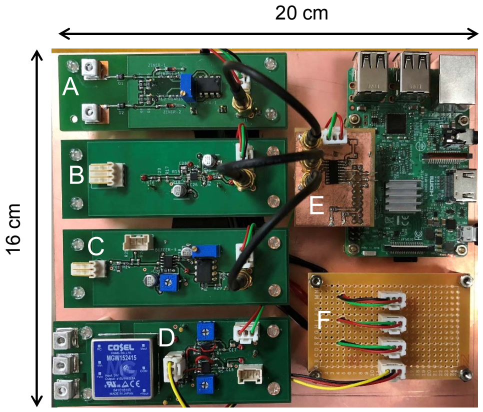
In this study, we demonstrated *V-I* curve based accurate monitoring system for both switching device *Vce(sat)-Ic* and power diode V_F–I_F with conduction current under 60kVA inverter operation.

II. SYSTEM CONFIGURATION

The proposed monitoring system shown in Fig. 2 consists of sensing circuits for voltage drop across main terminals of power semiconductor device, conduction current, and case temperature, an analog-to-digital converter (ADC) to convert monitored value to digital data, a control board (Raspberry-Pi-3) which triggers S/H of ADC and calculate the V-I curve from obtained digital data to display the curve on a small monitor. The digital data is stored on a memory which can access on-line via Wifi etc.

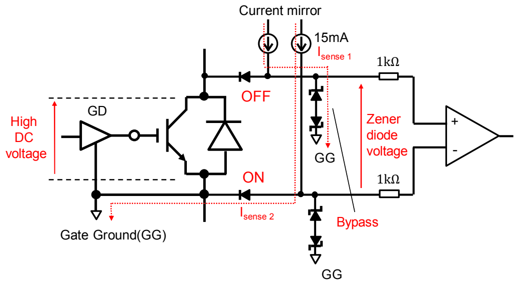
Figure 3 explains V-I curve monitoring. The voltage and the current are measured alternatively in every short interval of 20μsec and pairing the simultaneous voltage data and current data in a register on the Raspberry Pi. The case temperature is monitored once after every four set of V-I data capture. In the system, a 12bit 8ch AD converter IC of MCP3208 is used and CS signal and channel selection signal is generated in Raspberry-Pi. The signal resolution of the conduction voltage determined by ADC is 2.4 mV. The system for demonstration is shown in Fig. 4. The current is measured using a commercially available sensor (HC-U050V4B15).

The key function of the monitoring system is the voltage sensing circuit. The circuit is required to protect the differential amplifier from high voltage blocking state of IGBT, while the differential amplifier part is required to have accuracy of

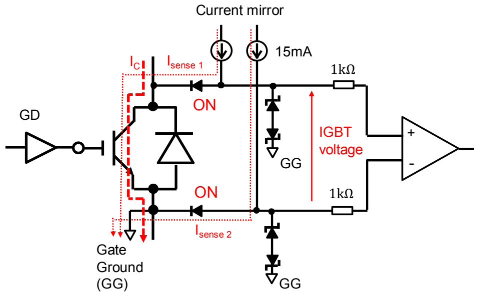


A) Differential voltage sense circuit
B) Gain control circuit of current sensor
C) Gain control circuit of thermistor
D) +15 V/-15 V & +5 V power supply
E) ADC and control board
(Raspberry Pi with memory)
F) +15 V/-15 V branch board

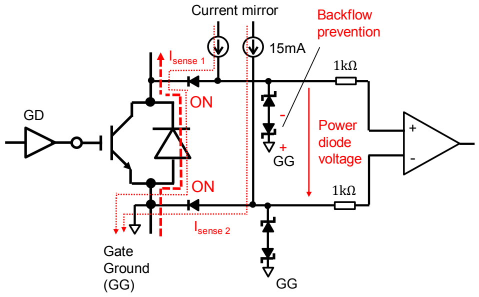
Fig. 4 Implemented V-I curve monitoring system on printed circuit board.



(a) Blocking state



(b) IGBT Vce(sat) monitoring state



(c) Diode VF monitoring state

Fig. 5 Circuit operation for blocking state with high voltage diode, IGBT conduction state and diode conduction state. Two identical diodes are connected to main terminals.

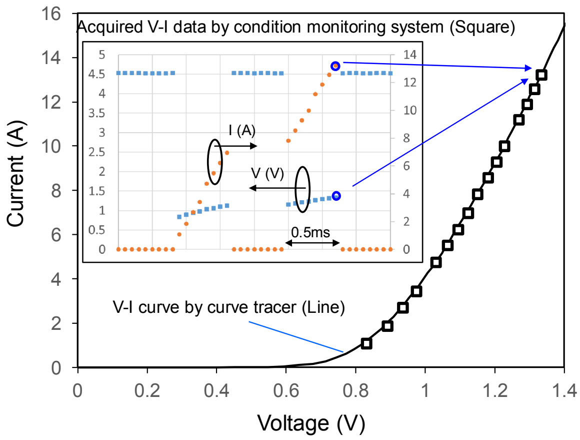


Fig. 6. Monitored V-I curve of IGBT by proposed system with chipper circuit burst pulse test.

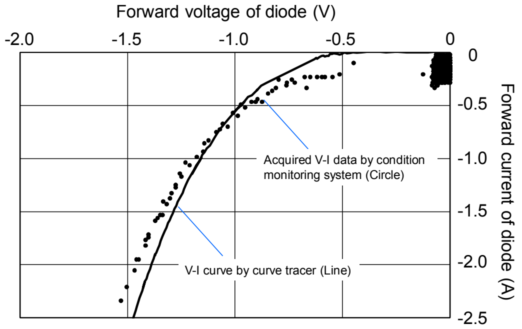


Fig. 7. Acquired V-I curve of power diode by proposed monitoring system with chipper circuit burst pulse test.

millivolts to monitor the voltage drop during conduction. To meet the requirements, a differential amplifier circuit inputs are connected to the main terminal of the power semiconductor to be monitored via two high voltage diodes (axial lead type with small current rating) with 15mA identical forward currents flowing for both diodes [10-12] to identify the voltage drops of two diodes so that the differential amplifier output will not affected the diode voltages. The operation detail is explained in Fig. 5 [13].

III. MONITORING TEST

V-I curve monitoring was tested with IGBT (IGW25T120) and power diode (RHR30120) chopper circuit by burst pulse of 1 kHz with duty 50% in room temperature. Because of the burst pulse test, device temperature maintains room temperature during the pulse. In the test, the maximum collector current was 13 A and DC voltage was 60 V. The maximum monitoring voltage for Vce(sat) and V_F are 4.5 V as the Zener diode voltage (see Fig. 5). The monitored data was compared with curve tracer (Iwatsu CS-3200) and found that average voltage measurement error is only 5.3 mV (see Fig. 6). V-I curve of power diode was monitored by the same circuit in the monitoring system board(Fig. 7).

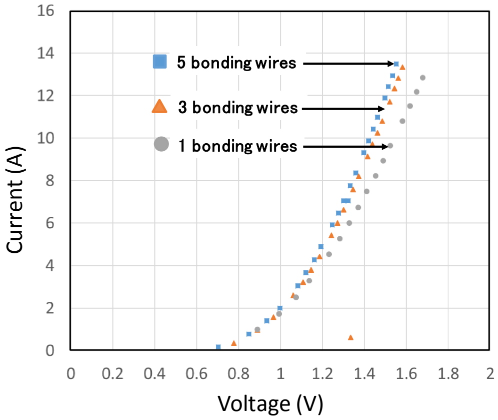
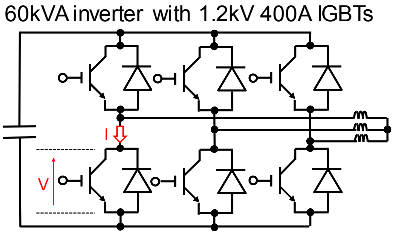
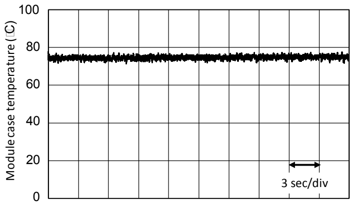


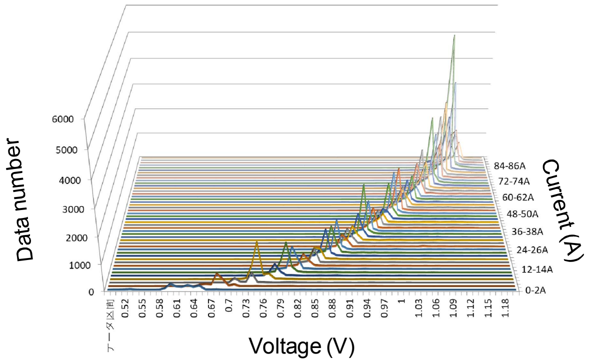
Fig. 8. V-I curve shift of IGBT with wire lift-off samples.



(a) Inverter topology for monitoring demonstration. 600VDC input and 400VAC output(max).



(b) Case temperature monitoring



(c) Histogram of monitored V-I data under inverter continuous operation

Fig. 9. Demonstration of the proposed monitoring system implemented into a commercial 60 kVA inverter.

V-I curve monitoring system was tested with IGBT lift-off samples. The monitoring system successfully monitored the reduction of connected bonding wires as the increase of Vce(sat) as shown in Fig. 8.

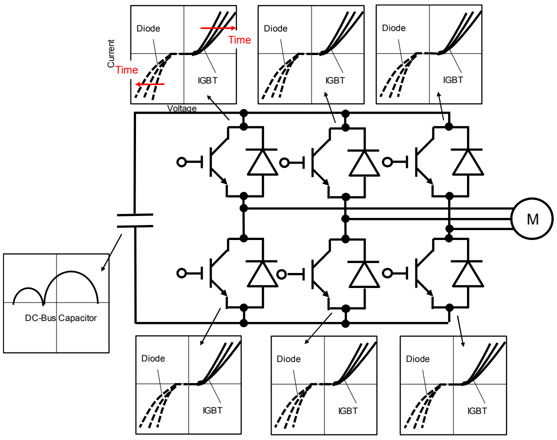


Fig. 10. Example of future monitoring system for CBM of power electronics systems such as motor drives.

IV. DEMONSTRATION OF V-I CURVE MEASUREMENT

The developed monitoring system was implemented in commercial 60 kVA inverter with 1.2 kV 2-in-1 400A IGBT module. Demonstration was performed under continuous operation of 70% of maximum output power. The gate driver board of the inverter supply the power to the monitoring system. The monitoring system successfully extracted V-I curve of the IGBT in the inverter with histogram plot shown in Fig. 9 although the data is influenced by the switching noise and gate driving noise under the high output power.

In practical implementation, degradation to failure is to be monitored by V-I curve shift as indicator as shown in Fig. 10. The V-I curve shift, however, occurs with chip temperature change according with power semiconductor loss under inverter operation condition such as output power, power factor or ambient temperature ([8]). As future research, discussions on algorithm to decompose temperature effect and / or monitoring method of additional indicator will be needed as well as another component condition monitoring methods([14]).

CONCLUSION

V-I curve based condition monitoring system has been developed for the use of future condition based maintenance (CBM) of power semiconductor devices in power electronics systems such as motor drives. The developed monitoring system was tested and it was confirmed that the stored data of IGBT Vce(sat)-Ic curve and power diode VF-IF curve was sufficiently accurate for future condition monitoring.

The system has digital interface by built-in Raspberry-Pi computer board so that the data can be stored on-board memory and / or remotely accessible in real-time basis.

The system was implemented commercial based 60kVA inverter with 1200V IGBTs and V-I curve acquisition was successfully demonstrated under continuous operation with 70% of maximum power.

The results imply that condition based maintenance (CBM) of power semiconductor devices will be adopted to many types of reliability critical power electronics systems and have opportunities of operating and maintenance cost reduction of power electronics systems.

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