

REMOTE MONITORING OF SEMICONDUCTOR SWITCHES' TEMPERATURES IN A BIDIRECTIONAL DC / AC / DC CONVERTER

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Abstract: The paper presents a temperature monitoring system of a bidirectional DC / AC / DC converter. The system allows for remote monitoring of two temperatures (the number can be increased if necessary). The monitoring console is available on any mobile or stationary device connected to the local Wi-Fi network or to the Internet (if it has a static IP). By implementing the remote monitoring, important temperatures of working converter can be monitored from any place with the Internet access. The presented solution may be used in laboratories developing new topologies of power converters that should be monitored for a long time before practical implementation.

Keywords: Digital temperature sensors, Temperature monitoring system, 1 - Wire bus, Node-RED.

1. INTRODUCTION

Semiconductor power devices are crucial components in modern power electronic systems. Their condition has big influence on the overall system performance and can cause system's malfunction in a worst case. One of the important parameters, which give information about their condition and which can be easily observed on-line during the system operation, is the temperature of the power semiconductor devices. The power semiconductor devices frequently operate in thermally stressful conditions. The increasing junction temperature of a power semiconductor device is directly related to increasing power losses and can lead to semiconductor failures. Rising temperature also decreases the region of safe operating area of the semiconductor device. Monitoring of the temperature is therefore important for optimal operation and for reliability reasons. If the switch temperature (junction or case) is known during the operation of a power converter, real-time control systems could be developed to improve the system reliability.

The most popular methods used to estimate the temperature of power semiconductor devices using thermo-sensitive electrical parameters are discussed in [1]. The methods are based on measurement of specific parameters like: the collector-emitter voltage under low current levels, the threshold voltage, the voltage under high current levels, the gate-emitter voltage (for IGBT transistors), the saturation current, and the switching times. All these methods have different characteristics in terms of sensitivity, linearity, accuracy, calibration needs and possibility of characterizing the thermal impedance or the temperature during operation of the converter. The collector-emitter voltage measured

during conduction of low currents is the most suitable method of the chip temperature estimating [2]. An analysis of suitable and temperature sensitive electrical parameters (TSEP) for SiC power MOSFET condition monitoring is presented in [3]. The drain current switching rate and its temperature dependency have been measured and analyzed for different SiC MOSFETs showing that at lower switching speeds, i.e. using higher gate resistances, it can be a suitable TSEP for condition monitoring [3]. The impact of temperature on the switching speed indicates that the current switching rate is an effective TSEP for higher current rated devices but there is necessary sacrifice in the switching speed for enabling the ability of estimating the junction temperature. In particular case it may be an important disadvantage. Authors in [1] propose using of the IR camera for junction temperature evaluations in a power IGBTs. It seems interesting and can be useful in practice but it is a relatively expensive solution and needs special software to recognize separate temperatures of each monitored switch. Additionally, an automatic control may be complicated. Temperature measurements of power semiconductor devices is important in many applications. The presented simple solution, thanks to the temperature monitoring possibility, allows for detection of abnormal states in the low side and high side converters of the bidirectional DC – AC – DC system and gives possibility to test the maximal output power. This is important in laboratories developing new topologies of power converters that should be monitored for a relatively long time before practical implementation. The monitoring system is based on the DS18B20 digital temperature sensors which communicate through the 1-Wire bus with a single-board microcomputer operating the Node-RED dashboard for remote control.

2. BIDIRECTIONAL DC / AC / DC CONVERTER

The bidirectional power conversion system is shown in Fig. 1. It consists of two bridge current mode converters indicated as L and H . They are galvanically isolated by the high-frequency transformer T_R . During energy transmission from the low voltage source V_L , the converter L operates as an inverter, and the H converter works as a rectifier. During the reverse transmission, the H converter operates as an inverter and the L converter becomes the rectifier. Switching process of both inverters is supported by a series-parallel

resonant circuit. It is composed of C_L and C_H capacitors, shunting individual switches and a resonant inductor L_H .

A detailed description and analysis of the converter is presented in [4]. The control of the energy transfer between V_L and V_H sources in the presented converter, is accomplished by switching frequency changes, while maintaining a fixed off time. The L inverter control pulses are shown in Fig. 2.

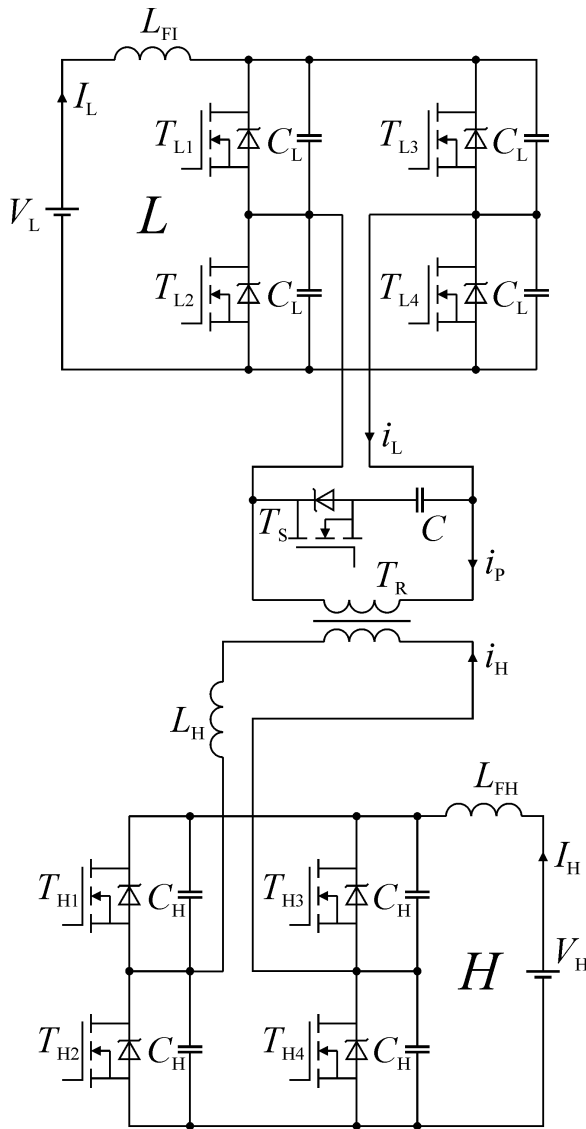


Fig. 1. Bidirectional DC/AC/DC converter

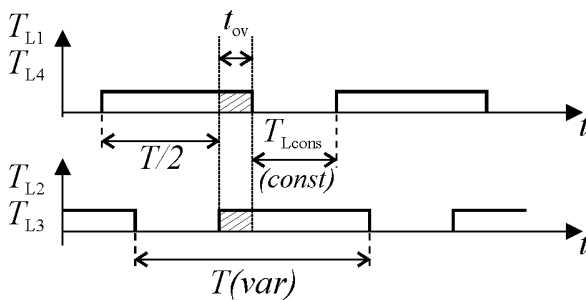


Fig. 2. Control pulses of L inverter

There is an interval, during the switching period T , when all the L inverter switches (T_{L1} , T_{L2} , T_{L3} and T_{L4}) are turned on simultaneously (Fig. 2, interval t_{ov}). The length of this interval increases with decreasing of the control

frequency, due to the maintenance of a fixed interval T_{Lcons} . The result is an increase of the L inverter output voltage during the boost operation. The increase in V_L voltage causes an increase in I_L current and introduces an increase in amount of the energy transferred from the source of low voltage V_L . The increase in the control frequency causes at some point that the t_{ov} interval disappears. When there is no t_{ov} interval at all, the voltage is not increased and the energy is not transmitted in the direction from L to H . The process of energy transmission from the H source to the L source is different. Since increase in voltage is not required in that case, the H inverter can be controlled in a higher frequency region, and t_{ov} interval is not present. The corresponding diagram of the H inverter control pulses at its maximum switching frequency is shown in Fig. 3.

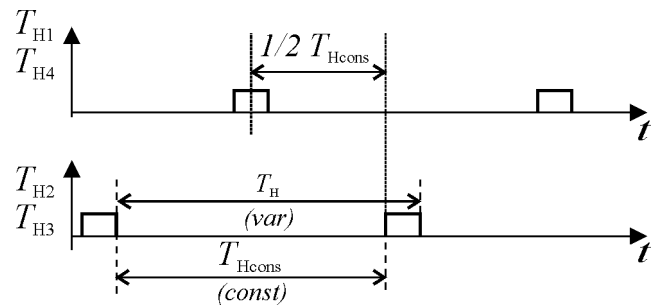


Fig. 3. Control pulses of H inverter

The increase in the amount of energy transmitted from the source H to L occurs with decrease in the control frequency. To ensure soft switching of the H inverter switches, there is a possibility to include additional parallel capacitor C . The additional capacitor C is switched by the transistor T_S (Fig. 1). When the T_S transistor is turned off, resultant capacitance consists of a relatively small output capacitance of the T_S transistor connected in series with the capacitor C .

3. NODE-RED

Node-RED is an open-source graphical development tool for wiring together hardware devices, APIs and online services. Originally developed as an open source project at IBM in 2013 [5], to meet the need to quickly connect hardware and devices to web services and other software – as a sort of glue for the IoT (Internet of Things) – it has quickly evolved to be a general purpose IoT programming tool. It provides a browser-based editor that makes it relatively easy to wire together flows (basic Node-RED projects) using a wide range of nodes (basic flow's code blocks) in the available palette. The connected nodes making the flow may be divided into input nodes, processing nodes and output nodes. Correct and complete flows can be deployed to the runtime in a single-click. A built-in library allows to save useful functions, templates or flows for re-use. The light-weight runtime is built on the Node.js (JavaScript runtime), taking full advantage of its event-driven, non-blocking model [6]. It can be installed anywhere node.js can run, including IoT devices like a Raspberry Pi, BeagleBone, or Intel Edison. This makes it ideal to run even sophisticated projects on low-cost hardware such as the Raspberry Pi as well as in the cloud. With over 225,000 modules in Node's package repository [5], it is easy to extend the range of palette nodes to add completely new, application specific capabilities.

4. TEMPERATURE MONITORING SYSTEM

In the presented power converter, two temperatures are monitored remotely. Namely, it is the temperature of the L bridge radiator and the temperature of the H bridge radiator. The monitoring system can be extended to measure more temperatures and other parameters if necessary. The control panel is available through the local Wi-Fi network on any device with an Internet browser. The temperatures are measured by DS18B20 digital sensors. They are connected to the Raspberry Pi board (RPI v. 3 B, GPIO4) by 1-Wire interface with an external pull-up resistor. The control panel is built based on the Node-RED software. If the RPi board has a static IP in the network, the control panel is available from the Internet. The Node-RED flow of the proposed temperature monitoring system is presented in Fig. 4. Functions for 1-Wire communication and for temperature measurement are implemented in the nodes *Temp1* and *Temp2* (Fig. 4). The *Temp1* is set for a different 1-Wire temperature sensor address (0xFFB11F3B0400) than the *Temp2* (0xFFF91F3D0400). The nodes *H Bridge* and *L Bridge* trigger temperature measurements based on a preset time interval. The node *msg.payload* is used just for debugging purposes and during initial tests was reconnected to different places across the flow to allow proper configuration of all the nodes. Nodes *Gauge 1* and *Gauge 2* displays the measured temperatures in a graphical form on the control panel.

It is possible to export the flow to a text file, which can be used for quick implementation on another machine. A part of such text description of the presented system is depicted in Fig. 5. Fig. 6 presents the configuration window of the *Gauge 2* node. It is visible, that the color gradient of the *Gauge* can change according to the current readings. The user can define threshold temperatures between the color changes (*Sectors* in Fig. 6).

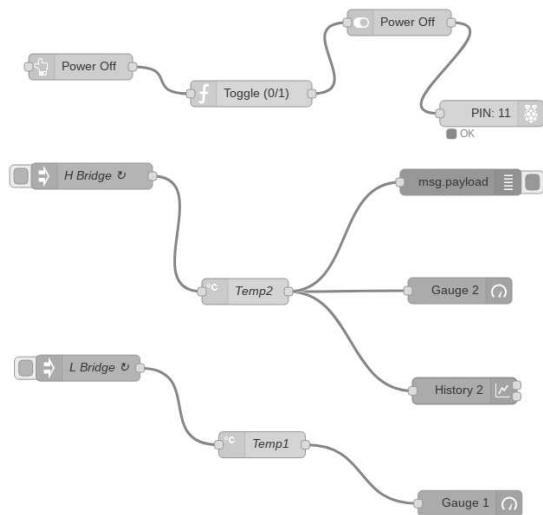


Fig. 4. Node-RED flow of the temperature monitoring system

The *Power Off* switch node controls GPIO11 pin of the Raspberry Pi. Because the RPi board is supplied from a 3.3 V source, and it is not enough to directly control an external power MOSFET transistor, an additional circuit is necessary to rise the voltage to the desired value.

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[{"id":"ca0f9b8d.123168","type":"inject","z":"3c7e7645.26378a","name":"H Bridge","topic":"FFF91F3D0400","payload":"","payloadType":"date","repeat":1,"crontab":"","once":false,"x":374,"y":236,"wires":[["1b163eba.4fb621"]]}, {"id":"41934bc4.fc6434","type":"rpi-gpio-out","z":"3c7e7645.26378a","name":"","pin":"11","set":false,"freq":"","out":{"out":{"x":835.8333740234375,"y":163.8333282470703,"wires":[]},"id":"ee408611.7823f8","type":"ui_gauge","z":"3c7e7645.26378a","name":"","group":"a279c82d.b14de8","order":0,"width":0,"height":0,"gtype":"gauge","title":"Gauge 2","label":"Celsius","format":"{{value}}","min":15,"max":90,"colors":["#17c415","#d07810","#d6093a"],"seg1":45,"seg2":75,"x":799,"y":368,"wires":[]},"id":"1b163eba.4fb621","type":"rpi-ds18b20","z":"3c7e7645.26378a","topic":"FFF91F3D0400","array":false,"name":"Temp2","x":551,"y":369,"wires":[["46c630a9.16b01","ee408611.7823f8","93ceab5b.a501d8"]]}, {"id":"93ceab5b.a501d8","type":"ui_chart","z":"3c7e7645.26378a","name":"","group":"a279c82d.b14de8","order":0,"width":0,"height":0,"label":"History 2"}

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Fig. 5. Part of the flow's text description

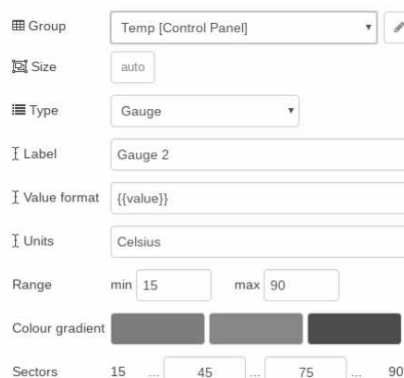


Fig. 6. Gauge 2 configuration

5. EXPERIMENTAL RESULTS

To verify the operation of the DC / AC / DC system and remote temperature monitoring, the laboratory breadboard was built. Experiment setup: V_L was varied from 25 V to 50 V, $V_H = 300$ V, $L_{FI} = 100$ μ H, $L_{FH} = 400$ μ H, resonant inductance $L_H = 24$ μ H, resonant capacitance $C_L = 30$ nF, $C_H = 10$ nF, $C = 120$ nF. Switching frequency was changing in the range from 195 kHz to 310 kHz.

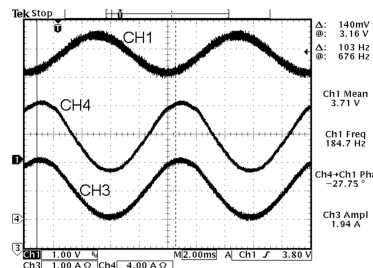


Fig. 7. "CH1" - reference signal, "CH3" - i_H current, "CH4" - i_L current. L converter supplied from $V_{DC} = 48$ V, $f = 103$ Hz

Fig. 7 presents waveforms obtained during energy transfer in direction from H bridge to L bridge. Fig. 8 shows waveforms obtained during energy transfer in direction from L to H . Fig. 9 shows the Raspberry Pi based temperature monitoring console. There are two visible temperature gauges 1 and 2 showing current temperatures from power semiconductor radiators from the bridges L and H respectively. The gauges are able to automatically change colors when the monitored

temperature crosses predefined levels (for example from green to orange and red). The gauges are refreshed every second (it can be changed by modification of the *H Bridge* and *L Bridge* nodes time intervals).

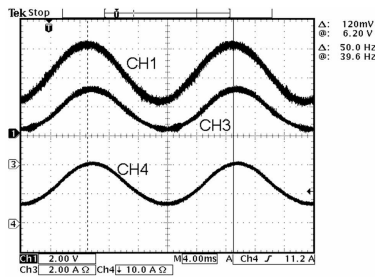


Fig. 8. "CH1" - reference signal, "CH3" - i_H current, "CH4" - i_L current.

L converter supplied from $V_L = 26$ V, $f = 50$ Hz

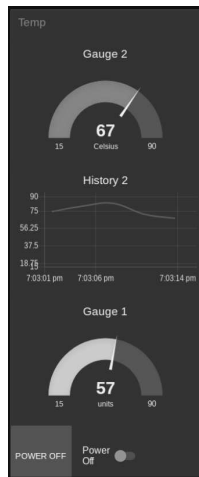


Fig. 9. Monitoring console

Additional chart *History 2* shows history for Gauge 2. Parameters of the *History 2* like sampling interval, min, max, number of points can be modified according to user needs. The control panel also allows for sending commands to the controlled system. In the presented system it is a command to turn off the power in the controlled system.

6. SUMMARY

The paper presents the temperature monitoring system of a bidirectional DC / AC / DC converter. The system works well and allows for remote monitoring of two

temperatures (the number can be extended). The monitoring console is available on any mobile or stationary device connected to the local Wi-Fi network or to the Internet (if has a static IP). By implementing the remote monitoring, important temperatures of working converter can be monitored from any place with Internet access. The presented solution may be used in laboratories developing new topologies of power converters that should be monitored for a long time before practical implementation. It is possible to increase number of temperature sensors and to add another kinds of sensors and actuators to the system. Such an extension may be conducted with a minimal hardware modifications.

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7. REFERENCES

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SYSTEM ZDALNEGO MONITOROWANIA TEMPERATUR TRANZYSTORÓW PRZEKSZTAŁNIKA DC / AC / DC

W artykule przedstawiono system zdalnego monitorowania temperatur półprzewodnikowych przyrządów mocy w przekształtniku DC / AC / DC. Prezentowany system pozwala na monitorowanie dwóch temperatur, jednak liczbę czujników oraz aktuatorów można znacznie rozszerzyć w razie potrzeby. Aktualnie monitorowane są dwie temperatury radiatorów górnego i dolnego mostka przekształtnika DC /AC /DC. Proponowane rozwiązanie bazuje na cyfrowych czujnikach temperatury DS18B20. Są one podłączone poprzez magistralę 1-Wire z jednopłytkowym mikrokomputerem Raspberry Pi w wersji 3. Interfejs 1-Wire oraz interfejs użytkownika umożliwiający monitorowanie temperatur zostały zaprojektowane w środowisku Node-RED. Konsola użytkownika jest dostępna na każdym urządzeniu podłączonym do lokalnej sieci Wi-Fi. Jeśli zastosowane Raspberry Pi posiada stały adres IP dostęp do konsoli jest możliwy z sieci Internet. Proponowane rozwiązanie może być przydatne przy projektowaniu i badaniu nowych konfiguracji i topologii pracy przekształtników energoelektronicznych, które powinny być testowane przez długi czas w laboratorium zanim znajdą zastosowanie komercyjne. System umożliwia przesyłanie sygnałów do przekształtnika czyli zdalne ustawienia.

Słowa kluczowe: cyfrowe czujniki temperatury, system monitorowania temperatury, magistrala 1-Wire, Node-RED.