Power Switch Fault Signatures in a Full Bridge DC/DC Converter of PV System

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ABSTRACT

Photovoltaic power generation stations are remotely located. Surveys have shown that semiconductor power devices are prone to failure due to several stress factors. Redundancy based fault diagnosis schemes in such remote power stations help to automatically diagnose the faulty component. This will reduce time for fault diagnosis. For development of reliable fault diagnosis scheme, proper understanding of fault signatures is essential. This communication deals with examination of fault signatures at various test points in full bridge DC-DC converter. Fault signatures due to open circuit power switch faults in converter are studied here. A model for full bridge DC-DC converter with photovoltaic array as input source has been developed. Open circuit power switch fault is introduced in model and its effect at several test points like across power switch, at transformer primary and secondary, at emitters of lower power switches, at inductor and at output is observed. Simulation results have shown that significant changes take place in the signals at test points. RMS/average value computation of these signatures and comparison with the signals in fault free states is an efficient way of diagnosing exact faulty power switch.

Keywords
open circuit power switch fault, fault signature detection, full bridge DC-DC converter, fault indicators

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Introduction

Nowadays many researchers are working on reliability improvement aspects of converters. Many surveys, articles suggest that power electronic systems are prone to failure due the fragile nature of component. This section discusses contribution by researchers on development of power switch fault diagnosis and tolerant schemes in power electronic systems. Fault diagnosis schemes for motor applications are not discussed here. According to Yantao Song et al [1] devices like power switches and electrolytic capacitors reduces the reliability of power electronic systems. Thermal management techniques, fault diagnostic and prognostic methods are ways to improve reliability. These techniques monitor voltage and current hence are costly. An industrial survey [2] was conducted and it was found that power semiconductor devices are most brittle components in converters due to factors like stress from environmental changes, heavy loads, transients etc. Respondents of this survey expected for better fault diagnosis and tolerant methods. According to authors of this survey converter condition monitoring and temperature monitoring could lead to reliable system. Reference [3] deal with study of problems and challenges in photovoltaic power systems, according to authors design, development and manufacturing of power processing circuits with higher efficiency and lower failure rates is a challenge. Physics of Failure (PoF) based strategy for reliability improvement has studied in ref.[4], authors states that power electronic systems should be designed by considering reliability aspects, selection of suitable devices, modulation scheme, reduction in thermal loading, condition monitoring etc. are some of the methods for reliability improvement. Component failure rates have been computed using Military Handbook MIL-HDBK-217F for reliability prediction of electronic equipment [5]. Markov reliability model is developed here to calculate Mean Time to Failure (MTTF), Mean Time between Failures (MTBF). Performance of interleaved boost DC-DC converter is assessed [6] according to authors' power stages should be designed by considering reliability aspects, major stress is because of temperature factor. Different types of failures, failure mechanisms in IGBTs are discussed [7]. Authors state that catastrophic faults should be paid much attention. Scheduled maintenance and fault monitoring techniques are the keys for reliability improvement in IGBT based converters.

Many researchers have valuable contribution in development
of fault diagnostic and fault tolerant techniques. Accordingly Xuejun Pei et al designed and developed open circuit fault diagnosis and fault tolerant scheme for phase shift full bridge DC-DC converter [8]. The primary voltage of transformer has been monitored where the pattern of voltage depends upon normal/ abnormal conditions of power switches. Whenever any switch becomes faulty the waveform pattern at transformer primary changes from which faulty switch is localized. Open switch fault diagnosis strategy for semiconductor power switches in dual active bridge DC-DC converters is developed [9]. The fault diagnosis strategy presented here is based on two techniques i) measurement of ON state voltage across power switch and ii) sending faulty signal to microcontroller for comparison. For open circuit power switch fault at different switches different patterns of voltage and current are observed. Simulation and experimental results verified the scheme presented here. In [10] redundancy based fault tolerant strategy for three level boost converter applied to PV array has been presented. In this PV panel, capacitor, inductor and triac are the additional components for fault tolerant competence. Authors in ref. [11] suggested multilevel

converter topology for H-bridge DC-DC converter. In this fault tolerance competence is achieved by redundancy approach by connecting additional auxiliary switches, bidirectional switches, and selector cells. Reference [12]

presented fault tolerant approach for step down DC-DC converter in which open circuit fault in MOSFET is detected by measuring the voltage across collector to ground. On occurrence of OC fault the voltage reduces to zero in this case alternate MOSFET is activated by the controller and same inductor and capacitor are maintained in the operation. Voltage divider network, voltage and current sensors are used for fault detection. According to authors high current spikes, voltage stress, gate over voltage are some of the reasons for MOSFET failure. Two transistor based DC-DC boost converter topology is proposed (13) in which fault tolerant transistor work in case of open circuit fault in main transistor. When main transistor works fault tolerant transistor is inactive. The converter is synthesized by using graph theoretical approach. Existing IGBT fault diagnosis and protection methods for inverter are presented in (14). Various fault diagnosis methods are compared, according to authors modified normalized DC current measurement method is meritorious. Various types of fault in power switch, their diagnostic methods and fault tolerant actions are discussed [15]. A novel fault tolerant converter topology based on half and full bridge operation is discussed [16]. Ref. [17] discusses a system in which remote PV power stations are monitored via ICT based techniques to know the status of fault.

From literature review it is clear that fault diagnosis is an important issue in converters and power switches are most brittle components. Therefore in this communication fault signatures generated due to open circuit power switches in full bridge DC-DC converter are studied. The converter model is developed in MATLAB SimPowerSystems toolbox. Open circuit power switch faults are automatically generated in the model and simulation results are studied. Section 2 presents simulation results in different faulty conditions. Summary of fault signatures is presented in section 3.

Full Bridge Dc/Dc Converter Operation

Fig. 1 shows full bridge DC-DC converter. In first cycle diagonal power switches Q1-Q4 conduct so that diodes D1-D4 also conduct providing current through load. In second cycle power switches Q3-Q2 conduct so that D3-D2 pair is brought in operation. LC filter ensures ripple free output.

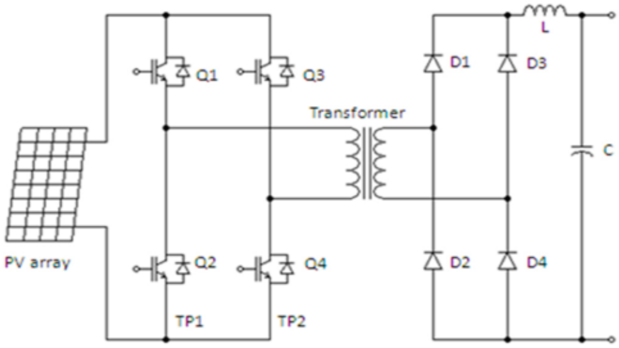

Figure 1- Full bridge DC-DC converter

In this section fault signatures generated in FBDCDC converter due to open circuit power switch fault are studied. Open circuit fault is generated at 0.25 seconds by disabling gate driver pulses automatically [8].

A. Q1 open circuit faulty state

Q1 open circuit fault is automatically generated in the model and results are presented here. Figure 2 shows gate driver pulses automatically disabled thereby making power switch Q1 OFF (open circuit condition) at 0.25 second. Figure 3 shows voltage pulses at transformer primary while transformer secondary voltage pulses are shown in figure 4. Current pulses at test points TP1 and TP2 are shown in figures 5 and 6 respectively. It can be seen that voltage / current patterns shown in these figures changes after switching Q1 to OC faulty state.

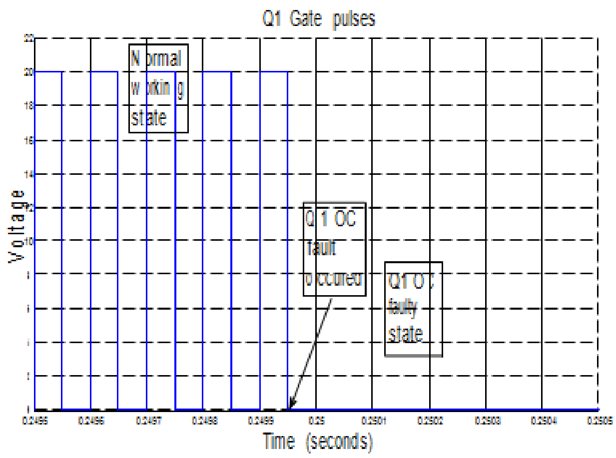

Figure 2- Gate drive pulses of power switch Q1

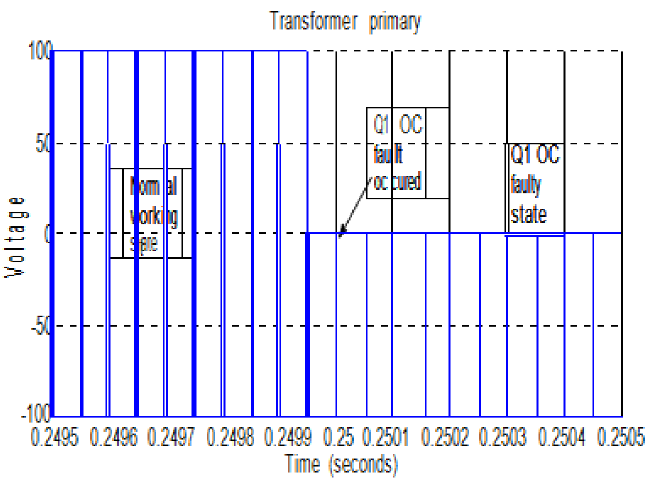

Figure 3- Transformer primary pulses

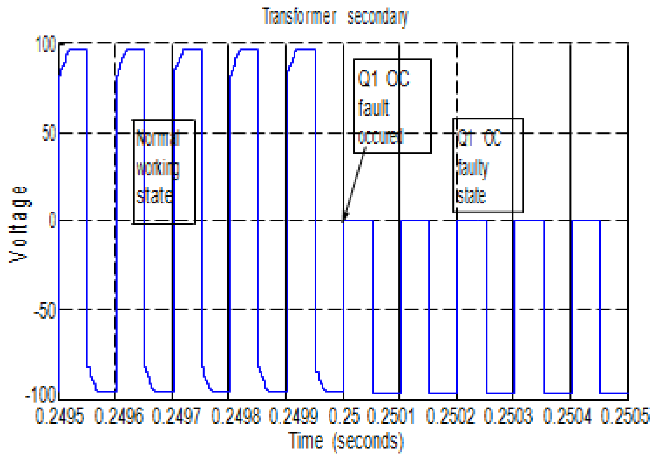

Figure 4- Transformer secondary pulses

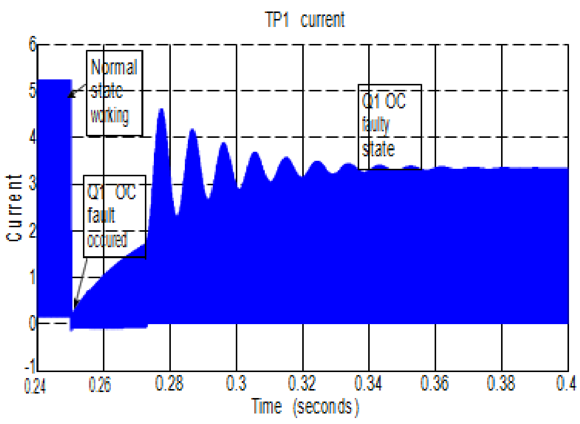

Figure 5- Current pulses at test point TP1

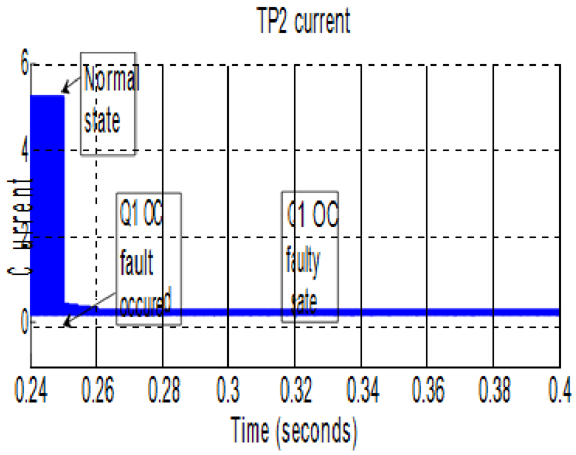

Figure 6- Current pulses at test point TP2

B. Q2 open circuit faulty state

A gate driver pulse of power switch Q2 is automatically disabled to generate open circuit fault. The pulses obtained at various test points are shown here. Transformer primary voltage pulses are shown in figure 7, transformer secondary voltage pulses are shown in figure 8 while figures 9 and 10 shows current pulses at test points TP1 and TP2.

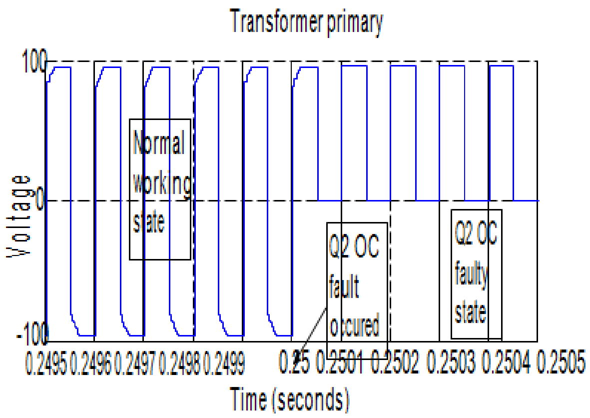

Figure 7- Transformer primary voltage pulses

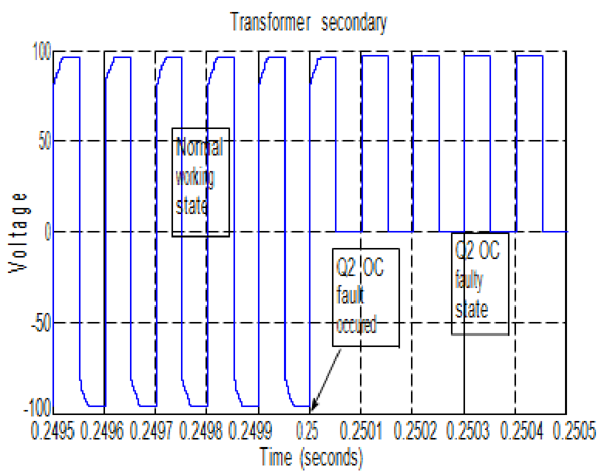

Figure 8- Transformer secondary voltage pulses

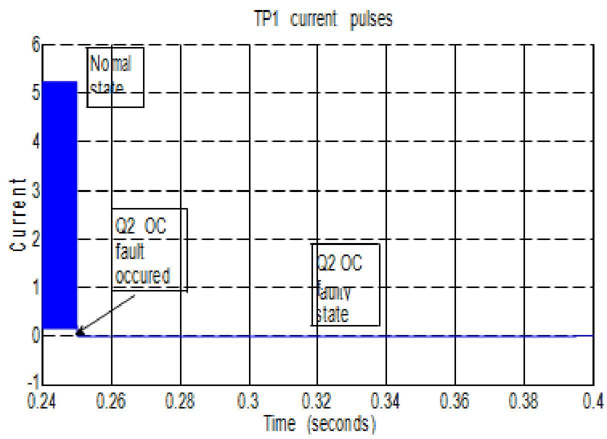

Figure 9- Current pulses at test point TP1

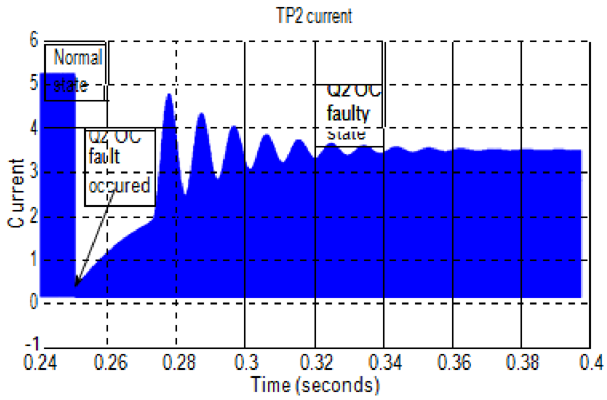

Figure 10- Current pulses at test point TP2

C. Q3 open circuit faulty state

Similarly Q3 is made open circuit and voltage and current patters are analyzed. Figures 11, 12 shows transformer primary and secondary voltage pulses while figures 13, 14 shows current patterns at test points TP1 and TP2

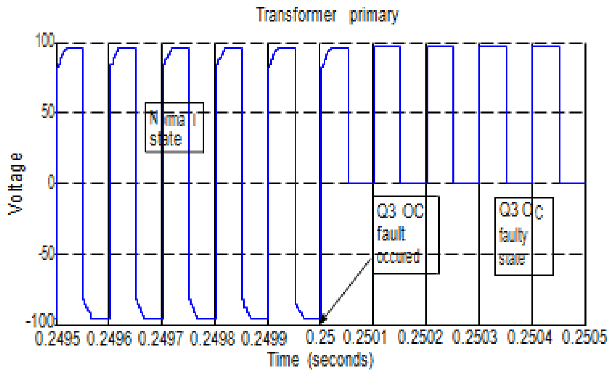

Figure 11- Transformer primary voltage pulses

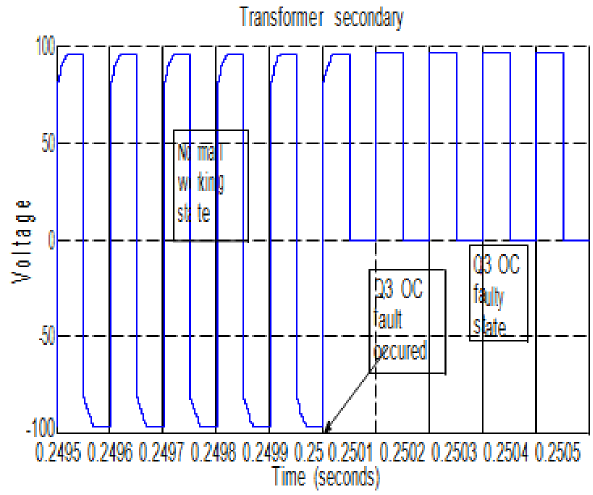

Figure 12- Transformer secondary voltage pulses

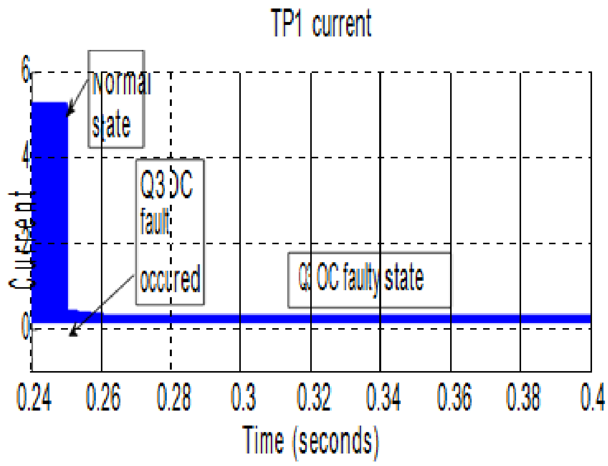

Figure 13- Current pulses at test point TP1

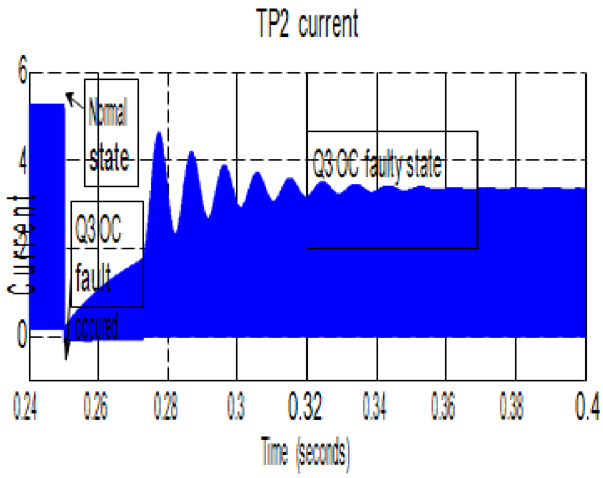

Figure 14- Current pulses at test point TP2

D. Q4 open circuit faulty state

When Q4 power switch is made open voltage pulses at transformer primary and secondary are shown in figures 15 and 16. While figures 17, 18 shows current pulses at test points TP1 and TP2.

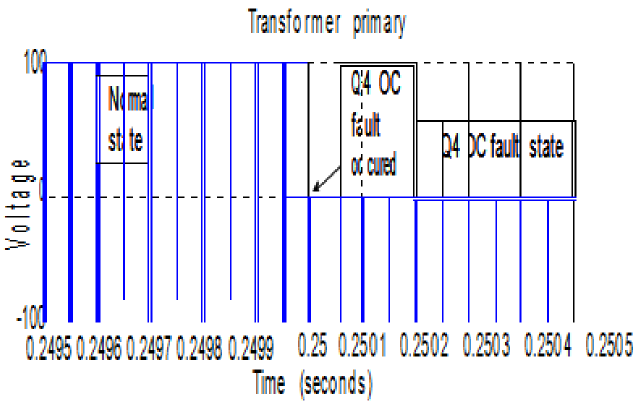

Figure 15- Transformer primary voltage pulses

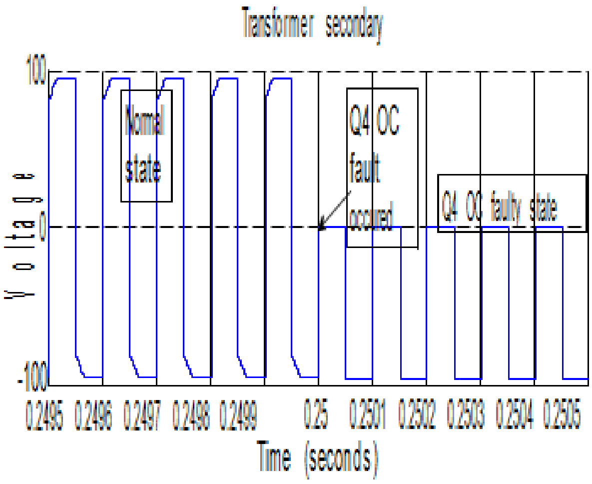

Figure 16- Transformer secondary voltage pulses

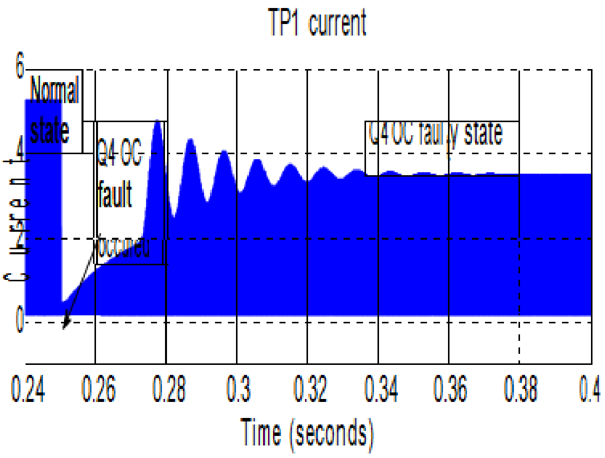

Figure 17- Current pulses at test point TP1

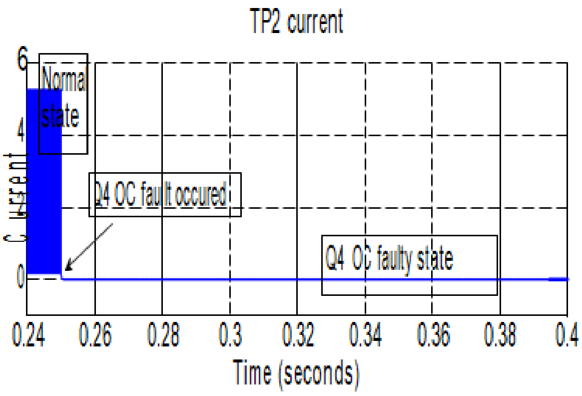

Figure 18- Current pulses at test point TP2

Figures 3-18 has shown fault signatures due to open circuit power switches. The abrupt changes in voltage and current patterns at various locations can be seen. Figures 19-23 shows voltage and current patterns obtained at output and at inductor in all above mentioned four cases. Change in output voltage due to open circuit power switch fault (Q1 to Q4) is shown in figure 19. Similarly change in output current due to any of the open circuit power switch fault is shown in figure 20. Figure 21 shows change in inductor current on occurance of open circuit power switch fault. Inductor current pattern after open circuit power switch fault is shown in figure 22.

Voltage across power switch when it is open circuit faulty is shown in figure 23

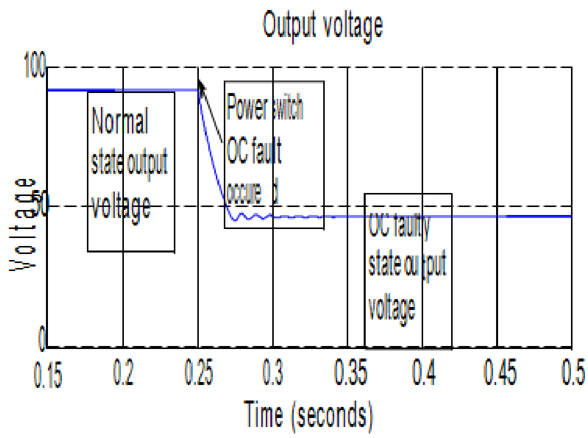

Figure 19- Output voltage in open circuit power switch faults

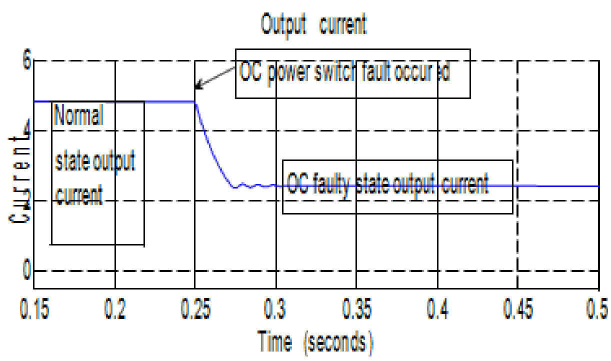

Figure 20- Output current in open circuit power switch faults

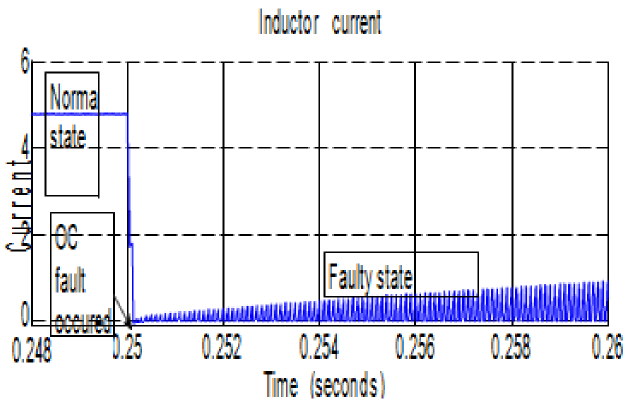

Figure 21- Inductor current on occurrence of OC power switch fault

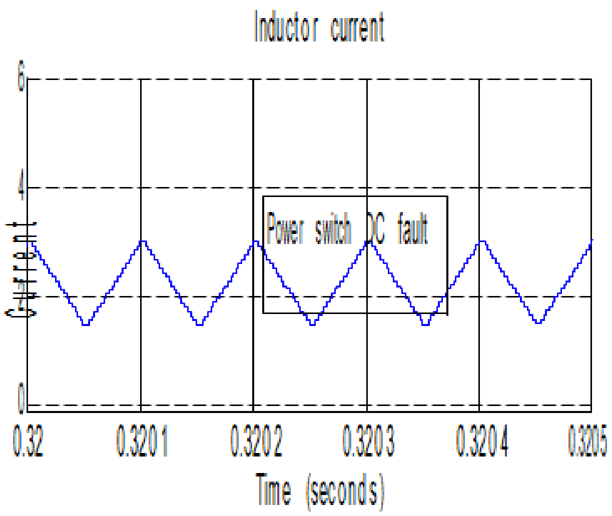

Figure 22- Inductor current after OC power switch fault

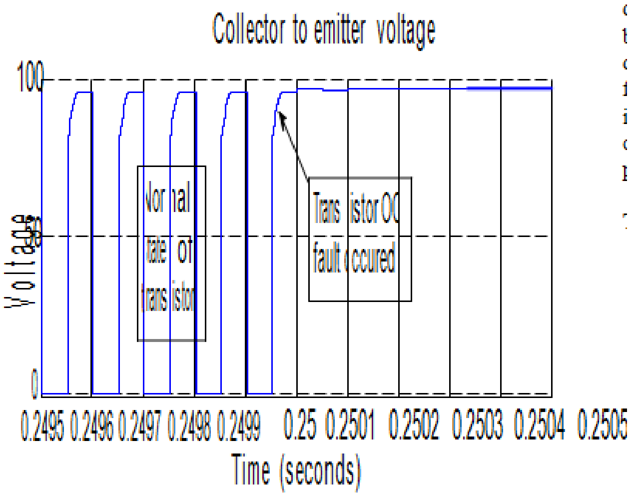

Figure 23- Voltage across faulty power switch

Discussions On Results

Simulation results showed that any open switch fault in power switch generate fault signatures at power switch, transformer primary and secondary, emitters at lower power switches, across inductor and at output. Summary of the results is presented below-

1) Change in output voltage and current

It is observed that output voltage and current drops below certain level. Drop in the level depends upon the output capacitance.

2) Change in inductor ripple current

Due to OC power switch fault inductor ripple current increases.

3) Transformer primary and secondary voltage pattern

In normal state voltage levels at transformer primary and secondary are bipolar; however advent of open circuit power switch fault results in unipolar pulses at transformer primary and secondary. The nature of pulses depends upon transformer properties like magnetization resistance, magnetization inductance, coil resistance, coupling etc.

4) Current pattern at test points

It is found that current pattern at emitters of power switches changes according to fault location. Power switches Q1 and Q4, Q2 and Q3 have same type of current pulses at emitters. Transformer specifications affect the nature of current patters at test points. Magnetization resistance and inductance are modeled as infinite in a transformer.

5) Voltage across power switches

In open circuit state voltage VCE across power switch is same as applied input voltage.

Fault signatures discussed here can be used for localization of faulty power switch. OPAMP based RMS/average detector circuits or microcontrollers in which RMS/average computation algorithms are embedded are good choice for fault signature processing.

In this communication short circuit power switch faults are not discussed but in hardware implementation phase SC faults can be detected using gate drivers with built in short circuit detection scheme which switches OFF the power switch in few micro-seconds as soon as short circuit power switch fault is detected. This creates condition resembling with open circuit power switch fault; the fault signatures can be processed further

Table 1 simulation parameters

Parameters	Rating
PV voltage rating	96V
PV current rating	5.5A
Gate pulse frequency	10 KHz
Duty Cycle	50 %
Filter Capacitor	1500 µF
Filter Inductor	1.5mH
Load Resistor (R_L)	19.2 ohm
Transformer Nominal power	1KW
Magnetization Resistance	infinite
Magnetization Inductance	infinite
Power switch internal resistance	1mΩ

Based on the fault signatures at various nodes, a system can be developed for full bridge converter to detect faulty power switch. If the converters are located on site at remote place, then occurrence of fault and faulty power switch can be detected remotely and necessary preventive action can be taken quickly. Typical flow chart for such a system is described in figure 24. It shows a flow of a system in which power switch fault detection circuits are used based upon the characteristics of fault signatures at various nodes. The system continuously applies PWM pulses and output is regulated, the fault signature detecting circuits senses the changed values of signatures, detects exact faulty power switch and informs remotely regarding the faulty power switch. The mechanisms like automatic fault recovery , component replacement etc. can be initiated without wasting time and without temporarily halting the electricity

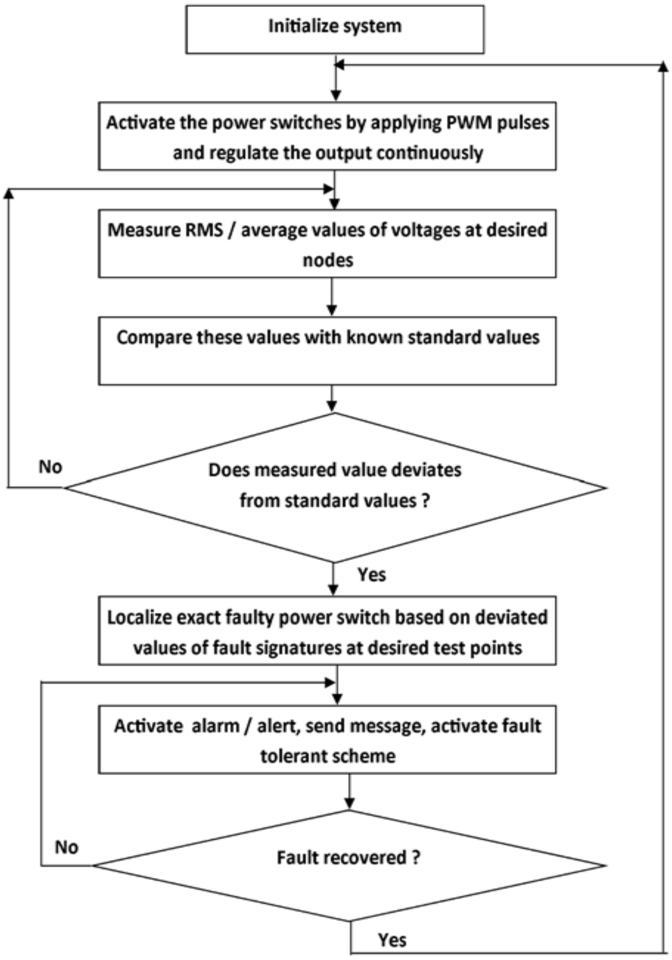

Figure 24- Typical system with fault tolerant or fault alert scheme for remote PV power station

Conclusions and Future Work

Since power switches are prone to failure, fault diagnosis and fault tolerant circuits will improve the reliability of power electronic systems. Simulation results have shown that open circuit power switch faults in full bridge DC-DC converters generate fault signatures which can be processed using RMS/average computations for fault detection. This paper discussed different test points where fault signatures can be monitored. Exact faulty power switch can be located if VCE across it is monitored, this is costly approach as more number of sensors are required. Photovoltaic power stations are remotely located hence to avoid temporary shut down or decrease in power level redundancy based circuits can be implemented. The cost for redundant components will be very less compared with cost due to power shut down or decrease in power level. Focus is required to develop fault diagnosis and tolerant scheme for all components in full bridge DC-DC converter with least number of components.

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References

[1] Yantao Song, Bingsen Wang, “Survey on reliability of power electronic systems”, IEEE transactions on power electronics, Vol. 28 No.1, pp. 591-604 , 2013.

[2] Shayong Yang, Angus Bryant, Philip Mawby, Dawei Xiang, Li Ran, Peter Tavner, “An industry based survey of reliability in power electronic converters”, IEEE transactions on Industry Applications, Vol. 47 No. 3, pp.1441-1451 ,2011.

[3] Giovanni Petrone, Giovanni Spagnuolo, Remus Teodorescu, Mummadi Veerachary , Massimo Vitelli. “Reliability issues in photovoltaic power processing systems”, IEEE transactions on Industrial Electronics, Vol.5 No. 7, pp. 2569-2580, 2008.

[4] H.Wang, , K.MA, F.Blaabjerg, “Design for reliability of power electronic systems”, in Proc. IECON, pp.33-44 ,2012.

[5] S.V.Dhople, A. Davoudi, P.L.Chapman, A.D.Dominguez-Garcia, “Reliability assessment of fault tolerant DC-DC converters for photovoltaic applications”, IEEE Energy conversion congress and exposition,pp. 2271- 2276 , 2009.

[6] Hugo Callega, Freddy Chan, Israel Uribe. “Reliability oriented assessment of a DC/DC converter for photovoltaic applications”, IEEE power electronics specialists conference ,pp. 1522-1527, 2007.

[7] Wu Rui, Blaabjerg, F., Wang, H., Liserre, M., & Iannuzzo, F. “Catastrophic Failure and Fault-Tolerant Design of IGBT Power Electronic Converters - An Overview”. 39th Annual Conference of the IEEE Industrial Electronics Society, IECON, pp.507-513 , 2013.

[8] Xuejun Pei, Songsong Nie, Yu Chen, Yong Kang, “Open circuit fault diagnosis and fault tolerant strategies for full bridge DC-DC converters”, IEEE transactions on

Power Electronics, Vol. 27 No.5, pp.2550-2565 , 2012.

[9] A.M.Airabella, G.G.Oggier, L.E.Piris-Botalla, C.A. Falco, G.O.Garcia “Open transistors and diodes fault diagnosis strategy for dual active bridge DC-DC converter”, 10th IEEE/IAS International Conference on Industry applications ,pp.1-6, 2012.

[10] Eunice Ribeiro, Antonio J. Marques Cardoso, Chiara Boccaletti, “ Fault tolerant strategy for a photovoltaic DC-DC converter”, IEEE transactions on power electronics, Vol. 28 No.6, 3008-3018, 2013.

[11] Khalid Ambusaidi, Volkar Pickert, Bashar Zahawi, “New circuit topology for fault tolerant H-bridge DC-DC converter”, IEEE transactions on power electronics, Vol. 25 No.6, pp.1509-1516 , 2010.

[12] John Long Soon, Dylan Dah-Chuan Lu, “A simple open circuit fault detection method for a fault tolerant DC/DC converter”, IEEE PEDS Australia 2015.

[13] Lu D.D.C, Soon J.L. Verstraete D., “Two transistor step down DC-DC converters with fault tolerant capability”, Australian universities Power Electronics Conference, pp.1-5, 2014.

[14] Bin Lu, Santosh K. Sharma, “A literature review of IGBT fault diagnostic and protection methods for power inverters”, IEEE transactions on industry applications, Vol. 45 No. 5, pp.1770-1777, 2009.

[15] S.B.Chavan, M.S.Chavan, “Power switch faults, diagnosis and tolerant schemes in converters of photovoltaic systems- A review”, International journal of advanced research in Electrical, Electronics and Instrumentation Engineering, Vol.3, issue 9,pp. 11729-11737, Sept. 2014.

[16] L.Costa, G. Buticchi, M. Liserre, “A fault tolerant series resonant DC-DC converter”, IEEE transactions on power electronics, Vol. 32,No.2, pp. 900- 905, 2017.

[17] S.B.Chavan, M.S.Chavan, “ Web based condition and fault monitoring scheme for remote PV power generation station”, in Proceedings of Information and Communication Technology for Sustainable Development 2016, Springer Lecture Notes in Networks and Systems,pp- 133-141