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Improving Fault Isolation in DC/DC Converters Based with Bayesian Belief Networks

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Abstract: This paper lies in the domain of Fault Detection and Isolation (FDI). A Bayesian Naïve Classifier (BNC) structure is selected and used as a first attempt to use Bayesian Belief Networks (BBNs) for DC/DC power converter FDI. In order to highlight the BNC capabilities, it is compared to the well known and used FDI method based on Proportional Observer (PO). This comparative study is based on real data collected from a Zero Volt Switch (ZVS) Full Bridge Isolated Buck converter.

Keywords: Fault Detection and Isolation (FDI), DC/DC converter, Bayesian Belief Network, Observer design, Bayesian Naïve Classifier.

1. INTRODUCTION

Nowadays, electrical machines are used everywhere in our daily life. Electrical power represents the core of any new invention. Actually, It is the main power that keeps our life going on. These facts, increase the demand of continuous electrical energy, and therefore, the demand of reliable electrical supplying systems in order to satisfy the consumers. Continuity requires a fault-free system which can prevent and treat any fault occurrence. For that, it is necessary to have a Fault Detection and Isolation (FDI) system, that can detect the occurrence of the faults as soon as possible, and then isolate the type of the detected faults.

Power converters play an important role in the electrical energy lifecycle and are used in almost all the electrical engineering systems. Thus, in our work we are going to focus on such equipments, especially the ZVS full bridge isolated Buck converter. Such a converter is used in some topologies of Systems of Multi Sources of Energy (SMSE) such as the one shown in Fig.1 (Guerin et al 2012). This DC/DC converter is used to manage the coupling and decoupling of the energy sources on the DC-bus according to the load demand and available power.

Many studies have been done to detect and isolate faults in power converters. A method for MOSFET faults in a ZVS full bridge isolated Buck converter using the DC link current patterns as the signatures of these faults was proposed in (Kim et al. 2008). Authors in (Chen et al. 2011) describe another method based on fast Fourier transform of magnetic near-field of dc-dc converters. In (Meziane et al. 2015) a model-based approach FDI method was proposed, following a sliding mode observer based on a residual generation that was applied on a three-cell power converter. Moreover, in (Guerin et al. 2009), a set of residuals were generated using parity space algorithm according to a variable structure state space model in order to detect sensor faults in ZVS full bridge isolated Buck converter. This work was completed in (Guerin et al. 2011) by using an additional measurement depending on the use of a magnetic near-field probe.

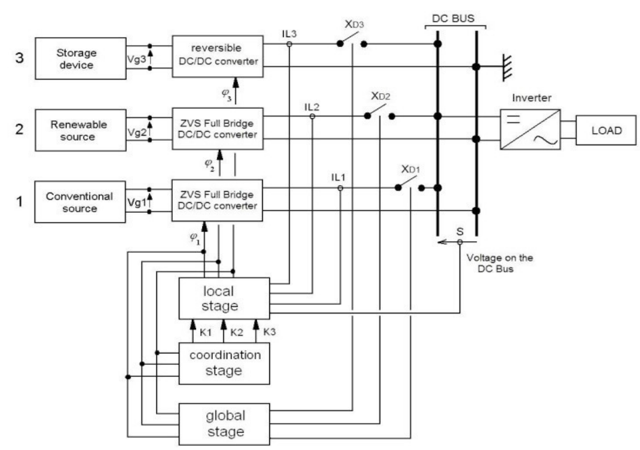

Fig. 1. Topology of the SMSE.

In this paper, a Bayesian Naïve Classifier (BNC) structure is selected and used as a first attempt to use Bayesian Belief Networks (BBNs) for DC/DC power converter FDI. BBNs have been used for FDI and they proved a high efficiency (Zhao et al. 2016). The capabilities of BBN is highlighted with a comparative study between BNC as a simple form of BBN, and the Proportional Observer (PO) as a well known and used FDI method (Blanke et al. 2003), and as the simplest form of observers. The obtained results, show clearly that the BNC surpasses the PO and prove its capabilities for DC/DC power converter FDI.

2. STUDIED SYSTEM AND CONSIDERED FAULTS

2.1. ZVS full bridge isolated Buck converter model

The structural diagram of the ZVS full bridge isolated Buck converter is represented on the Fig.2. These DC/DC converters are isolated (HF transformer TR1) Buck converters (D5, D6, D7, D8, L, Ce, Re) with a full bridge

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(Q1, Q2, Q3, Q4) and ZVS. The full bridge control (Q1, Q2, Q3, Q4) is realized by a phase shift controller UC3879 through specialized MOSFET drivers IR2113. The duty cycle value φ is modified by the phase shift between V_a and V_b voltages. The phase shift is controlled by an analog DC voltage (between 0V and 5V) which represents the DC/DC converter analog voltage control input.

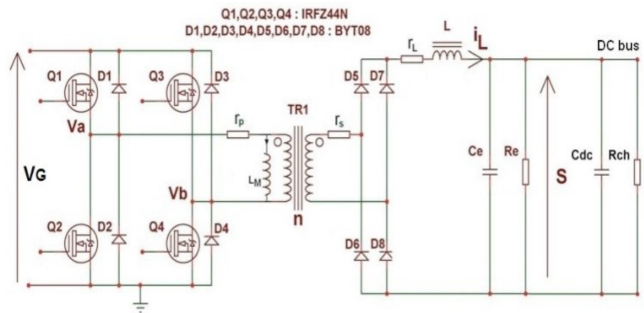

Fig. 2. Structural diagram of the ZVS full bridge isolated Buck converter.

Four running phases must be distinguished:

Phase 1: (Q1Q4) closed: from $t = 0$ to $t = \varphi T_0$

Phase 2: (Q1d3) closed: from $t = \varphi T_0$ to $t = T_0$

Phase 3: (Q2Q3) closed: from $t = T_0$ to $t = (1+\varphi)T_0$

Phase 4: (Q2d4) closed: from $t = (1+\varphi)T_0$ to $t = 2T_0 = T$

Let us define i_M as the magnetizing current (A) of the HF transformer, i_L as the inductance current (A), i_g as the source current (A), s as the DC/DC converter output voltage (V), V_g as the source voltage (V) and V_d as the threshold diode voltage (V).

The authors (Mboup A.B. et al 2008) have developed an average state space model that depends on the duty cycle value $\varphi(t)$, controlled by the analog voltage control input.

Let us define the state, control and output vectors of the average model as:

- $X_M = (I_M, I_L, S)^T$
- $U_M = (V_g, V_d)^T$
- $Y_M = (I_{mg}, I_{mL}, S_m)^T$

where:

- I_M, I_L and S stands for the average values of i_M, i_L, and s respectively.
- I_{mg} is the measured average value of the current sinked from the source (A).
- I_{mL} is the measured average value of the current provided to the load (A).
- S_m is the measured average value of the DC/DC converter output voltage (V).

The average model is represented with the equations (1) and (2). This model will be used as a reference model in the next section in order to design the observer used for fault detection and diagnosis.

$$\dot{X}_M = A_M(\varphi(t)).X_M(t) + B_M(\varphi(t)).U_M$$
$$Y_M(t) = C_M(\varphi(t)).X_M + d(t) \qquad (1)$$

where $d(t)$ represents the measurement error vector. A_M, B_M and C_M are given by equation (2):

$$A_M(\varphi) = \begin{pmatrix} \frac{R_{mos}\,\varphi + R_{mos} + r_p}{L_M} & 0 & 0 \\ n & & \\ -\frac{n(2R_{mos} + r_p)}{L} & -\frac{r_L + \varphi r_s + n^2\varphi(2R_{mos} + r_p)}{L} & -\frac{1}{L} \\ 0 & \frac{1}{C_{eq}} & -\frac{1}{R_{eq}C_{eq}} \end{pmatrix}$$

$$B_M(\varphi) = \begin{pmatrix} 0 & 0 \\ \frac{n.\varphi}{L} & -\frac{2}{L} \\ 0 & 0 \end{pmatrix}, \qquad C_M(\varphi) = \begin{pmatrix} \varphi & n.\varphi & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$R_{eq} = \frac{R_e R_{ch}}{R_e + R_{ch}} \;;\; C_{eq} = C_e + C_{dc} \qquad (2)$$

r_p, r_s, L_M and R_{mos} are respectively the primary resistance, the secondary resistance, the magnetizing inductance of the HF transformer (TR1) and the MOSFET transistors (Q1,Q2,Q3,Q4) channel resistance. L, r_L, C_e and R_e are respectively the coil inductance, the coil resistance, the capacity and the resistance of the Buck converter. n is the ratio of the HF transformer. R_{ch} is the load (assumed to be resistive).

GREAH Research Group of the University of Le Havre (France), has designed and developed a ZVS full bridge isolated Buck converter with ability to simulate ten faults (Fig 3): (1) phase shift controller stuck ON (+15V), (2) phase shift controller stuck OFF(0V), (3) MOSFET open circuit, (4) MOSFET driver stuck ON (+15V) (5) MOSFET driver stuck OFF (0V), (6) MOSFET short circuit, (7) diode short circuit, (8) coil open circuit, (9) diode open circuit, and (10) clock frequency deviation including the considered open circuit faults. This system supports our work with the required real data.

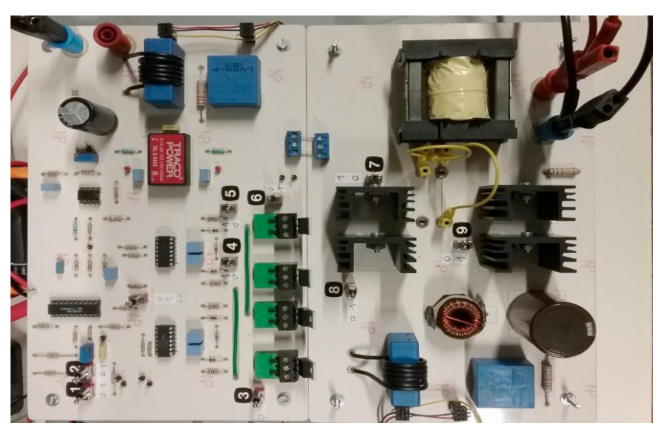

Fig. 3. ZVS full bridge isolated Buck converter

2.2. *Considered faults*

ZVS full bridge isolated Buck converter is mainly used in some topologies of Systems of Multi Sources of Energy (SMSE) as in (Guerin et al 2013). Its main role is to couple and decouple the sources of energy according to their availability and the load demand. Such DC/DC converters are exposed to faults that may be very harmful due to the environment they work in. Electrical faults can be a short