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Fault Detection and Identification Scheme for Boost Converter for Hybrid Vehicles

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ABSTRACT

In a wide range of applications, such as smart buildings, electric vehicles, hybrid systems, and renewable energy, dc dc converters are crucial. The dc dc converters have many topologies, and the boost converter is one of the most important. The problem. The boost converter is connected to other sensitive devices and components, so any fault in the Boost converter will lead to a system issue, which may cause catastrophic damage to humans and related devices. These faults include parameter degradation of passive components, open switch failure, and sensors failures. Goal. The development of a fault detection and identification scheme for a dc-dc boost converter is the main goal of this study. Therefore, it is essential to make sure that the converters are safe from malfunctions and that there are no major accidents or disasters in order for them to carry out their vital jobs. Methodology. The scheme covers a wide range of potential faults, such as parametric degradation of passive components, open switch fault, and sensors failures. We created the scheme as a structured algorithm based on residuals between observers and measurements from the sensors, residuals between open switch fault signature and measurements from the sensors, residuals between assumed values of the sensors and real measurements, and carefully considered thresholds to compare these residuals with. Results. Simulations were used to assess the proposed scheme. The results show the effectiveness of the scheme in detecting and identifying faults quickly and accurately. The originality. of this work lies in the creation of a fault detection and identification scheme using luenberger observers and specific thresholds without the need for additional sensors or devices.

1. Introduction

DC-DC converters are used in electrical systems and hybrid energy systems, which has many applications as it is used in electric and hybrid vehicles, solar panels cell phones and laptops, to store and reuse electrical energy [1], [2].

To ensure the safe operation of these devices and vehicles, it requires full assurance of the safety of the dc dc converter from faults [3], correcting them and even predicting faults before they occur

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[4], and for this many studies have been conducted on fault detection and identification in dc-dc converter [5]; as dc-dc converter faults are divided into three types [6], fault in switches, fault in passive components and fault in sensors; Several studies have been conducted to develop methods for detecting open switch fault [7]-[18], and in [19] the authors Utilizes a current-based fault diagnosis method, in [20] the authors Utilizes inductor current without extra sensors, in [21] the authors Proposes a Luenberger observer-based fault diagnosis method, in [22] the authors Utilizes a current sensor for fault detection and in [23] the authors Focuses on open-circuit and short-circuit faults and Utilizes an adaptive threshold approach for fault detection, Others have studied passive parameters estimation [24], [25] and in [26] focus on adaptive rules to estimate the values and in [27] designs a new type of adaptive sliding mode observer, And there are those who have studied the sensor malfunction [28]-[34] where in [35] they used luenberger observer in boost converter. In addition, there are some fault detection and identification schemes [36]-[50].

In this paper, we have developed a scheme for fault detection and identification (FDIS), where there are fault detection observers to detect the presence of a fault, and when a fault is found, the fault identification algorithm starts working to identify the faulty element.

2. Modeling of Boost Converter

The dynamics of a power electronic converter are described by a linear switching model. Any power electronic converter can be broadly described using piecewise linear elements as follows [43]: Simulation strategy for the proposed FDIS shown in Fig. 1.

$$\dot{x}(t) = A_{\alpha(t)}(t)x(t) + B_{\alpha(t)}(t)u(t) \tag{1}$$

$$y(t) = C\,x(t) \tag{2}$$

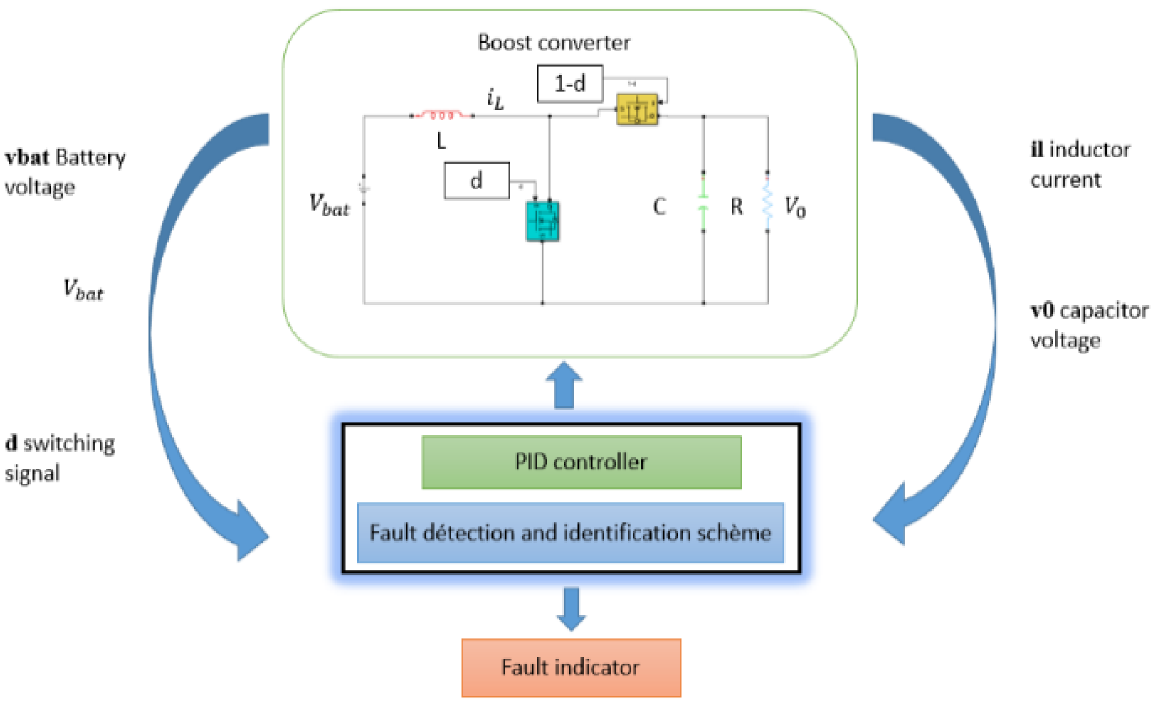

Fig. 1. Simulation strategy for the proposed FDIS

The converter's states and outputs are denoted by x (t) and y (t), respectively. The converter inputs are denoted by u (t). The active switch configuration of the circuit is indicated by α (t), a continuous time switching signal. In the continuous conduction mode, the linear-switched state-space model of the dc-dc Boost converter is as follows:

The linear-switched state-space model of the dc-dc bidirectional buck boost converter in the continuous conduction mode is given by:

Boost mode:

$$\begin{bmatrix} \dot{\hat{\mathrm{i}}}_{\mathrm{L}} \\ \dot{\hat{\mathrm{v}}}_{0} \end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{(1-\mathrm{D})}{\mathrm{L}} \\ \dfrac{(1-\mathrm{D})}{\mathrm{C}} & -\dfrac{1}{\mathrm{RC}} \end{bmatrix} \begin{bmatrix} \hat{\mathrm{i}}_{\mathrm{L}} \\ \hat{\mathrm{v}}_{0} \end{bmatrix} + \begin{bmatrix} \dfrac{1}{\mathrm{L}} & \dfrac{\mathrm{V}_0}{\mathrm{L}} \\ 0 & -\dfrac{\mathrm{I}_{\mathrm{L}}}{\mathrm{C}} \end{bmatrix} \begin{bmatrix} \hat{\mathrm{v}}_{\mathrm{bat}} \\ \hat{\mathrm{d}} \end{bmatrix} \tag{3}$$

3. Fault Modeling

There is three types of possible faults in this dc dc converter:

1. The model component fault of passive elements in the Boost converter

$$\dot{x}(t) = (A_{\alpha(t)}(\mathrm{t}) + \partial A_{\alpha(t)}(\mathrm{t}))\,\mathrm{x(t)} + (B_{\alpha(\mathrm{t})}(\mathrm{t}) + \partial B_{\alpha(\mathrm{t})}(\mathrm{t}))\,\mathrm{u(t)} \tag{4}$$

$$\dot{x}(t) = A_{\alpha(t)}(\mathrm{t})\,\mathrm{x(t)} + B_{\alpha(\mathrm{t})}(\mathrm{t})\,\mathrm{u(t)} + \mathrm{K}\,f_i(\mathrm{t}) \tag{5}$$

Where i = 1..., M M is the number of passive converter component parameters in the linear-switched state space model; K is an identity matrix, and $f\_i\ (t)$ is the component fault vector (Table1).

2. Open switch signature the same structure of luenberger observer but with d=0

$$\dot{z}(t) = A_{\alpha(t)}(\mathrm{t})\,\mathrm{z(t)} + B_{\alpha(\mathrm{t})}(\mathrm{t})\,\mathrm{u(t)} + \mathrm{Lr(t)} \tag{6}$$

$$y(t) = C\,x(t) \tag{7}$$

3. The model of sensors fault

$$y(t) = (C + \partial \mathrm{C})x(t) \tag{8}$$

$$y(t) = C\,x(t) + \mathrm{K}\,f_{si}(\mathrm{t}) \tag{9}$$

4. Design Approaches for Fault Detection and Identification

There is four approaches using in our fault detection and identification scheme, through which we identify the damaged element.

1. Fault detection observers: The following set of equations gives the linear switched FD observers

$$\dot{z}(t) = A_{\alpha(t)}(\mathrm{t})\,\mathrm{z(t)} + B_{\alpha(\mathrm{t})}(\mathrm{t})\,\mathrm{u(t)} + \mathrm{Lr(t)} \tag{10}$$

$$y(t) = C\,z(t) \tag{11}$$

$$\mathrm{r}_{\alpha(\mathrm{t})}(\mathrm{t}) = \mathrm{y(t)} - \mathrm{Cz(t)} \tag{12}$$

Where r (t) is the filter residual vector, which is the difference between the measured output y (t) and the estimated output C z (t), z (t) is the state estimation vector and L is the filter gain matrix that satisfies the criteria that the eigenvalues of $A_{\alpha(t)}(\mathrm{t}) - \mathrm{LC}$ is strictly negative, $\alpha\ = 1, 2:\ \ \alpha\ = 1$ current observer, $\alpha\ = 2$ voltage observer

Fault detection logic: A binary decision is made that there is an error when the residues between the actual current and current observer exceeds a threshold, which is determined by the user by observing the upper value of the system errors in the absence of any error $r\ (t)\ >\ \Gamma$, and the same

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thing with the residue of the voltage between the actual values and voltage observer, if there is an error the fault identification algorithm determines the faulty element and the error value.

2. Open switch signature

To detect open switch fault we use open switch signature we use a luenberger observer with open switch model and compare the actual value of current and voltage with the current and voltage of this observer, when this residues less a threshold there is open switch (osw) fault

3. Parameters estimation

To identify faults of passive elements we estimate their values, we use high gain luenberger observer to estimate it; when the estimates value of inductor less a threshold the system indicate the faulty elements is the inductor and the same thing with the capacitor.

4. Sensors faults

To identify the faulty sensor, we take the residues of compare the actual current value with the current of the model of boost converter without faults; when the residue exceeds a threshold the system identify the faulty sensor is the current sensor, and the same thing with voltage sensor.

5. Fault Detection and Identification Scheme for Boost Converter

The proposed fault detection and identification scheme designed for boost converter the figure (Fig. 2) describe this scheme, the scheme into two principal part, the first part is fault detection; when the system begin the observers of fault detection is working, when one of them detect a fault the second part fault identification is working like algorithm. The first step of second part is compare the current and voltage of the system with osw signature; if the residues of this comparison less a specific threshold FI algorithm identify the faulty component is the switch and its status is open, else FI algorithm move to the next step.

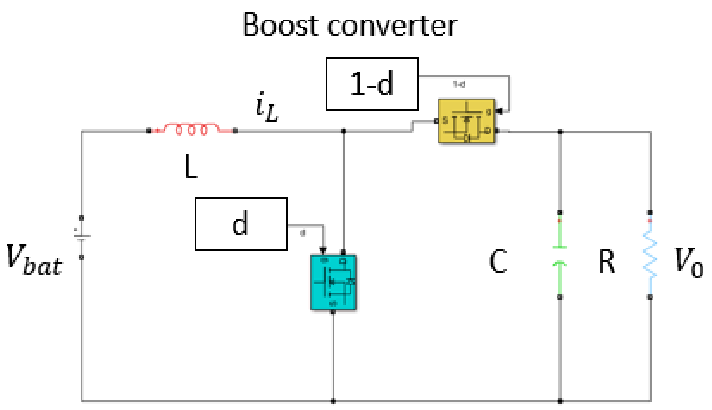


Fig. 2. Boost converter

The second step FIA estimate the value of inductor, if the estimates value less a threshold FIA identify the faulty component is the inductor and gives the estimate value's, if else FIA move to next step. The third step is FIA estimates the value of capacitor with the parameters estimation approach if the estimates value less a specific threshold FIA identify the faulty component is the capacitor and gives the estimate value's, if else FIA move to next step.

The fourth step is FIA compare the value of current sensor with the estimates current of the mathematical model of the boost converter without faults, if the residue exceeds a threshold, then FIA identify the fault component is the current sensor, if else FIA move to next step. The fifth step is the FIA compare the value of voltage sensor with the estimates voltage of the mathematical model of the boost converter without faults, if the residue exceeds a threshold then FIA identify the faulty component is the voltage sensor, if else FIA stop and return into FD part. Flowchart of the system shown in Fig. 3.

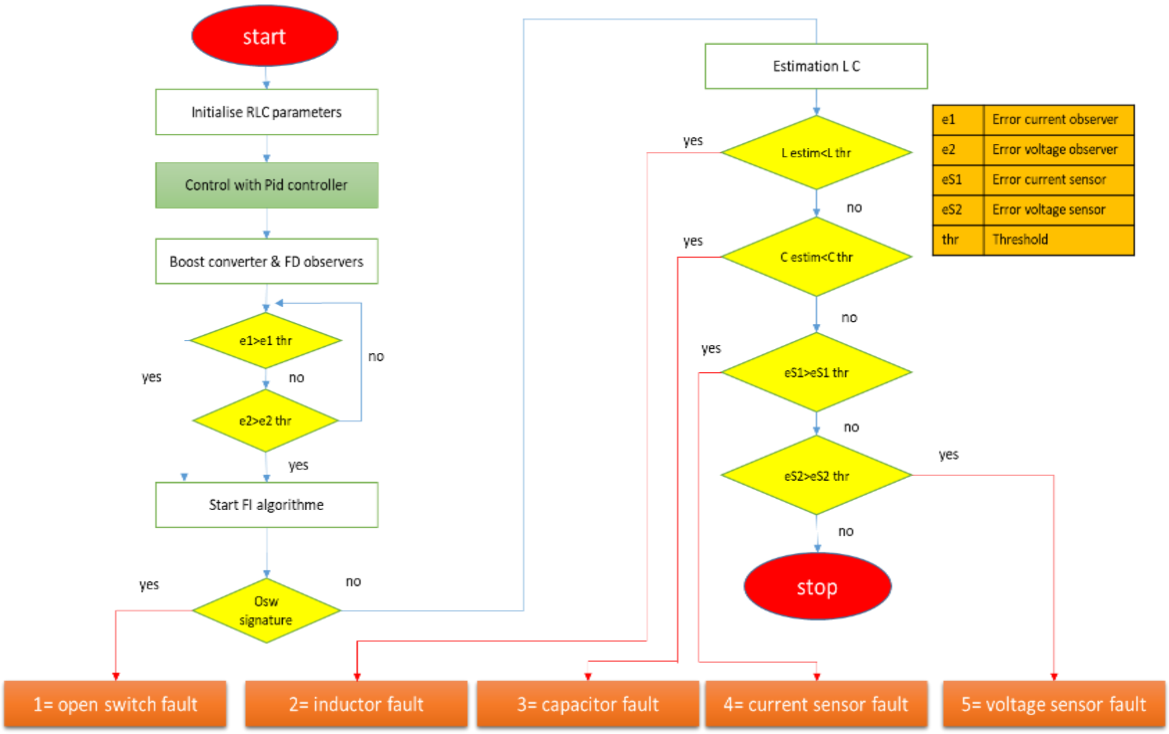


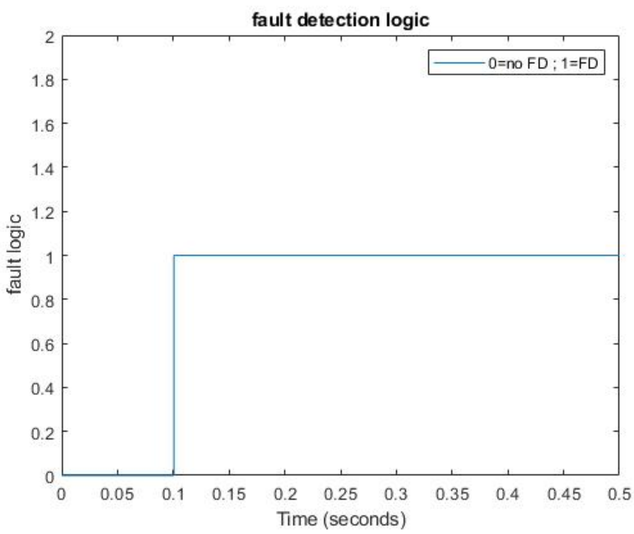
Fig. 3. Flowchart of the system

Table 1. Parameters

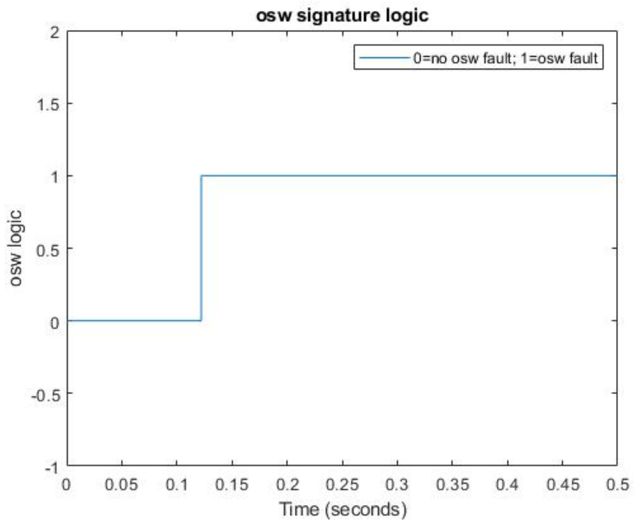
Parameter	**Value**
Inductor	$L = 0.0047\ H$
Capacitor	$C = 0.00047\ F$
Load	$R = 40\ Ohm$
Battery	$Vbat = 40\ V$

6. Simulation Results

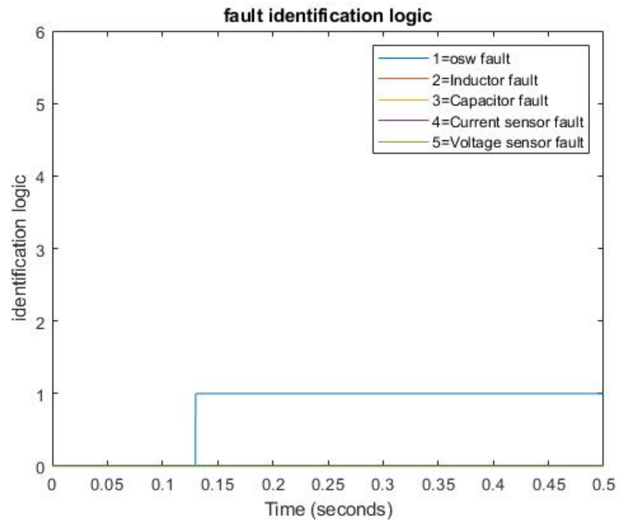
Simulation results are presented for detecting and identifying five different kinds of converter component faults which include open switch fault (Fig. 4) and decrease value in capacitance C (Fig. 5) and decrease value in inductance L (Fig. 6) and current sensor fault (Fig. 7) and voltage sensor fault (Fig. 8).



(a) Fault detection logic



(b) Osw signature logic



(c) Fault identification logic

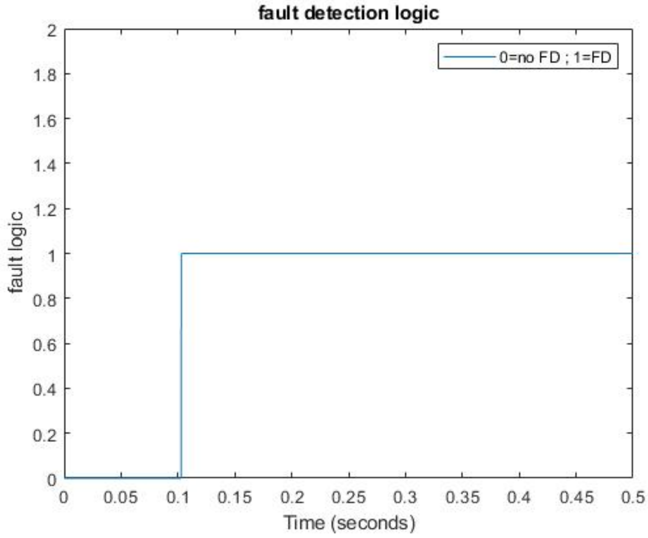
Fig. 4. demonstrate the steps of FDIS to detect open switch fault

Fig. 4 demonstrate the steps of FDIS to detect open switch fault, when we inject osw fault in 0.1 S the FDIS (Fault detection and identification scheme) detect a fault with FDA (Fault detection algorithm) in the system in 0.001 S and make a flag=1, after this flag FIA start working and after 0.03 S identify the faulty component is the switch and represent its flag.

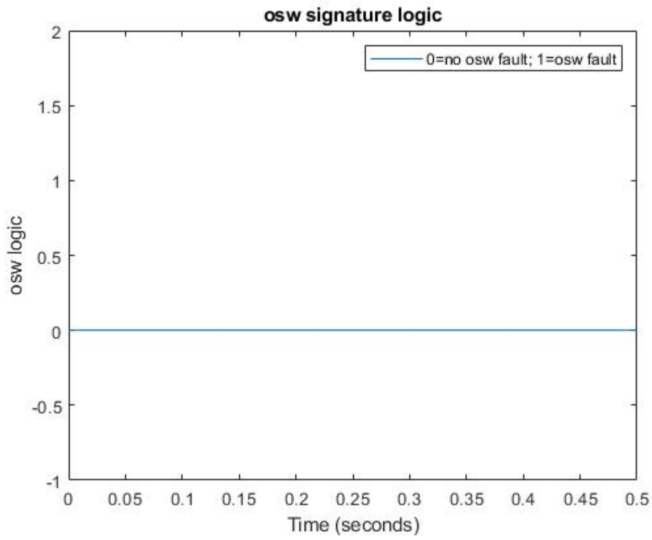
Fig. 5 demonstrate the steps of FDIS to detect inductor fault,when we inject osw fault in 0.1 S the FDIS detect a fault with FDA in the system in 0.001 S and make a flag=1, after this flag FIA start working,The signature of the open switch indicates that there is no error with it, after that FIA estimate the value of inductor and the estiate value exceed a specific threshold, after 0.03 S from the detection FIA identify the faulty component is the inductor and represent its flag.

Fig. 6 demonstrate the steps of FDIS to detect capacitor when we inject osw fault in 0.1 S the FDIS detect a fault with FDA in the system in 0.001 S and make a flag=1, after this flag FIA start working,The signature of the open switch indicates that there is no error with it, after that FIA estimate the value of inductor and also indicate there is no error in the inductor, after that FIA estimate the of capacitor, the value of capacitor exceed a specific threshold, after 0.03 S from the detection FIA identify the faulty component is the capacitor and represent its flag.

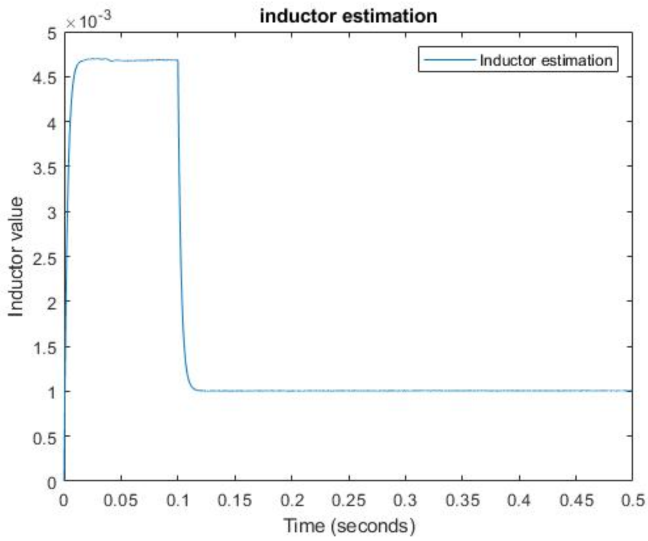
Fig. 7 demonstrate the steps of FDIS to detect current sensor fault, after verifying that there is no osw fault and no passive elements faults, FIA check the current sensor fault, There was a difference between the value of the sensor and its assumed value that exceeded a specific threshold, after 0.03 S from the detection FIA identify the faulty component is the current sensor and represent its flag.



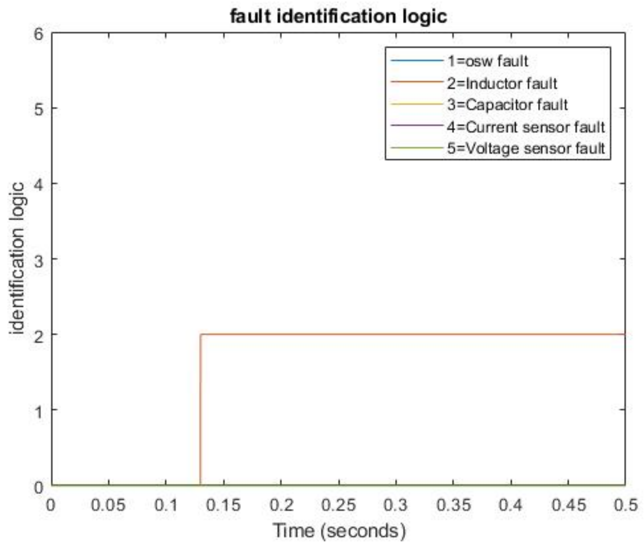
(a) Fault detection logic



(b) Osw signature

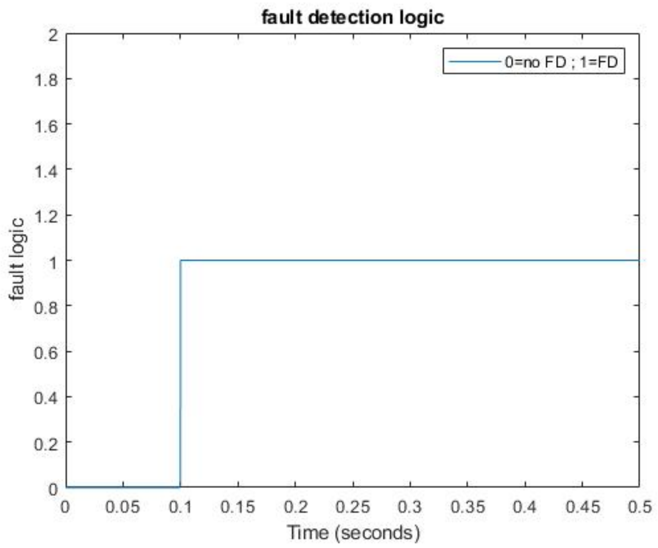


(c) Estimation inductor value

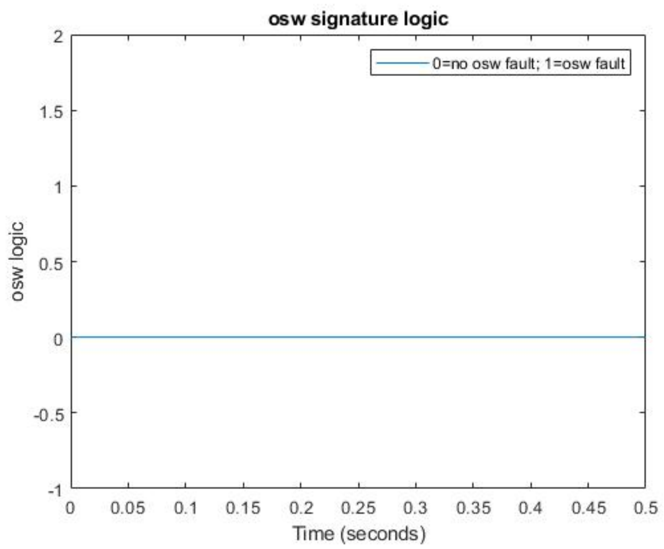


(d) Fault identification logic

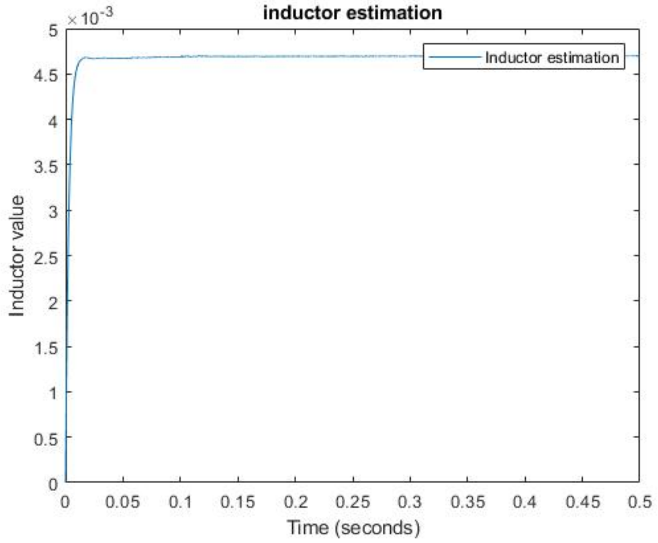
Fig. 5. Demonstrate the steps of FDIS to detect inductor fault



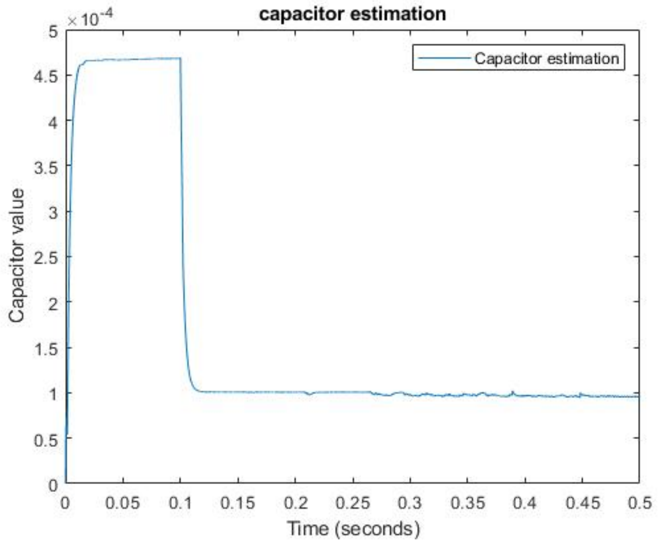
(a) Fault detection logic



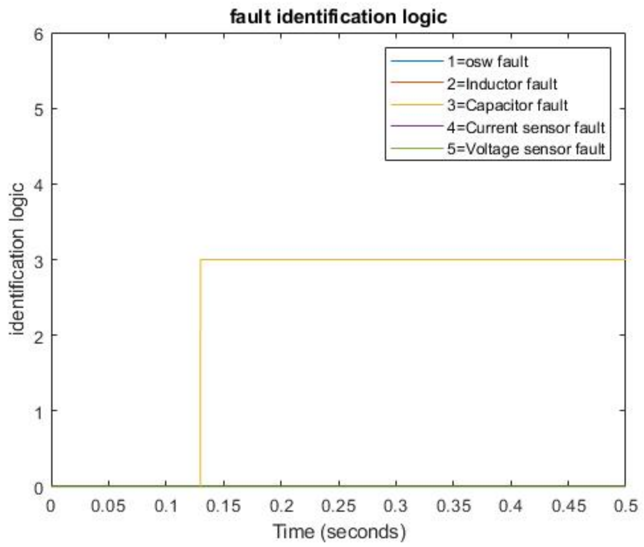
(b) Osw signature



(c) Estimation inductor value



(d) Estimation capacitor value



(e) Fault identification logic

Fig. 6. Demonstrate the steps of FDIS to detect capacitor fault

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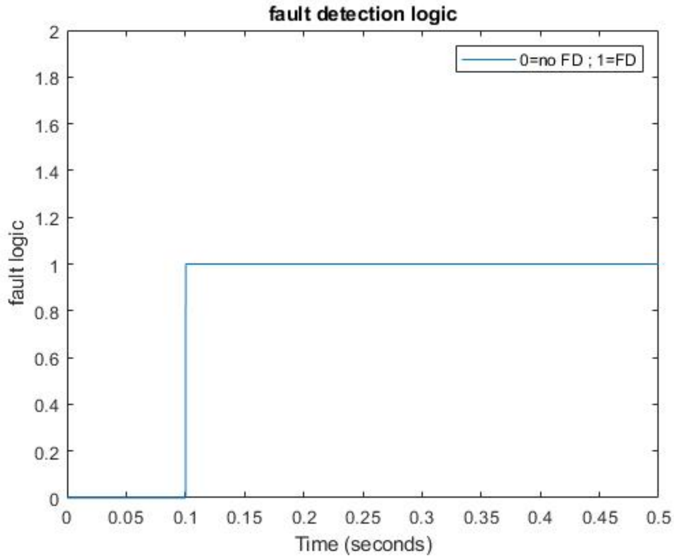
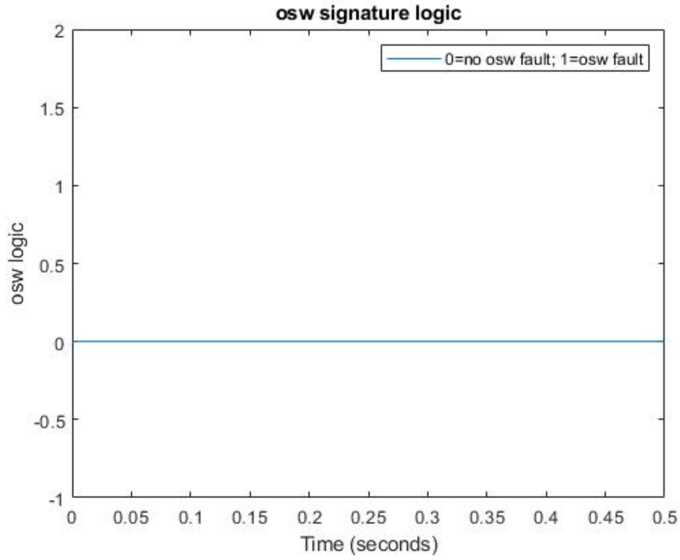
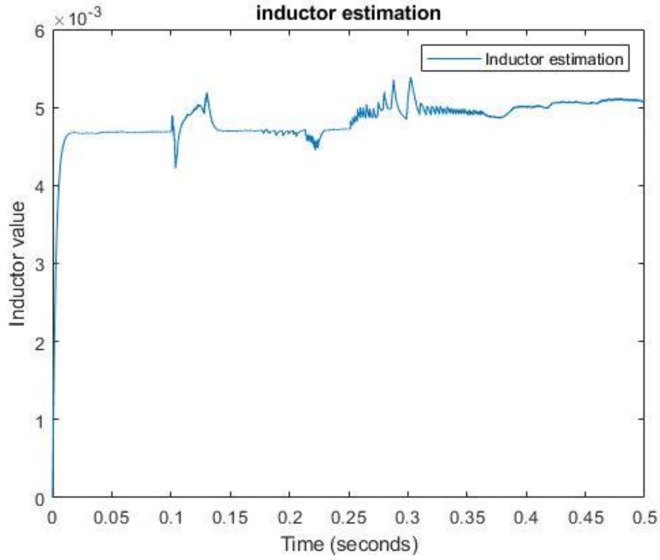


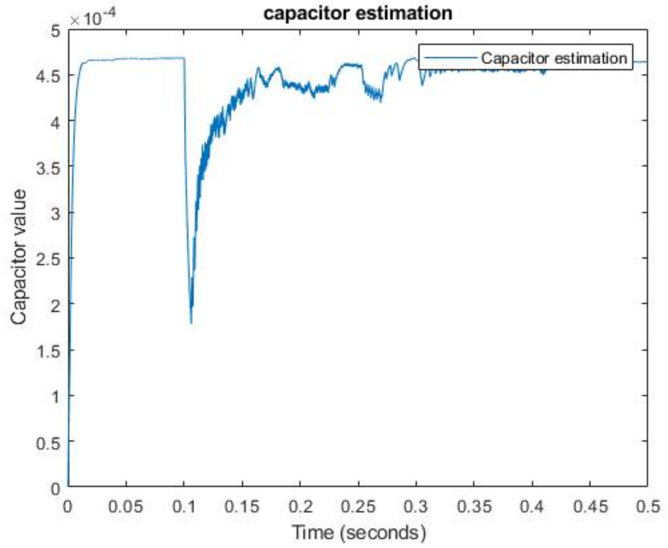
(a) Fault detection logic



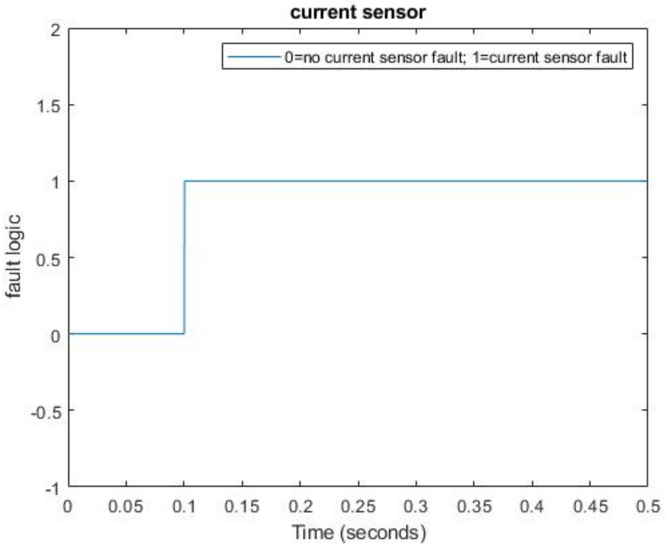
(b) Osw signature



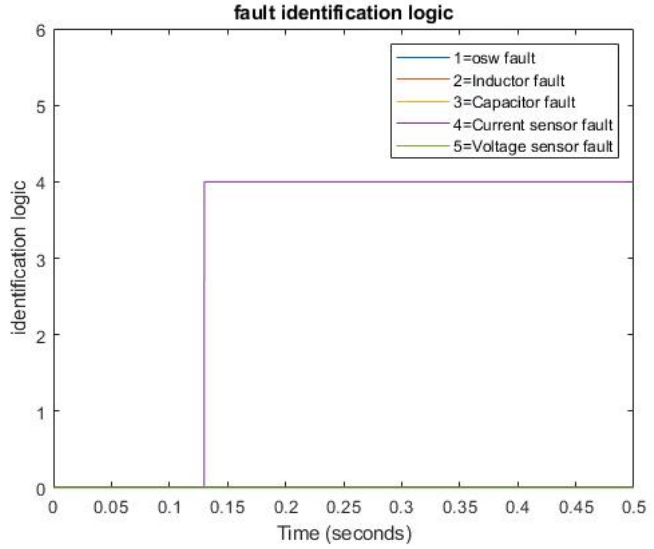
(c) Estimation inductor value



(d) Estimation capacitor value



(e) Fault current sensor logic



(f) Fault identification logic

Fig. 7. Steps of FDIS to detect current sensor fault

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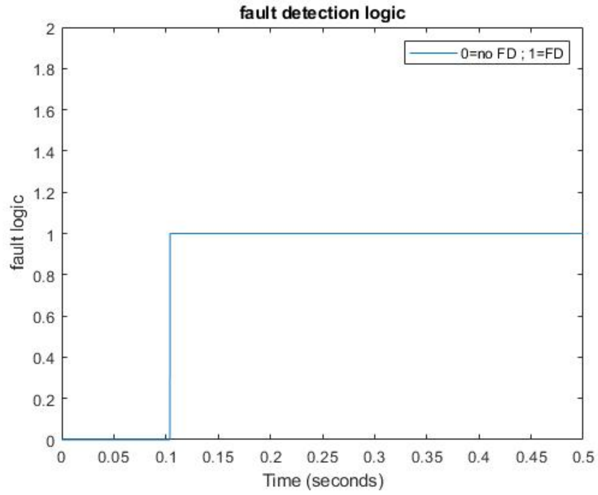
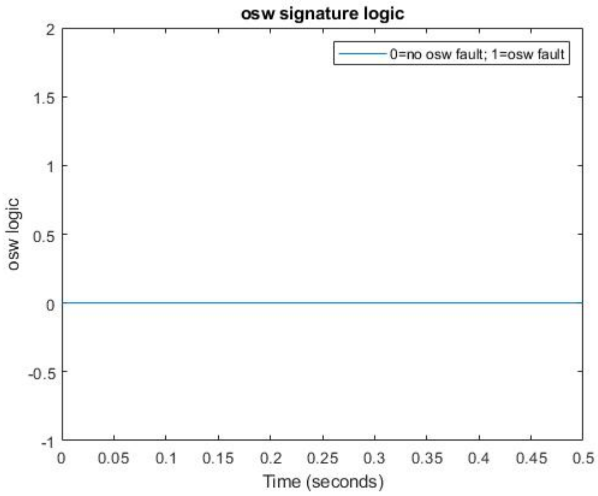
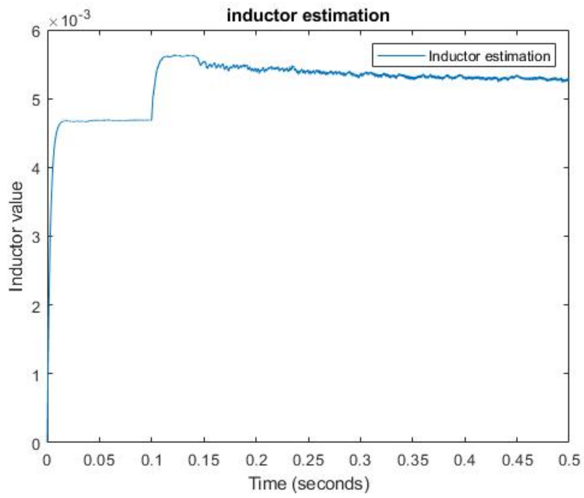
Fig. 8 demonstrate the steps of FDIS to detect voltage sensor fault, after verifying that there is no osw fault and no passive elements faults and no current sensor fault, FIA check the voltage sensor fault, there was a difference between the value of the sensor and its assumed value that exceeded a specific threshold, after 0.03 S from the detection FIA identify the faulty component is the voltage sensor and represent its flag. Components, parameters, and fault vectors for the boost converter shown in Table 2.



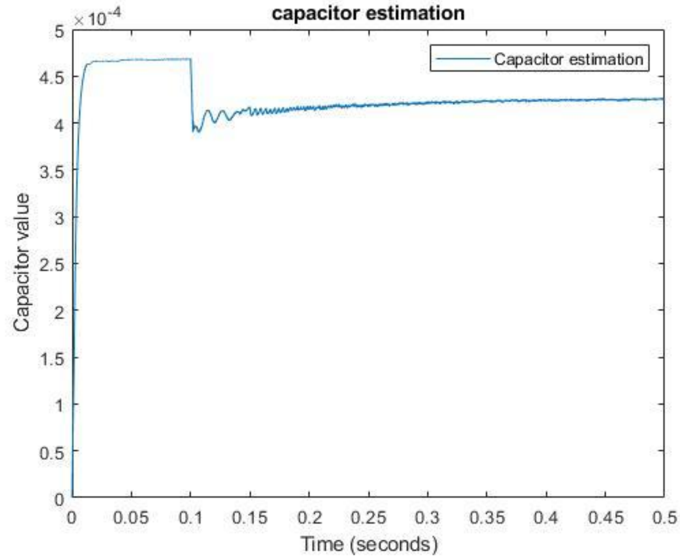
(a) Fault detection logic



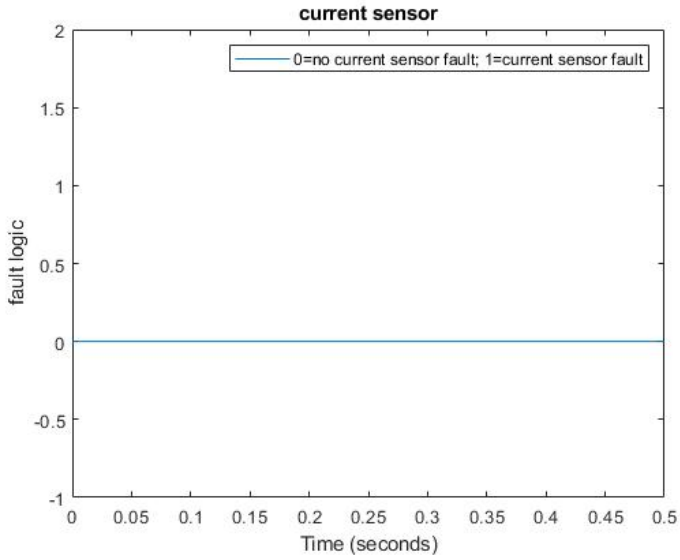
(b) Osw signature



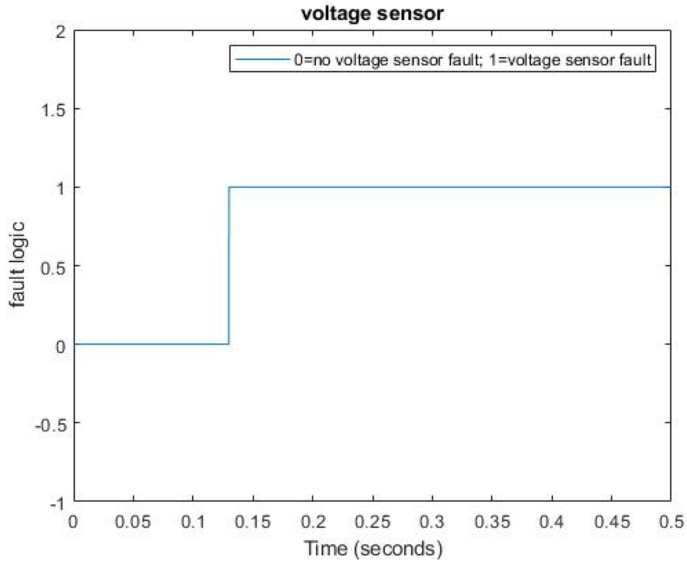
(c) Estimation inductor value



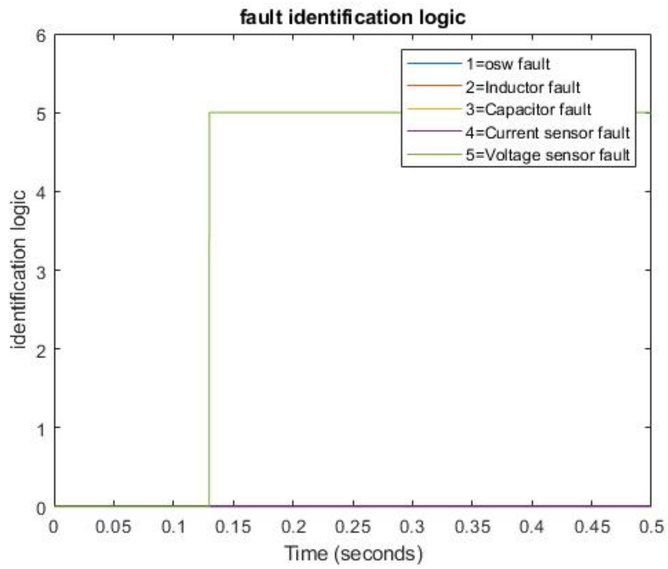
(d) Estimation capacitor value



(e) Fault current sensor logic



(f) Fault voltage sensor logic



(g) Fault identification logic

Fig. 8. Steps of FDIS to detect voltage sensor fault

Table 2. Components, parameters, and fault vectors for the boost converter

Fault number	Parameter	Fault vector fi(*t*)
$i = 1$	Inductor (L)	$[\Delta L/((L+\Delta L))\,((1-D)\,V_0 - V_{bat} - V_0\,\hat{d});\,0]^T$
$i = 2$	Capacitor (C)	$[0;\,\Delta C/((C+\Delta C))\,(-(1-D)\,i_L + 1/R\,V_0 + I_0\,\hat{d})\,]^T$
$i = 3$	Osw (open switch)	$[-(V0/L\,d);\ Il/C\,d]^T$
$i = 4$	Current sensor	$\partial\, i_L + \partial\, e_1$
$i = 5$	Voltage sensor	$\partial\, V_0 + \partial\, e_2$

7. Conclusion

The need to maintain the safety of people and equipment necessitated us to study ways to detect and identify faults quickly. We have created a fault detection and identification scheme for dc dc boost converter, as the scheme covers almost all possible faults, from degradation parametric faults in passive elements, open switch fault and sensors faults.

The scheme is divided into two main stages, the first stage is the stage of detecting the presence of a fault in the system and this stage depends on luenberger observers and specific thresholds, while the second stage is the stage of determining the fault, which contains several steps and elements, including signature comparison of open switch fault, passive parameters estimation and signature comparison of sensors, This scheme proved to be effective in rapid fault detection and identification after it was simulated in Matlab simulink, where it detected and identified the fault in a short time.

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Conflicts of Interest: The authors declare no conflict of interest.

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