Modeling of Sensor Faults in Power Electronics Inverters and Impact Assessment on Power Quality

Faizan Mehmood, Panayiotis M. Papadopoulos, Lenos Hadjidemetriou, Marios M. Polycarpou
KIOS Research and Innovation Center of Excellence, Department of Electrical and Computer Engineering,
University of Cyprus, Nicosia, Cyprus
mehmood.faizan@ucy.ac.cy

Abstract—Sensors are crucial for the operation of power electronics converters. Voltage and current sensors, widely used in power electronic converter systems, are prone to malfunction or failure mainly due to varying environmental conditions, broken connectors, and ageing of electronic circuit components. Therefore, it is important to characterize the behavior of these sensors under a number of possible faulty conditions and study their impact on the performance of the system. Further, the distinct behavior of such sensors, under different fault types, encourages us to correlate them with the generic fault models. In this paper, a root cause analysis for each type of sensor fault is presented and experimental validation for five fault models is performed, where the parameters of key components in the power electronics voltage and current sensor are intentionally modified to emulate a specific type of fault. Moreover, the impact of each fault on the power quality of Grid Side Converter (GSC) under various types and magnitudes of sensor faults are assessed and validated experimentally. The results of this work are useful to ensure the design for the reliability approach in power electronics converters and provide an assessment of the impact of a sensor failure in the overall operation of power electronics converters. Further, the impact of sensor faults in the overall operation of a power electronics converter gives some directions to design algorithms that can improve the reliability and robustness of the power electronics converters.

Index Terms—Circuit faults, DC-AC power converters, fault models, power quality, sensor systems.

I. INTRODUCTION

Power electronics converters are comprised of a number of voltage and current sensors that rely on the Hall-effect. These sensors are utilized to control and monitor the operation of a closed-loop power electronics converter system. However, these sensors are susceptible to internal and external failures caused by disruption of electronic components or semiconductor package, mechanical stress through vibration, thermal stress through losses, and electromagnetic interference (EMI) [1]. The inaccurate voltage-current measurements obtained by faulty sensors may disturb the operation of a Grid Side Converter (GSC) controlled system, leading towards reliability and power quality issues [2]. Further, the sensor faults may cause a catastrophic failure for the GSC, a discontinuous operation of a renewable energy source, high operation and maintenance costs, etc. Moreover, in some extreme cases, it may damage the entire GSC and renewable energy system [3]. Therefore, it is important to study the possible causes, types, and impact of sensor faults on such systems.

Although extensive work has been carried out to diagnose the sensor fault by using generalized fault models, little attention has been paid to the causes and modeling of different fault types [4] in a hardware sensor, and their impact on the operation of power electronics-based system. The understanding of sensor fault types is studied in aerospace applications and large scale wind turbine bearings [4], [5]. The susceptibility of Hall-effect current sensors to EMI is analyzed in [6] using the bulk current injection, transverse electromagnetic cell, and direct power injection methods in an experimental setup. Although this approach is effective, it does not take fully into account the peripheral components, the driving circuits, and the amplifying stages of a voltage or current sensor.

In the area of fault diagnosis in power electronics converters, previous work has overlooked the categorization and diagnosis of each type of possible sensor fault. In [7], [8], the diagnosis and mitigation of Hall-effect sensors malfunction using fault identification and mitigation techniques in a grid-connected photovoltaic system are presented. The same problem was solved for a brushless DC motor application using the direct redundancy-based approach [9], [10]. These works have not considered different types of sensor faults for the diagnosis and design of fault-tolerant control systems.

The key contribution of this paper is the development and experimental validation of five models to describe each type of possible sensor faults in power electronics converters. This is achieved by changing the state (i.e., open-circuit, short circuit) or varying the parameters of key components in an actual voltage-current hardware sensor to emulate a specific failure. The fault models resulted by this work are useful for evaluating a fault diagnosis algorithm under realistic sensor faults. Further, an impact assessment of each fault type on power quality of GSC is performed. For this assessment, different power quality indicators (PQIs) have been used to quantify how the intensity of sensor fault in each type of failure can affect the reliability and quality of power electronics converter. This stresses the need to have a sensor fault-tolerant controller design integrated within the controller of a GSC.

II. SYSTEM DESCRIPTION

In this section, the architecture of the GSC system and the structure and characteristics of a Hall effect-based voltage or current sensor are presented.
A. GSC System Description

The architecture of an interconnected GSC system along with an advanced GSC controller is presented in Fig. 1. A photovoltaic (PV) system delivers power to the grid via a two-level GSC based on Insulated Gate Bipolar Transistors (IGBTs). Measurements taken from voltage and current sensors located at the Direct Current (DC) and Alternative Current (AC) side of the GSC are used to drive the GSC controller. The GSC controller includes a synchronization unit based on a phase-locked loop algorithm, advanced current controller, advanced PQ controller and perturb and observe (P&O) algorithm based maximum power point tracking controller. A more detailed insight into the operational capabilities of GSC controller can be found in [11]. Advance research has already been conducted to improve the efficiency and enable new operational capabilities of the GSC. However, limited research has been conducted to analyze the response of a faulty sensor in order to define the mathematical models for a faulty sensor, and to investigate the impact of such sensor failures on the operation of a GSC.

In Fig. 1, $x_d$ and $x_i$ denotes the actual grid voltage and line current at the AC side of the GSC, while $y_v$ and $y_i$ are the corresponding measurements, provided by the sensor output. Similarly, $x_{dc}^v$ and $x_{dc}^i$ are actual DC-link voltage and current, while $y_{dc}^v$ and $y_{dc}^i$ represent the corresponding measurements by the voltage and current sensor at the DC side.

B. Voltage and Current Sensor Description

The Hall effect-based transducers with galvanized isolation between the primary and secondary circuits are typically used in such power electronics applications for sensing voltage and current. A generic block diagram of a Hall-effect based sensor with an external amplifying stage is presented in Fig. 2. The operation of a closed-loop Hall-effect sensor is based on a magnetic field that is produced by a primary current flowing through the conductor. The flux concentrated in the core produces a voltage that is proportional to the flux density. Then, in an internal amplifying stage, an operational amplifier (OP-AMP) is used to amplify the Hall voltage, which is then fed to the push-pull amplifier to drive the secondary winding of the core. An output resistor is placed at the secondary coil to the ground to convert the secondary current to the voltage.

Further, an external amplification stage is sometimes necessary to re-scale or shift the sensor output to appropriately fit within the analogue to digital (A/D) conversion limits of the GSC controller. More details regarding the Hall effect-based voltage sensor can be found in [12].

![Fig. 1: Structure of an interconnected GSC system along with its controller and sensors](image)

![Fig. 2: Block diagram of Hall-effect based sensor](image)

The internal structure of the Hall-effect sensor has both OP-AMP and push-pull amplifying stage, which show similar characteristics as of external amplifying stage. It is noted that in some cases, the external amplifying stage can be neglected if the output voltage is well-fitting the A/D conversion range of the GSC controller. However, the external amplifying stage is intentionally used in this work to emulate failures that may occur in either the internal or external amplifying stage and affect the sensor output likewise. Since the internal amplification stage is not directly accessible, the failures are performed only to the components of the external amplifying stage in the experimental setup used in this work. The input/output (I/O) relationship of voltage transducer based on the above-mentioned sensing phenomena can be represented as,

$$V_m = \left(\frac{x_v}{R_I}\right) \cdot CR \cdot R_m$$  \hspace{1cm} (1)

where $N_1$, $N_2$ are the primary and secondary coil turns and $CR = N_1/N_2$ is the conversion ratio, respectively. Moreover, $R_I$ and $R_m$ are the series input resistor of the primary coil and the shunt output resistor of the secondary coil respectively and $v_x$ is the line to neutral voltage to be measured (sensor input).

The design procedure of a voltage sensor in GSC requires the proper selection of the maximum input voltage, the primary nominal current of the Hall sensor, the output sensor voltage, and range of the A/D conversion of the controller. It is worth mentioning that optimal accuracy can be obtained at a nominal primary current [13]. Further, the measurable output voltage of the sensor can be re-scaled and offset to a particular value by an appropriate gain selection of the external amplifying stage (based on an OP-AMP in a non-inverting configuration). The output voltage including both amplified output voltage and DC offset voltage can be written as,

$$y_v = \left(1 + \frac{R_2}{R_1}\right)V_m \pm \frac{R_2}{R_1} \cdot V_{cc}$$  \hspace{1cm} (2)

where $V_{cc}$ is the supply voltage of OP-AMP and $R_2$ and $R_1$ are gain setting resistors. Moreover, $(R_2/R_1) \cdot V_{cc}$ term is responsible to provide an offset to the sinusoidal AC signal, which can either be in upward or downward direction based on the supply voltage across variable resistor ($R_1$). The sensed phenomena and I/O characteristics of current sensor are similar to those of voltage sensor, except that $x_v/R_1$ is replaced by $x_i$, as line current is the direct input of a current sensor.

By considering (1) and (2), the generalized output equation of a voltage or a current sensor can be written as,
where $G = (1 + \frac{R_k}{R_1}).CR$, $R_m$, $\beta_f = \frac{R_k}{V_{cc}}$ and $n$ are the gain (including both internal and external amplifying stage), DC offset of external amplifying stage and random white noise from the environment, respectively. Further, $x$ is the actual quantity to be measured. Moreover, variation of gain and DC offset caused by parametric variation of sensor components, external amplifying stage and variation of supply voltage leads to different types of faults, described in Section III.A.

III. DEFINITION AND VALIDATION OF SENSOR FAULT MODELS

The I/O characteristic equation presented in the previous subsection emphasizes the proper selection of circuit components to achieve the required operational and technical specification objectives. However, a malfunction or failure of any of these electronic components has a different impact on the output sensing voltage. This section discusses the generic fault models depicting the response of a sensor under different hardware faults and validates the defined sensor models in an actual sensor hardware setup.

A. Definition of Sensor fault Models

The possible causes of malfunction or failure of electronic components include thermal heating, overload stress, mechanical shock and vibration, exposure to cycling ambient temperature and high humidity, and EMI [3]. The malfunction mechanism of the Hall effect-based sensors can be attributed to either failure of specific components, for instance, resistor or capacitor, or failure of a chip, like the integrated circuit of an OP-AMP or of the Hall sensor, which is incipient in nature. Further, the cosmic radiation may cause single-event burnout of the sensor. This section describes the categorization of fault types based on malfunction or failure of different electronic components, which are as follows,

1) Type A: Offset fault (Bias fault): The bias fault appears as a constant DC offset from the nominal signal value caused by an external amplifying stage (OP-AMP in non-inverting configuration). It is based on the amplifier gain and operating voltage applied to the variable resistor ($R_1$), as described in (2). For instance, by setting positive (+$V_{cc}$) and negative ($-V_{cc}$) terminals of supply voltage across the variable resistor ($R_1$) to 0 V and -12 V, respectively, an upward shift of sinusoidal secondary voltage signal occur. Such kind of failures may lead to an offset fault, which can be model as

$$Y_k = x_k + \beta_f + n_k,$$  \hspace{1cm} (4)

where $Y_k$, $x_k$ are the time-varying output measurement and actual quantity to be measured, respectively. Furthermore, $\beta_f$, $n_k$ denotes the constant offset value introduced by the bias fault, time varying noise of the sensor, respectively. Note that, $k$ depicts either the current (i) or the voltage (v).

2) Type B: Multiplicative fault (Degradation fault): The multiplicative gain fault behaves as a constant scaling of the magnitude of a signal, can be obtained by changing the primary coil resistor ($R_1$) or the secondary coil resistor ($R_m$), as described in (1). For example, a decrease of primary coil resistor causes an increase of output measured voltage, which is multiplicative in nature, can be model as,

$$Y_k = x_k + Fx_k + n_k$$ \hspace{1cm} (5)

where $F$ is a constant scaling factor for the multiplicative fault.

3) Type C: Absolute minimum rating of transducer fault (stuck at 0 V fault): The hard fault of stuck the sensor output at a minimum value can be obtained by short circuit the secondary coil resistor ($R_m = 0 \Omega$), which results as zero voltage at the output terminal, as defined in (1). This can be expressed mathematically as,

$$Y_k = \beta_{min} + n_k$$ \hspace{1cm} (6)

where $\beta_{min}$ is a zero-volt reference point.

4) Type D: Absolute maximum rating of transducer fault (stuck at +$V_{cc}$ fault): The hard fault of stuck the sensor output at a maximum value can be attained by open circuit the secondary coil resistor ($R_m = \infty \Omega$), which results in +$V_{cc}$ (supply voltage of amplifier) across the measurement resistor that can be analyzed from (1).

$$Y_k = \beta_{max} + n_k$$ \hspace{1cm} (7)

where $\beta_{max}$ is the constant maximum supply voltage of sensor.

5) Type E: Saturation fault (Clipping fault): The saturation fault in a sensor occurs when we try to measure value beyond the dynamic range of the sensor. The effect of saturation fault includes the clipping of the negative cycle of output voltage, which causes a large accumulation error, and information is lost in a huge data area. This fault can be attained in a sensor by connecting the negative terminal of a supply voltage of the sensor and OP-AMP to the ground, which can be modeled as,

$$s(x_k) = \begin{cases} 
\bar{x}_k, & x_k \geq \bar{x}_k \\
\bar{x}_k, & x_k \leq \bar{x}_k \\
 x_k, & \text{otherwise} 
\end{cases}$$ \hspace{1cm} (8)

where $\bar{x}_k$ and $\bar{x}_k$ are the constant upper and lower thresholds and clipping of signal occur after those particular thresholds.

Based on the sensor fault models mentioned above, the generalized sensor fault model that characterizes various types of sensor faults correlates to the generalized output equation of a voltage or a current sensor, can be written as,

$$Y_k = G(1 + F)s(x_k)x_k + \beta_f + n_k$$ \hspace{1cm} (9)

where $G$ is the gain under healthy condition, describe in (3) and the terms $\beta_f$, $(1 + F)$ and $s(x_k)$ characterize offset, multiplicative and saturation faults respectively, describe in (4), (5) and (8). Note that, for particular type of sensor fault, only the corresponding parameter change, for instance, $\beta_f$ changes only for offset fault condition.

B. Experimental Validation of Sensor Fault Models

In this section, the accuracy and effectiveness of the fault models, mentioned in the above subsection, are developed in a real-time control board (dSPACE 1104). The five sensor fault models described in Section III.A is experimentally verified by comparing them with the results obtained by changing the parametric value of an actual hardware sensor with an external...
amplifying stage, as represented in Fig. 2. The Hall-effect based current and voltage sensors used in the experimental study are (i) LA25-NP and (ii) LV25-P with a nominal rating of 25 A and 500 V, respectively.

The outcome of the experimental validation of the proposed sensor fault models is presented in Fig. 3, where the output signal of the sensor in the presence of five types of faults is given. Specifically, Fig. 3(a) shows the phase B of grid voltage that is the actual input to be measured by the voltage sensor with a peak to peak voltage of 340 Vpp, shown. Note that, the output voltage of the sensor under a healthy condition with primary \( R_p \) and secondary \( R_m \) resistance of 47 kΩ and 220 Ω respectively is calculated equal to 7.8 Vpp by both hardware sensor output (cyan solid line) and fault model (yellow solid line) as shown in Fig. 3(b). Further, for simplicity of selecting the value of resistors in the gain selection of OP-AMP, \( R_2 \) is fixed to 1 kΩ and a variable resistor \( R_1 \) of 50 kΩ is used to adjust the gain. The results showing the comparison of different fault types with respect to the healthy operation of sensor are presented in Fig. 3 (c)-(g), which are obtained by component variation of sensor and external amplifying stage.

The DC offset fault with \( \beta_f = 3 \) V and a multiplicative fault with \( F = 1 \) are shown in Fig. 3 (c) and (d), respectively. The offset fault of 3 V is attained by using input and feedback resistor of external amplifying stage to be \( R_1 = 6.3 \) kΩ and \( R_2 = 1 \) kΩ, respectively. Moreover, the multiplicative fault of \( 1 \times x_b^d \) is obtained by varying the primary resistance \( R_1 \) of voltage sensor to 25 kΩ instead of 47 kΩ used in the case of healthy sensor. The stuck at an absolute minimum and absolute maximum fault having a voltage of \( \beta_{\text{min}} = 0 \) V and \( \beta_{\text{max}} = +12 \) V, obtained by short-circuited and open-circuited the secondary resistor \( R_m \) of sensor respectively, are shown in Fig. 3 (e)-(f). Finally, the saturation fault with a negative clipped voltage of 4.8 V is shown in Fig. 3(g), which appear as a result of changing the negative terminal of supply voltage of the sensor from \(-V_{cc}\) to 0 V. The result analysis obtained via parametric variation of sensor hardware, sensor model and I/O characteristics relationship of (1), exhibits an accuracy of fault model to be more than 97%.

IV. IMPACT ASSESSMENT OF POWER QUALITY

This section presents the assessment of impact on the power quality caused by the presence of sensor faults in GSCs. In this investigation, the discrete-time samples of the actual quantity to be measured denoted by \( [x_k], \forall k = 1...N \) for a specific time window \( T_W \), obtained before and after the occurrence of a fault and steady-state conditions, are calculated and analyzed by a set of statistical parameters. In this study, both classical statistical metrics and well-known advance analysis methods are used to attain an accurate and efficient power quality measurement under different types of sensor faults.

Some of the important classical statistical metrics for analyzing the power quality of the grid integrated power electronics converters are mean, median, crest factor (CF), per unit (pu) variation-oscillations of active-reactive power (PQ) signals [14]. The CF is an indicator of showing how extreme

\[
\%\text{VAR} = \frac{(I_{af} - I_{bf})}{I_{bf}} \times 100
\]

where \( I_{af} \) and \( I_{bf} \) are the signal values for a specific \( T_W \) before and after the occurrence of a fault. This shows an effect of the fault on the system with respect to a healthy condition.

Some advance analysis methods used in analyzing the power quality of a power electronics converter are Total Harmonic Distortion (THD) with or without including the effect of DC component, positive, negative and zero symmetrical sequence components, distortion or harmonic power factor (HPF), displacement factor (DPF), and power factor (PF) [14]. The well-known THD and symmetrical components indices have important information about the harmonics exist within the signal and asymmetries of three-phase system under both normal and abnormal condition respectively. The HPF consider as a measure of distortion component related to harmonics current presented in a system, is derived from the formula of THD expressed as,
\[ \text{HPF} = \frac{I_1}{I_{\text{rms}}} = \frac{1}{\sqrt{1 + \text{THD}^2}} \]  

where \(I_1\) and \(I_{\text{rms}}\) are the fundamental and RMS value of the current respectively.

Moreover, an asymmetry in the shape of signals, measure as a phase shift between the current and fundamental line frequency component of the voltage, can be determined as DPF. Finally, the overall efficiency of the system is determined by PF, which can be calculated by taking the product of DPF and HPF under no background distortion.

A. Simulation Results

This subsection presents the simulation results that show an effect of each type of sensor fault on the power quality of three-phase GSC having a maximum power of 3 kW, by measuring the AC line current of each phase. The system is operated at 60% of maximum power with reactive power (Q) injection of 1.8 kVAR at sampling frequency of 4 kHz. The \(T_W\) of 8-cycles is used for the calculation of PQIs before and after the occurrence of a fault and during steady-state conditions. The simulation model is developed in MATLAB/Simulink in accordance with the architecture of Fig. 1.

An overview of the impact of different types of sensor faults on various PQIs is presented in Table I. The ✓ sign represents that a specific PQI is affected by a particular sensor fault, while ✗ sign means that it is not affected. The effect of different types of faults on only selected PQIs is shown in Fig. 4.

Comparing the PQIs calculated in \(T_W\) for simulated signals of Fig. 4, it can be noticed that an offset fault (Type A) in the measurement of AC line current of the GSC causes both mean and peak value of the current to decrease in the corresponding faulty phase. As a result, a decrease of CF of the faulty phase occurs, as shown in Fig. 4(a). Further, a DC shift in a sinusoidal current may also increase the harmonic distortion of a signal. However, the value of THD considering DC component is quite low to not significantly affect the HPF. Moreover, the DC offset in an AC signal having a nominal frequency of 50 Hz results as P and Q oscillations with 50 Hz, presented in Fig. 4(a). The multiplicative nature of fault may cause phase unbalancing, resulting in a higher negative sequence component. This may also result in a decrease of PF on the faulty phase, due to asymmetry in the shape of voltage-current signals as shown in Fig. 4(b). Likewise, one may see that both absolute minimum and absolute maximum faults affect the sequence components, PF and DPF. Moreover, both saturation and absolute maximum fault show similar behavior towards the P and Q oscillations, symmetrical components, PF and DPF, as in all of these cases the system operates at an extreme condition.

B. Experimental Results

In this section, an experimental investigation is performed for the impact of sensor faults on a prototype GSC setup. The setup configuration includes (i) grid-tied inverter (SEMIKRON Semiteach B6U+E1C1F+B6CI), (ii) PV emulator (Chroma 62000H-S), (iii) Voltage and current sensors (LA 25-NP and LV25-P), (iv) dSPACE controller board (DS-1104) to develop the fault models and GSC controller using the Real-Time Interface of MATLAB/SIMULINK. The average of PQIs is taken offline from the collected data samples of voltage and current signal with a \(T_W\) of 5 seconds.

In this experimental investigation, the effect of a current sensor fault on the operation of a GSC is evaluated. In Fig. 5(a)-(c), the three-phase current injection by a GSC is presented under healthy sensors, positive offset fault (Type A), multiplicative current sensor fault (Type B) respectively. Comparing the grid currents under different fault modes, one can see that a Type A fault decreases the mean and RMS value of current of the faulty phase while increases the mean value of current of the healthy phases, which is also affecting the CF as shown in Fig. 5(b). Likewise, the operation of the GSC under Type B fault is highly affected and a negative sequence current is introduced causing a highly asymmetrical current injection, which can be seen in Fig. 5(c).
Table I: Impact Assessment of Different Fault Modes on Power Quality of GSC

| Index No. | PQIs                                      | A   | B   | C   | D   | E   |
|----------|-------------------------------------------|-----|-----|-----|-----|-----|
| 1.       | % THD of current                          | ✓   | X   | X   | X   | ✓   |
| 2.       | % THD of current excluding DC component   | ✓   | X   | X   | X   | ✓   |
| 3.       | CF of current                             | ✓   | X   | X   | X   | ✓   |
| 4.       | P oscillation (pu)                        | ✓   | X   | X   | X   | ✓   |
| 5.       | Q oscillation (pu)                        | ✓   | X   | X   | X   | ✓   |
| 6.       | Mean values                               | ✓   | X   | X   | X   | ✓   |
| 7.       | Positive seq. component of current        | X   | X   | ✓   | ✓   | ✓   |
| 8.       | Negative seq. component of current        | ✓   | ✓   | X   | X   | ✓   |
| 9.       | PF                                        | X   | ✓   | ✓   | ✓   | ✓   |
| 10.      | HPF                                       | X   | ✓   | ✓   | ✓   | ✓   |
| 11.      | DPF                                       | ✓   | X   | ✓   | ✓   | ✓   |
| 12.      | PF excluding DC component                 | X   | X   | ✓   | ✓   | ✓   |
| 13.      | HPF excluding DC component                | X   | X   | ✓   | ✓   | ✓   |
| 14.      | DPF excluding DC component                | X   | X   | ✓   | ✓   | ✓   |

The average of the magnitude of three-phase PQIs is calculated in percentage of the nominal current and power rating of the inverter, which is 13 A and 5 kW. Note that, the percentage deviation of CF ($\Delta$ Index3) and PF ($\Delta$ Index9) are calculated with respect to their ideal values, which are $F_{\text{nom}} = 1.41$ and $F_{\text{nom}} = 1$ using (12). It can be observed that under the normal condition, the deviation is close to 0, showing high power quality for the GSC. However, a significant deviation is observed under faulty conditions.

$$\Delta F = \frac{\sum_{p \in \mathcal{P} = \{a, b, c\]} |F_p - F_{\text{nom}}|}{3F_{\text{nom}}}$$  (12)

where $F_p$ and $F_{\text{nom}}$ denotes the quantity of a factor of each phase and its nominal value respectively.

Comparing the PQIs calculated in time domain under offset fault (Type A) and multiplicative fault (Type B) for experimental signals in Fig. 6, one can see that under the healthy condition the GSC is able to achieve high power quality with purely symmetrical current injection with THD < 5%, and a near to nominal CF and PF. In the case of Type A, the CF and the mean value of the current, and P and Q oscillations are highly affected, reducing the power quality of the GSC. Moreover, the Type B fault affects the negative sequence component and PF. Moreover, the comparison of simulation and experimental results (see Fig. 6 and Table I), shows the deviation of the same PQIs that validates our simulation results for offset and multiplicative faults.

Fig. 5: The actual line current $x_i$, for each phase $p \in \mathcal{P} = \{a, b, c\}$, of the GSC (a) under healthy condition, (b) under offset fault of magnitude 5 A at phase A, (c) under multiplicative fault of 2 $x_i$ at phase B, experimental setup: power rating is set to 1 kW and 0 VAR.

Fig. 6: Impact assessment of sensor faults on power quality of GSC, evaluated in an experimental setup (see Section IV-B).

V. CONCLUSION

In this paper, a comparative study is carried out to define and assess the accuracy of fault models under different types of sensor faults, obtained by a failure or parameter variation in an electronic component of an actual voltage or current sensor. Further, an impact assessment of sensor faults on the power quality of a GSC is evaluated, both via simulation and experimental investigations. This work can help in the design and need of a sensor fault-tolerant controller for the reliable power electronics converters.

REFERENCES

[1] X. Hu, K. Zhang, K. Liu, X. Lin, S. Dey, and S. Onori, “Advanced fault diagnosis for lithium-ion battery systems: A review of fault mechanisms, fault features, and diagnosis procedures,” IEEE Ind. Electron. Mag., vol. 14, no. 3, pp. 65–91, 2020.
[2] S. Peyghami, F. Blaabjerg, and P. Palensky, “Incorporating power electronic converters reliability into modern power system reliability analysis,” IEEE Trans. Emerg. Sel. Topics Power Electron., vol. 1, pp. 1–1, 2020.
[3] J. Falck, C. Felgemacher, A. Rojko, M. Liserre, and P. Zacharias, “Reliability of power electronic systems: An industry perspective,” IEEE Ind. Electron. Mag., vol. 12, no. 2, pp. 24–35, 2018.
[4] E. Balaban, A. Saxena, P. Bansal, K. F. Goebel, and S. Curran, “Modeling, detection, and disambiguation of sensor faults for aerospace applications,” IEEE Sens. J., vol. 9, no. 12, pp. 1907–1917, 2009.
[5] Z. Liu and L. Zhang, “A review of failure modes, condition monitoring and fault diagnosis methods for large-scale wind turbine bearings,” Measurement, vol. 149, p. 107002, 2020.
[6] O. Aiello, “Hall-effect current sensors susceptibility to emi: Experimental study,” Electronics, vol. 8, no. 11, 2019.
[7] S. Saha, M. Haque, C. Tan, M. Mahmud, M. Arif, S. Lyden, and N. Mendis, “Diagnosis and mitigation of voltage and current sensors malfunctioning in a grid connected pv system,” Int. J. Electr. Power Energy Syst., vol. 115, p. 105381, 2020.
[8] P. M. Papadopoulos, L. Hadjidemetriou, E. Kyriakides, and M. M. Polycarpou, “Robust fault detection, isolation, and accommodation of current sensors in grid side converters,” IEEE Trans. Ind. Appl., vol. 53, no. 3, pp. 2852–2861, 2017.
[9] M. Aqil and J. Hur, “A direct redundancy approach to fault-tolerant control of bldc motor with a damaged hall-effect sensor,” IEEE Trans. Power Electron., vol. 35, no. 2, pp. 1732–1741, 2020.
[10] A. Tashkori and M. Ektebsi, “A simple fault tolerant control system for hall effect sensors failure of bldc motor,” in IEEE IICIEA, 2013, pp. 1011–1016.
[11] L. Hadjidemetriou, E. Kyriakides, and F. Blaabjerg, “A robust synchronization to enhance the power quality of renewable energy systems,” IEEE Trans. Power Electron., vol. 62, no. 8, pp. 4858–4868, 2015.
[12] “Voltage transducer LV 25-P data sheet,” LEM, Gross-Gerau, Germany.
[13] L. C. T. Staff, “Isolated current and voltage transducers characteristics – applications – calculations,” LEM Component Lab, Tech. Rep., 2010.
[14] R. Dugan, M. McGranaghan, S. Santoso, and H. Beatty, Electrical Power Systems Quality, Third Edition. McGraw-Hill Education, 2012.