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Diagnosis And Mitigation of Voltage and Current Sensors Malfunctioning in a Grid Connected PV System

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Abstract

A grid-connected photovoltaic (PV) system cannot function effectively without sensors that accurately measure the voltage, current, and AC currents flowing between the VSC and grid. As the impact of erroneous measurements propagates through the controllers in a PV system, they can cause significant disruptions to the system's operation due to malfunctioning of the aforementioned sensors. PV system sensor failures are referred to as sensor faults in this paper. A method for diagnosing and correcting PV system sensor faults is presented in this paper. The sliding mode observer (SMO)-based fault detection and identification theory, which is capable of accurately estimating faults from sensor measurements, serves as the foundation for the fault diagnosis strategy. In the proposed method, the fault mitigation technique is used to correct the sensor measurements using estimated faults. In order to guarantee the PV system's fault-tolerant operation, the controllers use rectified sensor measurements rather than potentially incorrect sensor measurements. Extensive simulation and experimental research has shown that the proposed method works

1. Introduction

The integration of renewable energy sources (RESs) have increased enormously over the years around the world. Drivers for the widespread integration of RES include goals of reducing greenhouse gas emissions and minimizing power losses by locating generation sources closer to load centers in the form of distributed generation [1]. Among these RESs, PV systems are gaining more popularity, especially in residential applications due to their smaller modular sizes and noiseless operations [2]. Power electronic converters play an indispensable role in the integration of PV systems into the distribution network.

The efficient and reliable operations of PV systems depend on the proper control of power electronic devices interfacing it with electric power networks [3]. One of the most commonly used topology for interfacing a PV system is the DC-DC boost converter coupled with a voltage source converter (VSC) through a common DC-link capacitor. The switches of the boost converter are controlled to extract maximum possible power at any given weather condition, and the control algorithms used for this purpose are commonly called maximum power point tracking (MPPT) algorithms [4].

There has been a mammoth amount of research carried out over the years in regards to MPPT control algorithms for PV systems, among which, incremental conductance, perturb and observe and hill climbing methods are most commonly used [5–7]. The VSC converts the extracted DC power by the PV array to AC power by controlling the switching pulses to the VSC switches. Though there is various different VSC control approach available in the literature [8–10], in almost all the approaches, the power flow between VSC and grid is controlled indirectly by controlling currents. It should be noted that successful implementation of MPPT and VSC controls in a PV system depends on accurate sensor measurements of PV array output voltage, current, and the current flowing between VSC and the grid. This is due to the fact that these measured quantities are used by the MPPT and VSC controllers to generate appropriate switching signals for the power electronic converters.

Malfunctioning of the sensors measuring these quantities will cause erroneous control signals and as a consequence, the PV system fails to perform optimally. The erroneous measurements can mainly be attributed to the malfunctioning of associated sensor devices. Errors in the current transformer (CT), which is used along with the current sensor and data acquisition (DAQ) devices for the measurement of current flowing to the grid, is the potential sources of erroneous current measurements. The accuracy of CTs are usually measured in terms of the composite errors, which includes magnitude errors, phase errors, and harmonic errors.

These composite errors are defined as the difference between the ideal and actual secondary currents of the CT. Other possible sources of erroneous current measurements are malfunctioning of current sensors (for example, loss of sensors) and DAQ devices. In regards to the measurement errors in the PV system DC side voltage and currents, i.e., PV array voltage and currents, the key sources of errors are malfunctioning of associated sensor and DAQ devices. Also, physical damage in the connectors associated with the components in the current and voltage sensors can be a potential cause of measurement error.

In summary, any malfunctioning of the associated devices in a current/ voltage sensor will cause error in the measurements. It should be noted that any malfunctioning in the current and voltage sensor devices are random events. Several factors such as, aging of the sensor devices, weather conditions, mal handling of the sensor devices, etc. may significantly contribute to the sensor malfunctioning and in the degree of measurement errors. It is very difficult to have a prior knowledge regarding the time of sensor malfunctioning. And also the amount of deviation in the voltage and current measurements from their actual quantities are very difficult to predict in advance. In this paper, any deviation in the measurement due to malfunctioning in any component in the associated sensor device is considered as sensor fault.

Most of the existing literatures related to MPPT and VSC controls for PV systems are not designed to ensure resilient operations against such sensor faults. The existing fault diagnosis approaches [11–14] for PV systems deal with faults such as wear and tears in physical components, for example, fixed object shedding, dirt in the PV module, hot spots, module degradation, etc. Most of the existing fault diagnosis approaches for PV systems compare the monitored PV system output power.

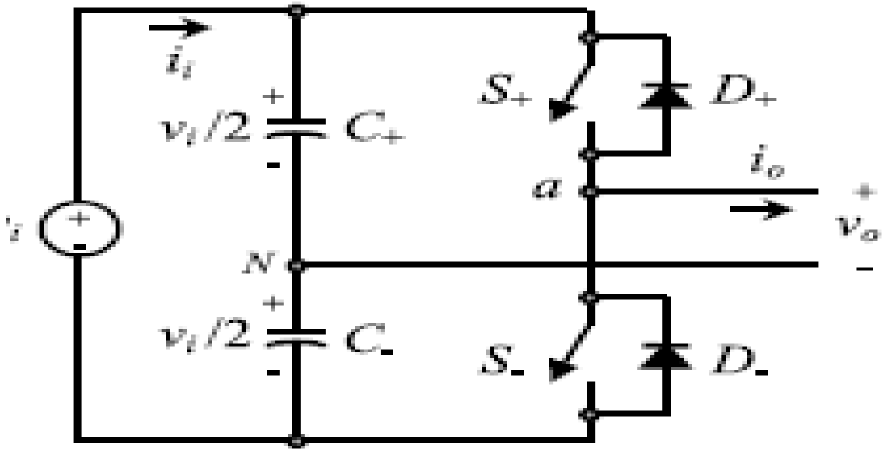

FIGURE 14.2 Single-phase half-bridge VSI.

Fig.1 VSI

2. Literature Review

Artificial neural network and wavelet analysis based approaches for detection of fault in PV module are presented in [18,19], respectively. However, the existing PV system fault diagnosis approaches do not cater for diagnosis of sensor malfunctioning. Research on the malfunctioning of sensors in inverter interfaced systems is not new [20–23]. Especially, impacts of sensor malfunctioning and their diagnosis have been well studied in inverter interfaced motor drives [24–26]. Some recent studies are developed for sensor faults in wind energy conversion system (WECS) [27,28]. It can be seen from the literature that if malfunctioning of sensors are left undetected and no remedial measures are taken, the control operation of the power electronic interfaces of the corresponding systems can be significantly disrupted, as the erroneous measurements due to sensor malfunctioning are used by the controllers driving the power electronic interfaces.

Similarly in a PV system, accuracy of the sensor measurements are of paramount importance for its efficient operation. This is due to the fact that the sensor measurements are used by the controllers driving the power electronic devices in a PV systems (DC-DC converter and three phase inverter) to ensure its efficient operation. Impact of measurement errors due to malfunctioning of sensors will propagate through the controllers, which will hinder the efficient operation of the power electronic devices and in-turn the PV system. Even though sensor malfunctioning can significantly hamper efficient operation of the PV system, a very little research has been carried out in this regard. It should be noted that, the existing sensor fault diagnosis approaches (for motor drives, wind energy) reported in the literature can not be readily used for diagnosis of sensor faults in PV systems, as these reported approached are developed based on the dynamic model of the corresponding system (motor drives [24–26], wind energy [29,27,28]) and can only be applied for the system under consideration. Moreover, most of the existing approaches regarding sensor malfunctioning for inverter interfaced systems are developed based on the generation of residuals using observer

(Luenburger observer [30], Kalman filter [24], adaptive observer [31], etc.) of the inverter interfaced system model under consideration.

However, the existing observer based approaches are mostly developed with a view to only detect and classify the type of sensor fault; do not cater for mitigation of such sensor faults and unable to provide resiliency against such sensor faults. Though there are a few observer based fault tolerant control approaches exist in the literature [30,25], they require additional redundant circuitry or reconfiguration of the nominal system control is required. In order to combat sensor malfunctioning and ensure efficient and optimum operation of a grid connected PV systems, this paper presents an approach which not only diagnoses sensor faults, but also mitigates it and ensures efficient and optimum operation of the PV system.

In this paper, any error in the measurements of PV array output voltage, current, and the current flowing between VSC and the grid due to malfunctioning of associated sensors or any associated sensor devices such as CT, PT, DAQ devices, etc. are considered as sensor faults.

In the proposed approach, a sliding mode observer (SMO) based fault detection and estimation algorithm has been developed for diagnosis of measurement errors of the aforementioned PV system quantities due to malfunctioning of associated sensors. The proposed approach is agnostic of the type of current and voltage sensors and other associated sensor devices that are used in the measurement of aforementioned PV system quantities. Any error in sensor measurements, due to any malfunctioning of associated sensors are treated as sensor faults by the proposed approach, which is estimated by the SMO. The estimated measurement errors are used to devise mitigation actions to negate the impact of erroneous measurements on the control operation of the PV system. The main contributions of the proposed approach are summarized below:

Development of a diagnosis and mitigation approach for grid connected PV systems, which ensures resiliency of PV systems against sensor malfunctioning. The existing sensor fault diagnosis and mitigation approaches are not readily applicable to PV system.

The proposed approach utilizes sliding mode observer (SMO) based fault detection and estimation theory for estimation of errors in sensor measurements due to malfunctioning of corresponding sensors in a grid connected PV system. The most of the existing sensor fault diagnosis approaches only capable of detecting any sensor malfunctioning, but are not able to estimate the measurement errors due to sensor malfunctioning.

In the proposed approach, the estimated measurement errors by the SMO based fault diagnosis algorithm are used to devise mitigation regimes to negate the impacts of measurement errors on the performance of grid connected PV systems. This enables continuing efficient and reliable operation of the PV system even under sensor was malfunctioning. Application of the proposed approach will allow the maintenance team of the PV system to replace the malfunctioning sensor without hampering the operation of the PV system.

The proposed approach has been validated through rigorous simulation studies under varying fault and operating conditions. The simulations results demonstrate that the proposed approach can accurate diagnose and mitigate sensor faults in a grid connected PV system under different fault and operating conditions.

Furthermore the real-time implementation and practical applicability of the proposed approach is validated through a detailed experimental study by implementing the proposed approach in D space Micro Lab Box.

Integrating a high share of electricity from non-dispatch able Renewable Energy Sources in a power supply system is a challenging task. One option considered in many studies dealing with prospective power systems is the installation of storage devices to balance the fluctuations in power production. However, it is not yet clear how soon storage devices will be needed and how the integration process depends on different storage parameters. Using long-term solar and wind energy power production data series, we present a modeling approach to investigate the influence of storage size and efficiency on the pathway towards a 100% RES scenario. Applying our approach to data for Germany, we found that up to 50% of the overall electricity demand can be met by an optimum combination of wind and solar resources without both curtailment and storage devices if the remaining energy is provided by sufficiently flexible power plants. Our findings show further that the installation of small, but highly efficient storage devices is already highly beneficial for the RES integration, while seasonal storage devices are only needed when more than 80% of the electricity demand can be met by wind and solar energy. Our results imply that a compromise between the installation of additional generation capacities and storage capacities is required.

There are 3 versions of the TurtleBot model. TurtleBot1 was developed by Tully (Platform Manager at Open Robotics) and Melonee (CEO of Fetch Robotics) from Willow Garage on top of the iRobot's Roomba-based research robot, Create, for ROS deployment. It was developed in 2010 and has been on sale since 2011. In 2012, TurtleBot2 was developed by Yujin Robot based on the research robot, iClebo Kobuki. In 2017, TurtleBot3 was developed with features to supplement the lacking functions of its predecessors, and the demands of users. The TurtleBot3 adopts ROBOTIS smart actuator DYNAMIXEL for driving. For more information on the TurtleBot series, please see the following link.

TurtleBot3 is a small, affordable, programmable, ROS-based mobile robot for use in education, research, hobby, and product prototyping. The goal of TurtleBot3 is to dramatically reduce the size of the platform and lower the price without having to sacrifice its functionality and quality, while at the same time offering expandability. The TurtleBot3 can be customized into various ways depending on how you reconstruct the mechanical parts and use optional parts such as the computer and sensor. In addition, TurtleBot3 is evolved with cost-effective and small-sized SBC that is suitable for robust embedded system, 360 degree distance sensor and 3D printing technology.The TurtleBot3's core technology is SLAM, Navigation and Manipulation, making it suitable for home service robots. The TurtleBot can run SLAM (simultaneous localization and mapping) algorithms to build a map and can drive around your room. Also, it can be controlled remotely from a laptop, joypad or Android-based smart phone. The TurtleBot can also follow a person's legs as they walk in a room. Also the TurtleBot3 can be used as a mobile manipulator capable of manipulating an object by attaching a manipulator like Open MANIPULATOR. The Open MANIPULATOR has the advantage of being compatible with TurtleBot3 Waffle and Waffle Pi. Through this compatibility can compensate for the lack of freedom

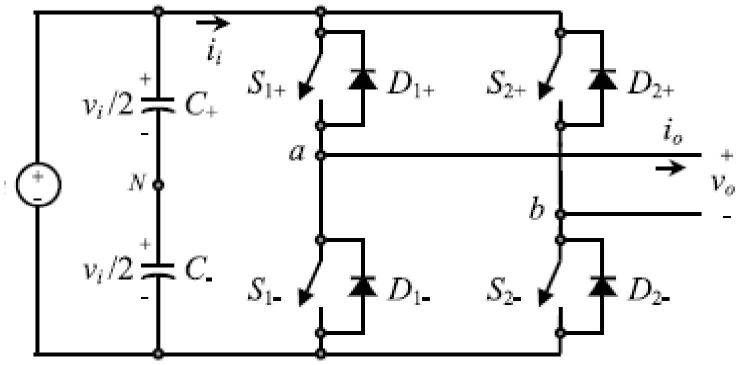

Fig.2 Full bridge VSI

3. Proposed System

The photovoltaic effect, first observed by Becquerel, is how solar radiation is converted. The emergence of an electric voltage between two electrodes attached to a solid or liquid system when light is shined onto this system is the most common definition. Solar cells are energy conversion devices that use the photovoltaic effect to convert sunlight into electricity. A single converter cell is known as a solar cell or, more generally, a photovoltaic cell. A solar module or solar array—hence the name "Photovoltaic Arrays"—is a collection of such cells designed to increase electric power output. Solar cells can be arranged into large groups called arrays. Solar energy can be converted into electrical energy and distributed to industrial, commercial, and residential users by these arrays, which are made up of many thousands of individual cells. Panels, or solar cells in their smallest form, are commonly referred to as solar cells. A P-N junction in a semiconductor serves as the development point for the photovoltaic voltage in practically all photovoltaic devices. Silicon is the most frequently utilized semiconductor material in the solar panels.

As the materials range from amorphous (non-crystalline) to polycrystalline (single crystal) to crystalline (single crystal) silicon forms, the vast majority of solar cells are constructed from silicon, which increases efficiency and reduces costs. Solar cells, in contrast to electric generators or batteries, have no moving parts and do not require fuel or chemical reactions to generate electricity.

An optical coating, also known as an antireflection layer, prevents light from reflecting off the device and allows light to enter; By encouraging the light's transmission to the energy-conversion layers below, it effectively traps light that hits the solar cell. Typically, the antireflection layer is a silicon, tantalum, or titanium oxide that is formed on the cell surface through spin coating or vacuum deposition.

The top junction layer, the absorber layer, and the back junction layer are the three energy-conversion layers below the antireflection layer. The absorber layer is the core of the device. To complete an electric circuit, two additional electrical contact layers are required to carry the electric current out to an external load and back into the cell. The electrical contact layer on the face of the cell through which light enters typically has a grid pattern and is made of a metal or other good conductor. The grid lines are as thin and spaced as possible so that the cell's current can be collected because metal blocks light. There are no such diametrically opposed restrictions on the back electrical contact layer. It must only serve as an electrical contact and cover the entire cell structure's back surface. Metal is always used for the back layer because it must also be a good electrical conductor. A solar cell absorber ought to be effective at absorbing electromagnetic radiation at wavelengths in the visible range because the majority of the energy in sunlight and artificial light is in that range. Substances that have a high absorption of visible light are classified as semiconductors. All incident visible light can be absorbed by semiconductors with thicknesses of less than one hundredth of a centimeter; A solar cell's thickness is essentially that of the absorber because the contact and junction-forming layers are much thinner. Silicon, Gallium Arsenide, Indium Phosphide, and Copper Indium Selenide are all semiconductors used in solar cells.

Electrons in the absorber layer of a solar cell are excited when light hits it, moving from a lower-energy "ground state" where they are bound to particular atoms in the solid to a higher-energy "excited state" where they can move through the solid. Since these "free" electrons are moving at random without the junction-forming layers, there can't be an oriented direct current. However, when junction-forming layers are added, a built-in electric field is created, which results in the photovoltaic effect. The electrons, in effect, are collectively moved by the electric field as they move through the electrical contact layers into an external circuit where they can perform useful work.

The crystal structure and type of semiconductor used in the manufacturing of solar cells are just two of the many factors that influence the cell's efficiency and price. Other external factors, such as the temperature, lighting, and shading of the surrounding environment, also affect the output of the solar panel. The objective is to create a system that will maximize power extraction regardless of solar cell efficiency or the surrounding weather.

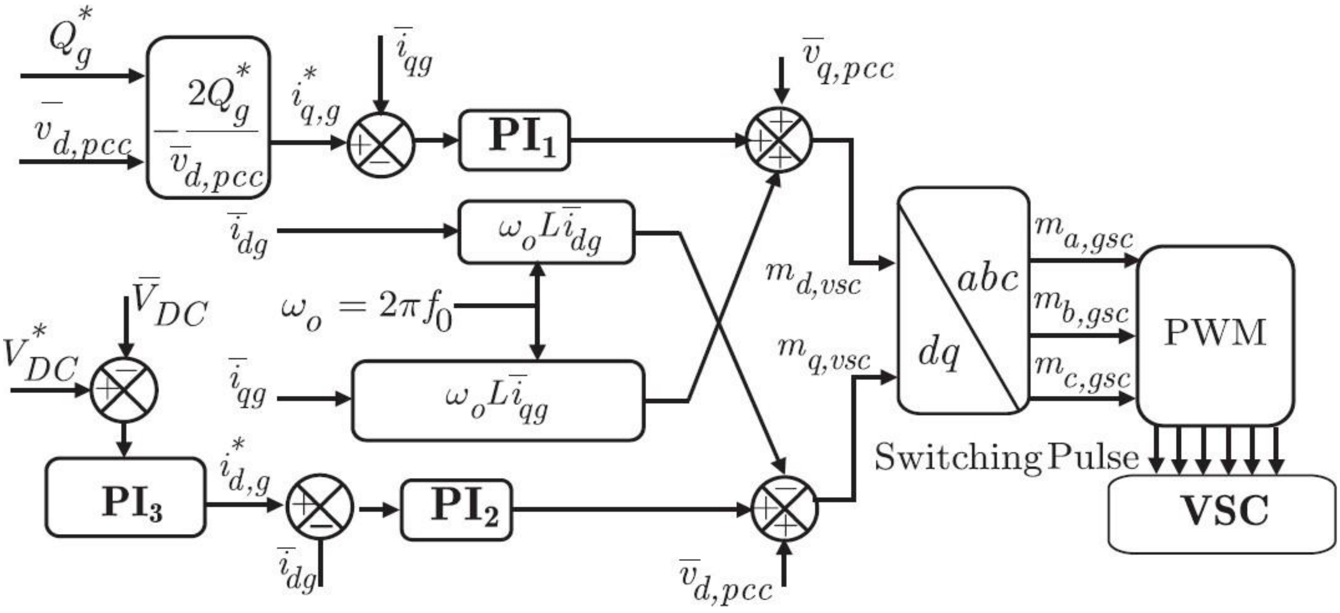

Fig.3 Proposed Method

4. Conclusion

This paper presents an approach for diagnosis and mitigation of malfunctioning of sensors measuring PV array output DC voltage and current as well as the sensor measuring the ac current flowing to the grid in grid connected PV systems. The proposed approach diagnoses malfunctioning in the aforementioned sensors using SMO based fault detection and identification technique, which estimates the errors in the measurements due to malfunctioning in the corresponding sensors. The estimated errors are used by the proposed mitigation approach to rectify the erroneous measurements. The rectified measurements are fed to the PV system controllers (MPPT and VSC controller) to ensure reliable operation of the PV system. Rigorous simulation and experimental studies are carried out to demonstrate the adverse impact of sensor malfunctioning, as well as the effectiveness of the proposed approach in diagnosing and mitigating the sensor faults and ensuring reliable operation of a grid connected PV system under sensor malfunctioning

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