PATTERN RECOGNITION FOR FAULT DIAGNOSIS OF SOLAR POWER INVERTER BY TRAJECTORY IMAGE UNDERSTANDING

Jaeho Hwang[1], Nanhwa Kim[1], Neajoung Kwak[1] and Wonpyo Hong[2]
[1]*Dept. of Electronic Eng., Hanbat National University, Daejeon 305-719, Korea*
[2]*Dept. of Building Services Eng., Hanbat National University, Daejeon 305-719, Korea*

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Abstract: This paper presents an approach based on pattern recognition to detect and diagnose faults of solar power inverter by its fault trajectory image understanding. The drive system for simulation is modeled using Matlab Simulink toolboxes. Solar power device uses control/filter structure to connect the pulse width modulation (PWM) inverter. Multistage diagnosis factors are calculated from faults patterning procedure. It is based on the analysis of the vector trajectory and of the space syntax in faulty image mode.

1 INTRODUCTION

A Solar power inverter is a type of power electronics inverter that is made to convert the DC electricity from photovoltaic solar cells into AC sinusoidal one under various kinds of load, building appliances and a utility grid. In case of medium voltage solar inverter, switching mode PWM converters have been widely used because of its high efficiency and output power. However, electrical faults may exist in any component of the drive system. Once abrupt faults such as the breakdown of switching devices, the failure of the capacitor or inductor in the low-pass filter occur, the whole system will lose its operation and even propagate a series of troubles to whole power system. In addition to electronic troubles, the solar plant output voltage varies in a wide range. It has to be converged within a specified range in use of controller and a big input capacitor which is connected in parallel to the solar cells in order to fit the input voltage of DC-to-AC power inverter. The troubles in this device and input voltage ripple are the additional faults of solar power inverter.

The recent researches on fault diagnosis of power inverters have been focused related to three-phase induction motor derive system, inverter faults in variable speed AC drives, load short/open circuit and mechanical/insulation failure of the induction motor(Guan et al., 2007, Son et al., 2004, Ye and Wu, 2001). The method for fault detection and diagnosis is mainly based on the current trajectory and its instantaneous frequency at the output side of the inverter. However, with the increasing concern about natural energy source and environmental demand, the need to produce the green energy such as solar energy to replace fossil fuels has significantly increased. In an effort to utilize the solar energy, photovoltaic(PV) generation with power inverter is an effective method to supply the flexible power in a grid, not only AC motors, connected small and large power generation plants.

This paper develops a real-time faulty diagnosis method for photovoltaic inverter system based on the pattern recognition of current vector calculation. The performance and characteristic of the system faults are evaluated as the type of source image parameters for patternization.

2 SYSTEM AND FAULT ANALYSIS

2.1 System Schemes

The scheme of the proposed PV inverter system can be built in different ways, depending on the size of the system and on the desired energy management. It is composed of photovoltaic module, electrical, electronic device for control, DC/DC converter,

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inverter and grid. The output power produced by photovoltaic modules is significantly affected by the weather conditions. The PV sources depend on solar radiation and cell temperature during sun hour period. In order to extract maximum output power from PV source, solar power controller has to be incorporated to regulate the voltage to the Maximum Power Point Tracking(MPPT)(Bellini et al., 2008). This is achieved through controller of PV inverter system. Due to vary solar output, night or intermittent sun condition, battery is used to work as a standalone power source charged from PV source. It can be also connected to Grid sources as a backup source.

The single-stage for PV inverter system, illustrated in Fig.1, is employed to supply AC power to an available load. The output voltage is quite low and the MPPT is controlled by the inverter.

Figure 1: Single-stage PV inverter system.

On the utility inverter, a high frequency Pulse width modulated(PWM) inverter is designed and applied in order to maintain a power factor and low harmonic current, where the stored DC power in the battery is digitized to produce a sequence of PWM pulses at the output of inverter.

The general scheme for simple PV inverter is shown in Fig.2. Here the controller or controller with charge regulator is incorporated to regulate the output power of PV source.

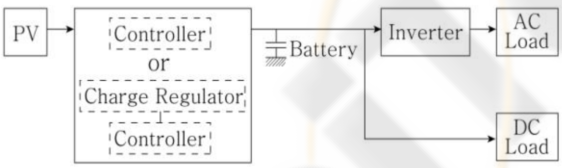


Figure 2: Grid tie PV inverter system.

The PV output voltage, which can vary in a wide range, has to be isolated in order to fit the input voltage of inverter. In case of Fig.2, it is realized by controller or charge-regulator with controller.

The schematic block diagram, where the grid system and PV system works as primary and back-up source, in shown Fig.3.

The system switch connects the inverter during sun hour and PV supplies electric power to the load through inverter. During night or intermittent sun condition, the grid source alone charges the battery and the load gets its power from the grid. The system switches over to the grid during inverter cut off.

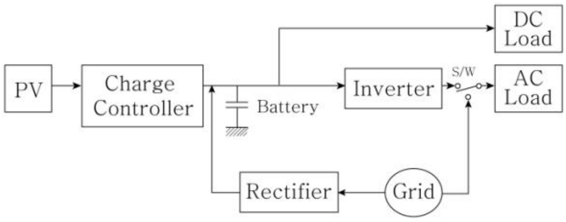


Figure 3: Grid tie PV inverter system.

2.2 Fault Analysis

Various types of faults might occur on the different parts of the PV inverter system, which include the following:

i) PV source;
ii) Controller, charge regulator or rectifier: breakdown of device, faults in the circuit ;
iii) Battery: capacitor breakdown;
iv) Load: one phase-missing, close to ground, short, open;
v) PWM inverter: faults on turning on-off or thyristor devices;
vi) Grid: switching fault, short;

In this paper, only faults occurred in the invert, controller, load and grid are considered. The other faults will be studied in another paper. Switching faults of PWM inverter, open or short circuit faults of control devices and defects on load and grid are analyzed in diagnosis model.

The grid system and PWM inverter are three-phase devices. The signals used for diagnosis model are inverter output three-phase currents. The faults in the inverter drive system due to electrical or switching causes are reflected in the current wave form at the output side of the inverter. The three-phase signals are transformed into a two-phase rector space by Concordia transform. It transforms a three-phase system into a further simplified two line currents based on $i_a + i_b + i_c = 0$.

$$i_\alpha = \sqrt{\tfrac{3}{2}}\, i_a \tag{1}$$

$$i_\beta = \sqrt{2}\, i_a + \sqrt{\tfrac{1}{2}}\, i_b \tag{2}$$

The trajectory of vector $\bar{i} = (i_\alpha, i_\beta)$ is periodically preserved image on $\alpha\beta$ plane because the trajectory for each fault mode is unique.

3 DIAGNOSIS MODEL AND PATTERN RECOGNITION

The diagnostics of PV inverter which is designed to draw photovoltaic energy from a battery can be implemented by checking the trajectory image of the current vector in $\alpha\beta$ plane(Peuget et al, 1998). It has its own trajectory mode, normal or faulty one. They can be plotted for the current of the inverter and different patterns are easily classified when switching device faults occur in the inverter. Each trajectory image represents full or half circle under ideal operation condition. In case of one switching fault, the phase currents of the load are no longer sinusoidal. The current of that phase can flow in one direction. The phase voltage during the half period does not appear because the phase current does not flow in positive or negative state. The phase current of fault device is null during half of the current period. The relation between i_α and i_β is $i_\alpha = \sqrt{3}\left|i_\beta\right|$ by equation (1) and (2). Therefore the corresponding trajectory is a half circle in $\alpha\beta$ plane.

3.1 Diagnosis Parameters

But both switching devices are faulty, the trajectory becomes a narrow line or a sector within a right angle. If both devices belong to one phase, the trajectory moves the β axis for phase A and becomes one line with 120 degree delay for phase B and C. If both devices belong to different phase, the trajectory becomes a sector within a right angle. The trajectory refers to a fault mode. In order to easily identify a fault mode of the PV inverter, four parameters related to the trajectory image are to be proposed within a normalized unit circle; shape, region, distributed angle and typical vector angle.

- Shape: line, fanwise sector
- Region: six regions (Fig. 4)

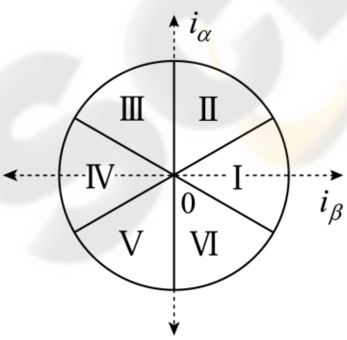


Figure 4: Trajectory regions.

- Distributed angle θ, (Fig. 5(a)): $60m(°)$, $m = 1, 2, 3$
- Typical vector angle ϕ, (Fig. 5(b)): $30n\,(°), n = 1, 2, \cdots, 11$

Typical vector is decided to halve the distributed angle.

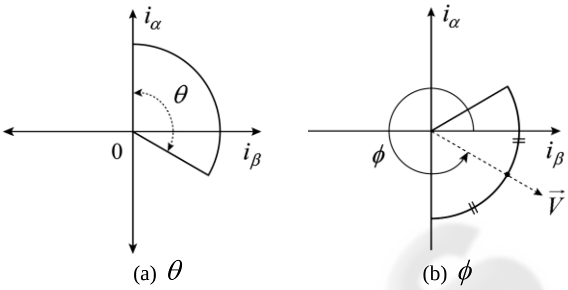
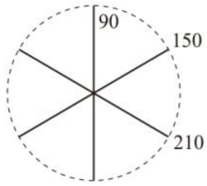


Figure 5: Distributed/typical vector angle (examples).

3.2 Tree for Pattern Classification

In fault analysis, a tree diagram is used as a pattern recognition model which maps observation about faults to pattern. The goal is to create a model that classifies the faults based on the proposed diagnosis parameters. Each interior node corresponds to one of the parameters, that is, input variables. This tree can be learned to refer to the outcome of the fault pattern (Table1, Fig. 6).

Table 1: Tree configuration.

node 1	node 2 (°)			pattern
line b1			b11,90	D1
			b12, 150	D2
			b13, 210	D3
sector b2	node 3, $\theta(°)$	node 4, $\phi(°)$		
	b21, 60	$30\,n$	b211~ b216, $n = 2k$	D4~D9
	b22, 120		b221~ b226, $n = 2k+1$	D10~D15
	b23, 180		b231~ b236, $n = 2k$	D16~D21

$* n = 0, 1, 2, \cdots, 5,\ b: branch$

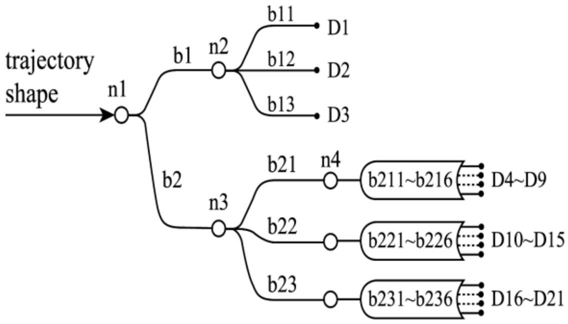


Figure 6: Tree and pattern recognition.

3.3 Simulation for Faulty Pattern

In general the PV inverter is a combination of electric and electronic devices. The proposed simulation model for PV inverter is grouped into several modules provided in Matlab Simulink as shown in Fig.2. The load current is simulated using three phase inverter module in SimPowerSystem library. In table2, the patterns for different faults modes are listed. The fault refers to the open-circuited of the relevant power-electronic device. The devices E1 and E6 are respectively upper and lower device of phase A. E3 and E2 are related to phase B, and E5 and E4 refer to upper/lower device of phase C.

Table 2: Fault patterns.

pattern	open-circuited devices	pattern	open-circuited devices	pattern	open-circuited devices
D1	E1 ∧ E6	D8	E1 ∧ E5	D15	E5 ∧ E6
D2	E4 ∧ E5	D9	E2 ∧ E6	D16	E6
D3	E2 ∧ E3	D10	E3 ∧ E6	D17	E3
D4	E3 ∧ E5	D11	E3 ∧ E4	D18	E4
D5	E4 ∧ E6	D12	E1 ∧ E4	D19	E1
D6	E1 ∧ E3	D13	E1 ∧ E2	D20	E2
D7	E2 ∧ E4	D14	E2 ∧ E5	D21	E5

*∧ : *and*

4 CONCLUSIONS

This paper proposed a method for patternization and its graphic recognition based on the analysis of trajectory modes image understanding when three phase PV inverter faults occur. System schemes and diverse fault mode are introduced. After parameters for diagnosis are identified, a decision tree is composed. The fault pattern can easily diagnose the each switching fault. This knowledge-based method has been tested in simulation using Matlab Simulink toolboxes. The proposed method can apply to an experimental system.

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