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Fault diagnosis method based on FFT-RPCA-SVM for Cascaded-Multilevel Inverter

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ABSTRACT

Thanks to reduced switch stress, high quality of load wave, easy packaging and good extensibility, the cascaded H-bridge multilevel inverter is widely used in wind power system. To guarantee stable operation of system, a new fault diagnosis method, based on Fast Fourier Transform (FFT), Relative Principle Component Analysis (RPCA) and Support Vector Machine (SVM), is proposed for H-bridge multilevel inverter. To avoid the influence of load variation on fault diagnosis, the output voltages of the inverter is chosen as the fault characteristic signals. To shorten the time of diagnosis and improve the diagnostic accuracy, the main features of the fault characteristic signals are extracted by FFT. To further reduce the training time of SVM, the feature vector is reduced based on RPCA that can get a lower dimensional feature space. The fault classifier is constructed via SVM. An experimental prototype of the inverter is built to test the proposed method. Compared to other fault diagnosis methods, the experimental results demonstrate the high accuracy and efficiency of the proposed method.

1. Introduction

With global expansion of economy, the demand for energy from all walks of life is increasing year by year. Countries in the world therefore try to explore every possible energy resource. The exploitation of renewable resources has become an international hot spot. Inverter system is a key part of renewable resources exploitation which converts DC to AC. Multilevel inverter is suitable for applications in the direct drive wind power system because it can reduce the switch voltage stress and the equivalent switching frequency. In recent years, cascaded H-bridge multilevel inverter system (CHMLIS), as a kind of multi-level inverter with good implementation properties, is widely used in high-power transform domain. It is used namely in the direct drive wind power system, which adopts a low-speed multi-phase permanent magnet synchronous generator. CHMLIS offers many advantages for high-voltage or high-power applications. However, with increasing number of levels, the probability of faults in wind power system will increase, such as open-circuit (OC) or short-circuit (SC) of the power switch transistors [1–3], which will cause the shutout of the wind power system or some catastrophic accidents. In order to guarantee normal operation of wind power system, the research on cascaded H-bridge multi-level inverter fault diagnosis has important theoretical significance and application values [4,5]. The faults of inverter, mainly composed of power switch transistors, are OC or SC [1–3,6]. For different fault types and locations, the system's voltage and current will be different. In order to achieve the purpose of quickly and effectively detecting the faults and estimating their type and location, the researchers usually combine a variety of fault diagnosis methods applied to the system current or voltage variation [7–10]. Several diagnosis approaches for inverter have been presented in [11–13]. But they have some problems such as nonlinear factors in the multilevel inverter and the complex circuit configuration. In [14], a novel approach based on an adaptive kernel principal component analysis and Support Vector Machine (SVM) is proposed for real-time fault diagnosis of high-voltage circuit breakers. SVM is powerful for small sample data classification, but the generalization ability of SVM will be decreased for large classification. A diagnosis approach using neural networks is proposed in [15] for fault identification using partial syndromes. Neural networks have strong nonlinear fitting capability, but the learning speed of ANN is rather slow. In [16], a multilevel principal component analysis based fault diagnosis method is proposed to provide meaningful monitoring of the underlying process and help faults diagnosis. However, multilevel principal component analysis is more powerful in fault detection than in fault diagnosis. Another fault diagnosis method based on the normalized DC current is

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presented in [17] for voltage source active rectifiers and in [18] for voltage source inverter. But, the output current of CHMLIS depends on the load variation, which leads to a false diagnosis when the load changes. In [19], a smart diagnosis method based on multi-kernel support vector machines and incremental learning is proposed to achieve accurate faulty-component classification based on observed errors. However, when the sample data or fault classes are big, the running time will be increased greatly. A sensor fault diagnosis approach is presented based on principle component analysis (PCA) feature extraction and SVM multi-classification in [20]. An approach based on lifting wavelet transform and SVM is proposed in [21] to improve the accuracy of fault identification. An imbalanced pattern classification method, based on under-sampling, for SVM is proposed in [22]. [23] proposes a control chart pattern recognition method based on genetic algorithm and PCA-SVM. However, the accuracy and efficiency of diagnosis should be improved due to the lack of data preprocessing. The method proposed in [1], can handle large transients such as load and speed variations, without emitting false diagnostics. However, this approach requires complex pattern recognition algorithms which are not easy to be integrated into the drive controller. The algorithm proposed in [24] detects effectively the inverter faulty phase, is capable of localizing the faulty power switch, and avoids the use of extra sensors or electrical devices and the subsequent increase of system complexity and costs. However, it can be observed that, for the case of open circuit faults, due to the specific features of power inverter topology, it is possible that a faulty insulated-gate bipolar transistor would not be localized if the failure occurs during the phase of demagnetization.

This paper proposes a cascaded multi-level inverter fault diagnosis strategy, which includes two parts. One is the test signals selection of CHMLIS: by the contrast analysis of the inverter output voltage and current signals when the switch transistors are in open circuit state, the output voltage signals have been chosen as the fault characteristic signals. The other is the proposed FFT-RPCA-SVM method. SVM is not good for large sample classification. So, FFT is used to preprocess the original signals to do data compression and feature extraction. And the relative principal component analysis (RPCA) is used to make data optimization and dimension reduction. Finally SVM is adopted to realize the faults classification. In order to obtain simulation data, a CHMLIS simulation model is constructed. In addition, a CHMLIS fault diagnosis experiment platform is constructed, which is based on dSPACE real-time system, to get experimental data. For verifying the effectiveness of the proposed method, the proposed technique and other traditional fault diagnosis methods are compared with the simulated and experimental data. The results show that the proposed fault diagnosis strategy improves the diagnosis accuracy and computational efficiency.

2. Signals selection of CHMLIS

CHMLIS is used in direct drive wind power system as shown in Fig. 1. Because the topology of every phase is the same, a single-phase cascaded H-bridge five-level inverter switch transistors in open-circuit (OC) is taken as an example (Fig. 2). OC fault means that the power semiconductor device remains in off-state permanently. Mostly OC fault appears when the gate driver unit or the gate firing hardware circuit fails [22]. This cascaded H-bridge five-level inverter simulation model is controlled by Subharmonic PWM (SHPWM) [30,31], the output voltage is obtained via an amplitude modulated wave with modulation ratio m_a. When m_a=0.86, the single-phase five-level inverter circuit output voltage and current waveforms are shown in Fig. 3. The inverter normal state's output waveforms with load resistance $R_{load}=1\ k\Omega$ are shown in Fig. 3(a). As shown in Fig. 3(a), the output voltage and current waveforms have the same shape; the proportionality between the waveforms is the load resistance. Fig. 3(b) and (c) shows the single-phase five-level inverter output voltage and current waveforms when the H-bridge S1 switch transistor is in OC fault with load resistance $R_{load}=1\ k\Omega$ and 100 Ω, respectively. It can be observed through analyzing Fig. 3(b) and (c), that the output voltage values remain constant with the change of the inverter load, but the output current waveforms change with the load variation. It can then be concluded, that the output current depends on the load variation, but the inverter output voltage is independent of the load variation, and the output voltage waveforms are different for different locations of switch OC faults as shown in Fig. 4.

It is very important to select the appropriate signals, for fault detection and diagnosis, which will directly affect the diagnostic performance. It can be observed from the above analysis, that the output current depends on the load variation, which will lead to a false diagnosis when the load changes. Therefore, it is inappropriate to only employ the output current waveforms as the model characteristic signals. The output voltage waveforms have the following merits: 1) less additional circuit where only a voltage detecting sensor at the inverter output terminal is sufficient; 2) the inverter output voltage does not change with the load variation; 3) the inverter output voltage changes with different faults; 4) simple calculation because only the inverter output voltage is used to locate the faults. Therefore the output voltage signals of CHMLIS are selected as the input fault classification characteristic signals for the fault diagnosis method in this paper.

A single-phase cascaded five-level inverter including H-bridge1 and H-bridge2 is shown in Fig. 2. Every switch may have open circuit fault, and the normal state is also listed as a special class of faults, generally there are 9 kinds of fault categories in single-phase cascaded H-bridge five-level inverter. The category labels are used to represent fault category as shown in Table 1. When a fault signal belongs to a fault category, the corresponding fault classification

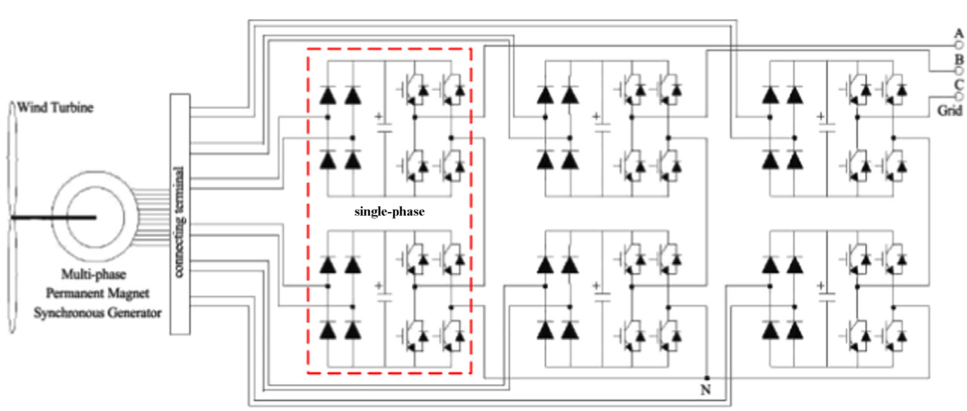

Fig. 1. Direct drive wind power system of cascade H-bridge five-level inverter.