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# SWITCH FAULT DIAGNOSIS IN GRID-TIED PV INVERTER USING MACHINE LEARNING TECHNIQUE

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***Abstract*—Due to depleted natural resources and rising pollution from fossil fuels and nuclear energy, renewable energy has gained popularity in recent decades. Power electronic engineers create grid-connected power conversion systems for these reasons. Multilevel inverters are popular because they provide better solutions and more power. Neutral pint clamped (NPC) inverters are commonly utilised in grid-connected systems and high-power industrial applications such as high-voltage dc transmission, static VAR compensators, and high-power adjustable-speed motor drives.NPC inverters have more switches than two-level inverters. NPC inverter switch faults are more likely. Short-switch and open-switch faults are switching device problems. A short-switch defect creates an abnormal overcurrent that damages power conversion system components. So, it is anticipated that such faults in the inverter must be detected in order to ensure reliability of the system.In this reagrd, the current study comprises the development of aapproach for detecting and fixing switch faults in a grid-connected NPC inverter, so guaranteeing the system's dependability and allowing for the PV system's redundant functioning. The suggested technique incorporates feature extraction using Wavelet transform followed by usage of the same feature set by Decision Tree classifier to identify and characterise the defect. The effectiveness of the suggested DT based fault diagnostic system for diagnosing the PV inverter switch problem is shown by its increased classification accuracy.**

***Keywords*— *Three-level neutral-point clamped (NPC) Inverter, switch fault; fault diagnosis, Discrete Wavelet transform, Decision Tree.***

## I. INTRODUCTION

As compared to the traditional two-level converters, the topologies of multilevel converters provide many benefits. These advantages include an increase in the maximum DC-link voltage that can be tolerated as well as improved harmonics in the input current. As a result, three-level neutral-point clamped (NPC) topology systems have been the subject of study in a number of studies and find widespread use in a variety of business sectors. The study areas that pertain to the NPC topology systems may be divided up into a few distinct categories. The majority of the study is focused on improving performance via the use of pulse-width modulation (PWM) methods [1–3] and balancing algorithms of neutral-point voltages [4–8]. The performance of NPC topology systems has significantly increased as a consequence of the accumulation of a number of different research endeavours

Because of the widespread use of the three-level NPC topology to a variety of different businesses, the dependability of the system has become an increasingly essential concern [9]. Harmonic filters, current and voltage transducers, gate driver circuits, and power semiconductors such insulated gate bipolar transistors are some of the components that make up the converter system. Other components include gate driver circuits (IGBTs). As a result of this factor, this system is susceptible to a wide variety of errors. When using a three-level NPC converter architecture, one of the most important challenges that must be overcome is troubleshooting the faults that are associated with the switching devices, gate drive circuits, and IGBTs. These errors in the switching devices are further broken down into two categories: open-switch faults and short-circuit faults respectively.

A malfunction in the gate drive circuit and an inherent failure of the IGBT, such as overvoltage or avalanche stress, are the most common causes of short-circuit defects [10]. If the converter system experiences a short-circuit failure, the circuit breakers or fuses will instantly disconnect the power grid from the converter system in order to prevent the system from being destroyed [11,12].

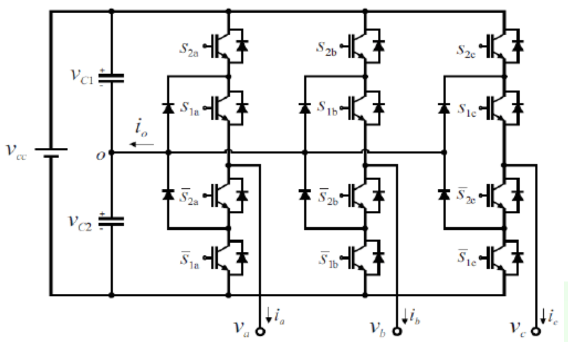

Figure 1: Neutral-point clamped (NPC).

A fluctuation in the voltage of the DC-link capacitor is caused by the distorted current, which also results in a voltage imbalance between the upper and lower capacitors. It is possible for further failures to occur on other devices and systems linked with the DC-link if the converter system is constantly run in the open-switch fault state. In most cases, the converter system will go into a pause mode in order to avoid future failure and repair. In the case of renewable power generation or certain manufacturing units, however, a sudden shutdown of the converter system results in considerable financial losses. Because of this, it is necessary to have a technique of fault identification and tolerant control in order to continue running the converter system.

Inverter bridge arms are A, B, and C. A-phase bridge arm contains four power switches, four free-wheeling diodes, and two clamping diodes. Each free-wheeling diode is linked antiparallel to the power switch to reverse the current. The clamp diode connects the power switches and capacitor midway. LC filters the inverter's three-phase output voltage signals to power the load. Bridge arms have 12 power switches. Gate signals control each power switch. When the gate signal is 1 (high level), the power switch is on; otherwise, it's off. Modulation approach determines inverter switching mode. PWM, SPWM, and SVPWM are common modulation techniques. SVPWM modulation has tiny harmonic components and good DC usage, thus it's employed to modulate the power switches' gate signals in this article.

Operationally, Protection circuits prevent short-circuits. Short-circuit faults in power switches rapidly detach the protection circuit, transforming them to open-circuit faults [10]. This research focuses on open-circuit faults in NPC three-level inverter power switches because short-circuit failures are short-lived and quickly become open-circuit problems. NPC three-level inverter power switches have 12 IGBTs. Due to the random position and quantity of malfunctioning power switches, open-circuit problems are common. It's unlikely that three or more power switches will open simultaneously. This study examines open-circuit problems in one or two power switches.

## II. LITERATURE SURVEY

In this part, we will examine and contrast a variety of defect detection and classification algorithms

In this study [5,] a novel approach to managing three-level neutral-point-clamped (NPC) rectifiers is used in order to achieve voltage equilibrium in capacitors. A model that takes into account phase-by-phase duty ratios serves as the foundation for the innovative control method. The model includes nine different duty cycle variables. Despite the peculiar wording, the control problem of currents and dc-link voltage may be described in a manner that is comparable to more conventional methods. The regulation of the capacitor voltage balance may be described using equations that are disconnected from the dynamics of the currents and the dc-link voltage. This can result in a specialized controller that does not affect the dynamics that came before it. The formulation of the recommended strategy already includes an element of the modulation stage. Examines and contrasts two controllers. This problem can be circumvented, according to the new controller that has been proposed, by accomplishing the same level of performance with fewer commutations.

It is possible, with the appropriate variable adjustments, to express dc-link voltage and active and reactive power management concerns in a manner that is comparable to other conventional approaches. As a result of the elimination of a crucial part of the modulation process, the voltage balance controller may be constructed quickly. As a result of this, the approach that was offered may be interpreted as a control method, with a portion of the modulation step integrated in the control formulation (ICM). Even if the recommended control rule is easier to implement than modified versions of space vector modulation (SVM) [16] that further handle capacitor voltage imbalance, it still has advantages over CB-PWM. The modulation step has been made simpler without compromising the adaptability of SVM

The author of this work [1] proposes fault diagnosis and tolerance control methodologies for an open-switch failure in a three-phase three-level NPC PWM active rectifier. They are presented in the context of the study. A three-level NPC dynamic rectifier that has an open-switch deficiency will create information stage current mutilation as well as a DC-interface capacitor voltage wave. The proper identification of the source of the problem and the implementation of lax control procedures are essential in order to forestall more dissatisfaction and corrector system corruption. This study examined the effect that a single open-switch failure has on the NPC PWM dynamic rectifier and offered a deficiency conclusion approach that makes use of the DC interface voltage and the information lattice voltage. This study provides a deficit forgiving control approach with the goal of minimising the open-switch impact by providing a reward for a misshaped reference voltage. The results of the trial provide support for the proposed deficiencies analysis and laxity control processes.

An approach that is based on phase current time series measurements has been proposed in this work [2] under a variety of different operating conditions (motor speed, load, and environment noise). The processes of fault identification and classification are investigated, and the usefulness of the selected criteria is established. For the purpose of increasing performance in defect identification, we make use of the first four statistical moments, extracted features, and the Cumulative Sum technique (CUSUM). For the study on categorization, we recommend combining statistical moments with Kullback-Leibler divergence, which may identify changes that are only beginning to take place. PCA is used in the classification process. Faults may be efficiently categorized using a 2D framework under the operational conditions that were taken into consideration for each fault duration that was specified.

The solution that has been proposed is straightforward, and it lessens the dv/dt as well as the total harmonic distortion in the ac output voltages. NPC inverters are used often in grid-connected systems as well as high-power industrial applications. Some examples of these applications are high-voltage dc transmission, static VAR compensators, and high-power adjustable-speed motor drives.

The NPC inverter has a greater number of switches than the two-level inverter. There is a greater likelihood of malfunctions with NPC inverter switches.

A system shut down is not required in the event of an open-circuit malfunction. It's possible that it will make some noise and vibrate. Faults in open switches that are not handled might cause secondary problems in other parts of the system. It is very important to monitor switching device faults; hence, the present research provides a technique for detecting and localizing an open-switch fault in a single switch for a grid-connected NPC inverter. This is because monitoring switching device faults is extremely important.

Most manufacturing operations might be more productive if they were less expensive to make. This is accomplished by boosting the output of all electrical machinery and equipment and expanding the size of existing installations. There are two routes to this boost in strength: By 1) creating a multilayer inverter and 2) constructing high-voltage semiconductors with voltage blocking capabilities of 3,300, 4,500, and 6,500 volts. The medium-voltage (MV) network may now be connected directly to the power converter. Just one structure, the voltage-source two-level inverter, is widely used at low voltage. At higher voltages, though, things change dramatically. Figure 2.1 shows how the market and uses for industrial MV drives are split across a number of different topologies. It is feasible to utilise either direct converters (cycloconverters) or indirect converters (with a dc connection of either current or voltage) for high-power applications.

In recent years, the nominal voltage and power ratings of self-commutated converters have increased dramatically thanks to the continuous development of high-voltage insulated-gate bipolar transistors (IGBTs) and integrated-gate commutated thyristors (IGCTs) and the application of these power semiconductors in several multilevel voltage-source converter (VSC) topologies. Thyristor-based converters have been mostly phased out in favour of pulsewidth modulation (PWM) VSCs. Reasons for this include the system's many benefits, such as its ride through capability, its ability to eliminate line harmonics, its longer working range, its changeable power factor at the point of common coupling, and its radically enhanced dynamic performance

In terms of architecture, voltage-source multilevel inverters are often categorized into neutral point clamped (NPC), flying capacitor (FLC), and cascade H-bridge designs. The NPC inverter, first developed 25 years ago, is the most extensively used high-power converter across all industries. It typically operates at 2.3 to 4.16 kV, but may go up to 6 kV in certain circumstances.

There are two broad categories into which the diagnostic methods described in the literature fall. Several techniques proposed by authors [12], [16] require measuring the voltage and/or current at each switch. The current and voltage sensors included into the gate drivers may be used for this purpose. This means that no extra hardware is required. In these cases, you may learn if a switch failed in a short or open circuit. For instance, if the voltage across a single switch is zero in all circumstances, regardless of the condition of the gate signal, this indicates a short-circuit problem at that switch. On the other hand, some approaches rely on output phase voltage or current measurements [7], [8] to provide a solution. After a problem, the phase voltage or current recorded in the defective leg is off from what would normally be seen. To ascertain which insulated-gate bipolar transistor (IGBT) has failed, an error signal is created and analysed

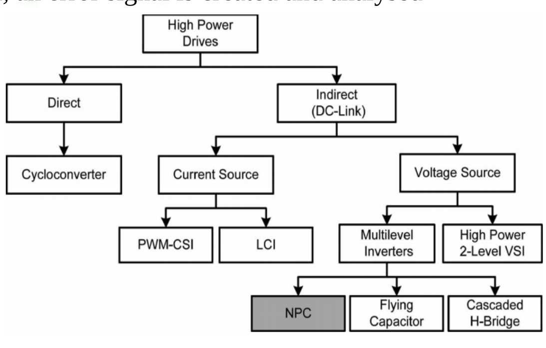


Figure 1: Classification of Inverter topologies used for High power applications

### A. *Summary of Literature Review*

The NPC inverter is already widely used in high-power applications and may be regarded a fully developed architecture. Redundant states definitively resolve the issue of capacitor voltage balancing, which was formerly seen as a shortcoming of this design

For operating with low switching frequency, as required by this architecture, the most popular modulation algorithms have been classical pulsewidth modulation, SVM, and SHE. Also popular is hysteresis control, which employs slower switching rates. The ANPC is used to remedy the issue of passive NPC's uneven loss distribution throughout its semi-conductors. DTC and field-oriented control are two of the most common methods used to regulate speed. Predictive control's ease of implementation and excellent performance make it a compelling option for future advancement. With their small size, high efficiency, and reliable operation, NPC inverters are quickly finding new uses

## III. FAULTS DIAGNOSIS METHODOLOGY

In this part of the article, the 5-level NPC inverter is used to explain the suggested technique

### *A. Simulation of Grid connected DC system with 5-level NPC inverter*

It is generally agreed that multilevel converters are the most effective topologies for use with renewable energy sources. [Citation needed] They are appealing for use in PV applications because to their excellent power quality as well as their high efficiency and performance. In low-power applications, such as photovoltaic (PV) systems installed on rooftops and linked to the grid, it is necessary to have power converters that are highly efficient and reliable. Because of this, designs based on 5 levels of NPC inverters have been designed and implemented within the industry.

### *B. Wavelet transform based feature extraction*

The wavelet-transform has gained popularity in extracting usable information from non-stationary data because it gives time and frequency domain representation. DWT's lower execution time and quicker responsiveness make it preferable for online verification [29][30]. DWT distinguishes between healthy and faulty circumstances based on noise-reducing building features and the right balance of precision and complexity. DWT's qualities make it ideal for transmission line protection. DWT analyses sampled voltage and current data by filtering time domain signals using high-passes and low-passes.

Wavelet Toolbox provides wavelets for continuous and discrete analysis. Orthogonal (Daubechies' extremal phase and least asymmetric) and B-spline biorthogonal wavelets are used for discrete analysis. Wavelet Toolbox programme provides Morlet, Meyer, Gaussian, and Paul wavelets for continuous analysis. Signal or picture parameters and application influence wavelet choice. If you understand analysis and synthesis wavelet qualities, you may pick an optimal wavelet. Wavelet families have several relevant qualities for image processing. Wavelet symmetry and antisymmetry.

Linear-phase filters complementing complete reconstruction. Vanishing moments. Wavelets with more vanishing moments express signals and pictures sparsely. Wavelet regularity. More frequency resolution with smoother wavelets. Iterative wavelet techniques converge quicker. scales. Wavelet Toolbox programme uses Fourier transforms to analyse and synthesise wavelets continuously. Wavelets with constrained Fourier transformations have a single integral inverse. This lets you rebuild a time- and scale-localized input signal. Raw data must be changed so compression can minimise duplicate and unnecessary information. Transformation domain allows rapid data computation. Wavelet's core function limits energy and time. Base functions are tiny waves. Wavelet transform is a foundation-function picture. It's time- and frequency-resolved. Wavelet transform allows multi-resolution signal or picture analysis.

### *C. C. Decision Tree (DT) based fault detector and locator*

Decision Trees, often known as DTs, are a kind of non-parametric supervised learning that may be used for classification and regression. The purpose of this project is to develop a model capable of predicting the value of a target variable by the discovery and application of simple decision rules derived from the characteristics of the data. One way to think about a tree is as an example of a piecewise constant approximation.

In the following illustration, for instance, decision trees learn from the provided data in order to approximate a sine curve using a collection of if-then-else decision rules. When there are more levels in the tree, the decision-making rules get more intricate, and the model becomes more accurate.

The following is a list of some benefits of using decision trees:

Easy both to comprehend and to grasp the meaning of. It is possible to picture trees.

Requires minimum data preparation. When using other methods, data normalisation, the creation of dummy variables, and the elimination of blank values are often required steps. Take note, however, that missing value support is not provided by this module.

The cost of using the tree, also known as the cost of making predictions, is proportional to the logarithm of the amount of data points that were used to train the tree.

Capable of working with numerical and category data simultaneously. Unfortunately, the current version of scikit-learn does not allow categorical variables in any form. The majority of the time, other methods are tailored specifically for the analysis of datasets that include only one kind of variable. For more details, please see the algorithm.

Capable of handling issues with many outputs

### *D. Algorithm flowchart-*

In figure 2, the flowchart of the proposed algorithm has been proposed. Below is the descriptionof the following steps involved in the flowchart-

Step 1:The Grid-connected PV system is simulated in MATLAB and the Neutral-point clamped (NPC) topology is modeled as PV inverter.

 

Step2:The open and short switch fault scenarios are created in the NPC topology and voltage-current signals are generated.
Step 3:The generated voltage-current signals undergo extraction of the features with the help of wavelet transform.
Step 4: In the next step, training of Decision Tree classifier is donein order to achieve the maximum training accuracy.
Step 5:During the testing stage, an unlabelled test case is given as input to the trained DT classifier in order to detect and classify the fault. No-fault is labelled as "0" and the open and short switch faults are labelled as "1" and "2" respectively.

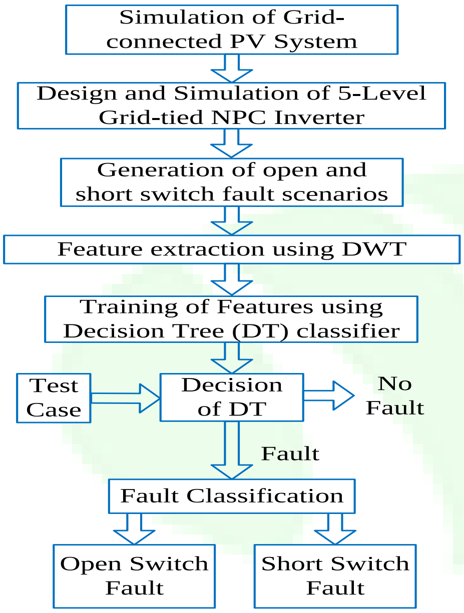


Figure 2: Flowchart of proposed algorithm

## IV. RESULT ANALYSIS

In this section, the performance of proposed algorithm has been analyzed under diverse switch fault scenarios created in the NPV inverter of Grid-tied PV system.

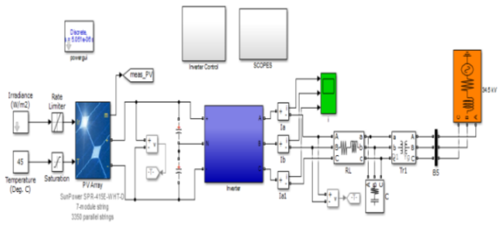

Figure 3: Grid connected PV system Simulink model.

Figure 3 shows a PV system that is linked to the grid but does not have an MPPT. Using this method will not allow you to reach the maximum power point, which will result in a significant loss of power from the PV array. In order to provide gate pulse to the inverter switches, this application makes use of the PWM approach.

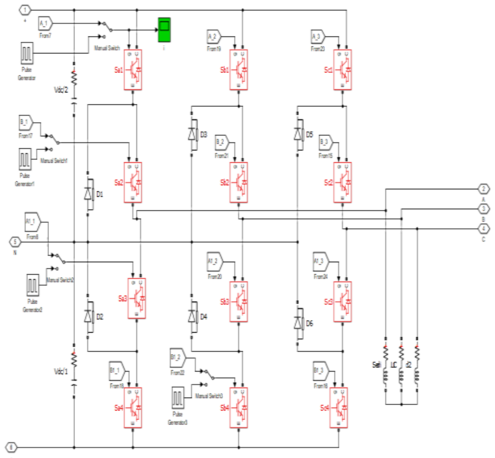

Figure 4: A simulink model of 5-level Neutral point clamped (NPC) inverter configuration.

The NPC multi-level inverter, seen in figure 4 above, is susceptible to errors when subjected to the high-frequency switching of power switches and complicated environmental circumstances. The majority of the problems with the inverter are caused by problems with the power switches. These problems might include both open-circuit faults and short-circuit faults in the power switches

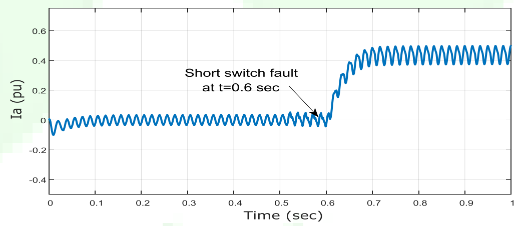


Figure 5:Current waveform ofphase A due to short-circuit operation of the switch Sa1 in leg 1 of NPC Inverter at t=0.6sec

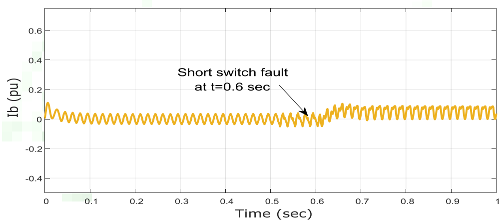


Figure 6: Current waveform ofphase B due to short-circuit operation of the switch Sa1 in leg 1 of NPC Inverter at t=0.6sec

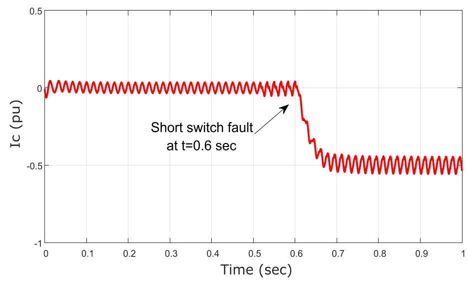


 

Figure 7**:** Current waveform ofphase C due to short-circuit operation of the switch Sa1 in leg 1 of NPC Inverter at t=0.6sec

In the above figure 7, the graphical representation of the Current waveform in all the three phases due to short-circuit operation of Sa1in leg 1 of the NPC inverter at t=0.6sec, has been depicted. As observed, there is significant effect of the fault in phase A and the same is quite lesser in phases B and C respectively.

Table 1: Performance of proposed DT based switch fault diagnosis scheme.

| **Cases** | **Faulty Leg** | **Faulty operation of Switch** | **Detection accuracy of DT (%)** |
|---|---|---|---|
| 1 | Leg a | Open switch fault | 98.9% |
| 2 | | | |
| 3 | | Short switch fault | 98.0% |
| 4 | | | |
| 5 | Leg b | Open switch fault | 99.1% |
| 6 | | | |
| 7 | | Short switch fault | 98.9% |
| 8 | | | |
| 9 | Leg c | Open switch fault | 99.0% |
| 10 | | | |
| 11 | | Short switch fault | 99.1% |
| 12 | | | |
| **Overall accuracy** | | | **98.83 %** |

The performance of proposed technique has been analyzed and summarized in Table 1. The tabular representation of the obtained values is shown which determines the performance of proposed DT based fault diagnosis scheme for PV inverter switch fault. The performance of proposed algorithm is demonstrated in each leg of the NPC inverter. It can be observed that in all the legs of the NPC inverter, nearly similar performance is obtained. Thus, an overall accuracy rate of 98.83% is achieved

## V.CONCLUSION

Renewable energy has gained popularity due to depleting natural resources and escalating fossil fuel and nuclear pollution. Power electronic engineers design grid-connected power conversion systems. Multilevel inverters provide superior power and solutions. NPC inverters are used in grid-connected systems and high-power industrial applications such as high-voltage dc transmission, static VAR compensators, and high-power adjustable-speed motor drives. In this regard, the present workinvolves the development of a technique for identifying and diagnosingswitch faults in a grid-connected NPC inverter in order to ensure reliability and providing the redundant operation of the PV system. The proposed algorithm involves feature extraction using Wavelet transform followed by utilization of the same feature set by Decision Tree classifier to detect and categorize the fault. The higher classification accuracy of proposed DT based fault diagnosis scheme for diagonising the PV inverter switch fault ascertain its efficacy in performing the intended task

## REFERENCES

[1]. Jun-Hyung Jung 1 , Hyun-Keun Ku 2 , Yung-Deug Son 3 and Jang-Mok Kim 1,*, Open-Switch Fault Diagnosis Algorithm and Tolerant Control Method of the Three-Phase Three-Level NPC Active Rectifier, 28 June 2019.

[2]. Mehdi Baghli 1,2, Claude Delpha 3 ,DembaDiallo 2,4,* , AbdelhamidHallouche 1 , David Mba 5 and Tianzhen Wang 4, Three-Level NPC Inverter Incipient Fault Detection and Classification using Output Current Statistical Analysis, 9 April 2019.

[3]. Wu, M.; Song, Z.; Lv, Z.; Zhou, K.; Cui, Q. A Method for the Simultaneous Suppression of DC Capacitor Fluctuations and Common-Mode Voltage in a Five-Level NPC/H Bridge Inverter. Energies 2019, 12, 779.

[4]. A. Joseph, T. R. Chelliah, R. Selvaraj, and K. B. Lee,"Fault diagnosis and fault-tolerant control of megawatt power electronic converter-fed large-rated asynchronous hydrogenerator," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 7, no. 4, pp. 2403–2416, 2019.

[5]. Antonio Ventosa-Cutillas1,* , Pablo Montero-Robina 1 , Francisco Umbría 2 , Federico Cuesta 1 and Francisco Gordillo 1, Integrated Control and Modulation for Three-Level NPC Rectifiers, 30 April 2019.

[6]. K. Zhang, C. Peng, and Z. Kang, "Health diagnosis method of power distribution equipment based on holographic timescalar measurement data," Computer Measurement & Control, vol. 26, no. 3, pp. 29–34, 2018.

[7]. H. Yan, Y. Xu, J. Zou, Y. Fang, and F. Cai, "A novel opencircuit fault diagnosis method for voltage source inverters with a single current sensor," IEEE Transactions on Power Electronics, vol. 33, no. 10, pp. 8775–8786, 2018.

[8]. Z. Wang, Z. Huang, C. Song, and H. Zhang, "Multiscale adaptive fault diagnosis based on signal symmetry reconstitution preprocessing for microgrid inverter under changing load condition," IEEE Transactions on Smart Grid, vol. 9, no. 2, pp. 797–806, 2018.

[9]. X. Wu, R. Tian, S. Cheng, T. Chen, and L. Tong, "A nonintrusive diagnostic method for open-circuit faults of locomotive inverters based on output current trajectory," IEEE Transactions on Power Electronics, vol. 33, no. 5, pp. 4328–4341, 2018.

[10]. C. Yong, L. Zhilong, and C. Zhangyong, "Fast diagnosis and location method for open-circuit fault in inverter based on current vector character analysis," Transactions of China Electrotechnical Society, vol. 33, no. 4, pp. 883–891, 2018.

[11]. X. Ge, J. Pu, B. Gou, and Y.-C. Liu, "An open-circuit fault diagnosis approach for single-phase three-level neutral-pointclamped converters," IEEE Transactions on Power Electronics, vol. 33, no. 3, pp. 2559–2570, 2018.

[12]. Hammami, M.; Rizzoli, G.; Mandrioli, R.; Grandi, G. Capacitors Voltage Switching Ripple in Three-Phase Three-Level Neutral Point Clamped Inverters with Self-Balancing Carrier-Based Modulation. Energies 2018, 11, 3244.

[13]. Son, Y.; Kim, J. A Novel Phase Current Reconstruction Method for a Three-Level Neutral Point Clamped Inverter (NPCI) with a Neutral Shunt Resistor. Energies 2018, 11, 2616.

[14]. Kang, K.P.; Cho, Y.; Ryu, M.H.; Baek, J.W. A Harmonic Voltage Injection Based DC-Link Imbalance Compensation

 

Technique for Single-Phase Three-Level Neutral-Point-Clamped (NPC) Inverters. Energies 2018, 11, 1886.

[15]. In, H.C.; Kim, S.M.; Lee, K.B. Design and Control of Small DC-Link Capacitor-Based Three-Level Inverter with Neutral-Point Voltage Balancing. Energies 2018, 11, 1435.

[16]. M. Trabelsi, M. Boussak, and M. Benbouzid, “Multiple criteria for high performance real-time diagnostic of single and multiple open-switch faults in ac-motor drives: application to IGBT-based voltage source inverter,” Electric Power Systems Research, vol. 144, pp. 136–149, 2017.

[17]. M. Sital-Dahone, A. Saha, Y. Sozer, and A. Mpanda, “Multiple device open circuit fault diagnosis for neutral-point-clamped inverters,” in 2017 IEEE Applied Power Electronics Conference and Exposition (APEC), Tampa, FL, USA, 2017.

[18]. J. He, N. A. O. Demerdash, N. Weise, and R. Katebi, “A fast on-line diagnostic method for open-circuit switch faults in SiC-MOSFET based T-type multilevel inverters,” IEEE Transactions on Industry Applications, vol. 53, no. 3, pp. 2948–2958, 2017.

[19]. I. Jlassi, J. O. Estima, S. K. elKhil, N. M. Bellaaj, and A. J. M. Cardoso, “A robust observer-based method for IGBTs and current sensors fault diagnosis in voltage-source inverters of PMSM drives,” IEEE Transactions on Industry Applications, vol. 53, no. 3, pp. 2894–2905, 2017.

[20]. Hu, C.G.; Holmes, G.; Shen, W.X.; Yu, X.B.; Wang, Q.J.; Luo, F.L. Neutral-point potential balancing control strategy of three-level active NPC inverter based on SHEPWM. IET Power Electron. 2017, 10, 1755–4535.

[21]. S. M. Kim, J. S. Lee, and K. B. Lee, “A modified level-shifted PWM strategy for fault-tolerant cascaded multilevel inverters with improved power distribution,” IEEE Transactions on Industrial Electronics, vol. 63, no. 11, pp. 7264–7274, 2016.

[22]. C. Shu, C. Ya-Ting, Y. Tian-Jian, and W. Xun, “A novel diagnostic technique for open-circuited faults of inverters based on output line-to-line voltage model,” IEEE Transactions on Industrial Electronics, vol. 63, no. 7, pp. 4412–4421, 2016.

[23]. T. Yang, H. Pen, Z. Wang, and C. S. Chang, “Feature knowledge based fault detection of induction motors through the analysis of stator current data,” IEEE Transactions on Instrumentation and Measurement, vol. 65, no. 3, pp. 549–558, 2016.

[24]. T. Wang, J. Qi, H. Xu, Y. Wang, L. Liu, and D. Gao, “Fault diagnosis method based on FFT-RPCA-SVM for cascadedmultilevel inverter,” ISA Transactions, vol. 60, pp. 156–163, 2016.

[25]. L. M. A. Caseiro and A. M. S. Mendes, “Real-time IGBT opencircuit fault diagnosis in three-level neutral-point-clamped voltage-source rectifiers based on instant voltage error,” IEEE Transactions on Industrial Electronics, vol. 62, no. 3, pp. 1669–1678, 2015.

[26]. Gui, S.; Lin, Z.; Huang, S. A Varied VSVM Strategy for Balancing the Neutral-Point Voltage of DC-Link Capacitors in Three-Level NPC Converters. Energies 2015, 8, 2032–2047.

[27]. A. M. Santos Mendes, S. M. A. Cruz, and M. B. Abadi, “Fault diagnostic algorithm for three-level neutral point clamped AC motor drives, based on the average current Park’s vector,” IET Power Electronics, vol. 7, no. 5, pp. 1127–1137, 2014.

[28]. Vazquez, S.; Leon, J.I.; Franquelo, L.G.; Rodríguez, J.; Young, H.A.; Marquez, A.; Zanchetta, P. Model Predictive Control: A Review of Its Applications in Power Electronics. IEEE Ind. Electron. Mag. 2014, 8, 16–31.

[29]. James J. Q. Yu , Member, IEEE, YunheHou, Intelligent Fault Detection Scheme for Microgrids With Wavelet-Based Deep Neural Networks, IEEE TRANSACTIONS ON SMART GRID, VOL. 10, NO. 2, MARCH 2019.

[30]. Debi Prasad Mishra, SubhransuRanjanSamantaray, Senior Member, IEEE, and GezaJoos, Fellow, IEEE, A Combined Wavelet and Data-Mining Based Intelligent Protection Scheme for Microgrid, 1949-3053 © 2015 IEEE.

 