ЭФФЕКТИВНОЕ И КАЧЕСТВЕННОЕ СНАБЖЕНИЕ И ИСПОЛЬЗОВАНИЕ ЭЛЕКТРОЭНЕРГИИ

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Сборник докладов ученых, преподавателей, аспирантов и студентов вузов и колледжей, специалистов и сотрудников России, Казахстана, Таджикистана, Польши, Анголы и Египта предприятий и организаций содержит результаты исследований и практической реализации в области эффективности производства, передачи, распределения и потребления электрической энергии, повышения её качества и анализа электромагнитной совместимости. Особое внимание уделяется электроэнергетике, электротехнологии, преобразовательной технике и электроприводу.

A. B. Kaidar, A. P. Kislov, V. P. Markovsky, V. F. Govorun,
B. K. Shapkenov, M. E. Volgin, N. M. Padrul', A. K. Zhumadirova,
Pavlodar State University S. Toraigyrov (Pavlodar, Kazakhstan)

FAULT RECONFIGURATION PARADIGM FOR THE CASCADED H-BRIDGE MULTILEVEL INVERTER DRIVE

Since MLID (multilevel inverters drive) multilevel inverters contain several semiconductors connected in series to achieve medium voltage and high power demand, one might consider that multilevel inverters are less reliable. In contrast, multilevel cascaded H-bridge inverters using modular series- cells with separated dc sources as depicted in [1,2] could improve reliability if the MLID has the ability to detect and bypass the faulty cell. If one of the power cells fails, it can be bypassed and operation can continue at reduced voltage capacity. The amount of reduction in capacity that can be tolerated depends upon the application; however, in most cases a reduction in capacity is more preferable than a complete shutdown.

The reliability of a multilevel inverter having the bypass function in each cell has been described in [1]. The article explains how the bypass function improves the drive reliability. The major idea to improve reliability is to bypass the damaged cells by using a magnetic contactor. The proposed solution in [1, 3] protects the failure of all components in the faulty cells, rather than the damage to some power switches. The definition of reliability given by [2] is *"the probability of a device performing its purpose adequately for the period of time intended under the operating condition encountered".* The word adequately permits some application at reduced capacity to be included in the probability calculations [1].

The engineering reliability analysis in a system is usually concerned with the reliability R and/or the probability of failure P. As a system is considered reliable unless it fails, the reliability and probability of failure sum to unity as explained in equation (1.1) [2].

$$R(t) + P(t) = 1,$$
$$R(t) = 1 - P(t),$$
$$P(t) = 1 - R(t), \tag{1.1}$$

where $P(t)$ is probability of a system will fail by time t,

$R(t)$ is probability of a system will still be operational by time t.

Therefore, (1.1) can be applied in MLID system reliability analysis. Suppose that the cascaded H-bridge MLID system as shown in [2] contains N cells and can not tolerate any failures; then, if the probability of a single cell will function properly during a time interval is R, so that the probability all N cells will function properly during the same time interval is R^N because the MLID system is considered as series system in this case. $P(t)$ and $R(t)$ can be defined as the point density functions;

then, $P = \dfrac{dP(t)}{d(t)}$ and , $P = \dfrac{dR(t)}{d(t)}$. Next, if the MLID has a cell which can tolerate failures, the MLID reliability will become

$R^N + [N \times R^{(N-1)} \times (1-R)]$ instead of R^N. It is obvious that the MLID with a tolerated failure cell has a higher reliability than the one without tolerance for failures. A numerical reliability example of a MLID can be illustrated in Table. Assume that the MLID in Table 1 has a cell reliability R of 99 % and it contains totally 15 cells. As can be seen, with one extra cell in each phase, the reliability of the MLID can increase from 86

% to 99.0 %; therefore, a fault diagnostic and fault reconfiguration (bypass) system can improve the reliability of the MLID system. In addition, for the case of m tolerated cells, the reliability function can be written as

$$R_m = \sum_{t=0}^{m} \left(\frac{N!}{(N-i)! \times i!} \times R^{(N-1)} \times (1-R)^i \right)$$
,
(1.2)

where m is number of tolerated cells,
N is number of cells in MLIDs,
R_m is total reliability of the system.

Table.
Numerical example of 15 cells MLID with 99 % reliability (R) in each power cell

N to fa	Reliability Function	Reliability (Percentage)
0	$R_0 = R^N$	86,00 %
1	$R_1 = R_0 + [N \times R^{(N-1)} \times (1-R)]$	99,04 %
2	$R_{\downarrow}(2) = R_{\downarrow}(1) + [(N \times [[(N-1) \times (R]]^{\dagger}((N-2))) \times (0,5 \times (1-R)^{\dagger}2)$	99,96 %
3	$R_{\downarrow}3 = R_{\downarrow}2 + [(N [[(N-1) \times (N-2) \times (R]]^{\dagger}((N-3)) \times (0,1667 \times (1-$	99,99 %

ARTIFICIAL INTELLIGENT APPLICATION IN CONDITION M O N I T O R I N G A N D D I A G N O S I S

The application of artificial intelligent (AI) in inverter drives is mostly based on speed or position controller applications. Fuzzy-logic (FL) and neuron network (NN) are mostly applied to such applications. Genetic algorithm is also applied on PI controller tuning and parameter estimation problems. The AI-based controllers could lead to improved performance, enhanced tuning and adaptive capabilities; however, there are additional possibilities in other aspects of AI-based applications in inverter drives or other power electronic areas.

It is possible that AI-based technique can be applied in condition monitoring and diagnosis. By using condition monitoring, vast savings may be made through improved maintenance procedures and policies. AI-based condition monitoring and diagnosis have several advantages; for instance, AI-based techniques do not require any mathematical models, therefore the engineering time and development time could be significantly reduced. AI-based techniques utilize the data sets of the system or expert knowledge. Moreover, the reliability of the system can also improve by using diagnosis; for example, in MLID applications, several types of signals such as voltage, current, noise, vibration, temperature, and flux signals which can convey valuable information for diagnosis on the electrical and mechanical state of a MLID system including motor, multilevel inverter and controller. The voltage and/or current signals could be used to diagnose a drift of power semiconductor switches in the multilevel inverter which contains numerous semiconductor switches.

AI-based fault diagnostic areas should include two different types of main tasks as follows:

– *Fault classification (detection):* The purpose of this task is to detect any selected signals (electrical or mechanical) in the system. This could permit the system to be scheduled maintenance and might also prevent incipient system fault and would allow improving safety and reliability of the system;

– *Fault localization:* The purpose of this task is to identify the location of occurring faults. This specifies the cause of the detected abnormal behaviors.

AI-based techniques can be applied to both diagnostic tasks. Fault classification is a part of a protection paradigm and can also be considered as pattern recognition problems or non-linear problems [4]. Therefore, artificial neuron network (ANN) can be used to perform the fault classification. ANN techniques permit input/output mapping with a nonlinear relationship between nodes; also, ANN techniques provide the ability to recognize anomalous situations because of their intrinsic capacity to classify and generalize. Especially, the sensitivity and response time of the original procedure presented for the on-line analysis of fault set repetition enable on-line fault location techniques to be developed [5]. The normal and abnormal data or signals can be used to train the ANN, so that the ANN can have ability to classify the difference between normal and abnormal condition of the system.

CONCLUSION

We offered the fault diagnostic, fault detection, and fault reconfiguration paradigm for the cascaded H-Bridge multilevel inverter drive by applying artificial intelligent based techniques. We diagnosed the fault locations in a MLID from its output voltage waveforms is considered. MLID open circuit and short circuit faults at each switch are considered. An example of a MLID open circuit fault at switch S_{A+} is represented in Figure.

S_{A+} fault will cause unbalanced voltage and current output, while the induction motor is operating.
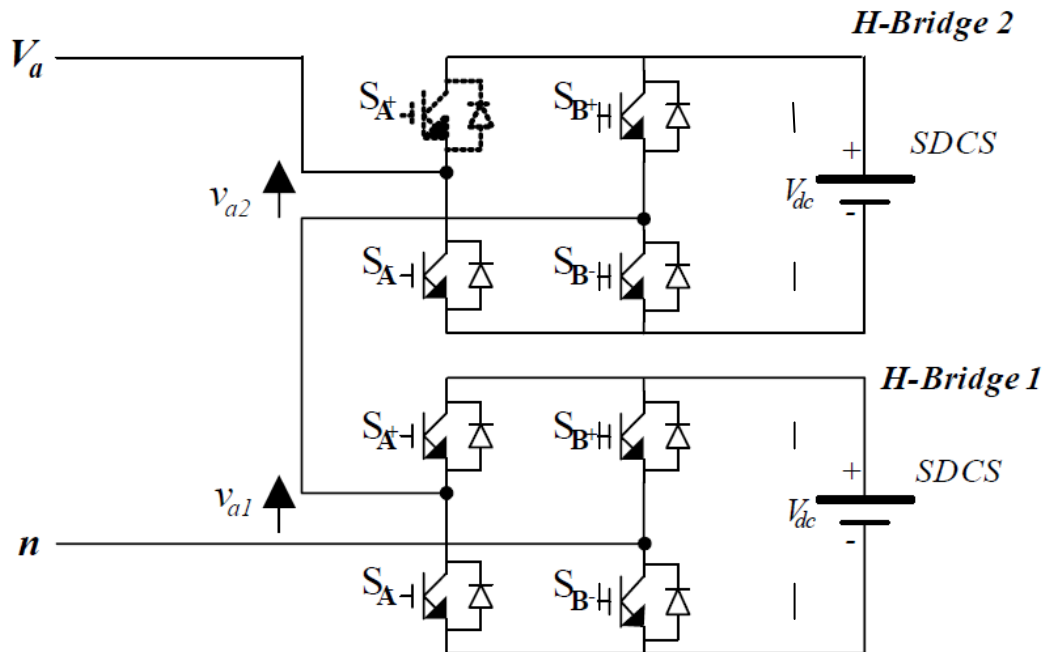

Fig. 1. H-Bridge 2 Switch SA+ open circuit fault at second level of single-phase multilevel-inverter

This unbalanced voltage and current may result in vital damage to the induction motor if the induction motor is run like this for a long time. The unbalanced condition from fault S_{A+} can be solved if the fault location is correctly identified. Switching patterns and the modulation index of other active switches in the MLID can be adjusted to maintain output voltage and current in a balanced condition. Therefore, the MLID can operate in a balanced condition at reduced power while the fault occurs until the operator knows and repairs the inactive switch.

All occurring fault features can be classified based on their effects of the output voltages; for that reason, one can use the output voltage signals as learning/training data to a neural network. A neural network has the ability to recognize anomalous situations because of their intrinsic capacity to classify and generalize. Genetic algorithm and principal component analysis can also be applied in feature extraction process in order to rate signals as an important feature. Thus, by applying the proposed AI-based techniques in a fault diagnostic system, a better understanding on fault behaviors, detections, and reconfigurations of a multilevel inverter drive system can be accomplished.

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