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Fault-Tolerant Operation of Medium Voltage PMSM Drive Systems Under Open-Switch Faults



Abstract— Medium voltage (MV) drive systems are extensively used in some critical industrial applications such as mining, marine operations, oil processing, and large-scale production. MV drives which are based on voltage source inverters remain vulnerable to semiconductor open-switch faults. Permanent Magnet Synchronous Motor (PMSM) drives are adopted largely by industry for their dynamic response, high efficiency, and compact design. This paper embeds a fault-tolerant control strategy that can be integrated into inverter-based MV drives. The system can enhance the post-fault drivability of MV PMSM drive systems under open-switch faults. The suggested methods consist of three main components. The first one is a comprehensive mathematical analysis of the post-fault voltage vector space, and it leads to a reallocation strategy for the vector acting time calculated by space vector pulse width modulation (SVPWM). Secondly, a fault-aware current prediction model is developed to make stable and smooth control mode transition between healthy and faulted conditions. Experimental and simulation results demonstrate that the proposed approach improves the current tracking accuracy and enhances operational robustness.

Keywords—PMSM, Medium voltage, Sensor, SVPWM, and Post-fault operation.

I. INTRODUCTION

A. Medium Voltage Drive Systems in Critical Industrial Applications

Medium voltage (MV) drive systems mostly operating in the range of the 1 kV to 11 kV, play an important role to power high power industrial processes including mining operations, marine propulsion, oil and gas processing, cement production, and large-scale manufacturing. These applications need improved and effective electric drive solutions that are capable of delivering continuous operation and high torque within harsh environmental and load conditions. MV drives allow a direct connection to the medium voltage grids, minimizing the need for bulky transforms and enhancing the entire efficiency of the system [1]. Because of the mission-critical nature of these processes, MV drive systems are expected to operate with high availability and reliability over the extended periods. Unplanned shutdowns caused by driven failures may lead to some substantial economic losses, safety risks and production interruptions that makes fault resilience an important need instead of an optional feature.

B. PMSM-Based MV Drive Systems

Permanent Magnet Synchronous Motor (PMSM) drives have been gaining adoption in the medium voltage industrial applications because of their better efficiency, high power density and higher dynamic performance [2]. Compared to the induction motor drives, PMSMs provide minimized losses and enhanced torque control that are especially beneficial in the energy-sensitive and precision-needs applications. In this context, advances in the power electronics and the control hardware have facilitated the deployment of PMSM-oriented MV drives using the voltage source inverters (VSIs). Therefore, the performance advantages of the PMSM drives are hugely reliant on effective current control and proper inverter operation. Any degradation in the inverter switching ability

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directly impacts the current regulation, torque production as well as the ensure better system stability that highlights the important dependence of the PMSM-oriented MV drives on inverter health.

C. Reliability Challenges in VSI-Based MV Drives

Instead of their widespread industrial use, VSI-oriented MV drives are vulnerable to the semiconductor faults because of the high voltage stress, thermal cycling, and long-term aging of power electronic devices [3]. Among these different failure models, open-switch faults are sometimes encountered and also re-considered non-catastrophic but performance-degrading events. In this case, an open switch fault leads to the loss of some particular switching states that resulted in distorted phase currents, increased torque ripple, and reduced voltage utilization. Conventional protection mechanisms mostly respond to these faults through triggering system shutdowns in order to protect further damages. While this approach ensures safety, it fails to meet availability needs of important industrial applications where continued operation within degraded conditions is often preferable.

D. Motivation, Objectives, and Contributions

The limitations of shutdown-oriented protection approaches have motivated the overall development of the fault-tolerant control (FTC) techniques which allow post-fault drivability of the MV drive systems. The proposed approach aims to manage a stable operation and acceptable performance without depending on the hardware redundancy. The important contribution of this work involves a detailed analytical characterization of the post-fault voltage vector space of an MV

VSI [4]. The development of a modified space vector pulse width modulation (SVPWM) scheme with the vector time allocation as well as the formulation of a fault-aware current prediction model that always ensures a smooth transition between the healthy and faulted operating modes.

II. LITERATURE REVIEW

The reliability of medium voltage inverter-fed drive systems has attracted a large number of researchers for their wider installation in industrial processes. VSI-based MV drives operating in PMSMs are highly sensitive to semiconductor failures. This section critically reviews the existing approaches to open-switch fault diagnosis and fault-tolerant control in inverter-fed drive systems.

A. Semiconductor Faults in Medium Voltage Inverter-Fed Drives

According to [5], MV inverter-fed drive systems are heavily dependent on the reliable operation of power semiconductor devices. These operations are mainly subjected to high thermal, electrical, and mechanical stresses during continuous industrial operation. The study of [6] explains that semiconductor faults in inverter-fed drives are generally classified into two parts that are short-circuit and open-switch faults. Short-circuit faults are catastrophic in nature, and immediate shutdown is required to protect from secondary damage [7]. But as per [8], the open switch faults are developed from the gate signal loss, driver failure, or internal device degradation. Such faults are critical due to the limited availability of hardware redundancy and high power failures. The occurrence of an open-switch fault alters the switching state availability of the inverter, and it leads to a decrease in the voltage vector space. This distortion is projected as increased harmonic content, unbalanced phase currents, and pronounced torque ripple in the permanent magnet synchronous motor (PMSM) drives. Traditional field-oriented control and standard vector pulse width modulation (SVPWM) schemes fail to maintain stable current tracking under such conditions [9]. Existing literature has explored numerous mitigation strategies for semiconductor open-switch faults such as fault-bypass circuits, redundant inverter legs, and reconfigurable hardware topologies. These approaches are impractical for MV systems due to increased cost, physical footprint, and complexity.

B. Fault-Tolerant Control Strategies for Open-Switch Faults

Fault-tolerant control strategies for open-switch faults have been extensively investigated in power conversion systems to improve operational reliability. As per [10], fault-tolerant techniques are designed to allow continued operation until the maintenance personnel can access the system and repair the faulty component. Numerous fault detection techniques have been proposed for addressing open-switch faults in power converters. Methods based

on magnetic near-field sensing utilise magnetic probes to gather switching-related field disturbances and frequency-domain analysis to get faulty signatures. However, these techniques are predominantly reported for low-voltage converters and are less commonly applied in medium-voltage VSI-fed motor drive systems. According to [11], these techniques are the reason for increasing system cost, complex signal processing, and high computational burden. Other approaches integrate inductor current slope analysis or DC link derivative monitoring to detect deviations indicative of switch faults. A few voltage-based methods such as switch voltage or monitoring diode patterns are also reported to address both diodes as well as switch open-circuit conditions. Stochastic diagnosis methods use probabilistic estimation techniques that have been further explored to increase robustness against parameter and noise uncertainty [12]. The study of [13] explains that, for the case of dc-dc converters, redundant switches are sometimes inactive at the time of normal operation and are activated only after fault detection. However, the hardware-based redundancy increases the system cost and complexity which makes it less effective for MV applications. Voltage source inverter (VSI)-based PMSM and open-switch faults lead to a reduction in available switching states and distortion of the inverter Output voltage. The VSI is defined as the power electronic converter that converts DC from a stiff voltage source into a controlled AC voltage with variable frequency, magnitude, and phase [14]. As per the study of [15], modified pulse-width modulation techniques such as reconfigured space vector pulse width modulation (SVPWM) are integrated to exploit the remaining healthy switching states and maintain acceptable voltage synthesis.

C. SVPWM-Based Fault-Tolerant Operation

Space Vector Pulse Width Modulation (SVPWM)based fault-tolerant operation has become popular as an effective control-oriented solution for decreasing open-switch faults in VSI-fed motor drive systems. SVPWM is an advanced modulation technique that is used in VSIs to synthesise a three phase AC output voltage by selecting and timing the inverter switching states within each switching period [15]. But the occurrence of an open-switch fault invalidates specific switching states, and it decreases the voltage vector space that conventional SVPM schemes fail to accommodate [16]. For addressing the limitations, reconfigured SVPM strategies have been suggested in the study [17]. Here, the faulty voltage vectors are excluded, and the remaining healthy vectors are utilised to approximate the reference voltage. Their performance is hampered by reduced voltage synthesis capability which leads to current distortion and torque ripple in the MV PMSM drive application. According to [18], SVPWM-based fault-tolerant schemes integrate predictive control principles to improve postfault performance. Fault-tolerant deadbeat model predictive current control (DB-MPCC) combined with the SVPWM has gained attention due to its fast dynamic response, and it improved current tracking capacity. Among these approaches, harmonic-less virtual voltage vectors are constructed to compensate for missing physical voltage vectors under open switch fault conditions. The amplitudes of the virtual vectors are adaptively adjusted to restore balance in the reduced vector space and suppress harmonic components in the stator currents. The study of [19] argues that the reference voltage vector is estimated within the reconstructed virtual voltage vector space by applying the deadbeat principle to the predictive motor model. This assists in the accurate prediction of the future current response and facilitates a smooth transition between healthy and faulted operating modes. The PMSM stator voltage model can be expressed by the equation below [20].

$$v_{\alpha\beta} = R_s i_{\alpha\beta} + L_s \frac{di_{\alpha\beta}}{dt} + e_{\alpha\beta}$$

Where R_s is the stator resistance, L_s is the stator inductance, and $e_{\alpha\beta}$ is the back-EMF vector.

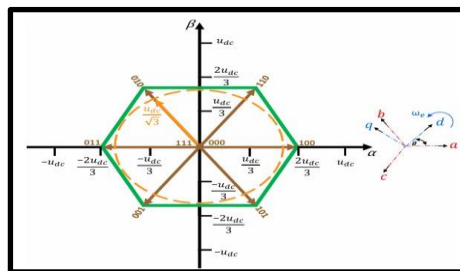


Fig. 1. Voltage Vectors of a 2-level Voltage Source Inverter [20]

D. Sensor Failures in MV PMSM Drive Systems

Medium voltage (MV) permanent magnet synchronous motor (PMSM) drive systems greatly depend on precise sensor feedback in order to operate in a stable and performance mode. As per the study of [21], industrial MV also exposes these sensors to harsh working conditions where there are high levels of electromagnetic interference (EMI), changes in temperature and mechanical vibrations, which cause the sensors to degrade or fail. The sensor faults in MV PMSM drives are generally divided into signal loss, offset errors, gain deviations, or intermittent measurement disturbances. Actual sensor malfunctions have a direct impact on current regulation loops and cause erroneous estimation of stator currents and loss of torque control. The faults of voltage sensors interfere with the DC-link voltage and inverter output voltage reconstruction, thus increasing the modulation accuracy. Structural faults of speed sensors and position sensors cripple the alignments of rotor fluxes and may lead to loss of synchronisation, hypnotic torque reaction, or system incongruities. Existing literature has explored different sensor fault detection and tolerance mechanisms in inverter-fed motor drives [22]. Analytical redundancy PMSM mathematical models are used to provide a reconstructed missing or corrupted sensor signal by analytical redundancy methods, and system states are estimated at observable electrical quantities by observer-based approaches [23]. It has been reported that model-based estimators in the form of state observers and adaptive estimation methods by widely employed techniques have been used to improve the robustness of sensor fault admission without any extra hardware redundancy. In the case of MV drive systems, software-defined sensor fault tolerance is somewhat appealing with regard to the constraint over cost and reliability of redundant sensing hardware. It indicates the significance of sound sensor fault tolerance protocols to keep MV PMSM drive systems working with compromised sensing conditions and retain control efficiencies in adverse sensing conditions. The current measured under-sensor fault can be calculated by the following equations [24].

$$i_m(t) = (1 + \Delta_g)i(t) + \Delta_o$$

Where, $i(t)$ is known as the actual phase current, $i_m(t)$ is called the measured current, Δ_g is referred to as the gain error, and Δ_o is the offset error.

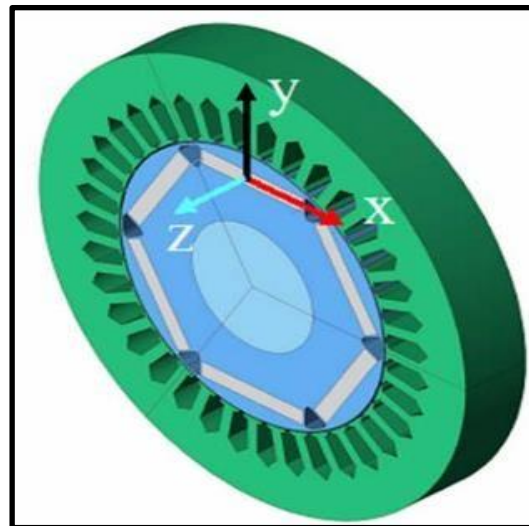


Fig. 2. 3D FE model of PMSM[24]

E. Research Gaps

Despite significant progress in fault-tolerant and fault diagnosis of inverter drive systems several research gaps also exist. Researchers often ignore the MV PMSM drives, and a large section of studies on open-switch fault detection and compensation has been conducted on low-voltage drives [25]. The direct application of these methods to MV drive systems is limited due to differences in converter topology, thermal constraints, operational environments, and switching device characteristics. Most fault-tolerant control strategies written in the literature address either semiconductor open-switch faults or sensor failures in isolation. MV PMSM drive systems are susceptible to simultaneous or cascading fault scenarios, and the lack of integrated fault-tolerant frameworks hampers the robustness of the existing solutions in industrial applications. Although SVPWM techniques have

been proposed for postfault operation, many approaches rely on simplified assumptions regarding voltage vector availability. The systematic integration of predictive control-based fault-tolerant methods with modulation strategies is also missing in existing research. Another noticeable gap is the smooth transition between faulted and healthy operating modes. A sudden switching between control strategies can start a transient disturbance, stability issues, and torque oscillations. All of these gaps reflect the necessity for an integrated and control-oriented fault-tolerant framework that can accurately operate in post-fault operation [26].

III. METHODS

A. Medium Voltage PMSM Drive System Description

The MV PMSM drive system considered in this study consists of a voltage source inverter (VSI) interfaced with a stiff DC-link and controlled by a vector control architecture. The system is designed to operate in the voltage range from 1 kv to 11 Kv and it is helpful for large-scale industrial applications [27]. The system can be utilised in marine propulsion, mining, and other heavy industries. Multilevel VSI topologies such as neutral-point-clamped (NPC) or cascaded H-bridge inverters are employed in MV drives to decrease voltage stress and to enhance output waveform quality. The electrical dynamics of the PMSM are expressed in the synchronous rotating dq reference frame [28].

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q$$

$$v_q = R_s i_q + L_d \frac{di_q}{dt} + \omega_e L_d i_d + \omega_e \Psi_f$$

Where, v_d, v_q and i_d, i_q are the stator voltages and currents in the dq-frame. R_s is the stator resistance, and Ψ_f is the permanent magnet flux linkage. The electromagnetic torque generated by the PMSM can be calculated using the equation below.

$$T_e = \frac{3}{2} p (\Psi_f i_q + (L_d - L_q) i_d i_q)$$

Where p shows the pole number pairs. The inverter output voltages are synthesised with the SVPWM, and it helps to map the reference voltage vector generated by the current controller. For the proposed fault-tolerant framework, the VSI operates under both healthy and open-switch fault conditions. The MV PMSM drive system provides a suitable platform for examining advanced fault-tolerant control strategies under degraded switching and sensing conditions. The fig. 3 shows a schematic diagram of an H-bridge Inverter [29].

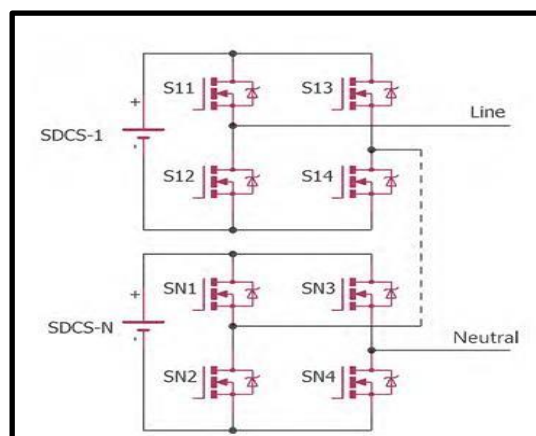


Fig. 3. H-bridge Inverter [25]

B. Open-Switch Fault Modelling in MV VSI

An open-switch fault occurs when a power semiconductor device permanently loses its gating capability due to a gate driver malfunction in medium voltage VSIs. Open-switch faults are non-catastrophic but significantly

alter the inverter switching behaviour and make accurate fault modelling essential for postfault control design [26]. For the case of the three-phase VSI, the healthy switching state of each inverter leg can be represented by a binary variable $S_x \in \{0,1\}$, where $x \in \{a, b, c\}$. The phase voltage can be calculated by the equation with respect to the DC-link midpoint.

$$v_x = \frac{(2S_x - 1)V_{dc}}{2}$$

Where V_{dc} is known as the DC link voltage. The corresponding switching state becomes constrained in the presence of an open-switch fault in a specific device. If the upper switch of phase-a is open, then S_a is equal to zero. The inverter output voltage vector in the stationary $\alpha\beta$ can be found by the equation below [30].

$$v_{\alpha\beta} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

Under the open-switch fault conditions, several active voltages are unavailable, leading to an asymmetric voltage vector space. This reduction reduces the ability of the inverter to synthesise the reference voltage vector, and it causes the increment of harmonic distortion. Accurate modelling of the reduced voltage vector set forms the basis for developing fault tolerant modulation and predictive control strategies that are capable of maintaining post-fault drivability in MV VSI-fed PMSM drives.

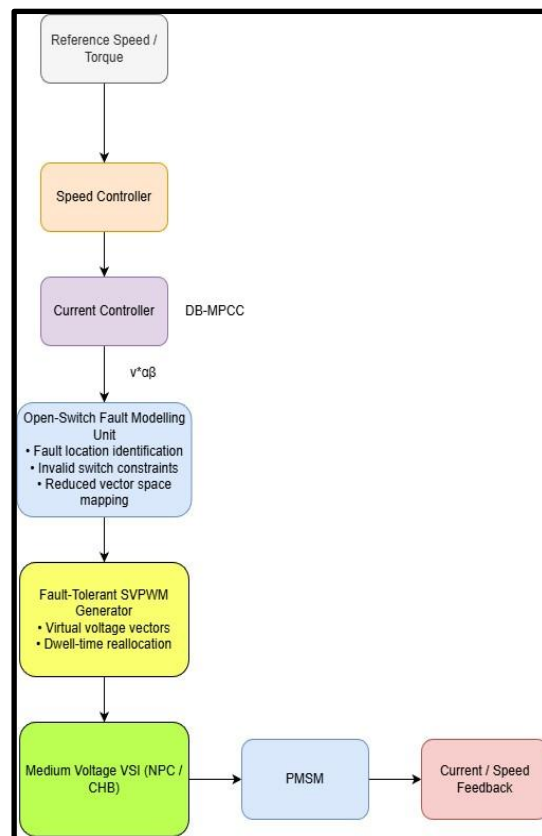


Fig. 4. MV VSI–PMSM Drive with Open-Switch Fault Modelling

C. Post-Fault Voltage Vector Analysis

A three-phase two-level VSI generates eight switching states and produces six active voltage vectors (fig. 5). Two zero

vectors are evenly distributed in the stationary $\alpha\beta$ reference frame, and these vectors enable full synthesis of the reference voltage required for table current control in PMSM drives. The post-fault available voltage vector set can be expressed by the following equation.

$$V_f = \{v_k | v_k \in V, v_k \text{ does not require the faulty switch}\}$$

Where V denotes the healthy voltage vector set. The maximum achievable reference voltage magnitude under the faulted conditions is consequently reduced. This reduction lowers the ability of the inverter to track the reference voltage vector, and it leads to an increase in current distortion as well as torque ripple.

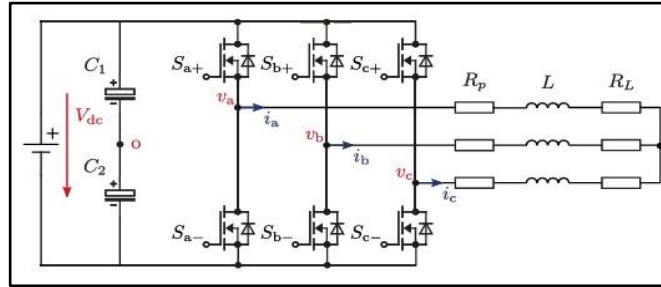


Fig. 5. Three-phase three-wire two-level VSI [27]

D. Modified SVPWM with Vector Time Reallocation

The desired reference voltage vector is synthesised by conventional space vector pulse width modulation (SVPWM) by choosing two adjacent active voltage vectors and one or two zero voltage vectors within a switching period. The dwell time of such vectors is determined in such a way that the mean inverter output voltage during the switching cycle is equal to the reference voltage vector. This method is based on the availability of a full as well as a symmetric voltage space. The results in distortion of the traditional SVPWM sector structure and the traditional dwell time computation do not synthesise the reference voltage with the expected degree of precision. When implemented directly, this causes voltage distortion, a current imbalance and ripple in the torque in PMSM drives. The space of reference voltage vectors is first projected onto the reduced post-fault voltage vector space. The closest available active vectors are picked based on their angular position. The major concept of the time reallocation of the vectors is that the dwell times of the unavailable vectors are proportionately reallocated among the available healthy vectors remaining. Zero use of vectors is also modified to have the switching rate constant and the harmonics of low order reduced. This modified SVPWM technique maintains the continuous modulation operation and smooth operation in case of a fault. It is also appropriate for MV drive systems in which hardware redundancy is small, and reconfiguring the system is desired to be controlled [31].

$$v_{ref}T_s = T_1v_1 + T_2v_2 + T_0v_0$$

Where T_s is the switching period, v is the selected healthy active vectors, and T_i is referred to as the reallocated dwell time under fault conditions.

E. Fault-Aware Current Prediction and Control Transition

The fault-aware current prediction method directly takes the decimated post-fault voltage set as an input factor into the predictive motor model. The controller takes into consideration the real voltage vectors that can be produced by the inverter following the fault occurrence to prevent the faulty selection of the inability of the voltage command to generate a current which results in current tracking error and oscillations. This predictive ability is essential when using deadbeat model predictive current control (DB-MPCC) to bring the currents on the stator to the desired reference values in a single sampling period. A controlled transition mechanism is adopted to avoid transient disturbances in the process of transitioning between healthy and faulted operation. Rather than a sudden change in the control logic, the controller progressively transitions to the fault-aware model as the open-switch fault is found and located in the healthy prediction model [32].

F. Sensor Fault Modelling and Fault-Tolerant Control

The sensor faults are normally displayed as gain errors, offset errors, signal drift or loss of signal entirely. The faults are causing some distortion of the measured feedback signals which the controller uses, making the state estimation inaccurate. In the PMSM drives in the vector-controlled mode, the fault of current sensors directly influences the inner control loop and the torque generation process. The fault of the speed sensor or position sensor directly influences the coordinate transformation process and the torque generation process. Disturbances of voltage sensors also pose an additional problem to space vector pulse width modulation (SVPWM) through the addition of DC-link voltage measurement errors [33]. A fault-tolerant control approach of the software type is used to guarantee further functioning under poor sensing conditions. The method depends on analytical redundancy as opposed to hardware redundancy which is specifically beneficial to MV applications because of the cost and complexity limitations. An estimated signal in the form of the model-based observer or predictive estimation algorithm is created and substituted for the faulty point measurement. This virtual feeling mechanism enables the controller to operate under a closed-loop mode in which reconstructed signals denote the feedback.

IV. RESULTS AND DISCUSSION

A. Results

The developed fault-tolerant DB-MPCC-SVPWM proposal scheme was tested with respect to extensive simulations and experimental validation of a medium voltage PMSM drive with a rated power of 3.3 kV and 1.2 MW. One phase of the inverters was opened in steady-state and dynamic operating conditions, and the performance was compared with traditional SVPWM powered vector control. The stator current tracking error of the RMS was kept to less than 1.8% under healthy operating conditions, and the total harmonic distortion (THD) of the phase current was found to be 3.6%. Traditional SVPWM caused a steep rise in current distortion, and current THD increased to 18.4%, and peak-to-peak torque ripple increased to 26.7% of rated torque [34]. The DC-link voltage use was reduced by around 22%, and this resulted in a weak voltage reference tracking. The post-fault current THD decreased to 6.9%, which was a 62.5 percent better performance than the conventional control. RMS current tracking error was reduced to 3.4 percent and torque ripple has been reduced to 7.8 which is within acceptable limits. The impulsive settling period during transitioning to the faulted state of health was 4.5 ms, which was in contrast to the 18.2 ms of the conventional control. Sensors' fault conditions were tested by introducing a 15% gain error and an error of 5 A to the current sensor feedback. The error in torque without compensation was more than 12 percent and the oscillation error at the speed was found to be 4.1 per cent. The reconstructed current estimation error was kept at a low value of less than 2.6% with the proposed sensor fault-tolerant control, and variation in speed was at a low error of less than $\pm 0.9\%$.

Table 1

Performance Metric	Healthy Operation	Open-Switch Fault (Conventional SVPWM)	Open-Switch Fault (Proposed DB-MPCC-SVPWM)	Sensor Fault (Without Compensation)	Sensor Fault (With Proposed FTC)
RMS Current Tracking Error (%)	1.8	9.6	3.4	8.9	2.6

Phase Current THD (%)	3.6	18.4	6.9	11.2	4.1
Peak-to-Peak Torque Ripple (% of rated torque)	4.2	26.7	7.8	12.0	3.1
DC-Link Voltage Utilization (%)	100	78	91	96	96
Transient Settling Time after Fault (ms)	–	18.2	4.5	15.6	5.2
Maximum Phase Current Overshoot (%)	2.1	21.3	6.2	14.8	4.7
Speed Deviation (%)	±0.6	±5.3	±1.4	±4.1	±0.9
Overall Control Stability	Stable	Marginal	Stable	Degraded	Stable

B. Discussion

The findings confirm that the proposed fault-tolerant strategy of DB-MPCC-SVPWM can substantially improve the post-fault operation of the medium voltage (MV) PMSM drive systems in case of open-switch faults as well as sensor failures. Conventional SVPWM has severe performance degradation in terms of current regulation and quality of torque when operated under open-switch fault conditions because the lower-voltage, asymmetric voltage space may lead to reduced and asymmetric torque in the expression space. This has been demonstrated with the excessive amplification of current harmonic distortion and torque ripple, which proves the shortcoming of using healthy-state modulation techniques in faulted operation. In comparison, the proposed method is successful in compensating these effects using integrated voltage vectors reconfiguration, predictive current control and vector time reallocation. The improved current THD and torque ripples show that the synthesis of harmonic-free virtual voltage vectors and fault-compensated current prediction can boost the compensation of hardware vectors. The re-used DC-link voltage consumption also serves to substantiate the fact that the changed SVPWM scheme effectively makes use of the surviving, healthy switching states, and this is very necessary since in MV contexts, voltage margins are tight. The high transient response to fault transitions indicates the efficiency of the deadbeat predictive control framework.

Conclusion and Recommendation

The current paper has proposed a combined fault-tolerant control system of medium voltage (MV) permanent magnet synchronous motor (PMSM) drive systems, which use semiconductor open-switch faults and sensor failure. The proposed methodology based on a combination of open-switch fault modelling, post-fault voltage vector analysis, fault-aware deadbeat model predictive current control and a modified space vector pulse width modulation (SVPWM) strategy, in conjunction with the use of vector time reallocation allows one to gain stable post-fault operation without hardware redundancy. The sensor fault-tolerant control with observers is provided to establish a precise feedback reconstruction when the sensing condition is not good. The numerical data shows a great deal of progress in terms of current tracking behavior, torque ripple reduction, DC-link voltage usage, and transient behaviour in comparison to the traditional control techniques. The integrated control architecture ensures the uninterrupted flow between healthy and faulted modes also improves operational resilience when faced with plausible industrial faults.

Some recommendations are suggested to further the fault-tolerant working of medium voltage (MV) PMSM drive systems. The proposed control framework needs to be expanded to handle short-circuit faults on semiconductors and multiple concurrent faults in the future. Fault detection can further be even more accurate and resilient in the face of parameter uncertainty by integrating state-of-the-art observer designs or data-driven methods. It is suggested that experimental validation at higher voltages and power, such as alternative multilevel inverter topologies, be done to determine the scalability and long-term reliability. To provide a safe operation under the long-lasting fault conditions, the thermal stress measurement of power semiconductor devices during the post-fault operation should be added. Lastly, real-time feasibility tests of implementing the suggested fault-tolerant control strategy under conditions of computational load and limitations of industrial controllers would enable the realistic application of the suggested fault-tolerant control strategy to large-scale MV drive setups.

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