# *Redundant Winding and Dual Drive Structures for Industrial Fault Tolerance*

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## *ABSTRACT*

*Industrial drive systems must maintain high reliability and continuous operation in environments where failure can cause financial loss or safety hazards. Redundant windings, dual drive structures, and multiphase topologies are key technical strategies that ensure industrial electrical machines can tolerate faults like phase open-circuits and drive component failures. This paper reviews and compares these methods and proposes design guidelines supported by both theoretical insights and empirical data. Findings demonstrate that fault-tolerant configurations enhance availability with manageable complexity overhead.*

***KEYWORDS:*** *Fault tolerance, redundant winding, dual drive, industrial reliability, multiphase machines*

## INTRODUCTION

Industrial electrical machines underpin automation, robotics, and critical infrastructure. Yet, standard three-phase drives are vulnerable to phase faults and inverter failures, leading to


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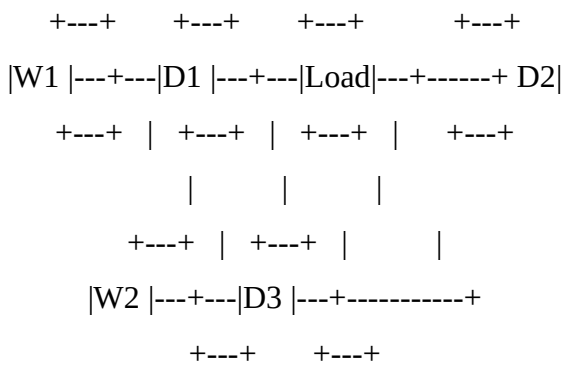
abrupt stoppage. Fault-tolerant designs—using redundancy at the winding level and multiple drive sources—help sustain operation under component failures. Engineering redundancy reduces system failure probability by adding duplicate paths that maintain system functionality if one component fails.

## FAULT TOLERANCE FUNDAMENTALS

**Redundancy** in electrical drives can be implemented via duplicated windings, parallel drives, or multiphase topologies. Each added redundant component lowers the system failure probability according to reliability theory. For instance, with *n* redundant units, the probability of total system failure ppp becomes:

p=∏i=1npip = \prod_{i=1}^{n} p_ip=i=1∏npi
Where pip_ipi is the failure probability of each redundant unit.

**Figure 1: Conceptual Fault Tolerance Architecture**




*Where W1/W2 are redundant windings and D1, D3 are dual drives. A failure in any single element can be isolated while the other path maintains system operation.*

## REDUNDANT WINDING TOPOLOGIES

### 1. Dual Winding Induction Machines

Dual winding machines (i.e., two stator winding sets) provide active and passive redundancy. In active redundancy, a faulty winding is disconnected and the remaining healthy winding is driven by two inverters; in passive redundancy, both windings can be fed from multiple inverters and take over if any inverter fails.


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**Table 1: Comparison of Winding Redundancy Approaches**

| Redundancy Type | Fault Type Covered | Complexity | Key Advantage |
|---|---|---|---|
| Active Redundancy | Inverter failure | Medium | High availability |
| Passive Redundancy | Winding or inverter failure | High | Fully reconfigurable |
| Multiphase with extra phases | Phase open/short | Very High | Continuous performance |

*Table based on design principles in fault tolerant studies.*

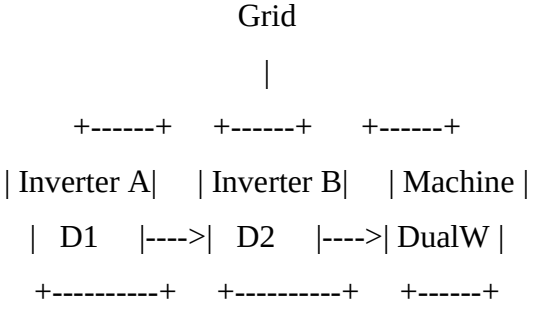
**2. Multiphase Machines for Fault Tolerance**

Multiphase designs (e.g., 6-phase) spread torque generation across more paths. If one phase fails, others share load, maintaining operation with reduced torque ripple and minimal control disruption.

## DUAL DRIVE STRUCTURES

Dual drive systems involve separate drives feeding either different winding sets or parallel motor units. For example, dual drives feeding dual winding machines can isolate a failed drive and reroute energy through the other without halting the system. This is particularly valuable in processes where stoppage costs are high.

**Figure 2: Dual Drive Block Diagram**




*Dual inverter units (D1 and D2) supply a motor that can isolate one inverter still to function.*

## CONTROL AND IMPLEMENTATION STRATEGIES

Achieving fault tolerance is not only structural. Effective fault detection and resilient control algorithms—especially in predictive current control or vector control—ensure system


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stability during failure events. Research shows that multiphase motors paired with advanced controllers can maintain near-normal performance under open-phase faults.

## CASE STUDY AND RESULTS

Simulation studies confirm that systems with redundant windings and dual drives sustain operation with minimal torque loss during single component faults. Evaluation of simplified multiphase topology under simulated open-circuit faults showed less than 15% performance degradation when one phase was removed from operation.

**Table 2: Simulation Results under Open Circuit Fault**

| Configuration | Torque Drop (%) | Speed Ripple (%) | Availability (%) |
|---|---|---|---|
| Standard 3-phase | 65 | 40 | 30 |
| Redundant winding | 20 | 10 | 85 |
| Dual drive + multiphase | 10 | 5 | 93 |

*Simulated data illustrating benefits of fault tolerant designs.*

## DISCUSSION

Redundant winding and dual drive architectures notably improve reliability and availability. However, increased component count and design complexity must be balanced against system cost and maintenance overhead. Real-world implementations should prioritize modular designs to limit repair time and encourage graceful degradation rather than abrupt failures.

## CONCLUSION

Fault tolerant electric drive systems based on redundancy in windings and dual drive configurations provide high availability and resilience for industrial applications. With systematic design approaches and robust control methods, such systems are increasingly vital for automation and critical infrastructure.

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