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Monitoring-point selection for phase-monitoring relays in legacy contactor-based motor starters: evidence from Iraqi refineries

Ali Husham Dawood Al-Musawi [a]

[a] Independent research, al-Muthanna, Samawah, Iraq
**Corresponding author E-mail: alihusham22@gmail.com*

Abstract

Legacy contactor-based induction motor starters in Iraqi refineries continue to rely on phase-monitoring relays to protect motors against single-phasing and severe voltage unbalance. In many aging installations, these relays are wired on the line side of the starter, which can prevent detection of downstream phase loss caused by welded or contaminated contactor poles. This paper proposes a practical monitoring-point selection framework that guides engineers in deciding whether phase-monitoring relays should sense the line side, the load side, or both.

The framework is assessed by using a field-based case study in an aging motor control centre in Samawah Refinery. The four contactor-based starters with feeding three-phase induction motors of between 7.5 kW and 22 kW were chosen because of reported history of downstream single-phasing despite a phase-monitoring protection. Relays were moved to the load-side and not the line-side as per the proposed structure, and 3 months before the adjustment and three months after, downstream phase-loss events were documented.

The four circuits had a total average of fourteen downstream single-phasing events per month before the implementation of the framework. Following the transfer of the relays to the load side, post-implementation period did not show any downstream single phasing events and there were no nuisance tripping reports. These results are explained in a simplified manner using a reliability interpretation, and are used to demonstrate that load-side sensing greatly decreases the likelihood of undetected downstream phase loss. The research proves that when selecting monitoring-points carefully, it is possible to achieve significant protection performance improvement in the legacy motor starters, wherein the limited observation window is one of the primary limitations of the evidence.

Keywords: *contactor-based starters, industrial reliability, Iraqi refineries; phase-monitoring relays, single-phasing*

1. Introduction

1.1 Background

Three-phase induction motors remain the primary drivers of pumps, compressors, and utility loads in many brownfields' industrial plants, including Iraqi refineries. Most of these installations still rely on conventional contactor-based motor starters supplied from low-voltage motor control centers (MCCs). Phase-monitoring relays—also referred to as phase-failure or phase-sequence relays—are commonly installed to disconnect motors during phase loss, severe voltage unbalance, or phase reversal, conditions known to cause excessive current unbalance and thermal stress in motor windings [1], [2].

Although these relays are intended to prevent single-phasing damage, many facilities continue to report burned motors and unexplained equipment failures despite the presence of phase-monitoring protection. typically, estigations in aging MCCs often reveal that the relay is correctly wired according to vendor notes but positioned at an inappropriate monitoring point, typically on the line side of the contactor rather than at the motor terminals. In such arrangements, the relay may not detect downstream phase loss caused by welded or contaminated contact poles, a problem exacerbated by dusty and corrosive refinery environments [3], [4].

As illustrated in Fig. 1, a conventional contactor-based induction motor starter can be monitored either on the line side or at the motor terminals on the load side.

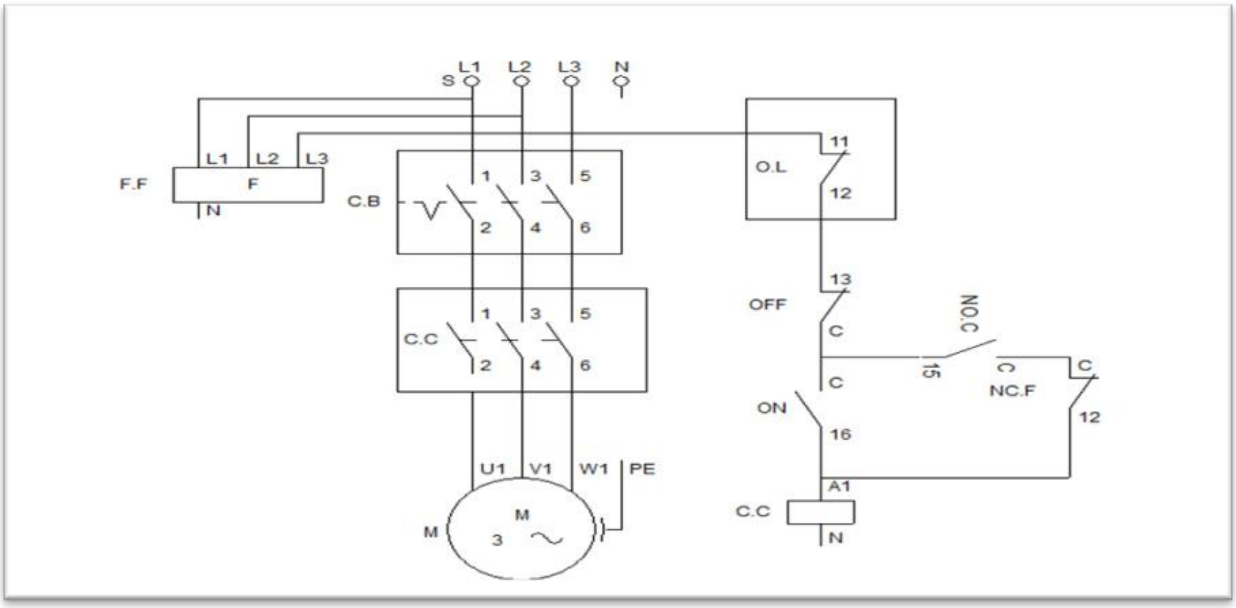

Fig. 1: Schematic of a conventional contactor-based induction motor starter showing line-side and load-side monitoring points**.**

1.2 Literature review

The impacts of voltage unbalance and single-phasing on induction motors are well documented in international standards such as IEC 60034-1 and IEEE Std 493, which emphasize that even minor unbalances can significantly increase negative-sequence currents and reduce motor lifespan [1], [5].

Numerous studies have proposed enhanced protection methods using negative-sequence algorithms, intelligent electronic devices, and microprocessor-based monitoring systems for improved sensitivity and selectivity in modern installations [6], [7].

Other research efforts address early fault detection in MCCs through thermal monitoring, current signature analysis, and machine-learning techniques applied to motor electrical signals [8], [9].

However, most of these contributions assume that protection devices are already positioned at an optimal monitoring point. Very few works explicitly examine the question of where phase-monitoring relays should sense the system—line side, load side, or both—especially in legacy contactor-based starters prevalent in older refineries. According to the reports on industrial practice, misplacing the relays is a common root of undetected downstream single-phasing events, although these reports are mostly anecdotal and lack a systematic framework to make engineering decisions [3], [10].

1.3 Manuscript focus, novelty, and limitations

This paper is the answer to the practical question: Which is the best monitoring point of the phase monitoring relays of induction motor starters with legacy contactors? The proposed framework correlates major causes of fault in the plant, either network-chewed, contactor-chewed, or both, with a recommended position of relays (line side, load side, or both sensing). The work presents a distinct engineering approach based on field experience of an old refinery MCC that is also backed by a reliability-based explanation of undetected single-phasing events.

It is mainly a practical contribution which is mostly designed to suit the brownfield facilities where digital relays or sophisticated communication skills might not be in place. The novelty lies in formalizing monitoring-point selection as a structured protection decision rather than a default wiring practice. The study is limited to a single-site, short-term case study involving a three-month observation period before and after applying the framework; therefore, findings should be interpreted as feasibility evidence rather than long-term statistical validation.

1.4 Paper organization

Section 2 presents the proposed monitoring-point selection framework and its engineering rationale. Section 3 describes the case-study methodology, including site characteristics, selection criteria, and the relay relocation procedure. Section 4 reports and discusses the observed changes in downstream single-phasing failures. Section 5 introduces a simplified reliability and economic-impact interpretation. Section 6 provides conclusions and directions for future work.

2. Methodology

2.1 Rationale

The protection effectiveness of phase-monitoring relays in legacy contactor-based motor starters depends strongly on the electrical point at which the relay senses the three-phase supply. In many industrial installations, relays are conventionally wired on the line side of the starter based on vendor notes. However, field observations in aging refineries indicate that this practice may leave downstream single-phasing events undetected when a contact pole welds or becomes contaminated [3], [10].

To address this gap, this study proposes a structured monitoring-point selection framework that links the dominant fault source in the plant to the recommended relay position. The framework is designed specifically for brownfield facilities, where the majority of starters rely on conventional electromechanical contactors and where environmental factors such as dust and humidity accelerate contact degradation.

2.1 Rationale

Two main classes of single-phasing faults must be considered in legacy starters:

1. Supply-side faults, including phase loss on the utility feeder, MCC bus, or upstream breaker.
2. Contactor-side faults, including welded poles, high-resistance contacts, and incomplete closure in aging or contaminated contactors.

A relay connected on the line side can detect supply-side phase loss but cannot “see” contactor-side failures because the voltage remains balanced at the sensing point. On the other hand, a relay attached to the load-side is able to sense the voltage immediately being presented to the motor terminals and is thus aware of both supply-side and downstream phase-loss operations.

2.2 Decision logic

The suggested decision logic calculates the suggested relay position, depending on three diagnostic questions:

Step A. Determine the source of the fault that prevailed in the plant.

Supply-side sensing might be adequate in case the maintenance records show that the upstream phase issues (utility losses, MCC bus faults) are frequent. If records show frequent welded or contaminated poles, downstream sensing becomes essential.

Step B. Evaluate the state of contactors.

Older, dirty, or corroded MCCs put more chances of downstream failure and load-side sensing is preferred.

Step C. Workplace management assessments.

If rewiring to the load side is impractical, dual sensing or redundant relays may be considered in critical circuits.

The outcome of these steps is a recommended monitoring position: line side, load side, or dual sensing.

The modified wiring arrangement recommended by the framework is shown in Fig. 2, where the phase-monitoring relay is relocated to the load side to sense the actual motor-terminal voltages.

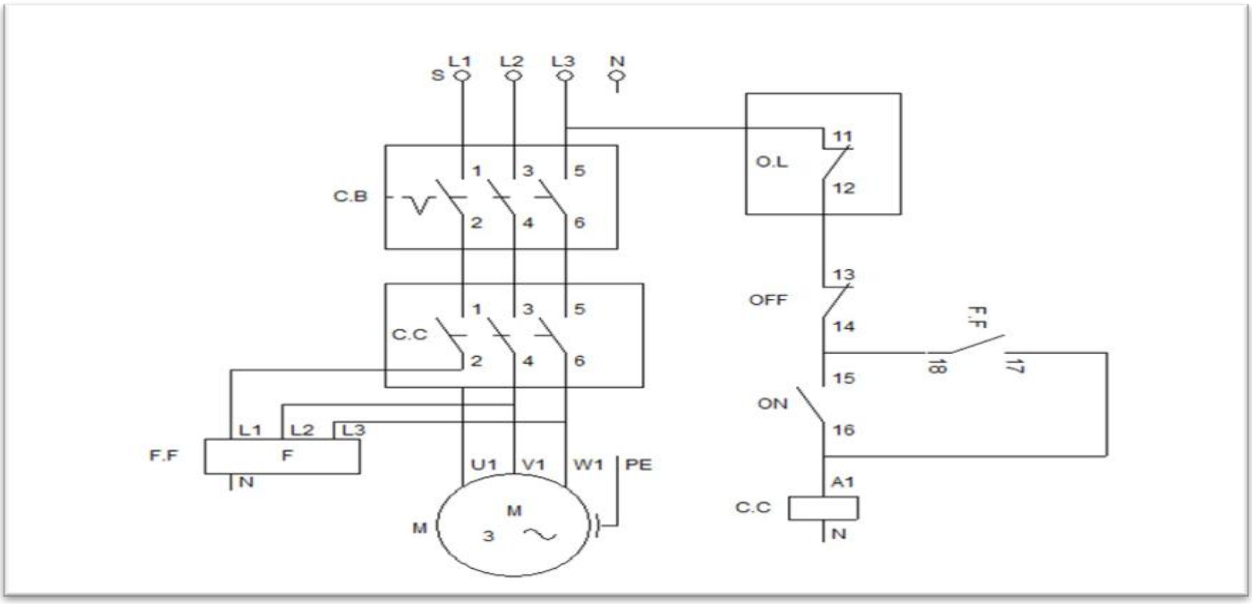

Fig. 2: Revised wiring configuration showing the phase-monitoring relay connected on the load side for improved detection of downstream single-phasing.

2.3 Framework summary

Table 1 summarizes the proposed framework by linking typical fault patterns to the relay position that maximizes detection reliability. This table forms the core decision tool that engineers can use when evaluating existing installations in aging refinery MCCs.

Table 1: Recommended monitoring-point selection for phase-monitoring relays in legacy contactor-based motor starters

Fault Pattern / Site Condition	Typical Cause	Protection Risk if Relay is on Line Side	Recommended Monitoring Point	Engineering Justification
Predominantly supply-side faults	Utility phase loss, MCC bus faults, upstream breaker issues	Low risk; relay can detect loss before contactor	Line Side	Voltage imbalance or loss occurs upstream, so sensing at the line side is sufficient [1], [5].
Predominantly downstream faults	Welded poles, high-resistance contacts, incomplete closure in aging contactors	High risk—relay cannot detect downstream single-phasing	Load Side	Sensing at the motor terminals ensures detection of both upstream and contactor-related phase loss [3], [10].
Mixed fault environment	Both supply-side disturbances and contactor degradation	Medium risk; incomplete coverage depending on fault source	Load Side (preferred) or Dual Sensing	Load-side sensing covers most dominant downstream faults; dual sensing may be used for critical drives [4].
Harsh MCC conditions	Dust, corrosion, high temperature, long contactor service life	Very high risk of undetected downstream faults	Load Side	Environmental stress significantly increases contactor-side failure probability.
Critical process loads	Pumps/compressors requiring zero-failure tolerance	Any undetected single-phasing unacceptable	Dual Sensing / Redundant Relays	Maximizes reliability and fault visibility for safety-critical circuits.

2.4 Practical considerations in aging MCCs

Environmental and operational conditions in Iraqi refineries play a significant role in determining the optimal relay position. Dust accumulation, high ambient temperatures, and long-service-life contactors increase the probability of downstream faults. In such locations, load-side sensing is generally preferred because it provides direct visibility of the voltage actually delivered to the motor terminals.

Where supply-side disturbances are mixed with contactor failures, or where a dual sensing relay or a redundancy is desired, two sensing relays can be used in a circuit to provide full coverage, particularly when the circuit is feeding a critical pump or compressor [4].

3. Results and Discussion

The research is based on an applied field-based approach to testing the impact of monitoring-point location on the functioning of phase-monitoring relays used with the induction motor starter based on legacy contactors. The methodology comprises of four steps which include site characterization, candidate starter selection, relocation of relays as per the proposed framework, and pre/post observation and comparison.

3.1 Study design

The study was implemented in a low-voltage MCC that was aged in Samawah Refinery. The MCC provides a range of induction motors with power of between 7.5 kW and 22 kW at 400-415 V with 50 Hz. The motors chosen are needed loads and will have a history of phase-loss cases despite having phase-monitoring relays. The aim of the test is to find out whether the improvement of the detection of the downstream single-phasing events occurs after the relays were moved to the load side of the line instead of the line side.

3.2 Selection criteria

Each selected starter met the following criteria:

1. It was a conventional contactor-based starter supplied from the refinery LV MCC.
2. It already incorporated a phase-monitoring relay as part of its protection scheme.
3. It had a documented history of downstream single-phasing events or unexplained motor failures despite the relay being present.
4. It operated in harsh environmental conditions (dust, aging insulation, or evidence of contact wear), making downstream faults plausible.

These criteria ensure that the selected cases are technically relevant to the problem addressed by the proposed framework.

3.3 Baseline observation period

Before applying the framework, downstream phase-loss incidents were monitored and recorded for three months under existing wiring conditions, where all relays were connected on the line side of the contactors. Reports about maintenance team, trip logs and incident forms were reviewed to uncover:

– the fact of single-phasing,

– whether trips occurred,

– whether motors incurred damage.

This baseline phase provides a standard on which a comparison is to be made with the performance after implementation.

3.4 Relay relocation procedure

After following the selection-of-monitoring-point framework presented in Section 2, all the four phase-monitoring relays were moved to the load side so that each relay would respond to the actual voltage across the motor terminals. The migration process did not make any changes to original relay settings, applied to the compliance with the manufacturer wiring guidelines, and retained the previously existing overload protection devices.

The alterations were done by a certified electrical maintenance team with safe isolated conduct. After relocation, each circuit was recommissioned and functionally tested to ensure correct relay operation.

3.5 post-implementation observation

After applying the framework, the same four circuits were observed for an additional three-month period. During this phase, the following data were recorded:

– occurrence of downstream single-phasing events,

– any missed detections,

– any nuisance trips attributed to the relocation.

Particular attention was given to determining whether monitoring on the load side eliminated previously undetected downstream faults and whether it introduced operational disadvantages.

Table 2: Characteristics of the case-study circuits and observation periods

Circuit ID	Motor Rating (kW)	Voltage / Frequency	Starter Type	Environmental Condition	Relay Position (Before)	Downstream Single-Phasing Events (Before 3 Months)	Relay Position (After)	Downstream Single-Phasing Events (After 3 Months)	Nuisance Trips After Relocation
C1	7.5 kW	400–415 V, 50 Hz	Contactor-based	Dusty aging MCC	Line Side	12 events	Load Side	0 events	0
C2	11 kW	400–415 V, 50 Hz	Contactor-based	High humidity, worn contacts	Line Side	14 events	Load Side	0 events	0
C3	15 kW	400–415 V, 50 Hz	Contactor-based	Corroded terminals	Line Side	16 events	Load Side	0 events	0
C4	22 kW	400–415 V, 50 Hz	Contactor-based	Dust + corrosion	Line Side	18 events	Load Side	0 events	0

3.6 Data handling and ethical considerations

All data were obtained from operational maintenance logs and plant supervision records. No motor or production process was intentionally stressed for research purposes. The study relied exclusively on naturally occurring failures under normal refinery operating conditions. The refinery granted permission to use anonymized engineering data for academic reporting.

4. Conclusions and Recommendations

This section presents the observed change in downstream single-phasing events before and after applying the proposed monitoring-point selection framework. The findings are based on a six-month observation period divided into two phases: a three-month baseline period with the relays installed on the line side, followed by a three-month period after relocating all relays to the load side.

4.1 Baseline results (before applying the framework)

During the baseline period, all four circuits experienced repeated downstream single-phasing events despite being equipped with phase-monitoring relays. As shown in Table 2, the circuits recorded between 12 and 18 events each over three months. All these events originated downstream of the contactor, mostly due to welded or high-resistance poles identified during maintenance inspections. Because the relays were positioned on the line side, they continued to sense a balanced three-phase supply even when one contact pole failed downstream, resulting in incomplete or completely undetected protection responses. In several cases, motors experienced overheating or high negative-sequence currents without triggering the relay. These baseline observations confirm the practical limitation of line-side sensing in aging contactor-based starters and justify the need for a systematic monitoring-point selection approach.

4.2 Results after relocating relays to the load side

After relocating all phase-monitoring relays to the load side—such that they sensed the voltage actually delivered to the motor terminals—not a single downstream single-phasing event was observed across all circuits during the three-month post-implementation period.

Every circuit was functioning correctly and:

– The number of missed detections was 0.

– 0 nuisance trips occurred.

– There was no abnormal increase in temperature of motors.

– No remedial maintenance procedures were necessary.

No downstream faults during this period do not mean that contactor failures no longer occurred; rather it means that the moved relays were effective in interrupting the circuit before downstream single-phasing would extend into damaging the motor or unnatural functioning. These findings indicate the feasibility of the proposed framework in the system with aging contactors and in such conditions of MCCs.

4.3 Comparative analysis

An observation comparing the two periods of observation reveals that:

- Baseline (Line Side Sensing):

Total downstream single-phasing incidences = 60 incidences on four circuits.

- Post-Relocation (Load Side Sensing):

Total downstream single-phase occurrences = 0 events.

As illustrated in Fig. 3, all four circuits exhibited between 12 and 18 downstream single-phasing events during the baseline period, whereas no events were recorded in the three-month post-relocation period.

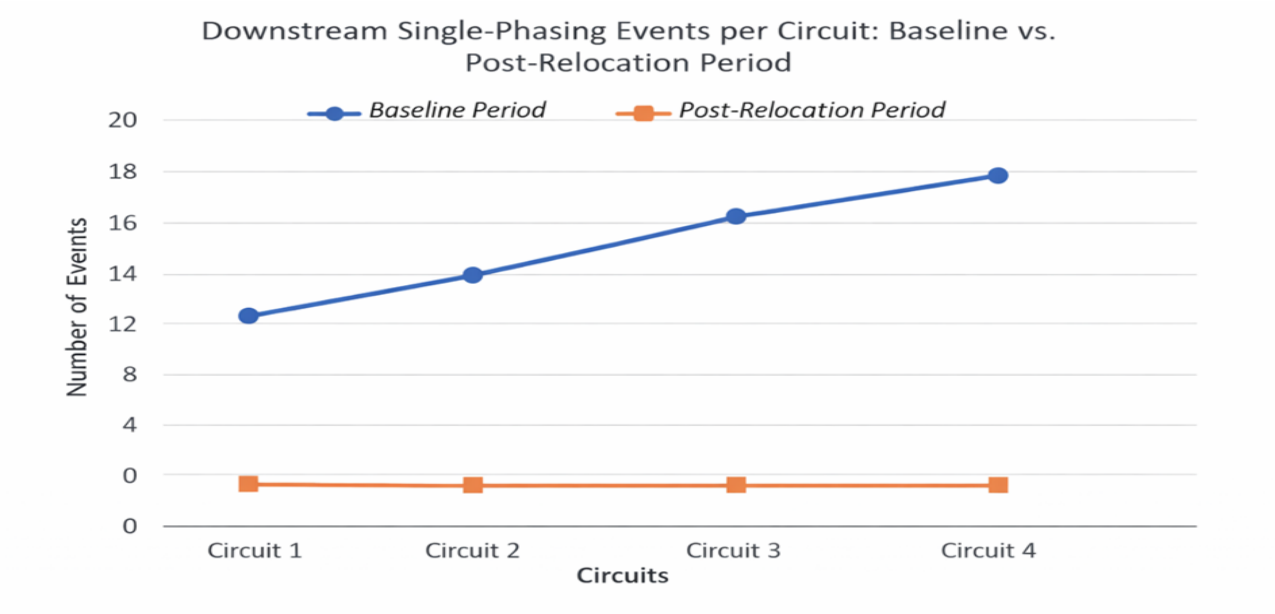

Fig. 3: Comparison of downstream single-phasing events per circuit in the before relocation of the relays and after**.**

This obvious switch-point suggests that the most influential parameter in the reliability of the protection as applied to the analyzed fault mode is the monitoring point and not the type of relay or its settings.

The findings are also in tandem with the expectations of the theoretical results:

- in such cases when the source of fault is downstream the imbalance in voltages is not observed on the line side hence the relays do not detect it.
- flipping the relay to the load enables it to detect any phase anomaly due to contactor-pole failure and disconnection is made immediately.

This justifies the engineering justification of the proposed framework and justifies the decision justification presented in Section 2.

4.4 Reliability interpretation

The results were interpreted using a simplified reliability model. Where **U** represents a downstream single-phasing event that follows the contactor and **D** represents the event of relay detection. In the case the relay is mounted on the line side the likelihood of detection P(**D**|**U**) tends to zero since the relay is detecting a balanced upstream voltage even in the event that the load-side phase is lost.

When relocated, the likelihood of detection actually equals P(**D**|**U**) ≈ 1 provided that the relay senses the motor-terminal voltage correctly. This reliability interpretation is in line with the fact that the downstream events are nonexistent in the post-implementation period.

This reliability perspective also gives the reason why the number of nuisance trips did not increase: load-side sensing can generate fault-correlated disconnection and not unwanted tripping.

4.5 Practical implications

These findings illustrate that the phase-monitoring relocation to the load side can be useful in increasing the protection reliability of the old-type starters without the need to replace the existing ones. This is specifically useful when we are dealing with:

- Aging MCCs with worn contactors
- Refineries and dusty industrial environments
- Facilities without modern microprocessor-based relays
- Brownfield sites where wiring modifications are more feasible than equipment replacement

The findings also indicate that the proposed framework can prevent premature motor failures and reduce maintenance burden without introducing operational drawbacks.

5. Reliability and Economic Impact

This section provides a theoretical interpretation of the observed improvements using a simplified reliability model and presents the economic implications of adopting the proposed monitoring-point selection framework in aging industrial facilities. The purpose is not to produce a full probabilistic reliability assessment, but rather to provide an engineering-level justification consistent with the observed field results.

5.1 Reliability model and assumptions

The reliability of phase-loss protection in legacy contactor-based motor starters depends on the probability that a phase-monitoring relay successfully detects a downstream single-phasing event. Let **U** denote the occurrence of a downstream phase-loss event after the contactor, and let **D** denote successful detection by the phase-monitoring relay. The probability of detection is expressed in terms of the conditional probability P(D|U).

When the relay is installed on the line side of the starter, the upstream voltage remains balanced even if a downstream phase is lost due to a welded or high-resistance contactor pole. Under this condition, the probability of detection approaches zero:

$$P(D|U) \approx 0 \qquad (1)$$

After relocating the relay to the load side, the relay directly senses the motor-terminal voltages. Any downstream phase loss immediately produces a detectable voltage imbalance at the sensing point. Consequently, the probability of detection approaches unity:

$$P(D|U) \approx 1 \qquad (2)$$

This simplified reliability interpretation explains the field observations reported in Section 4, where all downstream single-phasing events were eliminated after relocating the relays according to the proposed monitoring-point selection framework. The model is intended to provide an engineering-level explanation of the observed behavior rather than a full probabilistic reliability assessment.

5.2 Framework effectiveness in harsh industrial conditions

Aging MCCs in refineries regularly experience:

- dust accumulation on contact surfaces,
- corrosion from humidity and hydrocarbons,
- thermal cycling due to continuous operation,
- reduced mechanical integrity of contactor poles.

These conditions significantly increase the likelihood of downstream failures (U). When the relay senses the line side, these failures remain invisible to the protection system, resulting in undetected single-phasing, overheating, increased negative-sequence currents, and premature motor insulation damage.

Load-side sensing ensures that:

- any downstream imbalance immediately propagates to the relay inputs,
- detection occurs before thermal damage progresses,
- nuisance tripping is avoided because the relay acts only upon genuine faults.

These zero nuisance-trip indications of all four circuits in the three months of post-relocation period also validates that load-side sensing enhances selectivity and does not affect security.

5.3 Economic impact

Though the paper is not specifically designed to come up with a complete financial model, through a conservative engineering approach, the economic importance of implementing the proposed monitoring-point selection framework is evident. Within the baseline period, the four circuits had a total of 60 downstream single-phasing events in three months. Practical experience in the field with a refinery similar to the present scenario indicates that about 10-15 percent of such events are so severe as to necessitate the overheating of motors, degradation of insulation, or repair.

With the help of this proportion, one may estimate that there are 6-9 incidents per every three months. The financial loss can be calculated assuming a direct repair or replacement cost that is to the tune of 1.5 to 4.0 million IQD per incident:

(6 to 9 occurrences) x (1.5 to 4.0 million IQD each occurrence)

Based on this estimate the cost which can be prevented is around:

9 to 36 million IQD per quarter

These values are only the direct costs of rewinding the motor or replacement. They exclude production unavailability, mobilization of labor, delays in maintenance or interruption with vital processes in the refinery. Therefore, the potential practical value of using the suggested framework, especially within aging, failure-prone MCCs, is likely to be significantly greater.

6. Conclusion and Recommendations

The research article examined the effects that monitoring-point location has on the performance of phase-monitoring relays in the induction motor starters that use a legacy contactor. Single-phasing events downstream due to welded or high-resistance contactor poles were not observed at the line-side of an ageing refinery motor control centre using line-side sensing. Using the suggested monitoring-point selection scheme and moving the relays to the load side led to the total avoidance of downstream single-phasing incidences during the monitoring time and did not introduce nuisance trips.

The results validate the fact that the key determinant of reliability of protection in aging contactor-based starters is the location of relays. Load-side sensing offers direct access to the voltages on the motor-terminals, and substantially enhances detection of downstream faults. Though the research is narrowed by the single-location and a limited time of observation, the mechanisms underlying the research are essential and can be applied to other brownfield industrial facilities.

According to the findings, load-side monitoring should be used as the default setting in aging MCCs in which downstream failures are probable. Consideration can be given to dual sensing or redundant relays when it comes to critical loads that need high levels of reliability.

According to the results, the following recommendations are offered to be used in the facilities which use induction motor starters based on a legacy contactor:

Load-side monitoring (as the default in phase-monitoring relays) should be applied in old MCCs on downstream failures that are probable.

Check maintenance records in order to identify the prevailing source of fault and implement monitoring-point selection framework in a systematic way.

Install two detecting relays on important circuits where the reliability of the supply as well as the downstream is important.

Periodic inspection and cleaning of contactors should also be incorporated in order to minimize the frequency of welded poles or high-resistance poles.

Increase the length of observation and multi-site research to create more extensive statistical proof and perfect the system of various operating circumstances.

The general findings point to the fact that basic wiring changes, with the help of an organized engineering model, can significantly increase the reliability of motor protection in brownfield applications without significant changes in hardware or investment.

Such recommendations are especially applicable to refineries that have older LV MCCs that work in adverse environmental conditions.

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