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Adjustable Speed Drives and Motor Protection

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ADJUSTABLE SPEED DRIVES AND MOTOR PROTECTION

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Abstract – One of the application considerations that must be evaluated when utilizing an adjustable speed drive (ASD) is motor protection. This is not as simple as it may seem. There are many potential motor protection relay (MPR) options in the market; however, these MPRs have typically been designed to provide protection to motors operating on standard sine wave utility power at nominal frequencies assuming some form of direct or reduced online starting. As a result, there are a number of considerations that engineers must take when applying these relays to ASD applications, since the variation in frequency can render certain relay features ineffective.

Recognizing this, modern ASDs have integrated aspects of motor protection into their control architecture. The degree to which motor protection is provided by the ASD varies substantially according to the selected drive topology. The result is that some drive topologies may require additional discrete motor protection while others do not.

The paper will cover one user's experience related to the subject, the issues which they encountered and the resulting perspective that they now have related to this subject.

Index Terms — Induction motor, motor protection, adjustable speed drive

I. INTRODUCTION

One of the fundamental tasks that an electrical engineer must face during the course of designing an electrical installation is motor protection. Motors represent a large proportion of the electrical distribution for any plant. Over the past several decades, there have been major advances in electronic motor protection, leading to very sophisticated MPRs that can provide a wide range of advanced protective functions ranging from basic overcurrent elements to very sophisticated RTD biasing, zone interlocking, and other capabilities that require nearly a PhD degree on the part of the electrical engineer to complete. An interesting phenomenon that has occurred over the last several decades is the development of electronic protection relays and the parallel development of power electronics. While there have been adjustments on the part of MPR designs to allow for the use of the protective relays on reduced voltage applications and synchronous machines, etc., very little, if anything, has been done to address ASD applications. This could be because of the adjustable nature of drive output waveforms that are not the typically seen on the established applications. A further challenge is that the ASD's adjustable frequency output to control a motor's speed will reduce accuracy of a relay's current transformers, potentially providing misleading information to the relay and hindering its protective response time. Variations in ASD outputs to downstream motors can also dramatically change their performance and capabilities. These topics in relation to specific protective features will be discussed in more detail later in the paper. Regardless of challenges overcome by using MPRs with ASD functionality, it is important that the engineer consider all motor protective functions and how they are affected by including an ASD to drive a motor.

Drive manufacturers have responded to these challenges to some degree by building certain drive and motor protective features into their own equipment. This built in protection is primarily present to protect the drive itself, and to ensure that the ASD is providing the intended output. These built in functions can provide the necessary protection to the ASD, but can also protect the downstream motor. It is necessary to understand the ASD's internal protective functions to prevent unnecessary redundancy in the protective scheme, and to limit the amount of additional external devices installed on the system.

The variations in MPR and ASDs protective functionality means that it is not necessarily clear to the design engineer what is required to adequately protect the motor for some of the most basic motor protection elements, such as repeat starts, overload protection and ground fault to name a few. When in doubt, the best general policy usually is to install supplementary protection in the form of a motor protection relay downstream of the ASD in addition to the protection

already provided by the ASD. However, adding blanket motor protection downstream of the ASD may cause more problems than remediate them.

As mentioned earlier, MPRs have generally been designed to address across the line operation resulting in protective features and settings which are expecting an across the line starting and operating characteristic as well as 60/50Hz fixed frequency waveforms. This may mean that certain features must be disabled or set differently to work with the ASD. Redundancy between the MPR and the ASD may also lead to unnecessary added troubleshooting efforts by having more devices to troubleshoot and potentially adding false positive indication for MPR's that have not been properly set.

The intent of the paper is to discuss the challenges that engineers face when choosing their approach to motor protection, MPRs, and ASD protective functions, as well as provide a case study of potential complications when installed.

II. ADJUSTABLE SPEED DRIVEN MOTOR CHARACTERISTICS

To determine what the best protection for an ASD-driven motor is, we need to have a clear understanding of how a motor behaves when starting and running by means of an ASD. The utilization of ASDs can influence the design, performance and reliability of induction motors.

A typical starting current of six (6) times the rated running current and a skin effect induced locked rotor resistance of three (3) times the rotor steady state resistance causes rotor I^2r heating to be 108 times greater than normal running conditions.[6] Consequently an extreme temperature must be tolerated to start a motor from a fixed frequency supply. These characteristics are used to select appropriate protection functions and settings for across-the-line motor starting. Figure 1 shows different typical motor characteristics for across-the-line starting.

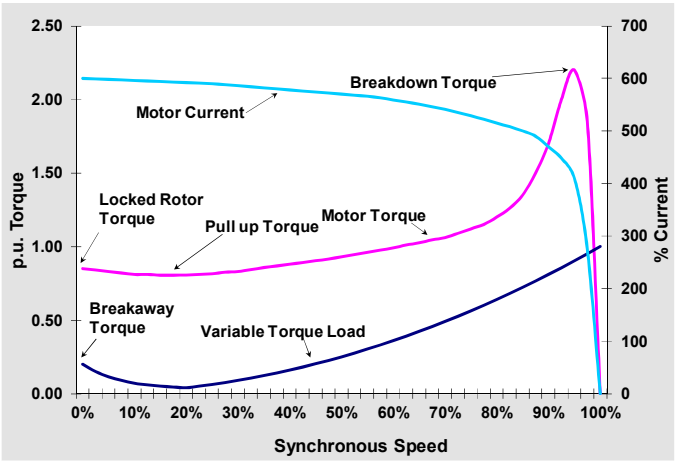

Fig. 1 - Typical Across-the-Line Motor Starting Characteristics [8]

Motor thermal curves are provided by manufacturers and are used by protection engineers to come up with the final settings for motor protection. A thermal limit curve is a plot of the maximum permissible time versus the percent of rated current in the motor winding, and depending on whether the motor is started from ambient temperature or operating temperature, are referred to as cold or hot thermal limit curves. Understanding these differences will help engineers to determine the most effective motor protection scheme.

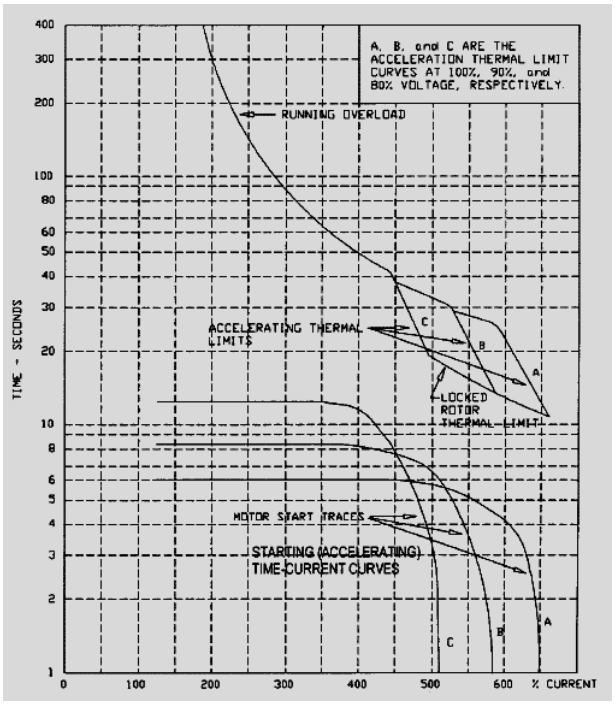

Fig. 2 - Typical Motor Thermal Damage Curve(s) [7]

On the other hand, a motor controlled by an ASD has very different characteristics. ASDs, by definition, operate over an adjustable speed range. On its most basic level, this is done by varying the output frequency. This is in contrast to the fixed 50 or 60 Hz operation of across-the-line operated motors. Some of the major advantages of using an ASD are:

1. ASD driven motors never approach locked rotor current draw
2. There is less stress to the mechanical components and rotating elements due to soft speed starting.
3. More motor thermal capacity remains after a slow start if a motor has stopped and a restart is needed.
4. ASD fed motors have the benefit of a balanced source since the drive supplies each of the 3 motor phases of the motor from a common DC supply, the DC link, which eliminates the voltage and resulting current unbalances to which the motor is subjected to when fed from a utility supply

Figures below show that typical ASD-driven motor starting curves and torque-speed curves at different frequencies are quite different than a normal across–the-line start.

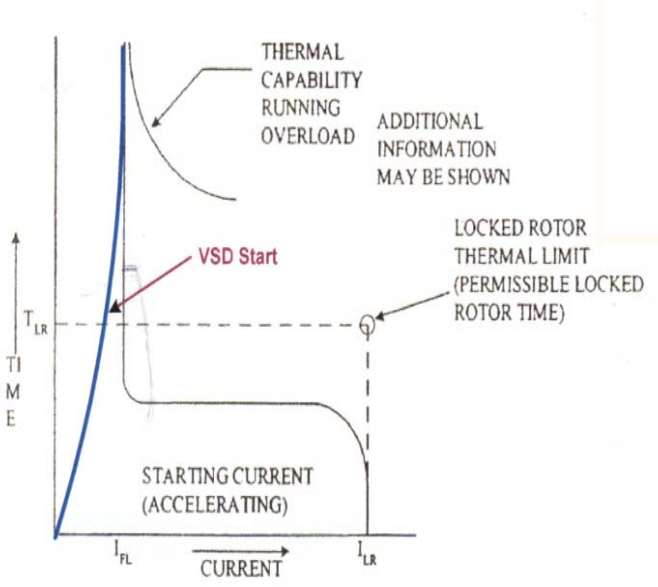

Fig. 3 - Typical Motor Thermal Damage Curve(s) [8]

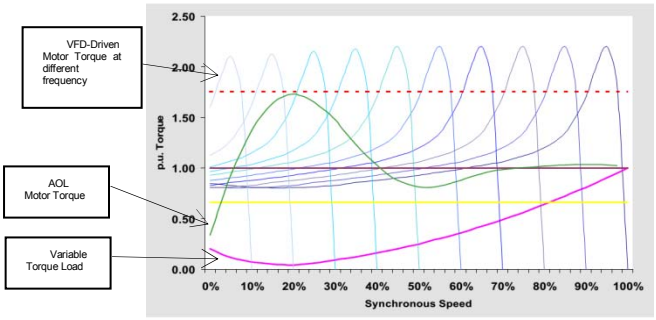

Fig. 4 - Motor Torque Characteristics with ASD [8]

There are also some important aspects to be considered when specifying motors for an ASD application:

1. The “Common Mode” Voltage
2. Harmonics
3. Speed Range
4. Starting Aspects
5. Motor Loading Restrictions - Per IEEE C37.96-2000 std "When comparing across-the-line motor operation with ASD operation, the ASD-operated motor can run hotter than its across-the-line equivalent because of increased heating from harmonic effects and reduced cooling from low-speed operation. As a result, the continuous torque available from an ASD-operated motor is often lower than with a line-connected motor."[7]

Due to the different characteristics of ASD starting and across-the-line starting, special care is needed to ensure that the motor is properly protected when starting with a drive.

The application of an ASD to a motor can have significant effects on the drive feeder and the load side of the drive, and add significant complexity to design considerations when it comes to the type of protective functions required at the output of the drive. In the following section, the most common protective devices used in across-the-line applications will be addressed when an ASD is added to the system.

The following protections may be required to properly protect an across-the-line motor, depending on the motor size, voltage, and application. [11]

- IEEE Device 50/51 – Overcurrent Protection
- IEEE Device 50/51G – Ground Fault Protection
- IEEE Device 47 – Phase Reversal/Voltage Unbalance
- IEEE Device 27/59 – Under/Over Voltage Relay
- IEEE Device 81 – Over/Under Frequency Relay
- IEEE Device 49 – Thermal Overload Relay
- IEEE Device 49T – RTDs – Protection against overheating of machine windings
- IEEE Device 66 – Starts Per Hour
- IEEE Device 38 - Bearing Temperature Relay/ RTD Protection
- IEEE Device 46 –Current Unbalance
- IEEE Device 87 – Stator Differential Relay
- IEEE Device 37 – Underpower Protection

The following figure provides a single line representation of a possible motor protection configuration.

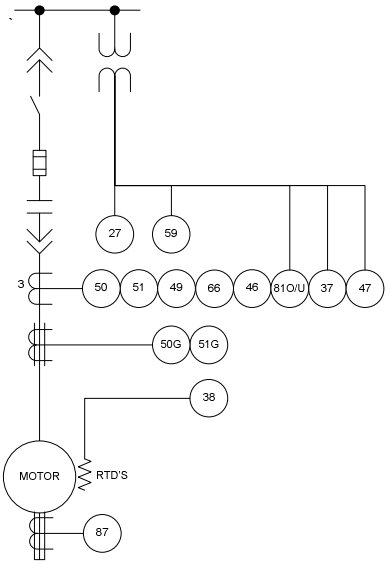

Fig. 5 - Single Line Representation – Fixed Speed Motor Protection

III. MOTOR PROTECTION ELEMENTS

A. Instantaneous and Inverse Time Overcurrent Protection (IEEE Device 50/51)

Overcurrent protection will still be required regardless of whether the motor is run across the line or through an ASD, as overcurrent and fault conditions can still occur. However, instantaneous and inverse time overcurrent protection is typically included in ASD protection and control packages, and will make additional downstream overcurrent protection redundant.

If, for some reason, additional overcurrent protection is used, the following considerations must be made:

- Downstream relays will need to be coordinated with upstream overcurrent protection, including the drive itself.
- ASDs have limited fault let-through currents, typically less than 200% of full load current. The engineer must ensure that device pickup settings aren't set above those values, otherwise a fault current event may never be detected by the relay.

B. Ground Fault Protection (IEEE Device 50/51G)

Regardless of whether a motor is started across-the-line or through an ASD, the electrical equipment will need to be protected against ground fault events. Ground fault protection comes standard with most ASDs, and will not need additional external ground fault protection.

C. Phase Reversal/Voltage Unbalance Protection (IEEE Device 47)

A phase reversal on a motor will cause it to rotate in the opposite direction. This can potentially cause large amounts of damage to the rotating equipment attached to the motor or other equipment such as piping, valves, etc., depending on the motor's application. Phase reversal protection can prevent the motor from running in the event that the rotation has been reversed at some point upstream of the motor protection relay.

Phase reversal relays can also be used to detect against voltage imbalances. A 1% voltage imbalance can cause a 6% current imbalance at the motor. This can lead to large negative sequence currents and overheating in the motor. [13]

When an ASD is used, the voltage output is controlled and balanced by the drive, effectively isolating the motor and its feeder from any voltage imbalances and phase reversals present at the drive's input. Due to the electrical proximity of the drive to the motor feed, the use of phase reversal on the load side becomes unnecessary. In addition, phase reversal relays are typically calibrated at a specific frequency. In applications where the drive's output frequency varies while running, the relay may nuisance trip due to abnormal phase conditions during frequency transitions.

D. Under/Over voltage Protection (IEEE Device 27/59)

In non-ASD applications, it is important to monitor and protect against under and overvoltage conditions. A higher than rated voltage at the motor overexcites the winding cores, leading to excessive current draw in an attempt to further magnetize the iron and causing additional heating to the motor. A lower than rated voltage at the motor will reduce the torque of the motor and could lead to an inability for it to start.

When an ASD is used, however, the high frequency or low frequency output can either over or under-excite the motor respectively. In order to avoid over/under-excitation of the motor, the voltage typically varies linearly with the frequency, rendering under and overvoltage relays a hindrance to the protection scheme. In ASD applications, a volts per hertz relay should replace the under/overvoltage protection. This protective function comes built into modern ASDs, and is unnecessary in downstream motor protection.

Use of under or over voltage protection will cause nuisance trips by the added external relay, since the voltage will be varying with the output frequency of the drive. Because of this, adding an external load side under/over voltage relay is not recommended.

E. Under / Over Frequency Protection (IEEE Device 81)

Under and over frequency protection may be applied in applications where a specific motor speed is required, as well as protecting the motor against running above or below its rated speeds. When an ASD is applied to the system, the motor still needs to be protected against running at speeds outside its rated range. Minimum and maximum speed parameters can be set within the ASDs internal controls making an external protective relay unnecessary.

F. Thermal Overload Protection (IEEE Device 49)[5]

The thermal capacity of motors that run across the line take into account cooling caused by its own rotation. While using an ASD, the intentional reduction in rotation has an adverse effect of reducing the motor's capability of keeping itself cool, thus modifying the thermal capacity of the motor. For full torque/low speed applications, a larger portion of the motor's thermal capacity is used up as the frequency output of the drive reduces. Standard thermal overload protection may not be sufficient to protect the motor in these conditions, since thermal capacity will be reduced. The design engineer should consider a correction factor that reduces the thermal overload pickup curve based on the frequency output of the ASD. The engineer should note that this correction factor will vary depending the presence and type of external cooling equipment installed at the motor.

In addition to the reduced thermal capacity, ASDs add harmonic frequencies to the system. These harmonic frequencies cause additional heating in the motor while running. Standard overload protection in multifunction relays isolates and monitors the fundamental frequency for its calculations. In order to get a complete picture, thermal overload protection needs to take into account the true rms current values of the motor, essentially monitoring the unadulterated current output from the ASD. Although taking into account unfiltered values is still recommended, additional heating caused by harmonic outputs is less of a concern than

in the past, since modern drives have much less output current harmonics than they used to.

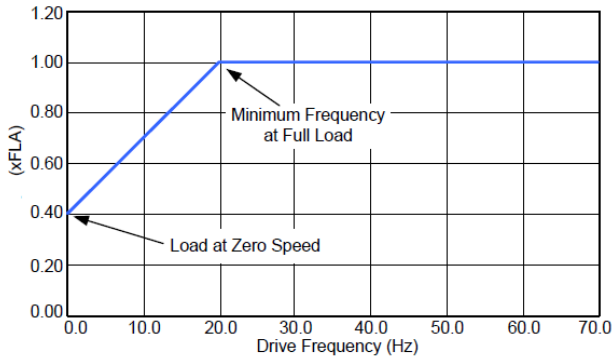

Fig. 6 - Thermal Overload Correction v Speed Example [5]

Modern medium voltage ASDs have built in thermal overload protection that takes into account, both the variations in motor thermal capacity caused by reduced rotation speed, and the harmonic frequencies that it produces at its output. Because of this, external thermal overload protection of the motor by a downstream motor protection relay is unnecessary. Including thermal overload protection downstream of the drive can also cause nuisance trips unless the relay is specified as being capable of monitoring adjustable speed output currents properly.

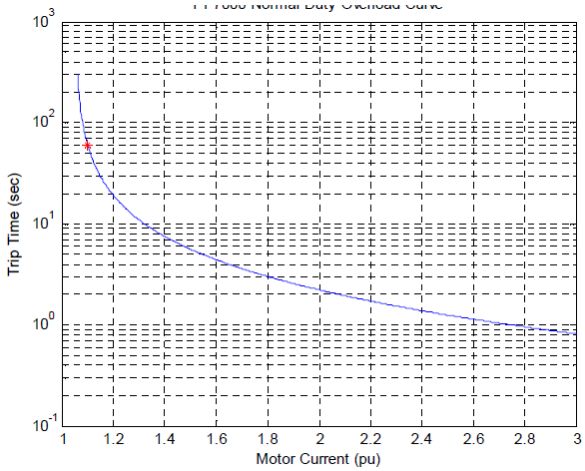

Fig. 7 - Example of Internal ASD Overload Protection

There are certain applications, however, where the use of thermal overload relays are necessary downstream of the drive. For example, individual thermal overload protection will be needed for each motor in an application where a single drive starts multiple motors. Multifunction relay manufacturers have begun to release relays with “VFD” monitoring capability, greatly facilitating determining the proper overload settings. If RTDs are used to monitor temperatures at the motor, as is typically done in most medium voltage and some low voltage applications, thermal overload protection becomes a secondary concern, since RTDs will be directly monitoring winding temperatures. RTDs will be further discussed in Section H.

G. Starts per hour protection (IEEE Device 66)

When a motor is started across-the-line, it draws an inrush current of approximately six times full load current, and then drops down to its normal running current once the motor has gotten up to speed. This inrush leads to a spike in how much thermal capacity budget is being used up by the motor. If the motor starts too many times in a short period of time, the motor can overheat and be damaged. In order to prevent such an event from occurring, the number of hot and cold starts per hour is limited depending on the application. For example, NEMA MG-1 limits to two cold starts in succession or one hot start, and API 541 limits to three cold starts and two hot starts for induction motors over 500HP.[9][10]

When a motor is started through an ASD, the starting inrush current is limited to up to approximately 1.5x the full load current of the motor, and has a low slip. The advantage to this is that the overall spike to the temperature of the motor will be minimal, meaning that the motor can effectively start more than two times per hour without causing serious damage to the motor,

H. Stator & Bearing Temperature - RTDs (IEEE Device 38 & 49T)

RTD sensors provide exact temperatures independent of whether the motor is being driven across the line or through an ASD. As a result, using an ASD will have no effect on the use of RTDs if they are required. An external relay will need to be installed to allow this information to be monitored. No special considerations will be required for temperature alarm/trip settings for motors fed by an ASD.

I. Current Unbalance (IEEE Device 46)

An imbalance of currents on the motor leads to circulating negative sequence currents in the rotor causing overheating. Applying a current unbalance relay at the starter in an across the line system will help to protect against this heating. However, in an ASD application, the drive isolates the motor from any unbalanced currents on the line side of the drive, eliminating the need for a current unbalance relay downstream of the drive.

However, unbalanced currents on the system should still be considered when applying an ASD to a motor. Although the motor will be isolated from these conditions, the drive itself may experience nuisance trips due to the unbalance. The use of a current unbalance relay may provide some protection against these conditions, but when the system is at a point where unbalanced currents cause nuisance trips, it is recommended that the engineer investigate methods for balancing the currents.

J. Stator Differential (IEEE Device 87)

Stator differential protection is applied in order to quickly detect phase-to-phase or phase-to-ground faults at the stator of the motor. If such a fault is detected, the motor winding insulation has failed and the likely resolution will require

rewinding the motor. The primary benefit of differential protection is that the early detection of an insulation failure in the stator windings will minimize or prevent damage to the iron in the motor so that the repair is limited to the cost of the rewind. The intent is to detect any disparity between the phase current entering the motor from that returning from the motor neutral point. A difference in the two currents indicates that current is being lost in the motor.

Stator winding "leakage" currents, the current being lost in the motor, can be caused by moisture, contamination or by winding insulation breakdowns which will eventually become faults if left to progress. In the event of a differential alarm or trip, the end user or a service engineer must isolate the problem to either the motor or the load cables using meggers and continuity testers, and correct the fault. If the leakage current is caused by moisture or contamination, the corrective action can be as simple as using compressed air to remove conductive dust or washing the windings and drying them to improve megger readings. If the cause of the low megger readings is due to an actual ground fault between the winding and stator core, tracking from the end windings to the bearing brackets or frame through faults in the coil ends, this means that the winding will need to be replaced.

Since faults can occur in the motor or feeder regardless of whether or not an ASD is applied, it is recommended that the presence of an ASD not play a determining factor on whether the motor requires stator differential protection. A common practice is to employ motor differential protection on larger motors typically 2500 HP or higher for a 4160 volt application for economic reasons. When stator differential protection is determined to be required, the standard approach involves the use of either 3 current transformers (CTs) in the motor junction box as shown in Fig. 8a, which is the most common approach, or 6 CTs as shown in Fig. 8b.

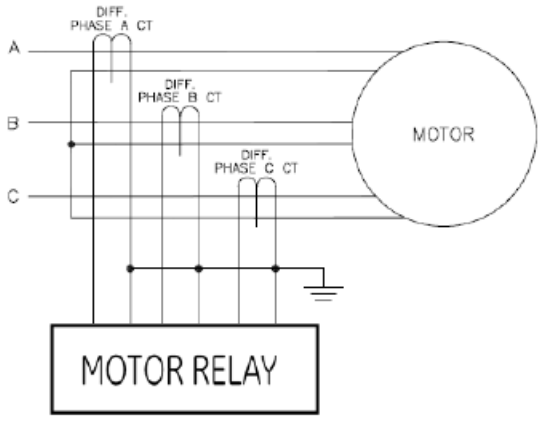

Fig. 8a Motor Stator Differential Protection – Core Balance

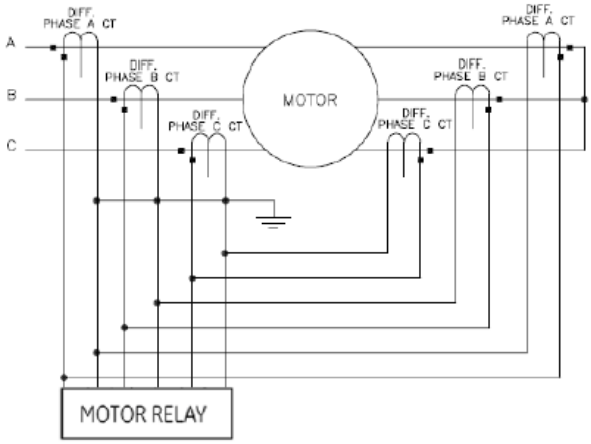

Fig. 8b Motor Stator Differential Protection – Summation

While the configuration is different, the theory remains the same which is that the magnitude of the phase current going to the motor should be the same as the current in the neutral of the motor circuit in a healthy motor. The core balance approach is the most common method. This scheme requires that 3 current transformers be supplied usually in the motor terminal junction box. The load conductor going to the motor as well as the motor neutral conductor for the same phase must pass through the same CT for each of the 3 phases going to the machine. In operation, the net current which will be seen by the CT should be zero provided that current is not being lost in the motor. The output of these CTs is taken to a 3 phase current detection relay or a MPR with the ability to support this function. An alarm or trip of this relay will result if a current is detected in any of the three phases should the setting be exceeded. The setting which is used must consider not only the desired protection level but must also allow for non -steady state conditions such as starting.

In the case of the 6 CT summation method, the approach remains the same as the core balance method, however, the configuration is different in that the current differential is determined with the use of 2 CTs per phase which are summed. The CTs are configured so that there is a set of CTs at the remote supply, a motor starter or ASD, and there will need to be a set at the motor for the neutral side of the circuit. It is important to make sure that the CTs are installed in the proper locations and any differences in ratio or characteristics must be compensated for both at steady state and starting conditions. The engineer should emphasize that the upstream CTs be installed on the load side of the drive in order to ensure that differential signals are not erratic and causing nuisance trip events due to the significant difference in the input and output waveforms of the drive.

This being said, when the above techniques are used on an ASD fed motor, there is a limitation in the ability to detect differential currents at lower frequencies due to the inherent characteristic of current transformers.

Some ASDs have flux and DC unbalance protection schemes which may be used either on their own or in conjunction with the core balance approach since the accuracy particularly at lower speeds is superior. These

protective functions are embedded in the ASD control, do not require CTs in the motor terminal box or the associated conduit and wiring runs between the drive and motor which is particularly significant when the motor is at a significant distance away from the controller.

As previously mentioned in Section II, the voltage supplied to each phase of the motor is derived from a common source, the ASD DC link, so the voltage balance between phases is ideal with little to no variation. In addition to the fact that this eliminates one of the leading causes of motor failures, overheating due to the current unbalances and the resulting motor insulation failures, this also serves to make unbalance detection schemes more effective. Statistics show that 30 percent of motor failures are attributed to insulation failure and 60 percent of these are caused by overheating. With the previously mentioned stator differential schemes, it is necessary to make allowance for inherent unbalances which will be seen under normal operation on utility power simply because this source is imperfect and subject to unbalances.

ASD flux unbalance protection capitalizes on the fact that vector control drives operate on the basis of a d-q model which separates flux (magnetizing) and torque producing currents. As the flux producing current is a fraction of the total current to the motor, the resolution of this unbalance detection is better than monitoring the total phase current.

With respect to DC unbalance protection, DC unbalances are also an indication of higher leakage currents to ground on one or two phases of the stator winding and output cables.

Adjustable parameters provided for these unbalance settings can be set during commissioning to a level high enough to avoid nuisance trips such that should the leakage current increase over time, an alarm or trip will be annunciated depending on the actual value of leakage current seen at the motor.

K. Underpower Protection (IEEE Device 37)

Underpower protection helps to detect a broken shaft or other mechanical problems with a pump. Due to its mechanical nature, if a motor would require underpower protection in an across-the-line application, an underpower protection relay should be used with an ASD. As with most crucial settings, the majority of ASDs have internal protective settings available to monitor underpower conditions. As a result, an external underpower relay is redundant and unnecessary.

L. Additional Protection & Application Considerations

Associated with the use of ASDs are new factors which must be considered which do not occur on fixed speed across the line operation

1) Synchronizing Bypass*:*

In the event that a bypass contactor is used in conjunction with an ASD, a standard across-the-line protective configuration must be used at the line side of the bypass contactor branch. This is because the motor will bypass the ASD electronics and most protective functions, requiring independent across-the-line protection.

As explained above, many of the key downstream protective functions required for an ASD-driven motor are included with the internal protective settings in modern ASD controllers. Table A-1 has been provided in Appendix A listing the motor protective functions provided by a number of medium voltage and low voltage ASD topologies. As can be seen from the table, while some ASDs provide more comprehensive integral motor protection than others, there remain typical motor protective functions which are not covered in the ASD control which require discrete protective devices to supplement the drive control. It is the responsibility of the engineer to ensure that all necessary protections are covered whether it is internal or external to the drive.

2) Common Mode Voltage*:*

Although common mode voltages do not need to be considered in across-the-line applications, use of an ASD can potentially create a common mode voltage at its output. Since common mode voltage can lead to circulating currents and static charge build up, common mode overvoltage protection should be considered on the load side of the drive.

ASD manufacturers have taken common mode voltage concerns into consideration, and have developed methods to reduce this voltage at the output of the drive. In addition these drives typically have a protective function setting for common mode overvoltage. Finally, proper grounding techniques at the motor will limit the negative effects common mode voltages have on the motor.

IV. CASE STUDY

The idea for this paper originated from the intermittent nuisance tripping of a user's ASD caused by a load side protective relaying. Prior to the installation of the ASD, the original pump configuration consisted of a 3000 HP motor design to push product on the average rate of 25,000 bbl per hour, which was protected with a power fuse and a solid state protective relay. The protective relay's trip signal was designed to open an across the line starter in the event of a fault.

After several years of service and with the advantage of utility rebates the pump was upgraded with an ASD. The improved design consists of utilizing the existing across-the-line-starter as the main disconnect for the ASD switchgear, which consisted of a load-break switch, a line reactor, and a capacitor bank. The existing solid-state relay was left in place with the motor RTDs still connected to the relay. An additional solid-state relay was added on the output side of the drive designed to protect the motor.

The solid-state relay had the following protective functions enabled:

- Phase Reversal
- Thermal Overload
- Instantaneous Overcurrent

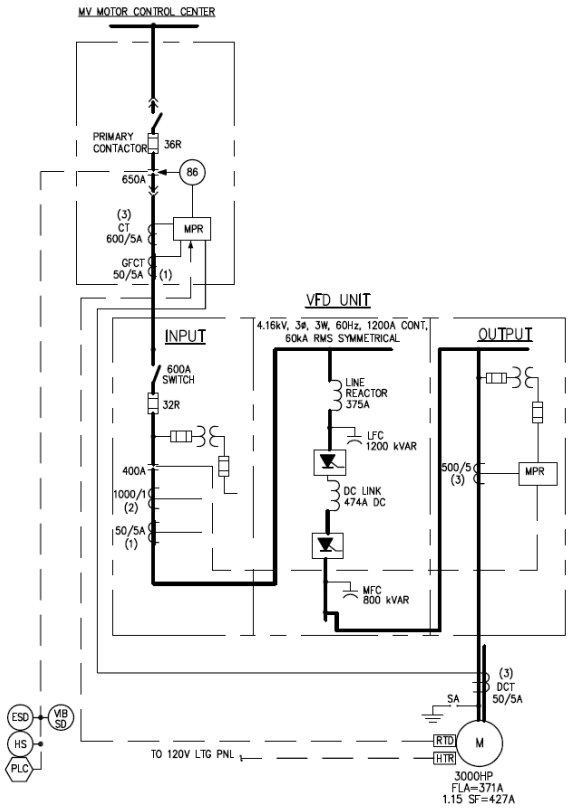

Fig. 9 – Case Study Single Line Diagram

While the ASD had the following protective functions enabled:

- Overcurrent (with Time Delay)
- Thermal Overload
- Overvoltage
- Overspeed
- Common Mode Voltage
- Motor Stall
- Current Unbalance
- Load Loss
- Flux Unbalance

The drive was programmed to ramp the motor up to speed within four minutes to allow for proper valve transition sequence. During the start up sequence, the solid state relay would intermittently trip the drive offline after about three minutes once the output frequency of the drive reached 40Hz. The trip output was caused by the pickup of a phase reversal fault condition on the secondary solid state relay. The ASD HMI did not indicate phase reversal, nor was there any fault triggered within the ASD system, and proper phasing was present at the motor.

As previously described, a phase reversal relay is rated for particular frequencies over a particular range. Once that range has been exceeded the relay may trip on a false phase reversal reading caused by this variation in frequency. The user later determined that the use of a phase reversal function on the output side of the ASD was counterproductive, and their ultimate decision was to turn the phase reversal function off, removing the nuisance tripping problem.

V. CONCLUSIONS

The application of load side protection on an adjustable speed application leads to many complications beyond those typically addressed for across-the-line applications. Each protective function has to be evaluated independently, while including the condition that an output signal has variable frequency, variable voltage, added harmonics, and other challenges, such as common mode voltage. Most standard relay devices are not equipped with the capability to analyze a power signal with these varying conditions, and the engineer should consider using the protective functions within the drives themselves when possible to eliminate complexity, and to avoid nuisance trip conditions. It is the responsibility of the engineer to ensure that the required functions are available in the drive. If they are not, the engineer must apply external protective relaying capable of analyzing the variable conditions present downstream of the drive. In addition to ASD protection, the following protective functions should be considered with the use of MPRs: RTDs and stator differential.

Solid state relay manufacturers have recently begun to develop new products with ASD functionality. If additional external relaying is necessary, it is recommended that these new products are considered to facilitate the complexity involved in properly protecting a motor.

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VII. VITA

Raymund Torres served 11 years in the US Navy and was a power distribution electrician for B. Braun Medical. He received his electrical engineering degree from California State University, Fresno in 2006 with emphasis in power and controls and an MBA from Regis University with emphasis on Operational Management in 2013. He is currently a facility electrical engineer for Tesoro Logistics. Mr. Torres is a registered Professional Engineer in the states of California and Nevada.

Amir Haghpanah received his Bachelor of Science in electrical engineering from California Polytechnic State, Pomona in 2005 and his Master in electrical engineering with emphasis on power from California State University, in Northridge in 2010. His experience includes design and analysis of heavy industrial plans such as petrochemical facilities, Water and Wastewater Treatment plans and Substation and pipelines. Mr. Haghpanah is currently working as a registered engineer with Mangan, Inc. He has a P.ENG in Alberta Canada and is a P.E. in the states of California, Texas, Arizona, Nevada, Georgia, Utah and New Mexico, He is an active member of PES, IAS and PCIC.

Tryton Bower received his degree in electrical engineering from University of California, Santa Cruz, in Santa Cruz, California in 2009. Since graduation, he has been employed with Mangan, Inc. His primary roles include the installation of low and medium voltage substations and motor control centers. Mr. Bower is a P.E. in the states of California, Texas, and North Carolina.

Robert DeLay has been a sales professional for over thirty years assisting customers in making informed decisions in the specification and selection of computers, control systems, electrical equipment, and associated solutions and services. He has a Bachelors of Science Degree in Electrical Engineering from California State Polytechnic University, Pomona, California and is currently working for Rockwell Automation as a Business Development Manager for the Oil & Gas Industry covering the ten western states. He joined Rockwell Automation in 2004 as a Senior Sales Engineer focusing on the Oil & Gas Industry in Southern California. Prior to that he spent eight years with Honeywell as a Senior Sales Engineer assisting customers in the selection of Distributed Control Systems, Instrumentation, and Advanced Control Solutions in the Refining Sector of the Oil & Gas Industry and ten years with Modular Computer Systems (MODCOMP) representing high-end real-time computers used in High Speed Data Acquisition for the Scientific and Government Sector.

Rick Paes received his degree in electrical/electronic engineering technology from Conestoga College, in Kitchener, Ontario Canada in 1981. Since graduation, he has been employed with Rockwell Automation. His primary roles include the application of various motor starting methods, including medium voltage drives for medium voltage induction and synchronous motors. He is a Senior member of IEEE, past Chair of the PCIC Transportation Subcommittee, current Secretary of the PCIC Marine Subcommittee, Chair of the IEEE 1566 Large Drive Standard, past committee chair for the 2001 & 2007 PCIC conferences in Toronto and Calgary as well as future committee chair of 2017 PCIC in Calgary, past chair of the 2007 Calgary and 2008 Edmonton IEEE IAS Mega Projects workshops. Mr. Paes is a P.L.(Eng) in the province of Alberta, Certified Engineering Technologist in the Province of Ontario as well as a certified PMP.

APPENDIX A

COMPARISON OF LV AND MV ASD MOTOR PROTECTIVE FEATURES

Protective Function Typically Applied To Motor Loads	Description Of Function	Functions Included in Medium Voltage ASD (Vendor #1)	Functions Included in Medium Voltage ASD (Vendor #2)	Functions Included in Medium Voltage ASD (Vendor #3)	Functions Included in Medium Voltage ASD (Vendor #4)	Functions Included in Low Voltage ASD (Vendor #2)	Functions Included in Low Voltage ASD (Vendor #1)	Functions Included in Low Voltage ASD (Vendor #3)	Functions Included in Low Voltage ASD (Vendor #4)
27	Undervoltage	X	X	X	X	X	X	X	X
59	Overvoltage	X	X	X			X	X	
59N	Neutral (Common Mode) Overvoltage	X							
47	Phase Reversal	X	X	X	X				X
81	Over/Under Frequency	X	X	X	X	X	X	X	X
50/51	Phase Overcurrent	X	X	X	X	X	X	X	X
50/51G	Ground Fault	X	X	X	X	X	X	X	X
37	Underpower	X	X			X			X
66	Starts Per Hour	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
46	Current Unbalance	X							
87	Stator Differential								
49	Thermal Overload	X	X	X	X	X	X	X	X
38	RTD Protection								
24	Volts/Hertz (Not Required Across-the-Line)	X	X	X	X	X	X	X	X

Table A-1