Considerations for the Protection of Adjustable Speed Drive Installations

Bhairavi Pandya and Derrick Haas
Schweitzer Engineering Laboratories, Inc.

Anil Pandya and Iulian Constantin
Tengizchevroil

This paper was presented at the 69th Annual Petroleum and Chemical Industry Technical Conference, Denver, CO, September 26–29, 2022.

For the complete history of this paper, refer to the next page.

Revised edition released November 2022

Previously revised edition released September 2022

Originally presented at the
69th Annual Petroleum and Chemical Industry Technical Conference, September 2022

CONSIDERATIONS FOR THE PROTECTION OF ADJUSTABLE SPEED DRIVE INSTALLATIONS

Bhairavi Pandya
IEEE Member
Schweitzer Engineering Laboratories, Inc.
5850 Rogerdale Road, Suite #150
Houston, TX 77072 USA

Derrick Haas
Senior IEEE Member
Schweitzer Engineering Laboratories, Inc.
5850 Rogerdale Road, Suite #150
Houston, TX 77072 USA

Anil Pandya
Tengizchevroil
QV1 Building
250 St. Georges Terrace
Perth, Western Australia
6000 Australia

Iulian Constantin
Tengizchevroil
74 Harold Street,
Mount Eden, Auckland
1024 New Zealand

Abstract—As the use of adjustable speed drives increases in popularity, additional considerations must be made for adjustable speed drive assemblies. For medium- and high-voltage applications, some of these considerations are as follows:

- Thermal protection of the motor being driven.
- Decreased levels of fault current at the motor level.
- Presence of unconventional multi-legged transformers to feed the drive.
- Introduction of harmonic currents and voltages.

This paper addresses how to protect an adjustable speed drive installation by breaking the application down into specific components: motor, drive, input mechanism, and feeder. The paper provides a brief background on the advantages and classifications of adjustable speed drives, followed by an overview of considerations for protecting adjustable speed drive feeders at different voltage levels. A real-world adjustable feed drive application fed from a high-voltage source is analyzed. Best design practices for selecting protection parameters are also shared.

Index Terms—Adjustable speed drives (ASDs), motor, input transformer, ASD protection, harmonic filter (HF), regenerative braking.

I. INTRODUCTION

With the increasing popularity of adjustable speed drives (ASDs), additional considerations must be made for the feeders protecting the motors run by ASDs. This paper addresses some of the specific considerations while protecting a feeder to an ASD controlled motor load. Section II includes a brief background and explains the advantages and classifications of ASDs, while Section III is an overview of approaches to protection of an ASD feeder. Sections IV and V discuss a real-world application of a large ASD fed by a 110 kV gas insulated switchgear (GIS). The paper concludes with a summary of protection methods.

II. BACKGROUND

As is evident by the name, an ASD provides the ability to control a motor's speed dynamically to meet the requirements of the driven load. Apart from the ability to control the speed on an alternating current (ac) machine, the following are some of the main advantages of ASDs from an operational point of view [1]:

- Accurate torque control.
- Reduced starting current.
- Reduced short circuit contribution.
- Reduced power consumption.
- Reduced motor maintenance.

Fig. 1 is a simplified representation of an ASD. The source feeds into a full wave rectifier, which feeds into the filter to be smoothed out, and then into a direct current (dc)-ac module that converts the dc to variable ac waveforms with desired frequencies. Depending upon the type of application, additional blocks, e.g., input transformers and harmonic filters (HF), can be a part of the assembly.

A wide range of ASDs are available for motors as small as 0.37 watts or as large as several megawatts. ASDs can be categorized by the methodology they employ for voltage wave conversion, including the following popular methods: variable voltage inverter, current source inverter, and pulse width modulation [2]. Another important criterion to classify the ASDs is the type of loads they control. The load characteristics may present constant or variable torque requirements.

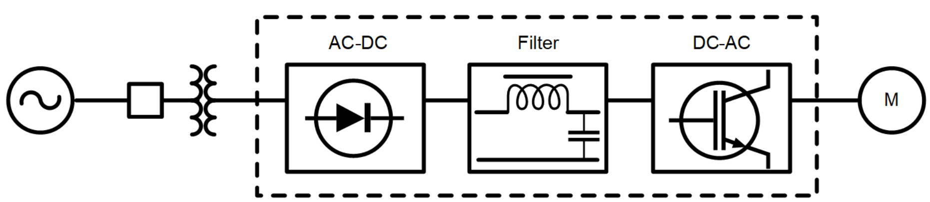

Fig. 1 Simplified Representation of a Typical ASD

When it comes to the protection philosophy, the topology of the ASD assembly is very important. The popular topologies can be broadly split into two: ASDs that are used only for a part of the motor's duty cycle, and ASDs that are in service for the entire duration of the motor operation. Because of their ability to reduce the starting current, ASDs may be used as a soft starter on smaller motors. For economic reasons, using a single ASD to start multiple motors is also common practice in the industry. For larger motors or motors that need a continuous speed control, torque control, or a combination of both, ASDs are in operation 100 percent of the time the associated motor is in operation.

In both cases, ASDs may be provided with a bypass mechanism that can take the ASD out of the system under a variety of circumstances (e.g., when there is a fault in the ASD assembly or when the ASD's output frequency matches that of the source or line frequency, or in other words, when the motor reaches full speed).

III. PROTECTION OF ASD FEEDERS

When protecting a feeder to an ASD controlled motor, there are four major components that must be considered: the feeder, the input transformer (if present), the ASD itself, and the motor [3] [4] [5]. Depending upon the amount of harmonic content, a fifth component in the form of a HF may also be a part of the assembly. The order of the harmonics introduced by the rectifying assembly depends on the rectifier design. An example of one such HF is discussed in Section IV.

Fig. 2 shows an overview of components to be protected starting from the feeder. The different highlighted sections also represent some of the possible topologies. For the remainder of this paper, ASD feeder protection refers to main short circuit protection of the feeder upstream of the ASD, while a motor's supplemental protection refers to protection of the motor itself independent of the drive.

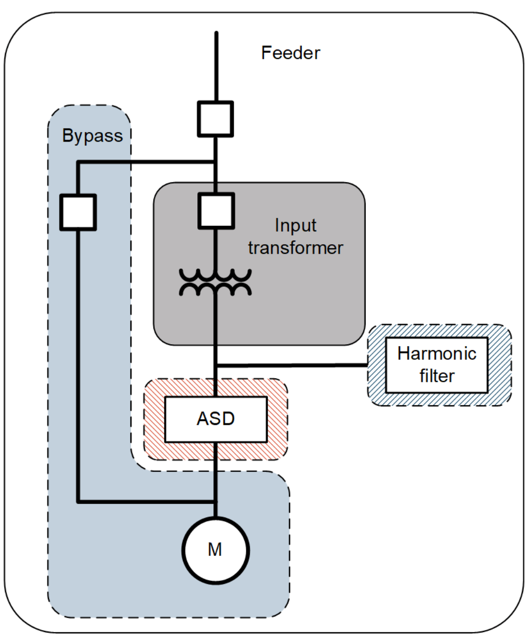

Fig. 2 Components of ASD Feeder Protection

A. Feeder Protection

Feeder protection is the breaker, contactor, or fuse protecting the feeder to the ASD assembly. It is also a form of backup protection for the motor and the drive and is of high importance for all ASD topologies. In cases where the ASD assemblies are already equipped with adequate motor protection, coordinating the rest of the system protection with the drive's built-in protection is of utmost importance.

Feeder protection consists of definite-time (50P/50G) or inverse-time (51P/51G) phase and ground overcurrent elements. Applying an ASD reduces the short circuit current contribution from the motor, and therefore a 51P based on a fundamental frequency may be set to a lower value. Due to its inherent directionality, the distance (21) element is also a good choice for feeders supplying larger motor loads. The element can be set to protect as far as the input transformer or even beyond it.

B. Input Transformer Protection

An input transformer provides a galvanic barrier between the supply and the rectifier. The transformer reactance also helps reduce the short circuit current. Additionally, depending upon the transformer configuration, it may also isolate zero-sequence components. Larger capacity ASDs are sometimes fed by a converter duty transformer. Despite the benefits, the input transformers introduce the following challenges:

- Larger number of windings.
- Nonstandard phase-angle shifts.
- Harmonics introduced by the rectifying and converting components of the drive.

Highly specialized protective devices are capable of effectively addressing the challenges listed here.

C. ASD Protection

Almost all ASD units come equipped with their own protection. While these assemblies require no external protection considerations, the feeder protection should provide sufficient backup protection for them. Protection elements typically included in the ASD and associated electronic components include over/undervoltage, overcurrent, overload, and overtemperature.

Additionally, simple communication-based control commands can also be set up between the ASD control and the feeder protection to trip the breakers faster in case of a fault at the feeder or a fault within the ASD. Interrupting the fault current quickly can save the power electronic components. Another example of an application for a communications-based command is when it is desired to exchange control signals between the ASD and the upstream switching device. A communication-based approach provides the flexibility needed for control actions.

D. HF Protection

Depending upon the size of the motor and power quality considerations, HFs may be necessary to filter out specific harmonic frequencies introduced by the drive. The HFs are often equipped with dedicated over/undervoltage and overcurrent protection along with dedicated switching devices. Ground fault protection may also be necessary. Capacitor components in larger units may also be equipped with phase current or voltage unbalance protection (60) [6].

E. Motor Protection

The use of ASDs introduces unique challenges when protecting the motor being controlled by the ASD. The ASDs controlling 100 percent of the motor's operation come equipped with motor protection in addition to the protection of the ASD assembly. In such a case, simply providing ASD feeder protection is generally sufficient. However, forms of supplementary protection features may be provided.

Because of the nonrated frequency applied to the motor, special considerations must be made while choosing the sensing and protective devices. In the case of an air-cooled motor run at low frequency, the motor's cooling may be negatively impacted. In such cases, temperature sensors (49R) rather than current and speed sensors may be better indicators of the state of the motor and should be used to provide supplementary protection. Another option to account for the reduced cooling, for certain motors running at lower frequencies/speeds, is included in certain modern digital relays. These devices can adjust their pickup, or in some cases, the full load ampere rating dynamically based on the frequency of the drive output, and reduce the pickup if the motor is running at a lower speed. Effects of off-nominal frequencies and reduced speed on a motor's performance introduced by the presence of an ASD are discussed in [7].

Unbalance-sensing protective elements are additional forms of supplementary protection for motors controlled by ASDs. For example, motor differential (87M) protection using core balance current transformers (CTs) can be provided for large motors. The 87M element must be able to function properly over a broad frequency range.

For applications where the ASD can be bypassed under normal conditions—for example, an ASD simply used as a soft starter and bypassed after the motor starts—conventional motor protection should be applied when the motor reaches full speed. In this case, dedicated motor protection may be provided using a suitable combination of thermal overload (49), resistive temperature detector protection (49R), phase and ground overcurrent (50P/50G), current unbalance (46) and undervoltage (27), load jam and motor differential (87M) elements, and in cases where a direct on-line motor start is permitted, motor start control (66) [8].

IV. CASE STUDY—PROTECTION SCHEME

In this section, the paper analyzes an application of ASD protection where considerations mentioned previously in Section III apply.

Fig. 3 is a simplified representation of the ASD application discussed here. The simplified one-line diagram applies to a set of 11 mostly identical applications, each fed from a breaker-and-a-half bay of 110 kV GIS. The drives feed compressor motors in the 30 to 50 MW range. The 110 kV feeders supplying the input transformers and drive are all less than 1 kilometer in length for all 11 applications. The protection philosophy remains the same for all 11 applications despite minor differences and shall be discussed. The ASD runs the motor for the entire duration and cannot be bypassed.

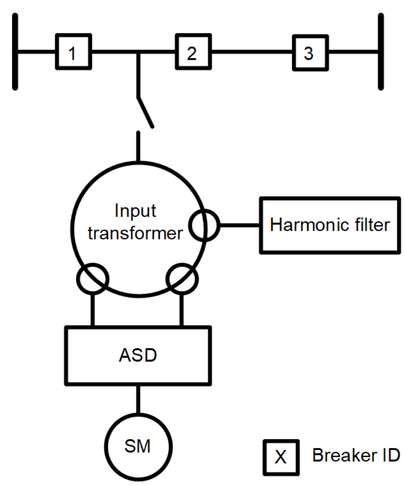

Fig. 3 Simplified One-Line Diagram

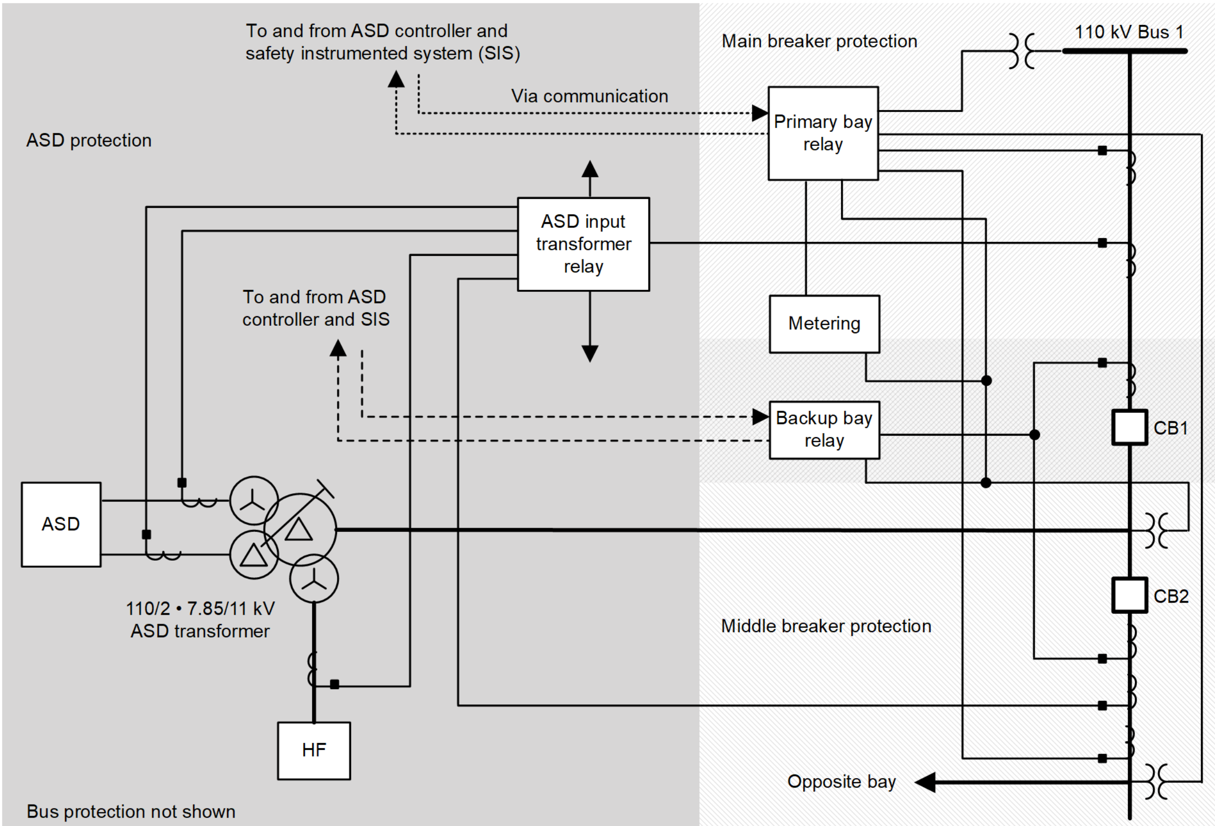

Fig. 4 Overall ASD Bay Zones of Protection

Fig. 4 shows the overall CT and potential transformer (PT) arrangement used for protective relaying and metering for a bay feeding an ASD assembly.

For simplicity, the discussion of the application is broken down into the following parts:

A. 110 kV GIS protection.
B. ASD input transformer protection.
C. HF protection.
D. ASD and motor protection.

Table I provides a list of active elements for each ASD bay but does not provide a complete representation of the overall protection philosophy. Different system components outside the scope of this paper (such as busbar protection and operation of the opposite bays) impact the overall application.

A. 110 kV GIS Protection

The ASD assemblies are fed by a breaker-and-a-half 110 kV GIS. The GIS protection philosophy uses a dual-redundant mode of protection for various circuit types within the GIS. Dual-redundant here refers not only to the protection functions, but also to the two completely independent hardware protection platforms performing identical primary and backup protection functions (see Table II).

TABLE I
ASD APPLICATION ACTIVE PROTECTIVE ELEMENTS

Circuit Type	Protection Functions
110 kV GIS incoming line	Phase and ground distance (21P/21G) Nondirectional phase and ground overcurrent (50P/51P and 50G/51G) Breaker failure Stub bus protection Bus differential (main breakers only) Synchronism check (25)
ASD input transformer	Transformer differential (87T) Nondirectional phase overcurrent (50P/51P) Buchholz relay (80) Transformer dissolved gas monitor (95)
HFs	Nondirectional phase overcurrent elements (67P/51P) Neutral voltage displacement
ASD and motor	Thermal overload (49) Abnormal pressure (63) Low liquid level (71)

TABLE II
GIS PROTECTION FUNCTIONS PER CIRCUIT TYPE

Circuit Type	Primary Protection	Backup Protection
Short lines to other substations	Line differential element (87L)	Phase and ground distance elements (21P/21G) or phase and ground overcurrent elements (50P/51P and 50G/51G)
Radial lines feeding load directly	Phase and ground distance elements (21P/21G)	Phase and ground overcurrent elements (50P/51P and 50G/51G)
Incoming supply lines from GTG units	Phase and ground overcurrent elements (50P/67P and 50G/67G)	Phase and ground overcurrent elements (51P and 51G)
110 kV GIS buses	Low-impedance bus differential protection (87B)	High-impedance bus differential protection (87Z)
All circuit types	Breaker failure Stub bus overcurrent (primary relay)	Breaker failure Stub bus overcurrent (backup relay)

The protection encompasses other circuit types including, but not limited to:

- Short lines to other substations.
- Short radial lines directly feeding loads via step-down transformers.
- Incoming supply lines from gas turbine generator units (GTGs).
- 110 kV buses.

Fig. 5 shows the zones of protection for the 110 kV GIS bay, and Table II provides an overview of primary and backup protection functions used to protect the 110 kV GIS. The primary protection philosophy of the GIS relaying is designed to not overreach into other system components; however, the scheme includes various combinations of overcurrent (directional or nondirectional) or distance protection functions that are expected to operate when the primary modes of protection fail.

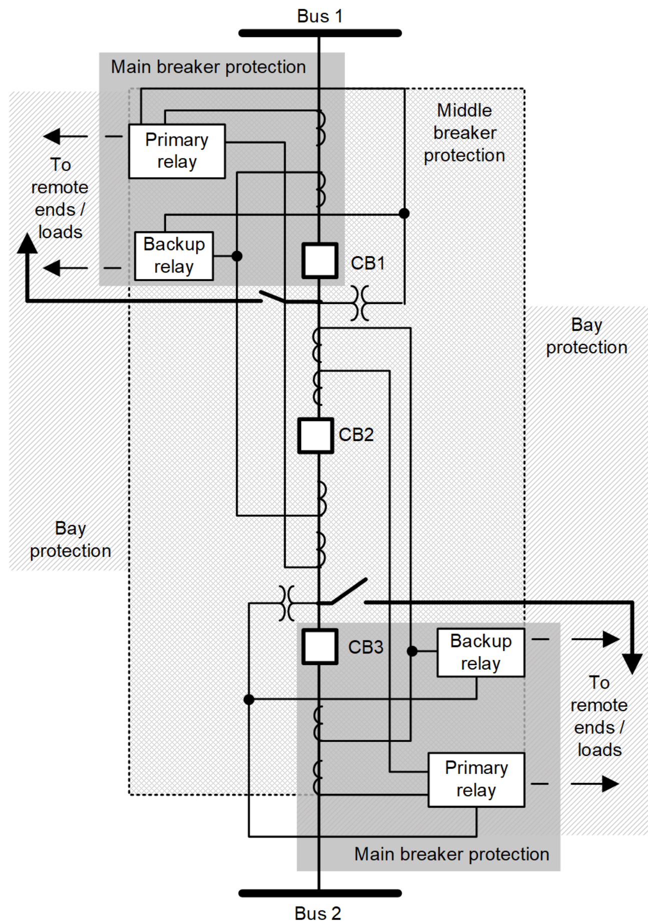

Fig. 5 110 kV GIS Bay Zones of Protection

B. ASD Input Transformer Protection

Fig. 6 shows the zones of protection for the four-winding (110 kV/7.85 kV/7.85 kV/11 kV) ASD input transformer with a Dd0y11y11 phase shift. The 110 kV winding (D) is fed by the GIS bay. Two of the three secondary windings feed the ASD (d0 and y11 at 7.85 kV), with the fourth winding (y11) feeding the HF (11 kV). The ASD input transformer relay protects the ASD transformer, as well as the high-voltage and medium-voltage cables. When it detects a transformer fault, it sends trip commands directly to the GIS breakers of the ASD bay and the ASD controller.

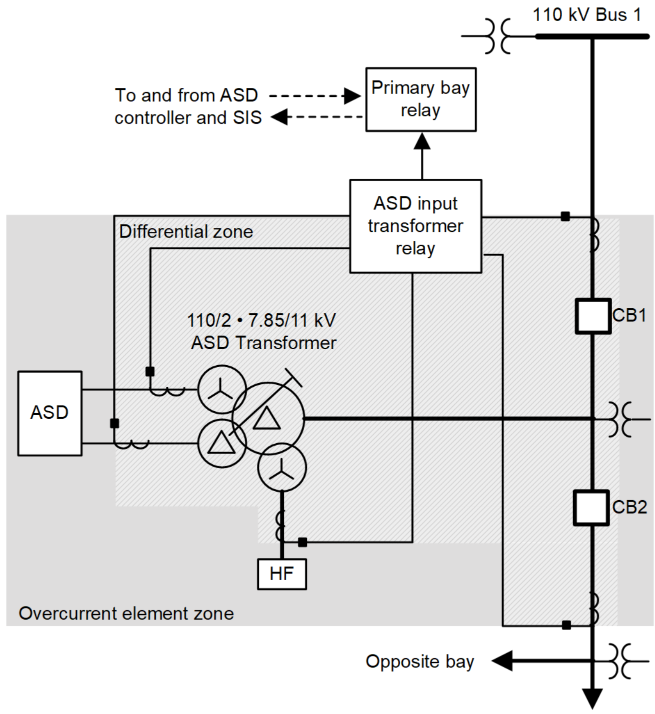

Fig. 6 ASD Input Transformer Zone of Protection

A conventional phase shift of Dd0y11y11 and adequate CT connections provided at each winding make the traditional transformer differential (87T) protection feasible. The transformer differential protection provides dedicated and secure protection using an adaptive-slope percent restraint characteristic for faults internal to the differential zone. Nondirectional overcurrent elements on all four windings provide backup protection to the incoming lines, the ASD, and the HF.

C. HF Protection

The ASD assembly uses a twelve-pulse rectifier, which introduces significant voltage and current harmonics. The HF is designed to filter harmonics of the 5th, 7th, 11th, and 13th order. As shown in Fig. 7, the 11 kV HF arm splits into two separate filtering circuits, each with a dedicated circuit breaker and protective relay. The relays provide nondirectional overcurrent protection to each arm. Given that the ASD and the HF are ungrounded, a neutral displacement voltage element is also set to protect for any ground faults.

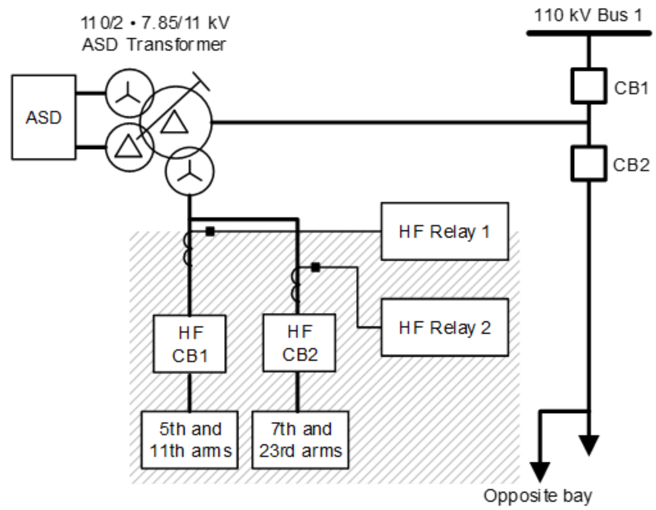

Fig. 7 HF Zone of Protection

D. ASD and Motor Protection

The ASD application discussed here is a standalone application without a bypass; in other words, it runs the motor during its entire operation. The ASD controller provides protection for both the drive and the motor.

Fig. 8 shows the zone of protection of the protective functions performed by the ASD controller. In addition to current- and voltage-based protective functions, the controller also performs thermal and overspeed protective functions. Protection, supply, and control of the fully redundant brushless AC exciter is also included in the complete converter line up; however, it is not discussed here for brevity.

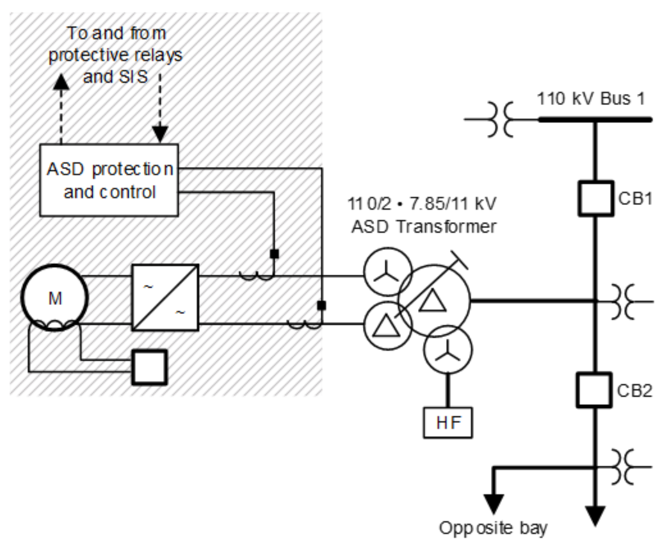

Fig. 8 ASD and Motor Zone of Protection

V. CASE STUDY—OPERATIONAL PHILOSOPHY

The system components described in Section V must work together in harmony to provide smooth operation of the motor via the ASD.

The GIS protection relays exchange trip and control signals with the ASD control panel, the safety instrumented system (SIS), and ASD input transformer relay. The mode of this signal exchange distinguishes the 11 applications, as the signals are hardwired in 4 of the 11 applications, while the remaining 7 applications use fiber optic-based communication protocol for this signal exchange.

A. Tripping Scheme

All protection trips from the ASD controller, the ASD input transformer relay, and the GIS relays trip the main and middle 110 kV GIS bay breakers. The trip signals are sent to the ASD controller. While the HF arms are equipped with dedicated circuit breakers facilitating fault isolation without interrupting the drive operation, certain trips from the HFs can be sent to the ASD controller. The trip command from the ASD controller uses a normally closed contact, while all other protective trips use a normally open contact. The breaker-and-a-half configuration of the 110 kV GIS also means that both main and middle breakers must be tripped in order to isolate trips along any part of the bay. The only exception to this is a bus-protection trip (87B or breaker failure), where an internal bus fault can be safely isolated without tripping the middle breaker, ensuring continuity of supply to both bays forming the breaker-and-a-half configuration.

An important feature of the tripping scheme is the pretrip signals sent to the ASD controller. The ASD controller must initiate a drive shutdown prior to the 110 kV breakers opening to avoid any abnormal conditions, including potential mechanical damage in some cases. The controller is capable of a drive shutdown within 80 milliseconds.

As a part of the shutdown sequence, ASDs may employ different static or dynamic braking mechanisms. This particular drive has a static braking feature enabled to help ensure proper shutdown of the power electronics components. Several varieties of dynamic braking are available, including braking resistors and dc injection [4] [5].

The drive in some installations is configured so that excessive mechanical energy, as the motor is spinning down, is exported onto the ac system. Such a mechanism requires specific design criteria on both the inverter and the rectifier of the drive system to allow power to flow from the motor back onto the power system. Often dynamic and mechanical braking systems are used together. In certain situations dynamic braking does not work as well. For example, dynamic braking does not keep a mechanical load stopped when the drive is disconnected, and in such a case both dynamic braking and mechanical braking systems work together.

From a practical standpoint, this means that for most conditions when the motor is stopped suddenly, the drive performs dynamic braking to avoid damage to the mechanical load. This dynamic braking method requires the ac system to serve to dissipate excess energy, versus other systems where braking resistors or dc injection are used. When the motor is tripped offline due to a protective relay, a signal is sent to the drive to allow it to start the dynamic braking controls before the breakers open. There is no intentional time delay between issuing the preleading trip signal and the breaker trip signal. However, if the drive shutdown times are longer, then a short time delay may be necessary to add to all breaker trip signals. Weighing the risk of mechanical damage of the motor against delaying the protection system during an actual fault is necessary in these situations. The timing diagram in Fig. 9 shows the timing of the preleading trip signal, drive shutdown, and breaker opening using generic values; here the drive finishes stopping before the breakers open with some margin. For systems like this, field validation of actual operation times of the drive, breaker, and other components are important to ensure proper operation of the system.

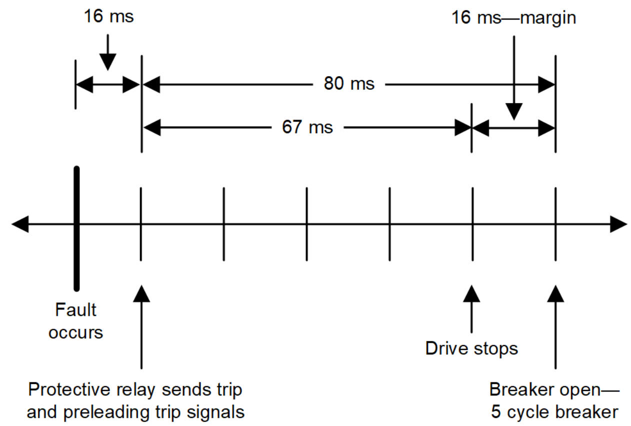

Fig. 9 Trip Timing Diagram

The GIS protection relays send a preleading trip under the following conditions:

- Distance or overcurrent trip.
- Main or middle breaker failure detected.
- Middle breaker failure intertrip received from the opposite bay.
- Busbar trip and middle breaker is open.

A preleading trip is sent only when the line disconnect switch is closed. If the line disconnect switch is open, this signal is not sent for any of the conditions listed above.

The ASD package has a SIS. Trip commands from the SIS are wired to the GIS relays as well as directly into the breaker trip circuits. The SIS trips are also a part of the pretrip signal to the ASD controller.

B. Breaker Failure Scheme

Breaker failure protection is provided by both primary and backup GIS protection relays. A comprehensive review of the breaker failure scheme for the 110 kV GIS is beyond the scope of this paper; however, the ASD bays, their associated breakers, and relays do participate in the breaker failure scheme.

Breaker failure initiates (BFIs) are signals initiating a breaker failure protection trip and can be categorized into two types. A BFI is considered “internal” when the signal is generated within the protective relay itself—all protective functions, listed under Table III, initiate internal breaker failure in the 110 kV GIS relays. In contrast to the internal BFI signal, a BFI signal is considered "external" when it is received from a different device within the protection scheme.

TABLE III
EXTERNAL BREAKER FAILURE INITIATE (BFI) SIGNALS

Protection Device	Protection Functions That Initiate Breaker Failure	Initiates Main Breaker Failure	Initiates Middle Breaker Failure
Primary bus-protection relay	87B or main breaker failure	Yes	No
Secondary bus-protection relay	87B or main breaker failure	Yes	No
Opposite bay primary relay	Middle breaker failure	Yes	No
Opposite bay backup relay	Middle breaker failure	Yes	No
SIS	SIS Trip	Yes	Yes

For an internal BFI, the relay measures the line current. If the line current stays above the threshold longer than the breaker failure time and the relay continues to receive a breaker closed status (52A) from either the main breaker or middle breaker, then the relay declares a breaker failure condition. It uses the breaker status 52A/52B along with current supervision to declare a breaker failure condition. The relay does account for contact status discrepancy and uses both 52A and 52B contacts to establish breaker closed status. In other words, 52A should be asserted and 52B should be deasserted simultaneously for the relays to declare breaker closed status.

When the BFI is received as an input from the bus-protection relay, the line may remain energized because the fault may not be on the line. However, if the main breaker has failed and the fault is in the bus, a high current is still expected to flow on the line. A combination of breaker status (52A/52B) and line current is used to declare breaker failure.

C. Control Commands

In addition to trip commands, the ASD control panel also issues breaker open and close commands. Open and close control signals are deemed less critical than trip commands and are sent to the primary GIS protection relay only. The primary GIS protection relay performs the breaker open and close function via normally open output contacts. Open commands are not deemed critical and do not initiate a BFI. The ASD controller sends a single open and close command to both breakers simultaneously. In other words, the command to open both main and middle breakers is the same signal. The close command is also to be applied to both breakers.

A close command must only be performed under healthy system conditions. To ensure safe operation, additional checks described below are performed before issuing a close command:

- No trips present.
- Absence of block-close signal from relay front panel.
- Voltage healthy conditions.

The primary protection relay has an additional ability to block each breaker from closing via HMI/front panel, which is aimed at providing operational flexibility in the events of breakers being unavailable, e.g., a breaker being out of service for maintenance.

Similar to the previously described control functions, voltage healthy condition checks are performed only in the primary protection relay. When the line disconnect switch is open, the relay allows the main breaker to close via both local and remote controls for the following set of combinations:

- Dead line—dead bus close.
- Dead line—dead bus open.
- Live line—dead bus close.
- Synchronism check ok.

For the middle breaker, the reference voltage for synchronism check comes from the line PT on the adjacent bay. For personnel safety, the middle breaker is prevented from closing when the adjacent line is dead. This restriction applies to both local and remote close operations in order to prevent the middle breaker from inadvertently energizing the adjacent bay.

When the line disconnect switch is closed, the ASD controller issues simultaneous close commands to both the 110 kV main and middle breakers received by the primary relay. Closing the two breakers simultaneously could defeat the synchronism-check logic and is not a recommended approach.

The middle breaker on an ASD bay can be opened or closed if the main breaker is closed and when the line disconnect switch is closed. This is done to be able to de-energize the adjacent line even when the ASD is online. Similarly, the main breaker can be opened or closed when the line disconnect switch is closed if the middle breaker is closed. The ASD controls are still able to open and close both the main and the middle breakers if the line disconnect switch is closed; however, a close from the ASD is prevented in an event of a dead supply on the opposite line. This is done in order to ensure personnel safety in case the line is deliberately isolated for any reason such as maintenance.

To prevent simultaneous closing of both the main and middle breakers, a staggered close permissive logic is used which identifies the two breakers as "lead" or "follow" breakers. The lead breaker can be the main or the middle breaker. Simply put, the lead breaker closes first, and the follow breaker closes 0.5 seconds after the lead breaker closes successfully. The assignment of lead and follow breaker status to the main and middle breaker is dynamic and performed automatically by the primary protection relay. The main breaker is the lead breaker and closes first in default conditions. A provision to prevent the close of the main or middle breaker is also provided in the form of pushbuttons.

VI. CONCLUSIONS

As both small and large ASDs become increasingly mainstream, providing adequate protection for all components introduces several interesting challenges. Adjusting the conventional methods of motor protection to account for off-nominal frequencies and lower motor currents becomes a crucial consideration for the protection engineer. The presence of harmonics injected into the system by the ASD introduces additional challenges. While in most cases, the drives come equipped with their own protection for all levels, protection of the ASD feeders and supplemental motor protection must be given due importance. Care must be taken when designing tripping and breaker failure protection to account for dynamic braking and other operational considerations for ASDs.

VII. REFERENCES

[1] J. D. Gardell, P. Kumar, and T.A. Farr, "Adjustable Speed Drive Motor Protection Applications and Issues," *IEEE Transactions on Industry Application*, Vol. 50, Issue 2, March 2014, pp. 1634–1372.

[2] Siemens Technical Education Program, "Basics of AC Drives," Siemens Energy & Automation, Available: electrical-engineering-portal.com/res/Siemens-Basics-of-AC-drives.pdf.

[3] *Eaton Cutler-Hammer Application Guide AP04014005E*, "AC Drive Theory and Application," May 2008. Available: eaton.com/ecm/idcplg%3FIdcService%3DGET_FILE%26dID%3D204675.

[4] IEEE Std 3004.8-2016, *Recommended Practice for Motor Protection in Industrial and Commercial Power Systems*.

[5] IEEE Std C37.96-2014, *IEEE Guide for AC Motor Protection.*

[6] E. Brandi, R. Abboud, and F. Calero, "Protecting Harmonic Filters in a ±600 kV HVDC Installation," proceedings of the 42nd Annual Western Protective Relay Conference, Spokane, WA, October 2015.

[7] R. Torres, A. Hagphanah, T. Bower, R. Delay, and R. Paes, "Adjustable Speed Drives and Motor Protection," proceedings of the IEEE Petroleum and Chemical Industry Technical Conference, San Francisco, CA, September 2014.

[8] A. D'Aversa, B. Hughes, and S. Patel, "Challenges and Solutions of Protecting Variable Speed Drive Motors," proceedings of the 66th Annual Conference for Protective Relay Engineers, College Station, TX, April 2013.

VIII. VITAE

Bhairavi Pandya is a PE licensed electrical engineer with over nine years of experience with a protection focus. Bhairavi has an MSEE from Michigan Technological University with specialization in power systems. She has extensive experience with both domestic and international protection system design and implementation. As a protection engineer for Schweitzer Engineering Laboratories, Inc. (SEL), she specializes in industrial protection systems at various voltage levels. She enjoys commissioning protection systems in various environments across the globe and has commissioned projects in the United States, Italy, Indonesia, and Kazakhstan. She has been a member of IEEE for the majority of her career. Bhairavi can be reached at Bhairavi_Pandya@selinc.com.

Derrick Haas graduated from Texas A&M University with a BSEE. He worked as a distribution engineer for CenterPoint Energy in Houston, Texas, until 2006 when he joined Schweitzer Engineering Laboratories, Inc. (SEL). Derrick has held several titles, including field application engineer, senior application engineer, team lead, and his current role of regional technical manager. He is a senior member of the IEEE and is involved in the IEEE Power System Relaying Committee. Derrick can be reached at Derrick_Haas@selinc.com.

Anil Pandya is a professional electrical engineer with over 31 years of experience covering various aspects including design, operation and maintenance, engineering and construction of greenfield and brownfield projects from concept to commissioning, high-, medium-, and low-voltage power system operation and maintenance, power system protection study, and relay coordination of electrical networks including power generation. He has worked in oil and gas in Australia and Kazakhstan, power generation and water treatment plants in the United Kingdom, and the fertilizer and petrochemical industry in India and Malaysia. Anil has led the design and execution of grassroots projects and plant upgrades and is skilled in analyzing failures, reviewing protection systems, and implementing remedial solutions to achieve power system reliability. Due to his work with industries where highly flammable gases and liquids are used for various process applications, Anil has gained knowledge of selection, installation, and commissioning of the electrical equipment in hazardous areas. Anil can be reached at Anil.Pandya@tengizchevroil.com.

Iulian Constantin is an experienced commissioning engineer with a demonstrated history of working in the oil and energy industry for over three decades. He is skilled in protection and control systems, SCADA, electrical wiring, Modbus, and power transmission and distribution. Iulian has a Master of Science (MS) focused in electrical engineering from Bucharest Polytechnic Institute in Bucharest, Romania. Iulian can be reached at IulianConstantin@tengizchevroil.com.

Previously presented at the 69th Annual Petroleum and Chemical Industry Technical Conference, Denver, Colorado, September 2022.

20221020 • TP7058