Mining Power System

Recommended Power System Design for Mid-size Iron Ore Mines

July 2019

Purpose of this guide

Power system equipment represents less than 5% of a mining project CAPEX but is essential for the safety and availability of the whole installation.

Traditionally, mining power systems have been designed by engineering companies (EPCs) and/or mining end-users applying their industrial process knowledge and their experience from previous projects. This results in robust installations that are often not optimized for cost and footprint because the electrical design process focuses on individual packages rather than considering the whole system.

Electrical equipment manufacturers are not usually involved in the design phase. They are only consulted during the request for quotation process once the design is completed. However, manufacturers have deep knowledge of product cost and technology limitations which could be used to further optimize the cost and reliability of the complete mining power system.

This guide will provide a concrete example of optimization that could be achieved when the end-user, EPC and manufacturer work together at early stage of the project.

Recommended Design Features that respond to Key End-User Needs

Key End-User Needs	Recommended Design Features
Operator Safety: Low risk of arc flash and electrocution accidents	• Limited fault currents by right electrical network architecture and component characteristics • Internal arc tested MV & LV switchgear with intuitive operation, earthed metal barriers and comprehensive interlocks
Low Total Cost of Ownership	• Choice of network voltages and equipment to minimize capital investment and operating costs due to system losses • Optimal power quality to reduce energy bills and avoid penalties • On-line asset management system to reduce maintenance costs
Power availability adapted to process	• High availability power supply for critical loads of process plant and site facilities • Proper protection system coordination to avoid unnecessary outages

Introduction

Mining site characteristics

- Open pit mine,
- Hard rock mineral
- Low grade hematite
- Production: 9 Mtpa
- Altitude: < 1,000 m
- Temperature: -5°C to 40°C
- Relative humidity: 80%
- Dust pollution: high
- Condensation risk: high
- Site surface: 8 km^2

The power system design described in this document is recommended for an open pit iron ore mining site producing 9 million tons per annum (Mtpa) or 25 kt/day.
It is designed **for reduced CAPEX and low total cost of ownership (TCO)** while providing **high level of operator safety**. Cost optimization is achieved using remotely monitored and controlled MV and LV equipment installed in factory-built package substations and E-Houses. An Ethernet based system integrates electrical network management, real time energy consumption and asset condition monitoring with the industrial process control.

Electrical Design Requirements

There is no specific requirement for power supply availability for extraction and crushing operations because the process includes buffer stockpiles. Critical loads in the flotation process need 99.99% power supply availability (< 10 min interruption/y) as any outage would generate significant financial losses.
The power system has an overall power factor (PF) of 0.95 and a Total Harmonic Distortion (THDI) at the point of common coupling (PCC) < 5% to comply with the grid code.

Site Electrical Loads

The main electrical loads for each production process are listed below.

Process type	Load type	Power	Share
Open pit extraction	Drills, shovels, crushers	6 MVA	15%
Ore concentration	Grinding mills, conveyors, flotation, de-watering	26 MVA	66%
Water plant	Pumps	2 MVA	5%
Concentrate handling	Stacker /reclaimer	3 MVA	7%
Ancillaries	Lighting, offices, canteen	3 MVA	7%

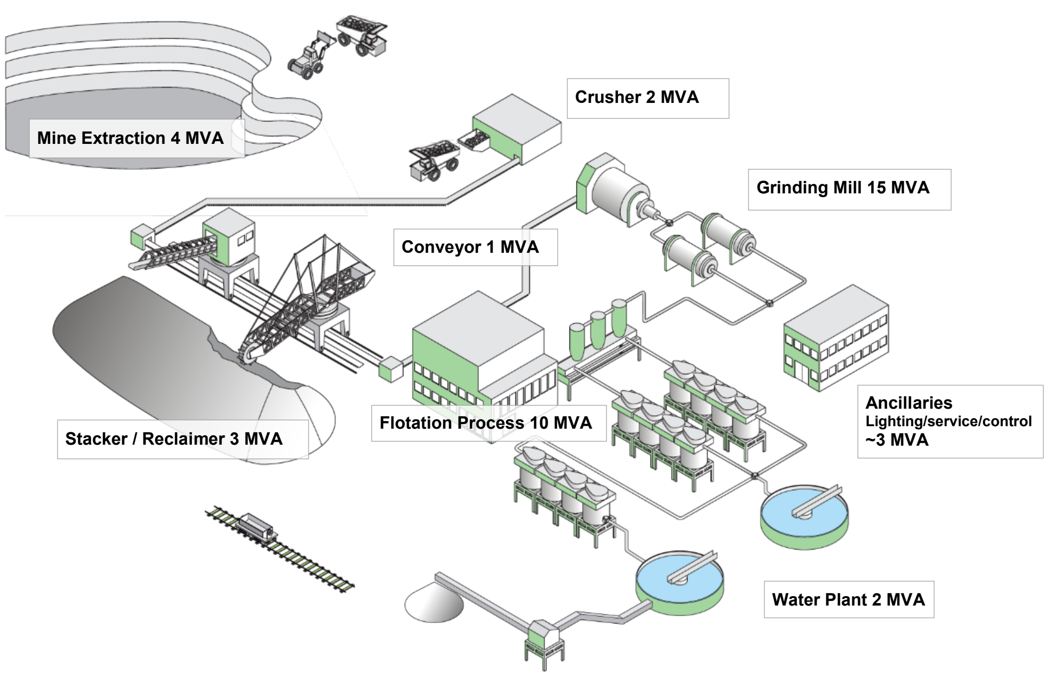


Figure 1

Overview of load distribution

Electrical Network Architecture

Power System Parameters

- Installed power: 45 MVA
- Utility supply voltage: 60 to 230 kV
- Frequency: 50 Hz
- MV levels: 11 kV and 6.6 kV
- MV neutral: resistor earthed
  11 kV network Isc < 25 kA
  6.6 kV network Isc < 25 kA
- LV levels: 690 V and 400 V
- LV neutral: TN-S
- Installation standard: IEC
- Motor load: 90 %
- Site power factor: 0.95
- THDI at PCC < 5%
- Total length of MV cables: 10 km
- Total length of LV cables: 30 km

Connection to the Electrical Utility Network

The capacity contracted from the utility is 45 MVA for a maximum demand of 40 MVA. The utility network voltage depends on the country and HV power line availability near the site. The 40 MVA load is connected to the HV (60 kV to 230 kV) sub-transmission network by single power line to minimize cost. The utility scope of supply includes the HV circuit breaker equipped with tariff metering equipment.

MV Distribution Network Characteristics

To optimize the MV switchgear current rating and cable costs, the main switchboard distributes power to secondary switchboards feeding motor loads and MV/LV transformers. The SAG mill and ball mills are connected directly to the main switchboards.

MV network voltage has a direct impact on TCO. The common practice is to use the same voltage as the local utility, but often this does not provide a cost optimized installation. Cost evaluations using 11 kV, 13.8 kV, 22 kV and 33 kV MV network voltage showed that the lowest TCO is achieved using 11 kV. This choice does not need additional MV/MV transformers to connect MV motors and enables the use of cost-effective MV switchgear, VSDs, motors and cables.

The MV network neutral earthing method determines the earth fault current magnitude and overvoltage level. The design uses a neutral earthing resistor to limit the earth fault current below 30 A. This choice provides a low TCO and high operator safety by limiting arc flash incident energy.

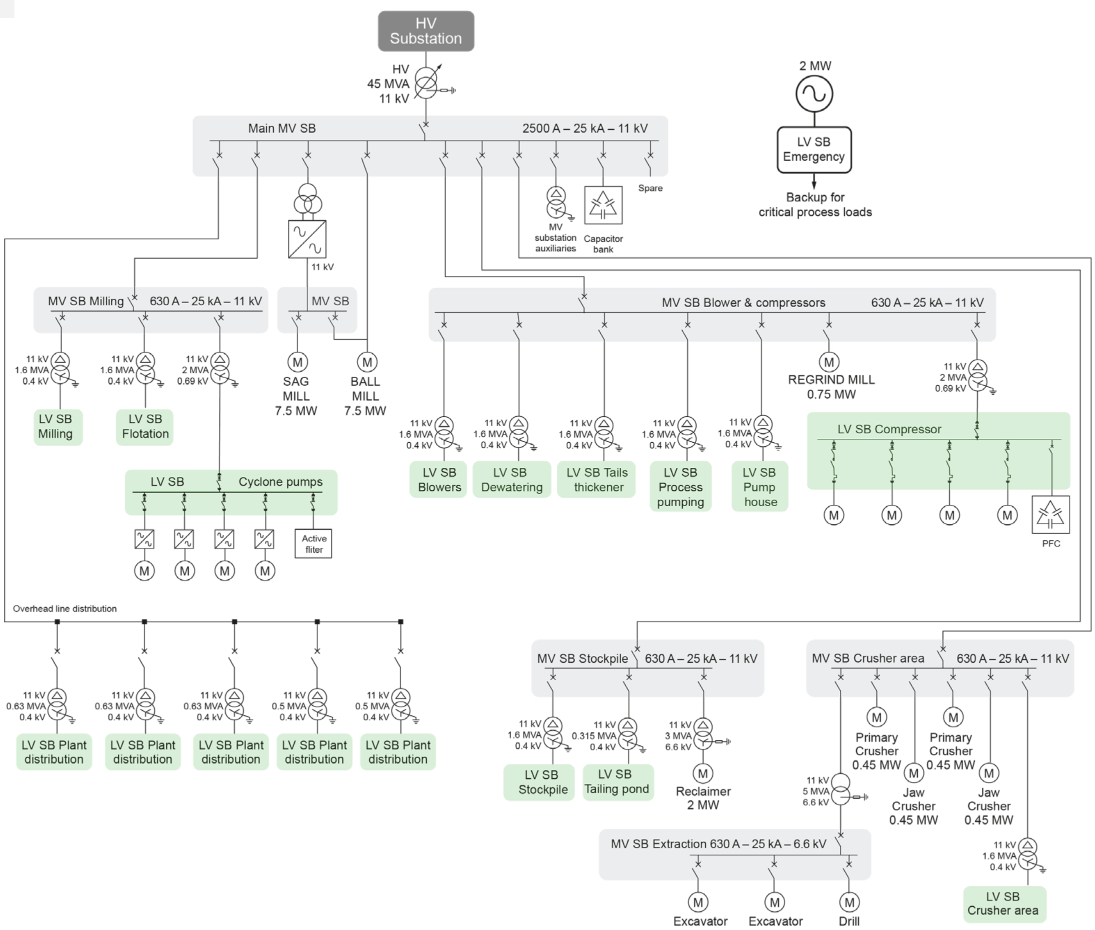


Figure 2

Recommended power system design for a 9 Mtpa iron ore mining

HV/MV transformer

- Primary voltage: 60 to 170 kV
- Secondary voltage: 11 kV
- Rated power: 45 MVA
- Zsc: 15%
- Efficiency: PEI> 99.724 %
- Winding connection: Dyn 11
- Insulation: mineral oil
- Cooling: ONAN
- Installation: outdoor
- Neutral earthing: resistor
- Voltage control: OLTC ± 4 steps of 2.5 %
- Standard: IEC 60076

Condition monitoring system

- Hot spot, oil temperature, dissolved gas analysis

HV/MV Power Transformer

The HV/MV transformer is the most critical asset for its impact on the whole system sizing and cost. The recommended design uses a 45 MVA HV/MV oil filled transformer with normal air cooling (ONAN). The HV/MV transformer short-circuit impedance (Zsc) is an important parameter impacting on the MV network fault current and the choice of MV equipment (switchgear, cables). Analyses have shown that Zsc=15 % value gives an optimum cost/performance ratio as it limits the 11 kV network fault current < 20 kA while allowing Direct on Line (DOL) start of 750 kW motor with an acceptable voltage drop (<15%). The transformer has an automatic On-Load Tap Changer (OLTC) on the HV winding for optimum voltage regulation. A high efficiency transformer with a peak efficiency index (PEI) compliant with the Ecodesign directive is used to minimize TCO due to energy losses.

The transformer availability is improved by a dedicated on-line digital condition monitoring system with temperature, oil and dissolved gas analysis. This plays a critical role as a failure would cause a complete shut-down and a replacement could be long (> 3 months) leading to huge revenue losses.

The Schneider Electric product is Minera MP with a condition monitoring system connected to EcoStruxure^{TM} Asset Advisor, the asset monitoring service for predictive and preventive maintenance.

Main MV Switchboard

- Rated voltage: 12 kV
- Busbar/Incomer CB: 2500 A
- Feeder CB In: 630 A
- Rated Isc: 25 kA
- Cubicle type: AIS LSC2B-PM
- CB type: VCB draw-out
- IAC: 25 kA (1 s) A-FLR
- Cabling: front
- Standard: IEC 62271
- IED Metering: U, I, kW, kVA
- Modbus TCP/IP

Incomer protection

- 50/51, 50G/51G, 64REF, 87T
- Arc flash optical detection

Cable & transformer feeders

- 50/51, 50N/51N

Main MV Switchboard

The main MV switchboard is air insulated switchgear (AIS), rated 12 kV, 2500 A and 25 kA, fitted with withdrawable vacuum circuit breakers (VCB) with motorized racking mechanism to improve operator safety by remote operation. It has A-FLR Internal Arc Classification (IAC) to ensure operator protection against arc flash. Cabling is from the front to minimize footprint in the E-House.

Each panel includes an Intelligent Electronic Device (IED) that provides protection, monitoring and control functions. The HV/MV transformer incomer protection includes overcurrent (50/51), earth fault (50G/51G), restricted earth fault (64 REF) and differential (87T). The main switchboard uses optical arc flash detection to ensure tripping < 100 ms in case of internal arc. Cable and transformer feeders are protected by overcurrent protection (50/51) and (50G/51G). MV DOL motor feeders use IED with advanced motor protection functions. All IEDs have power metering capabilities and communicate via Modbus TCP/IP.

The recommended Schneider Electric equipment is MCSet fitted with EasyPact EXE VCB and Easergy P3 protection and control IED.

Secondary MV Switchboard

- Rated voltage: 12 kV
- Busbar In: 630 A
- Incomer/feeder CB In: 630 A
- Rated Isc: 25 kA
- Cubicle type: 2SIS LSC2B-PM
- CB type: fixed VCB
- IAC: 25 kA (1 s) A-FLR
- Cabling: front
- Standard: IEC 62271
- IED Metering: U, I, kW, kVA
- Modbus TCP/IP

Incomer protection

- 50/51, 50G/51G

Cable & transformer feeders

- 50/51, 50N/51N

Secondary MV Switchboards

To minimize MV cabling cost, the network architecture uses 11 kV secondary switchboards with DOL motor feeders for crushers, MV/MV transformer feeders for excavators, drills and reclaimer and MV/LV transformers feeders for LV loads.

The MV secondary switchboard uses LSC2B-PM shielded solid insulation switchgear (SSIS) with fixed VCBs rated 12 kV, 630 A and 25 kA. The switchboards have A-FLR Internal Arc Classification (IAC) and protection category PA (accidentally touchable) to ensure operator safety. The SSIS cubicles are very compact and can be cabled from the front, minimizing the E-House footprint. The earthed screen allows operation in dusty and humid environments without the need for regular maintenance. The protection functions for cable incomers and feeders are overcurrent (50/51) and (50G/51G). The DOL motor feeders are equipped with dedicated motor protection relays. All IEDs have power metering functions and communicate via Modbus TCP/IP protocol.

The recommended Schneider Electric equipment is PremSet fitted with Easergy P3 protection and control IED.

Package substation
MV Switchboard

- Rated voltage: 12 kV
- Ring switches In: 630 A
- Circuit-breaker In: 200 A
- Rated Isc: 21 kA
- Cubicle type: GIS
- CB type: fixed SF6 - 3 position
- Cable earthing: integral
- IAC: 21 kA (1 s) A-FLR
- Cabling: bottom
- Standard: IEC 62271

Protection & Metering IED

- Relay 50/51 50G/51G
- Metering: U, I, kW, kVA
- Modbus TCP/IP

Ancillary Site Services Power Supply

The electrical power supply to the site ancillary services (offices, canteen and workshop) comprises an 11 kV overhead line and ground mounted 11 kV/0.4 kV substations with embedded remote monitoring, metering and control.

The outdoor package MV/LV substation has 4 components:

- 11 kV 3 position circuit-breaker with transformer protection relay
- 11 kV/0.4 kV oil insulated transformer
- 400 V panel with MCCB feeders and energy meter with Modbus TCP/IP
- Remote Terminal Unit (RTU) with Modbus TCP/IP communication.

This factory-built package provides the lowest cost as it can be installed outdoors without the need for a building and site work. The RTU has an integral fault passage indicator (FPI) and allows remote operation of the circuit-breaker from the electrical network control system.

The Schneider Electric recommended products are the Ringmaster CN2 circuit-breaker, Minera transformer, NS Feeder Pillar, PM5000 power meter and T300 RTU.

MV/MV transformer

- Primary voltage: 11 kV
- Secondary voltage: 6.6 kV
- Rated power: 5 MVA
- Zsc: 8 %
- Winding connection: Dyn 11
- Insulation: mineral oil
- Cooling: ONAN
- Installation: outdoor
- Neutral earthing: resistance
- Standard: IEC 60076

Condition monitoring

- Temperature monitoring
- Communication: Modbus TCP/IP

MV/MV Transformers

The 11 kV/6.6 kV transformer feeds the mining machines in the open pit mine area. The design uses an oil filled unit with normal air cooling (ONAN) rated 5 MVA 11 kV/6.6 kV. The winding connection is star-delta with the neutral point earthed via a resistance. This choice allows to use a cost-effective 6.6 kV switchboard.

A failure on this transformer would stop ore extraction from the mine. As there is stockpile of material, the process can continue operating for a few days. To avoid any unplanned outages, a basic on-line condition monitoring is fitted to the 11 kV/6.6 kV transformer.

The Schneider Electric solution used is a Minera MP oil filled transformer fitted with condition monitoring connected to EcoStruxure™ Asset Advisor.

MV/LV transformer

- Primary voltage: 11 kV

Type 1

- Secondary voltage: 0.69 kV
- Rated power: 2 MVA

Type 2

- Secondary voltage: 0.4 kV
- Rated power: 1.6 MVA
- Zsc: 6 %
- Winding connection: Dyn 11
- Insulation: mineral oil
- Cooling: ONAN
- Installation: outdoor
- Earthing: TN-S
- Standard: IEC 60076

Condition monitoring

- Temperature monitoring
- Communication: Modbus TCP/IP

MV/LV Transformer

The MV/LV transformers feed the 690 V and 400 V Power Motor Control Centers (PMCC) and VSDs. Standard oil filled ONAN transformers are used to minimize the cost of spare units.

- The 11 kV/ 690 V standard units have rated power of 2 MVA and Zsc 6% to keep In < 1600 A and Isc < 31.5 kA (including 690 V DOL motor contribution). This choice allows the use of cost-effective 690 V PMCC switchboards.
- The 11 kV/ 400 V standard units have a rated power of 1.6 MVA and Zsc 6% to keep In < 2500 A and Isc < 40 kA (including 400 V DOL motor contribution). This choice allows the use of cost effective 400 V PMCC switchboards.

The LV network earthing system is TN-S with separate neutral (N) and protective (PE) conductor.

The Schneider Electric products used are standard Minera oil transformers with thermal monitoring connected to EcoStruxure™ Asset Advisor.

High Power Motors (> 100 kW) Connection & Control Mode

The main motor loads for each production process are listed below.

Motor Power (MW)	Voltage	Process Function	Motor Control	Qty
7.5	MV	SAG mill, Ball mill	VSD	2
1 < P < 2		Drill, Shovel, Reclaimer	VSD	3
0.4 < P < 0.8		Crushers, Re-grinder	DOL	5
0.1 < P < 0.4	LV	Conveyor, pumps, filters, blowers, compressors	DOL, SS, VSD	30
0.1 < P < 0.01		Thickeners, pumps	DOL, VSD	130

The optimal choice of voltage and control mode for a given motor depends on the motor rated power, its function in the process and the nearby available voltage level. The choices described below are based on TCO calculations that include equipment CAPEX and energy savings (OPEX):

Grinding mills

The grinding process uses 2 mills driven by 7.5 MW induction motors connected to the main 11 kV switchboard to avoid additional transformers. The SAG mill requires a high starting torque and variable speed control to adapt to the type of rock load.
The ball mill also needs a high starting torque but once it reaches rated speed it can run without variable speed control. The design uses a single 11 kV VSD shared between both machines. The VSD starts the ball mill with high torque, synchronizes its output with the 11 kV network to ensure a smooth transfer of the motor to the system. The output is then transferred by a VCB to the SAG mill feeder to start the motor and control its speed at the value required by the milling process.

Re-grinding mill

This is a small mill that re-grinds the concentrated ore obtained from the flotation process. It is driven by a 750 kW induction motor at constant speed and is connected as a DOL feeder to the 11 kV secondary switchboard to minimize voltage dip during the start.

Air compressors

These compressors are used in the flotation process to blow air in the tanks.
They are driven by 280 kW motors connected to 690 V and controlled by DOL feeders to reduce cable costs and voltage dips.

Cyclone feed pumps

These pumps inject clean water in the flotation process. They are driven by 370 kW motors. As the load is variable, they are controlled by VSD to save energy.
To optimize the CAPEX, they are connected to 690 V to reduce VSD and cable cost.

Crushers

These mining machines break the rock into pieces of several cm. They are driven by 450 kW motors connected to 11 kV by DOL feeders to minimize the voltage dip at startup.

Mining machines

Drills and shovels are used in the open pit for extraction, handling rocks and loading them onto trucks. They are driven by several motors with a total power between 1 MW to 2 MW, supplied as a package by the machine OEM. They are connected to a 6.6 kV mobile substation and controlled by VSDs.

MV VSD for SAG and Ball Mill Control

The 11 kV VSD controlling the SAG and Ball Mill uses a multi-winding phase shift transformer and a series connected single phase LV IGBT inverter with Pulse Width Modulation (PWM). This multilevel architecture provides a smooth output voltage and a low current distortion on the grid side. This drive topology avoids the need for any harmonic mitigation equipment, reduces motor losses and prevents harmful vibrations and torque pulses.
The VSD is equipped with sensors to continuously monitor the condition of the input transformer, the power electronic modules and the MV motor. Connected to the asset management system via Ethernet, it provides preventive and predictive maintenance.

Sharing the 11 kV VSD between the SAG and Ball Mill motors is controlled by two MV circuit breakers located in the same E-House. The MV panel is similar to the secondary MV switchboards. It uses fixed VCB rated 12 kV, 630 A, 25 kA capable of 10,000 operations fitted with an IED providing overcurrent (50/51) and earth fault (50G/51G) protection. SSIS technology is chosen to reduce the E-House footprint and provide maximum operator safety.

The Schneider Electric products used in this design are:

- Altivar Process ATV 6000 (11 kV, 7.5 MW VSD) with Ethernet/IP and Modbus TCP/IP
- PremSet SSIS fixed VCB MV panels.

MV VSD

- Rated input voltage: 11 kV
- Rated motor power: 7.5 MW
- Rated output voltage: 11 kV
- Overload: 150% -1 min/10 min
- Output frequency: 0.1-120 Hz
- Efficiency: > 96 %
- Power factor: ≥0.96 from 20% to 100 % load
- Input TDHI < 1.5%
- Output THDU <2%
- Control mode: torque, speed
- No of quadrants: 2
- Local HMI: 10” LCD touch screen
- Cable entry: bottom
- Degree of protection: IP31
- Cooling: forced air ventilation
- Communication: Ethernet IP
- Standard: IEC 61800

LV switchboard **Common specification**

- Max rated voltage: 1000 V
- Form of separation: 3b
- Degree of protection: IP31
- Power & control cables: front
- Local control: Manual & HMI
- Auxiliary voltage: 24 V DC
- Standard: IEC 61439

Incomer ACB functions

- 49 RMS, 50/51, 51 N
- Metering: U, I, kW, kVA
- Communication: Modbus TCP/IP

Power Feeder MCCB functions

- Electronic trip unit
- Metering: U, I, kW, kVA
- Communication: Modbus RTU

LV iPMCC - **690 V**

- Busbar/ Incomer ACB: 1600 A
- Rated Icw: 31.5 kA – 1s
- Internal arc: 31.5 kA (0.3 s)

LV iPMCC - **400 V**

- Busbar/ Incomer ACB: 2500 A
- Rated Icw: 40 kA – 1s
- Internal arc: 40 kA (0.3 s)

LV Power and Motor Control Center Switchboard

The power control center (PCC) and motor control center (MCC) panels are LV switchboards that groups all LV motor feeders for a given part of the process and LV power feeders for non-motor loads such as lighting and HVAC. The LV switchboard has a horizontal busbar that distributes power to the vertical busbars that connect the LV feeders.

The LV switchboards use cable compartments accessible from the front to minimize footprint in the E-Houses and to simplify maintenance.

Each feeder is accommodated in a functional unit (FU). These can be withdrawable, disconnectable or fixed according to the load criticality. The MCC switchboards have Form 3b segregation between compartments and IP31 degree of protection.

PCC and MCC use IED (Intelligent Electronic Device) that can provide information over an internal network which can further support communication networks to higher level systems. This configuration, known as Intelligent Power Motor Control Center (iPMCC), is adopted in this design to reduce TCO and increase system availability.

The “power” side of the switchboard includes two types of FUs:

- **Transformer incomer:** withdrawable Air Circuit Breakers (ACB) equipped with a control unit with energy metering, circuit protection and control with Ethernet protocol. The protection functions include overload (49RMS), short-circuit (50/51) and earth fault (51N).
- **Power distribution feeders:** withdrawable Molded Case Circuit Breakers (MCCBs) equipped with a control unit for protection and measurement and Modbus RTU communication.

DOL Feeders

- Rated voltage: 400 V & 690 V

All-in-one motor starter

- Motor: < 15 kW
- Protection: IMPR
- Coordination: Total
- Measurement: I, V, kW, kVA
- Communication: Modbus RTU

Three discrete components

- Motor: 15 kW < P < 250 kW
- Protection: IMPR
- Coordination: Type 2
- Measurement: I, V, kW, kVA
- Communication: Modbus TCP/IP

The LV motor feeders are arranged in columns that include three types of FUs:

- **DOL Feeders:** most of the motors operate at fixed speed with a direct connection to the network. DOL feeders are used to control 400 V and 690 V motors. They use a combination of MCCB (fault tripping and disconnection function), contactor (motor load on-off switching function) and an Intelligent Motor Protection Relay (IMPR) with energy metering, motor protection, control functions and system connectivity. DOL feeders can use an all-in-one starter for motors < 15 kW and three discrete components for motors > 15 kW up to 250 kW.

  Motor feeders use withdrawable FUs to allow fast replacement in case of component failure. They are installed in the cubicle in half-width drawers for power up to 30 kW to increase the feeder density and reduce the footprint.

Soft Starter Feeders

- Rated voltage: 400 V
- Motor power: 250 kW
- Motor type: asynchronous
- Start current: 3 In < 25 sec
- SS feeder protection: MCCB
- Bypass contactor: 400 A AC3
- Measurement: I, U, kW, kVA
- Communication: Modbus RTU
- Standard: IEC 60947-4-2

- **Soft Starter Feeders:** they are used to control 400 V fixed speed motors that drive air blowers in the flotation tanks. They reduce starting current and mechanical coupling stress during motor start. Soft Starter feeders are placed in fixed FUs that include a MCCB for protection and disconnection, a power thyristor module and a contactor used to by-pass the power electronics module once the motor reaches nominal speed.

VSD Feeders

- Rated voltage: 400 V - 690 V
- Motor type: asynchronous
- Output frequency: 0 - 500 Hz

Standard VSD

- Efficiency > 98 % - THDI < 48 %

Low Harmonic VSD with AFE

- 3 level architecture
- Efficiency > 96 % - THDI < 5 %

- Control mode: torque, speed
- Measurement: I, V, kW, kVA
- VSD feeder protection: MCCB
- Local HMI: LCD touch screen
- Communication: Ethernet/IP
- Degree of protection: IP21
- Standard: IEC 61800

- **VSD feeders:** they are used to control 400 V and 690 V motors driving pumps and conveyors with variable loads to reduce energy consumption.
  VSD feeders include a MCCB for protection and disconnection and a power electronics VSD module. To optimize the cost and the footprint of the E-Houses, units with rated power < 75 kW are integrated in the LV iPMCC switchboard while VSDs with higher power are installed in separate IP21 wall-mounted or floor-standing enclosures.

The iPMCC includes the following safety features to provide a high level of operator protection against electrocution and arc flash:

- IP2X protection (finger safe) against accidental contact with live parts
- Draw-out FU with 3 positions (Connected, Test, Disconnected)
- Safety padlocks and clear indication in each of the three positions
- Internal arc withstands in compliance with IEC TR 61641
- Remote monitoring and operation of all FUs from the Control Room
- Local HMI control panel to minimize drawer opening.

The recommended Schneider Electric LV iPMCC switchboard is Okken or Blokset
The components used in the switchboard FUs are:

- **Incomer:** MasterPact MTZ ACB - Micrologic 6.0 X with embedded Ethernet interface
- **Power load feeder:** Compact NSX MCCB with Micrologic 5/6E and IFE Ethernet communication interface
- **DOL feeders- All-in-one starter:** TeSys U with Modbus RTU
- **DOL feeders- Three separate components:** TeSys GV or Compact NSX MCCB, TeSys D or Tesys F contactor and IMPR TeSys T with Ethernet/IP
- **Soft Starter feeders:** NSX MCCB, TeSys D contactor for by-pass and ATS48 Soft Starter with Modbus RTU
- **VSD feeders:** NSX MCCB, ATV 600 VSD for pumps and blowers and ATV 900 VSD for conveyors and stackers with Ethernet communication.

Power Quality Optimization

Power Quality includes transient voltage variations, harmonic distortion and power factor correction (PFC). A high PQ level is necessary for site energy efficiency and for compliance with the grid code. Failure to meet the utility set PQ values results in heavy financial penalties.

A typical requirement from electrical utilities is to achieve PF > 0.95 and THDI < 5 % at the point of common coupling with the public power supply system.

Capacitor bank

Rated voltage: 400 V & 690 V

- Rated power: 200 to 400 kvar
- Detuned reactor: required with polluted network
- Degree of protection: IP31
- Standard: IEC 61921 & 61439

PF Controller functions

- High temperature alarm
- High harmonic alarm
- Automatic PFC sequence
- Modbus RTU

Power Factor Correction

Power Factor Correction with capacitor banks is required because the main loads are DOL motors with low power factor. All motors driven by VSD have PF > 0.95 and do not require correction.

The solution with the lowest TCO to reach PF > 0.95 in this recommended design uses the following capacitor bank configuration:

- LV capacitor banks with automatic PFC controller connected to each LV switchboard.
- Single MV fixed capacitor bank connected to the 11 kV main switchboard.

The LV PFC equipment has an automatic power factor controller with Modbus RTU communication housed in a floor-mounted IP31 cabinet that is installed in the same E-House as the LV switchboards.

Active Harmonic Filter

Rated Voltage: 400 V / 690 V

- Rated current
  - 300 A @ 400 V
  - 200 A @ 690 V
- Rated frequency: 50/ 60 Hz
- Power module: 3 level IGBT
- Harmonic range: up to 51st
- Correction time: < 2 cycles
- Control system: closed loop
- Degree of protection: IP31
- Modbus TCP/IP

Harmonic mitigation

Harmonic mitigation is required to avoid disturbances of sensitive loads and to comply with the utility grid code or standards like IEEE 519. The objective is to keep the voltage distortion THDU lower than 5% in the installation at MV and LV level and to guarantee a current distortion THDI <5% at the point of connection to the grid.

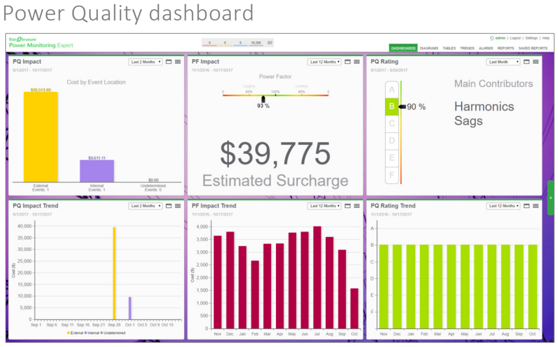
Harmonic pollution is mainly caused by VSDs with diode rectifiers. These standard VSDs cost less than low harmonic models with Active Front End (AFE) but their installation may require additional active harmonic filters (AHF). AHFs use power electronics technology and advanced controllers to generate harmonic currents that neutralize those created by the loads. In this design, the lowest TCO solution to reach the harmonic distortion objectives uses the following arrangement:

- Low Harmonic VSDs (THDI < 5 %) for MV and LV motors > 400 kW.
- LV VSD with diode rectifier (THDI < 48 %) for LV motors < 400 kW with an AHF connected to the LV switchboard to compensate the harmonic pollution.

Schneider Electric products used to meet the site PQ target are VarSet LV PFC equipment and AccuSine PCS+ active filter.

To monitor power quality disturbances, understand issues affecting the process, equipment and power meters are connected to EcoStruxure Power Monitoring Expert which can provide detailed PQ dashboards and reports.

Power Quality dashboard



Emergency Power Supply for Critical Loads

The critical motor loads are tail pumps and agitators in the flotation process.

All critical motors are connected to 400 V iPMCC motor feeders. Their function, rated power and control modes are listed below.

Load	Function	Qty	Motor Rated Power	Control
Tail pump	Cleaner	2	45 kW to 200 kW	VSD
	Flotation water supply	2	110 kW	VSD
Agitator	Conditioners, thickeners	7	5 kW < P < 30 kW	DOL

In case of interruption longer than 10 min, the dissolved material solidifies at the bottom of the tanks and pipes and the installation has to be cleaned before restart. The cleaning process is expensive and takes several days. To avoid this lost revenue, the 400 V switchboards feeding critical motors are provided with an alternative supply from a 2 MVA, 400 V stand-by diesel generator.

ATS Controller 400 V

- Transfer type: Open transition
- Transfer time: < 1 min

Protection

- Undervoltage
- Phase failure

Monitoring and Control

- ACB status
- Voltage presence
- AUTO mode ON
- Genset start/stop
- ACB trip/close
- Load shedding
- Communication: Modbus TCP/IP
- Standard: IEC 60947-6-1

ATS for Motor loads

In case of loss of the main supply, all motor feeders trip, disconnecting the loads. At the same time, the Automatic Transfer Switch (ATS) controller sends a signal to the Generator Control Unit (GCU) to start the diesel engine and opens the transformer incomer ACB. When the generator reaches nominal voltage and frequency, the ATS controller closes the generator incomer ACB to energize the LV switchboard and the control system will automatically re-start all motors.
Once the main power supply is restored, the ATS controller will transfer back the supply and the control system will sequentially re-start all motors. Mechanical interlocks ensure that both ACBs cannot be closed at the same time, which could put both sources in parallel. This open transition method is the most cost-effective solution when the critical loads can accept a supply interruption time of < 1 min.

The Schneider Electric products used in this design are TransferPact ATS equipment, including UA controller and MasterPact MTZ with rod mechanical interlocks, integrated in a single iPMCC column.

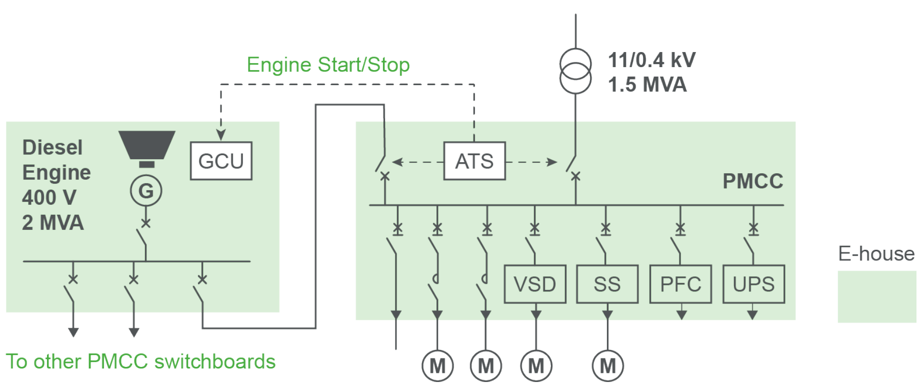


Figure 3

Recommended emergency power supply for critical loads

UPS

- Rated voltage: 400/415 V
- Rated power: 40 to 100 kVA
- Efficiency:
  - 97% with double conversion
  - 99% with ECOnversion
- Modular design
- Battery: Lead acid
- By-pass: integral
- Local HMI: LCD screen
- Degree of protection: IP21
- Cooling: forced air
- Communication: Ethernet
- Standard: IEC 62040-3 Class1

UPS for sensitive loads

Non-motor critical loads, such as the site data center, control room, process automation, fire protection and security systems are backed up by an Uninterruptible Power Supply (UPS) fed from the 400 V switchboard.
The UPS shields sensitive IT loads from the LV network PQ disturbances and provides 30 min battery back-up. A high-efficiency UPS using ECOnversion mode is used providing significant savings (99% efficiency) compared to a double conversion mode without sacrificing load protection. It recharges the batteries and corrects the PF to eliminate harmonics.
The savings are equivalent to the UPS acquisition costs after around two years.
The Schneider Electric product selected is Galaxy VS with Ethernet communication.

Integration in E-House

Characteristics

- Number of E-Houses: 5
- E-House surface: 500 m^2
- Main E-House: Interlock technology
- Secondary E-Houses: ISO container

E-House Design

The Electrical House (E-House) is a factory integrated, tested, validated, compact power distribution solution. The E-House contains Medium Voltage switchgear, LV switchboards, VSD, UPS, HVAC and control systems. It helps to increase safety, reduce construction lead times, optimize the cost of transportation, installation and commissioning and enhance uptime thanks to its qualified and reliable design.

The E-House design process takes several iterations to optimize its cost. The MV/LV network architecture design and equipment selection are done with the aim of reducing equipment footprint, height and weight, which are the parameters that determine the E-House manufacturing costs and transport to site.

E-House Optimization

E-House design optimization is performed using expert engineering capabilities to address the following items:

- Mechanical structure calculation taking into account seismicity, blast, wind response
- Thermal exchange calculation
- Internal arc behavior.

Three levers are applied to optimize E-houses:

- Layout optimization:
  - Footprint: overall dimensions of the E-house
  - Clearances: reduced clearances between equipment to comply with the codes and standards.
- Technology optimization:
  - Choice of adapted E-house type: fully welded, skeletal frame, interlock technology, sandwich panel.
- Component optimization:
  - HVAC type, HVAC duct type, fire suppression systems, gas selection, equipment doors, lighting systems, cable routing, cable tray, flooring material, internal and external linings.

In this recommended design, the main E-House uses interlock technology whereas E-Houses for secondary switchboards are made of pre-engineered modular solution using ISO containers with the advantages of low cost, fast construction and easy transportation.

Digital applications

The iron ore mining installation is equipped with a comprehensive digital monitoring and control system. Although this represents a higher CAPEX, it enables significant OPEX via lower maintenance cost, reduced energy consumption and higher plant availability by minimizing unplanned power supply interruptions.

The control system architecture, illustrated in Figure 4, was selected in order to minimize CAPEX while providing a good level of system availability. It is based on open communication standards such an Ethernet and Modbus TCP/IP, which reduces engineering costs, allows easy integration and ensures future evolution. The architecture allows to share information between the mining process and the electrical network control and asset management systems. The integrated system provides process control engineers with real time information on MV and LV motor feeder status, energy costs and electric motor condition, as well as START-STOP control. This allows them to make informed decisions to optimize the cost per ton of iron ore produced while minimizing the risk of unplanned outages.

The architecture is based on PLCs connected to an Ethernet ring network that uses Rapid Spanning Tree Protocol (RSTP) to manage Ethernet loop and provide good availability. Each PLC acts as a "Control Unit" integrating data from process controllers, field instruments and electrical equipment. All electrical network IEDs have Ethernet communication with native Ethernet/IP or Modbus TCP/IP as well as embedded Web servers. This choice minimizes the use of gateways and reduces system engineering workload and integration costs.

The PLC has an Ethernet communication module that provides access to both Ethernet/IP and Modbus TCP/IP networks with a baud rate < 100 Mbps. The MV switchboards internal communication network Modbus TCP/IP is integrated into the Ethernet network. The MV/LV package substation RTUs and the condition monitoring devices for the HV/MV and MV/MV power transformers are connected to a Modbus TCP/IP network, which is also controlled by the PLC.

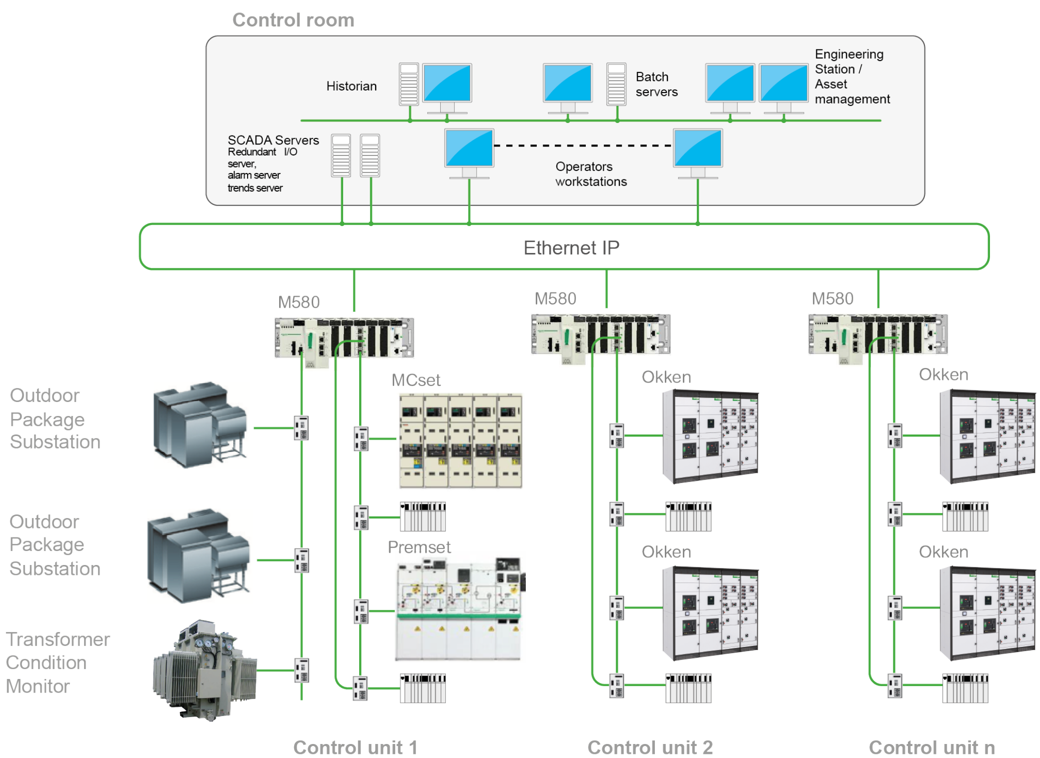


Figure 4

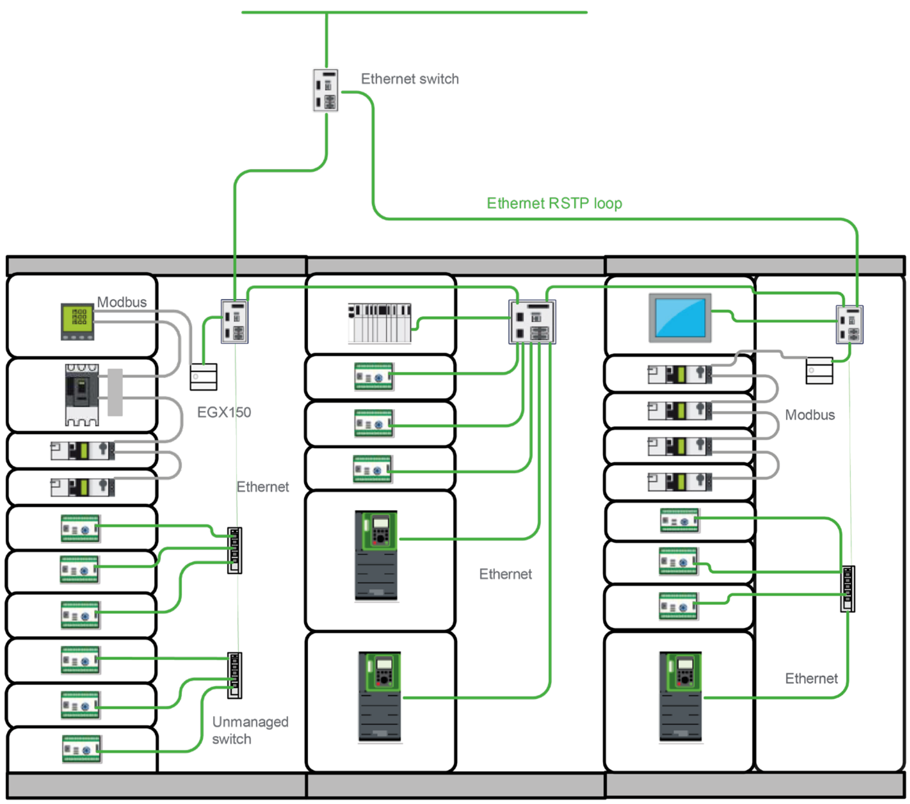
Electrical network monitoring and control system architecture integrated in Process Control System

The Schneider Electric Modicon M580 ePAC has a library of pre-configured screens and objects that include all the IEDs mentioned in this recommended design.
This minimizes the system design and integration costs while providing excellent system reliability.

The iPMCC internal communication illustrated in Figure 5 uses a hybrid architecture.
The switchboard is connected to the PLC Ethernet network using a cost-effective Ethernet unmanaged switch (e.g. ConneXium TCSESU05) that can connect up to 5 devices. Devices with Modbus RTU communication (MCCB, SS feeders) are connected via a Link 150 gateway to the Ethernet switch. Devices like VSD, DOL feeders with IMPR and local LCD control panel have native Ethernet communication links and are connected to the Ethernet switch.

Figure 5

Hybrid communication network using Modbus TCP/IP and Ethernet/IP in iPMCC



EcoStruxure™ solution

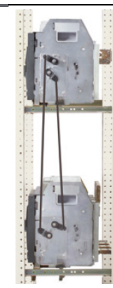
The recommended architecture for mine process automation is based on EcoStruxure™ Hybrid DCS.
The recommended architecture for the mine EMCS is based on EcoStruxure™ Power.
On the Edge control layer, the solution is to use Power SCADA Operation (PSO) for power management and control with advanced Power Monitoring Expert (PME) reporting and dashboards embedded in PSO.

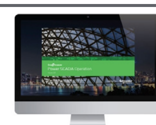
Cybersecurity

The product, solution and secure software development lifecycle conforms to Cyber-security standards, such as IEC 62443 and the ISO2700x suite.

Summary of Schneider Electric products used in this Design

Network function	Product name	Main technical characteristics		Link to offer
HV/MV transformer	Minera MP	Oil filled power transformer HV/MV, 45 MVA, ONAN		schneider.electric.com
Main MV switchboard	MC**Set**	AIS 17.5 kV, 2500 A, 25 kA, LSC2B-PM, motorized VCB and earthing switch, on-line temperature monitor		schneider.electric.com
	EasyPact EXE	VCB 17.5 kV, 25 kA, 2500 A integrated in MCset panel		schneider.electric.com
MV Secondary switchboard	Prem**Set**	SSIS 15 kV, 630 A, 25 kA, LSC2B-PM, fixed VCB, full earth screen		schneider.electric.com
MV Protection and control unit	Easergy P3	Protection relay with optical arc flash detection and Modbus TCP/IP used in MCset and PremSet		schneider.electric.com
MV/MV Transformer	Minera MP	Oil filled 11 kV/6.6 kV, 5 MVA, ONAN		schneider.electric.com
MV/LV Transformer	Minera	Oil filled 11 kV/0.69 kV, 2 MVA, ONAN Oil filled 11 kV/0.4 kV, 1.5 MVA, ONAN		schneider.electric.com
MV Variable Speed Drive	Altivar Process ATV6000	11 kV, 7.5 MW VSD with low TDH output and Ethernet/IP		schneider.electric.com
LV iPMCC switchboard	Okken or Blok**Set**	LV switchboard with high level of operator safety integrating LV incomers, power feeders, ATS, motor feeders (DOL, SS and VSD)		schneider.electric.com

LV transformer incomer	Master**Pact**™ MTZ	ACB with integral metering, protection and control IED with Ethernet/IP		schneider.electric.com
LV Automatic Transfer Source	Transfer**Pact**	UA controller with pre-defined ATS logic sequences		schneider.electric.com
		MasterPact™ MTZ with rod mechanical interlock mounted on LV switchboard		
LV power feeder	Com**Pact** NSX	LV MCCB with current rating 100 A < In < 630 A used in power and motor feeders		schneider.electric.com
	PowerLogic PM5000	Energy and PQ meter with Modbus TCP/IP		schneider.electric.com
LV DOL starter	TeSys U	All-in-one motor feeder < 15 kW with Modbus TCP/IP		schneider.electric.com
	TeSys GV, TeSys D, TeSys T, ComPact NSX	3 component DOL feeder with MCCB, contactor, motor IED with Ethernet		schneider.electric.com
LV Soft Starter	Altistart 48	400 V – 690 V SS motor feeder integrated in fixed FU with Modbus RTU		schneider.electric.com
LV Variable Speed Drive	Altivar Process ATV600	400 V – 690 V, VSD for pump, fan and compressor applications with Ethernet/IP		schneider.electric.com
	Altivar Process ATV900	400 V – 690 V, VSD for conveyors and hoisting applications with Ethernet/IP		
MV/LV outdoor package substation	Ringmaster RN2d	13.8 kV, 21 kA outdoor circuit-breaker		schneider.electric.com
	Minera	MV/LV oil transformer		
	NS Feeder Pillar	400 V panel with MCCB feeder		
	Easergy T300	Outdoor RTU with Modbus TCP/IP		schneider.electric.com
Power factor correction	Var**Set** LV	Automatic and fixed PFC equipment in floor- standing cabinet with Modbus RTU		schneider.electric.com

Active Harmonic Filter	AccuSine PCS+	Active filter for harmonic cancellation in floor-standing cabinet with Modbus TCP/IP		schneider.electric.com
Uninterruptible Power Supply	Galaxy VS	400 V, 40 kVA to 100 kVA 3 Phase UPS for industrial site applications with lead acid battery and Ethernet communication		schneider.electric.com
E-House		Pre-fabricated modular building accommodating MV and LV switchgear, VSD, PFC, AF, UPS, PLC, HVAC, F&S equipped with Ethernet connectivity		schneider.electric.com
Controller	Modicon M580	Ethernet Programmable Automation Controller		schneider.electric.com
Ethernet connectivity devices	Link150	Modbus RTU to Ethernet gateway		schneider.electric.com
	ConneXium TCSESU 05	Ethernet unmanaged switch with 5 ports		schneider.electric.com
Edge Control Software	EcoStruxure™ Plant Hybrid DCS	Integrated control system with specific mining library		schneider.electric.com
	EcoStruxure™ Power SCADA Operation	SCADA software system for electrical distribution monitoring and control		schneider.electric.com
	EcoStruxure™ Power Monitoring Expert	Power Management software		schneider.electric.com
Advisor Services	EcoStruxure Asset Advisor	Cloud-based asset monitoring service for predictive and preventive maintenance		schneider.electric.com

Appendix A: List of Acronyms

AHF	Active Harmonic Filter
AFE	Active Front End
ACB	Air Circuit Breaker
A-FLR	Authorized- Front Lateral Rear
AIS	Air Insulated Switchgear
ATS	Automatic Transfer Source
CAPEX	Capital Expenditure
CT	Current Transformer
DCS	Distributed Control System
DOL	Direct On Line
F&S	Fire & Security
FPI	Fault Passage Indicator
FU	Functional Unit
GCU	Generator Control Unit
HMI	Human Machine Interface
HV	High Voltage (> 52 kV)
HVAC	Heating Ventilation and Air Conditioning
IAC	Internal Arc Containment
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronic Engineers
IGBT	Insulated Gate Bipolar Transistor
IMPR	Intelligent Motor Protection Relay
iPMCC	Intelligent Power and Motor Control Center
LCD	Liquid Crystal Display
LV	Low Voltage (< 1 kV)
LSC	Loss of Service continuity
MCC	Motor Control Center
MCCB	Molded Case Circuit Breaker
MV	Medium Voltage (1 kV < MV < 52 kV)
OEM	Original Equipment Manufacturer
OLTC	On Load Tap Changer
ONAN	Oil Natural Air Natural
OPEX	Operating Expenditure
PAC	Programmable Automation Controller
PEI	Peak Efficiency Index
PFC	Power Factor Correction
PLC	Programmable Logic Controller
PCC	Power Control Center
PQ	Power quality
PWM	Pulse Width Modulation
RMU	Ring Main Unit
SAG	Semi Autogenous
SS	Soft Starter
SSIS	Screened Solid Insulated Switchgear
TCO	Total Cost of Ownership
THD	Total Harmonic Distortion
UPS	Interruptible Power Supply
VCB	Vacuum Circuit Breaker
VSD	Variable Speed Drive
VT	Voltage Transformer

Resources

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