Network Architecture for Optimized Mining Power System

Mining Power Systems Competency Centre
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Revision 00

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Executive summary

The choice of power system network architecture and MV distribution voltage have a major impact in the total cost of mining power systems and the availability of electrical power supply. To optimize the power system total cost and its impact on availability, different options need to be evaluated.
This paper gives recommendations for electrical network architecture optimization, illustrated by a case study of a mid-size iron ore mine.

Introduction

Power system equipment represents 5% to 10% of a mining project CAPEX but is essential for the safety and availability of the whole installation.

Traditionally, mining power systems are designed by engineering companies (EPCs) and/or mining end-users using their knowledge of the industrial process and their experience from previous projects. This results in simple and robust installations that are often not optimized for cost, footprint and power availability.

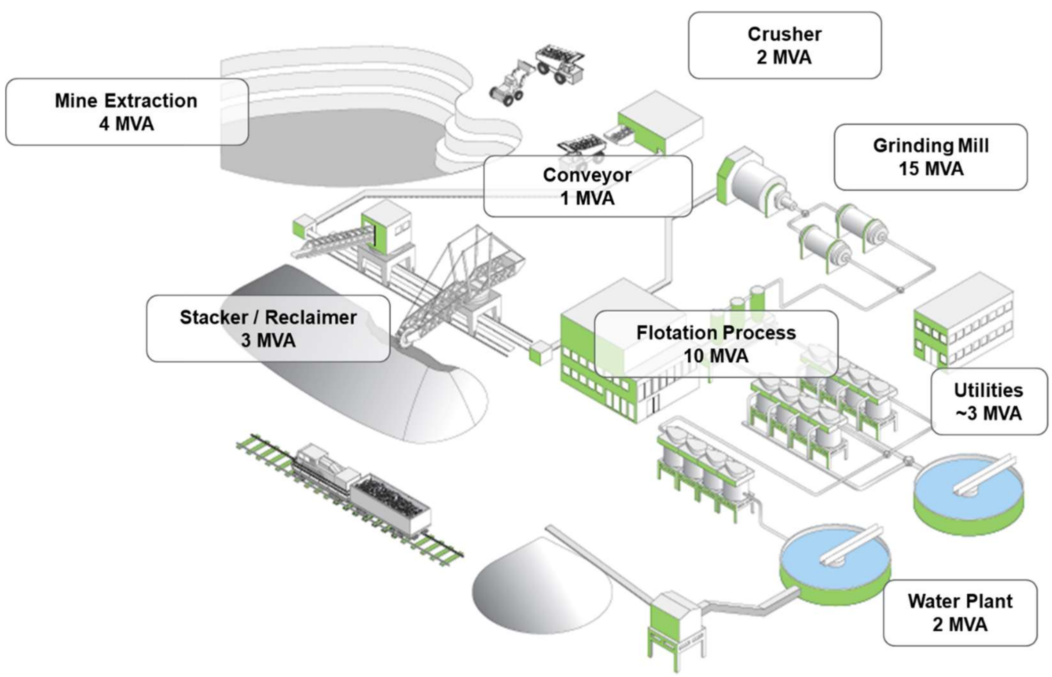
This document will provide recommendations to select the right distribution MV voltage levels and power system architecture for cost-effective and reliable electrical distribution in mining installations.

Characteristics of mining power systems

Figure 1 illustrates a complete mining and process plant which comprises diverse operating units responsible for mining, processing and shipping the finished product.
Within each operating unit, there are several individual applications each with its own MV/LV electrical network architecture, integrating the necessary control, monitoring and protection devices.
The different site areas are supplied by substations usually implemented in pre-fabricated E-houses or switchrooms.

Figure 1

Typical site overview of an open pit mine



Typical mining power system

Figure 2 shows the single line diagram (SLD) of a typical mining power system.

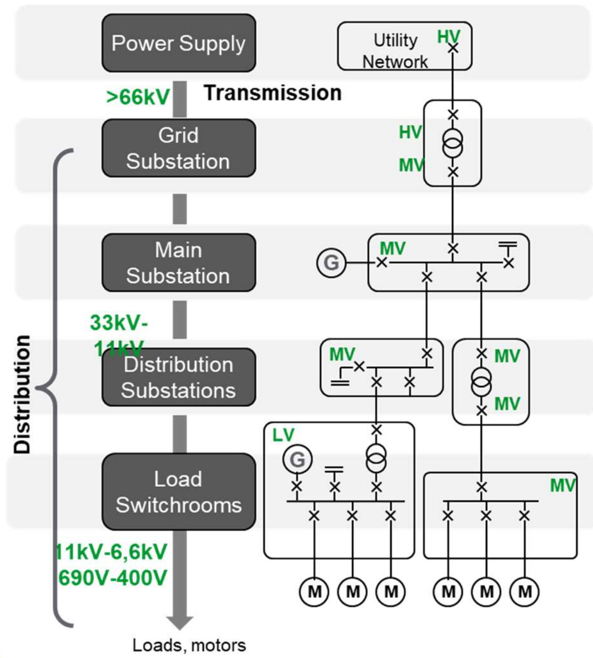


Figure 2

Typical Electrical distribution architecture

Power supply

The mining site can be supplied by the grid or local generation, or both, according to the electricity tariffs and supply availability. When the site can be connected to the utility network, the main power source is the High Voltage (HV) transmission grid. Connection voltages will range from 66 kV up to 230 kV depending on the mining site total load and the utility practice.

Use of renewable energy sources, when economically viable and technically feasible, is an opportunity for mining companies to reduce the environmental impact of their operations.

Grid substation

The mining site is connected to the public grid at HV level (66 kV to 230 kV) via a HV/MV substation that includes HV switchgear, HV/MV transformer and MV switchboard.

MV distribution

The MV distribution architecture connects the HV/MV transformers to the different MV substations. MV voltage levels can range from 6 kV to 38 kV depending on the installed power and distances to load centers. The MV distribution includes:

- Main substation: connected to the utility grid at HV transmission level. Its function is to distribute the electrical energy to the secondary substations.
- Local generation: diesel or gas generators, renewable sources.
- Distribution or secondary substations: connected to the primary one, they provide the energy to MV loads and to MV/LV transformers.

Electric loads

Typical installed power of mining sites ranges from 20 MVA to 300 MVA. The main loads are electric motors used to drive the different equipment required for the process.

The large motors in MW range powering mills are usually connected to the Main MV switchboard, either directly or via a MV/MV transformer. They are usually controlled by variable speed drives (VSD).

More information about motor management in mining installations can be found in white paper WP09.

Recommendations for power system design

Electrical distribution network architecture

The objective of the electrical distribution is to supply the different operating units with the most adapted power availability while minimizing the amount of copper required and the cost of equipment. This requires optimization of nominal currents and short-circuit currents.
The main parameters affecting the electrical distribution design are:

- Load characteristics,
- Locations of the process operations and distance from the main substation,
- Nominal voltage selected,
- Conductor type and cross-section.

MV distribution optimization is an iterative process that involves analyzing different options of MV network architecture, voltage levels and equipment cost.
Designers need to have a good understanding of the mining process and motor loads, MV network architectures, power quality and availability as well as electrical equipment cost,
A TCO calculation must be carried out, using the available offers in the country where the mine will be built, in order to choose the most optimized solution.
As indicated in figure 3, the optimized solution is a compromise between the CAPEX of electrical distribution and the cost of production losses in case of outage.

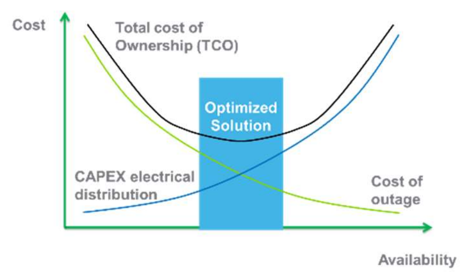


Figure 3

Total cost of ownership versus availability

MV feeder

The MV distribution between the main substation and the remote areas can be done via overhead lines or cables. Even if the cost of cables is higher, a comparison must be made to choose the best solution with an assessment on the power availability of the critical process.

Overhead line

Distribution feeders in mines can be achieved by overhead lines but the poor availability is a drawback. Weather conditions such as wind may bring overhead wires into contact and cause phase to phase short-circuits. Temporary contacts of trees or branches with live overhead conductors may generate phase to earth faults. Over voltages due to lightning strikes may generate flash-over across insulators and cause phase to earth faults.
As most of these faults are temporary, they disappear naturally with the interruption of the voltage and the supply can be restored after a short delay. The service continuity of overhead network can be improved significantly by using automatic reclosing facilities.

The use of covered conductor (unscreened insulated conductors) can significantly increase the overhead line availability by reducing the faults due to accidental contact of phases or falling trees.

Underground cable feeder

To minimize exposure to lighting strikes, falling trees and weather elements, it is recommended to use MV cables and surge arresters rather than overhead lines.
Experience shows that the failure rate of underground cables is significantly lower than the one registered for overhead lines. However, faults on underground cables are invariably permanent and take longer time to locate and repair.

MV Voltage selection

The choice of MV network voltage is one of the key power system parameters that impacts its cost. The mining company is free to choose any MV voltage in its private installation. However, the habit is to choose the MV voltages used by the local electricity utility. The advantage is wider availability of MV equipment and MV/LV transformers, but the disadvantage is that the local utility voltage is rarely the optimal choice for the mine installation resulting in additional cost.

The method proposed to select the MV network voltage is based on two criteria:

- Minimize MV voltage levels to reduce the number of MV/MV transformers

  Using the same MV voltage level all over the plant limits the number of transformers and increases supply availability. On another hand, it could be less energy efficient (and so cost more in OPEX) if it involves higher nominal currents.

- Keep MV switchgear specification in the optimum cost sweet spot to minimize MV switchgear cost

  The cost for MV switchgear depends on its nominal current (In) and its rated short circuit current (Isc). The different MV switchgear types used in mining applications, for IEC and ANSI standard, are described in WP03. MV circuit breaker panels used in Main MV switchboard are in the optimum cost "sweet spot" when nominal ratings are:

  - 1000 A < In < 2500 A
  - Isc < 25 kA

Distribution voltage

The choice of MV network voltage determines MV switchgear rated current In as a function of Sn. Table 1 shows the recommended values of MV voltages used in IEC mining power system designs to fit with cost-optimized MV switchgear.

Table 1

Recommended MV distribution voltage

Power Range	Recommended voltage	Typical transformer rating	Maximum current in MV
P < 20MVA	6,6 kV	5 to 10 MVA	<1250 A
20 MVA< P < 50MVA	11 kV or 13.8 kV	20 to 40 MVA	< 2500 A
50 MVA < P <100 MVA	22 kV	50 to 80 MVA	< 2500 A
P >100 MVA	33 kV	80 to 120 MVA	< 2000 A

Load voltage

Loads, such as machines or motors, connected at MV level with rated power less than 5 MVA are usually supplied at a voltage of 3,3 kV, 4.16 kV or 6,6 kV. Larger motors loads can be connected at 11 kV or 13.8 kV. Large mining machines can be connected to 11 kV or 22 kV as they include an input transformer to supply their internal motors.
Mining machines (drills, shovels) are commonly supplied at 6,6 kV due to the availability of trailing cables.

Recommendation for voltage selection

For sites with installed power less than 20 MVA using MV motors, it is recommended to have all the MV distribution with one MV level at 6,6 kV. For mid-size sites, one MV level at 11 kV is the preferred solution if the additional cost for the motors and machines is acceptable.

For large sites, two levels of MV are needed. A primary distribution voltage (11 kV, 22 kV, 33 kV) from the main substation to the load centers and a secondary voltage (4.16 kV, 6,6 kV, 11 kV) to supply the motors and large machines.

Architecture of main substation

Connection to the utility network

The voltage level selected to connect mining site loads depends on:
· Network voltage level available in the area of the site location,
· Maximum demand power requirements, including future expansions,
· Short-circuit current level required to start large MV motors in direct on-line mode.

HV substation

The installation contains all the HV switchgear and associated control, protection, metering and auxiliary equipment. HV switchgear consists of disconnectors, SF6 circuit-breakers, instrument transformers, surge arrestors and earthing facilities.
Utilities provide the HV power line, HV circuit breakers and metering equipment, that defines the boundary of electrical plant ownership
The HV/MV transformer ownership is subject to agreement between the utility and the end-user. Most frequently, the utility meter is on HV side and the end-user specifies, purchases and maintains the HV/MV transformers. More detail on HV/MV transformer specification for mining installations can be found in WP 02.

The site can be supplied by 1 or 2 overhead lines at a rated voltage that can vary between 66 kV to 230 kV depending on the region. Redundant incoming power supply is the preferred solution to minimize power outages
When the site is connected to a single overhead line, the end-user should consider the installation of local generation to provide an alternative supply and eliminate a single point of failure (SPOF).

Single supply architecture
Figure 4 describes the simplest solution with a single HV line and a single HV/MV transformer. The availability is low and in case of failure, the installation will have a long outage.

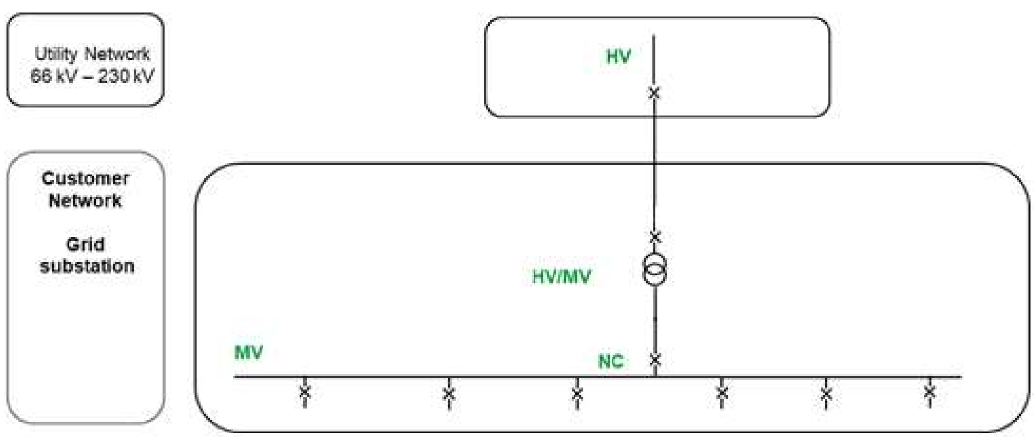


Figure 4

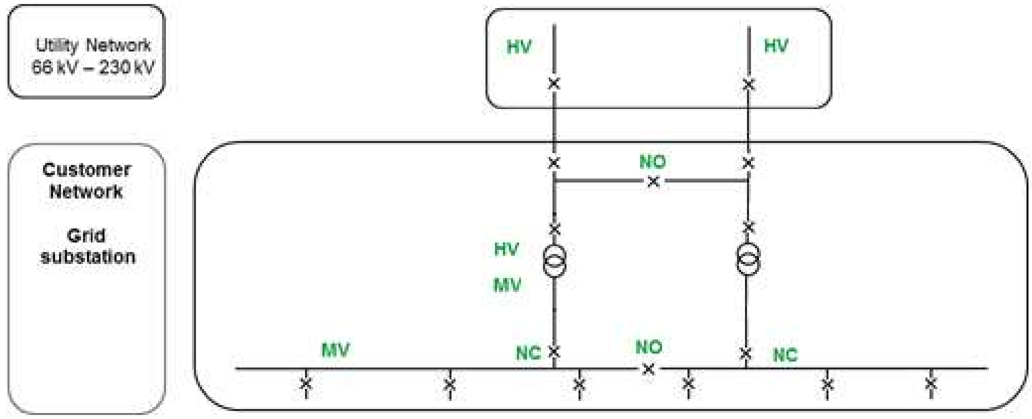
Architecture of grid substation with single HV incomer

Dual power supply

The recommended practice is to adopt a redundant configuration (2N) for the main power transformers as shown in Figure 5.

Figure 5

Recommended architecture of grid substation with single HV incomer



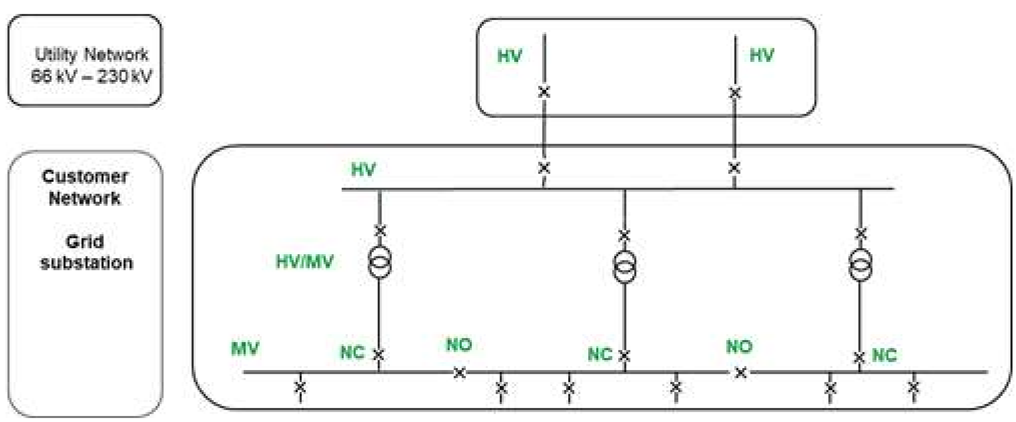
Both transformers are designed to take the full load. Under normal conditions the substation operates with the MV bus section circuit-breaker normally open (NO) and the transformer incomer circuit breaker normally closed (NC) so that the site load is equally shared between the two HV/MV transformers.
In case of unavailability of one HV/MV transformer, the automatic transfer system (ATS) will automatically open the incomer and then close the bus section circuit breaker after a time delay. Following a short supply interruption, the total site load will be fed by just one HV/MV transformer.
As the ATS ensures that both transformers are never connected in parallel, the maximum short circuit current of the MV network is rated considering the fault current contribution of just one transformer.
The drawback of this operating mode is that the motor load decelerates during the transfer. The control system must re-energize the motors in stages to avoid cumulation of inrush currents and mechanical damage in the machines. This does not pose a real problem in mining because most process can tolerate a temporary interruption.

Solution for large sites

For large sites (with installed power > 80 MVA), the recommended practice is to adopt a redundant configuration (N+1) for the main power transformers as described in Figure 6. The power is distributed through 3 transformers instead of 2. This architecture requires one additional HV feeder, but the transformer rating and the MV switchgear are optimized.

Figure 6

Recommended architecture of grid substation for large sites with 3 transformers



MV electrical distribution network architecture

Three types of network architecture providing different level of availability can be implemented in mining power systems:

- Radial single fed,
- Radial double fed,
- MV open ring.

The choice of the network architecture of a mine results in compromise made after several iterations. According to the availability requirements set by the end-user, a mix of different solutions can be implemented.

Radial Single fed MV architecture

The site is supplied from the utility in HV with one or two incomers and two HV/MV transformers. At MV and LV level, a single busbar allows basic and simple electrical distribution layout as indicated in Figure 7. This network architecture provides only one supply for the loads.

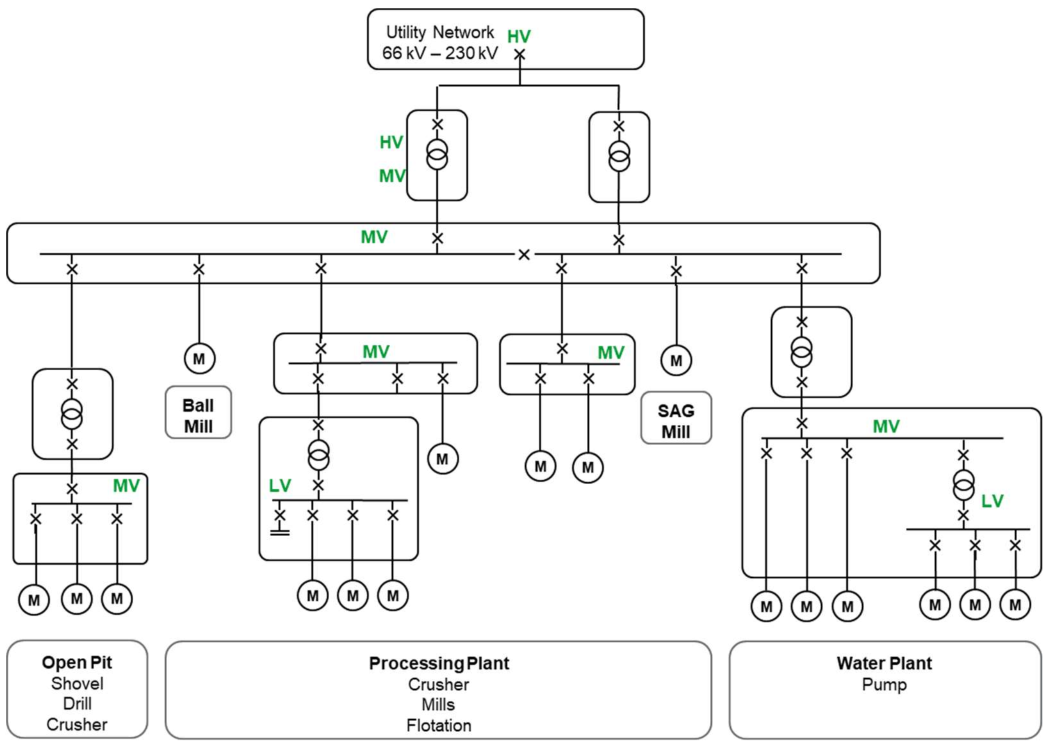


Figure 7

Single fed radial network architecture

Table 2

Characteristics of single fed radial architecture

Radial Single fed MV architecture	
Advantages	Disadvantages
• Simple layout helping operation and maintenance • Optimization of conductor cost in large sites with high currents • Lowest CAPEX solution	• Poor availability in case of equipment failure or maintenance • No backup in case of cable/overhead line failure

Radial – Double fed MV architecture

The site is supplied from the utility in HV with one or two incomers and two HV/MV transformers. Each LV and MV switchboard busbar is split into two half busbars linked with a bus-section that is open during normal operation as shown in Figure 8.
If one transformer fails, the other transformer must supply the entire load. This must be considered in sizing the transformer and MV switchgear.
This configuration improves power availability by providing a dual supply. Maintenance can be performed without stopping the process (one of the half busbars can be disconnected from the power supply while the other continues to supply the process). In the event of the loss of supply, this sequence can be performed manually or automatically with a SCADA system.

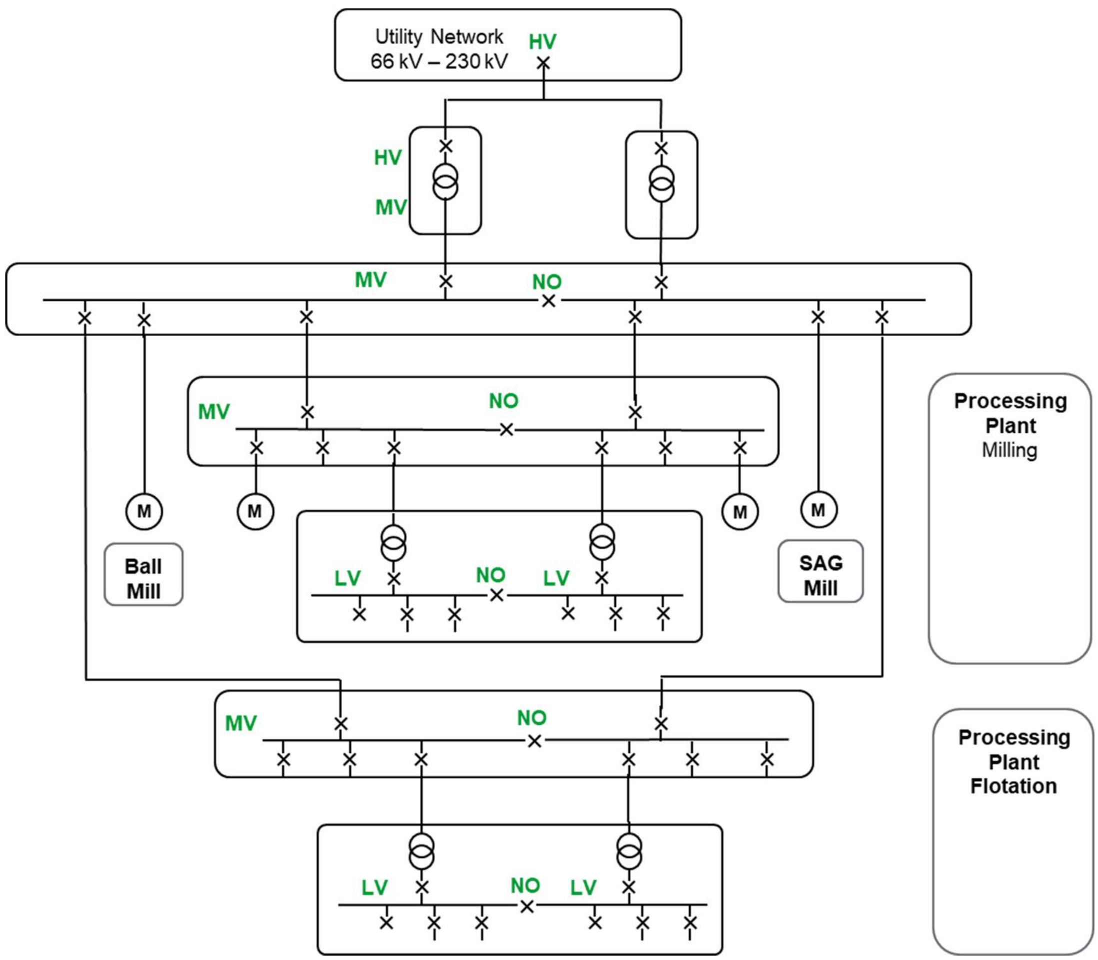


Figure 8

Double fed radial network architecture

Table 3

Characteristics of double fed radial architecture

Radial Double fed MV architecture	
Advantages	Disadvantages
• Enhanced availability of power supply • No outage during maintenance	• High CAPEX

MV Ring architecture

A ring is fed by two MV feeder circuit-breakers as indicated in Figure 9. The MV/LV substations are connected to the ring by load break switches, all are closed except one which is referred as the normal open point (NOP).
A MV feeder fault causes the feeder circuit-breaker to trip disconnecting all MV/LV substations fed from it. Supply can be restored to the healthy part of the system by opening switches at each end of the faulted cable to isolate the fault, then closing the primary feeder circuit-breaker and the NOP.
This open ring architecture uses ring main units (RMUs). RMU is a compact and cost-effective switchgear arrangement of two load break switches and one or more tee-off circuit-breaker of fuse switches. The use of circuit-breaker and relay is the preferred solution for the protection of MV/LV transformers as it provides better discrimination, improved protection, harsh climate withstand and reduced maintenance.
For a cost-optimized MV ring system, the maximum current in the feeder (in the worst case scenario) has to be less than 80 % of the cable capacity. With a 400 A MV cable the maximum power to be fed from one primary feeder is then 7.6 MVA @ 11 kV, 15 MVA @ 22 kV or 23 MVA @ 33 kV.

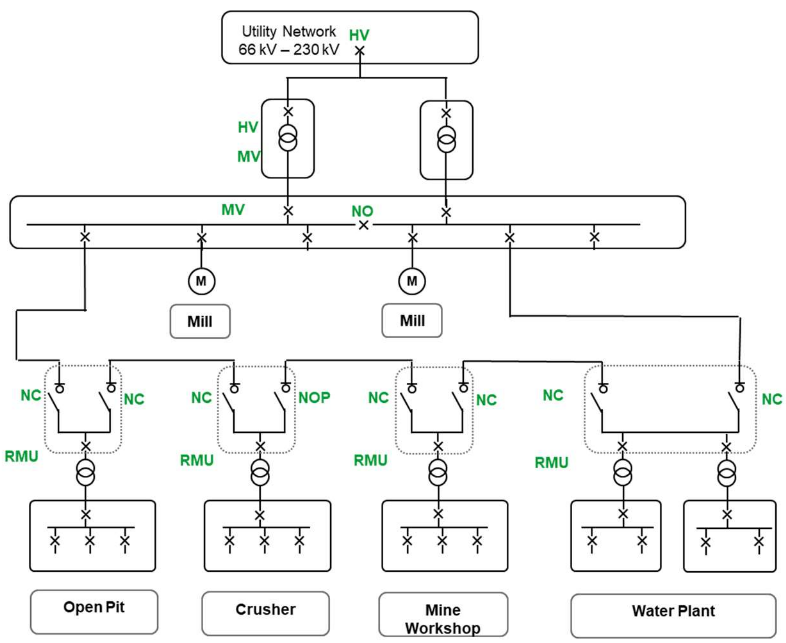


Figure 9

Open ring network architecture

A ring architecture, instrumented with fault passage indicators (FPIs), allows to identify a faulty cable in less than one hour, to disconnect it and to restore the supply to the substations in the ring. However, it requires the operator to visit all substations.
The procedures of fault detection, disconnection and supply restoration can be performed remotely in less than 5 minutes by dedicated functions integrated in SCADA. It requires MV switchgear equipped with motorized switches and remote terminal units (RTUs).

Table 4

Characteristics of ring architecture

MV Ring architecture	
Advantages	Disadvantages
• Better availability as the substations can be re-energized after a feeder failure • Maintenance performed without stopping production • Easy to add a new MV/LV substation	• Faulty segments can be isolated during loop reconfiguration • Limited to 630 A - 20 kA for cost-effective switchgear

Case Study

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
- Installed Power: 45 MVA
- Utility supply voltage: 110 kV
- MV distribution: 11 kV – 25 kA

The example described hereafter is an open pit iron ore mining site producing 9 million tons per annum (Mtpa) or 25 kt/day. See Recommended Design 01 for more detail.

MV network voltage choice

To choose the right voltage level, a comparison with TCO evaluation has been made with 3 different voltage levels 11 kV, 22 kV and 33 kV.
The architecture with one voltage level at 11 kV is retained because it is the most cost-effective solution even if the cost of MV cables and motors is higher:

- It reduces the number of transformers,
- It allows the use of optimized switchgear range (Isc 25 kA) with shielded solid insulation,
- The losses are reduced leading to a lower TCO.

Architecture for improved availability

The results of the availability calculation with a single fed radial architecture show that power failures cause some production losses about 2%. The biggest contributors to the mine process unavailability are:

- the HV/MV transformer,
- the main and secondary MV switchboards,
- the distribution transformers.

To avoid the weak points of the radial architecture, the single line diagram is modified with a combination of double fed and open loop architecture as shown in Figure 10:

- Two redundant HV/MV transformers and main MV switchboards
- Double fed architecture to supply the secondary switchboards for the process plant
- Open loop architecture to supply the secondary switchboards for the remote areas.

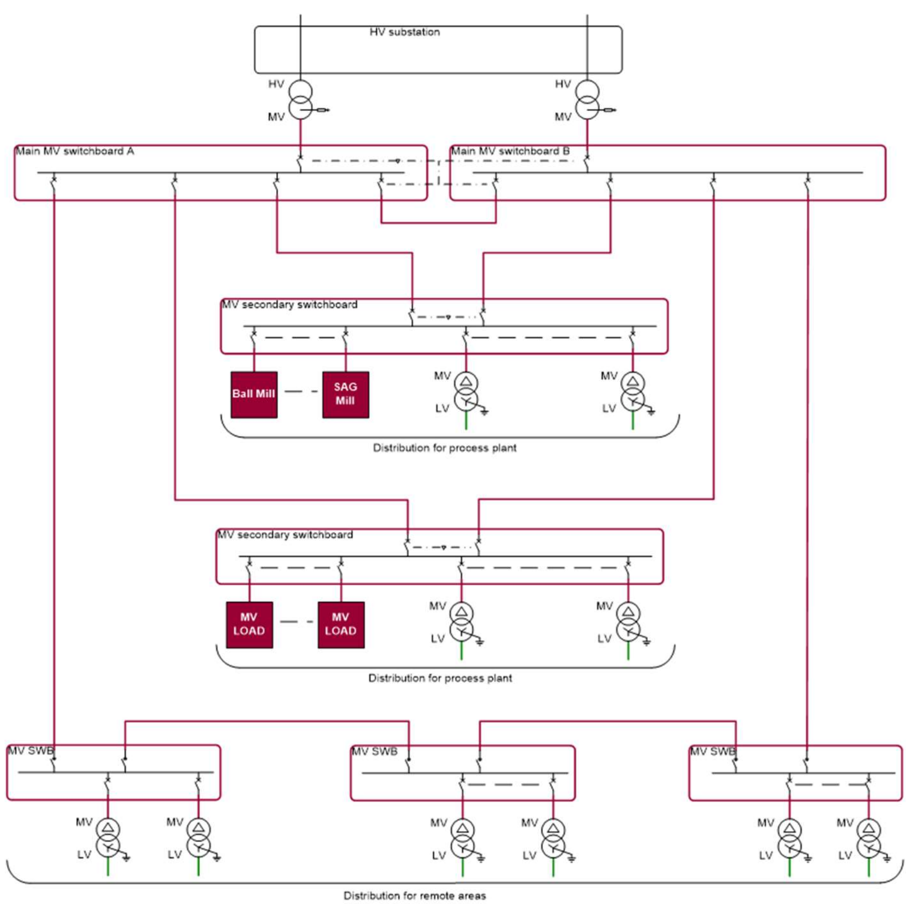


Figure 10

Improved availability electrical network architecture

Grid substation

The two HV/MV transformers are redundant meaning that each transformer can supply the full load. Under normal conditions, the substation operates with the MV bus section circuit-breaker normally open (NO). In case of unavailability of one HV/MV transformer, the failed transformer will be locked out by opening its HV and MV circuit breakers. The MV switch-board will be re-energized by the other transformer by closing the bus section circuit breakers. An interlock between the 2 incomers circuit breakers and the bus section circuit breakers is designed to prevent the coupling of the two HV/MV transformers in order to keep the short-circuit current under 25 kA rms.

Transformer power rating and ONAN/ONAF cooling

To optimize the power rating, the two transformers are designed to run in normal operation at around 60% of their rating (in AN cooling). In case of failure, the air forced cooling system (ONAF) allows the operation of the remaining transformer. This optimization of the power rating results in a reduction of the cost, weight and footprint of the HV/MV transformers and a lower short-circuit current in the MV network.

MV/LV distribution

For the process plant, as the loads are close to the HV/MV substation, the secondary switchboards are supplied by two feeders coming from the main switchboards A & B. For remote areas (pit area, stockpile area and small distribution), an open loop architecture is selected to minimize the MV cable length while providing a good availability.

Performance comparison

As indicated in Table 5Error! Reference source not found., the CAPEX difference of this version is substantial but the cost including the electrical losses in the transformers and cables, is just slightly higher.

The better availability will result in a reduction of production losses making this alternative, in the end, more attractive for the mining company.

Table 5

Comparison of different architectures

	Radial architecture	Improved availability version
CAPEX Electrical Distribution	100	125
CAPEX + losses over 20 years	100	105
Unavailability due to power failure	2 % 175 hours/year	0.15 % 15 hours/year

Conclusion

The choice of MV voltage and network architecture are key parameters to obtain a cost optimized power system with proper availability.
Different options need to be evaluated for an optimal choice. A combination of radial distribution for the concentration plant and open loops for remote areas represents a good compromise.

About the authors

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Glossary

ANSI	American National Standards Association
BIL	Basic Insulation Level
DOL	Direct on Line
EU	European Union
FPI	Fault Passage Indicator
HV	High Voltage (Un > 52 kV)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers (USA)
LIWV	Lighting Impulse Withstand Voltage
LV	Low Voltage (Un < 1 kV)
MV	Medium Voltage (1 kV < Un < 52 kV)
OLTC	On Load Tap Changer
PCC	Point of Common Coupling
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
TCO	Total Cost of Ownership (CAPEX + OPEX)
VSD	Variable Speed Drive

Resources

Schneider Electric Medium Voltage Technical Guide-2018
(www.schneider-electric.com/en/download/document/AMTED300014EN)

Electrical installation guide Schneider Electric
www.electrical-installation.org

Mining Power Systems Competency Center- Recommended Power System Design for Mid-size Iron Ore Mines- IEC Standard
(https://www.se.com/ww/en/download/document/998-20637454/)

Mining Power Systems Competency Center- Recommended Power System Design for High Altitude Lithium Mines-IEC Standard

Mining Power Systems Competency Center- White Paper 02- Power transformer specification for optimized mining power systems

Mining Power Systems Competency Center- White Paper 03–MV switchgear for mining power systems applications- IEC vs ANSI

Mining Power Systems Competency Center- White Paper 08-MV Variable Speed drives for mining power system applications

Mining Power Systems Competency Center- White Paper 09 -MV and LV Motor Management in mining power systems.

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