Novel Fast Transfer System

How to Ensure Electrical Safety, Maintain Process Continuity and Deliver Equipment Cost Savings

by Jean-Luc Belletto

Executive summary

This white paper introduces a novel approach to rotating load transfers for meeting process continuity constraints in heavy industries. The proposed solution avoids the need to oversize equipment and minimizes electro-mechanical transients during the transfer. Its operation is illustrated with laboratory tests.

Contents

Glossary

AC:	Alternating current
ANSI:	American National Standards Institute
CB:	Circuit breaker
DOL:	Direct-on-line motor starter
IEC:	International Electrotechnical Commission
NC:	Normally closed (contact)
NEMA:	National Electrical Manufacturers Association
NO:	Normally open (contact)

Introduction

To ensure process continuity in case of failure or for maintenance purposes, electrical loads need to be easily transferred from one supply to another without disruption. Induction motors are often the subject of such transfers in industrial systems and present a challenge in terms of their electrical and mechanical constraints.

This paper presents an innovative fast transfer system where a virtually closed transition is achieved without source overlapping, allowing economic sizing of busbars and current interruption equipment. Laboratory tests demonstrate the operation and confirm the proposed approach.

Typical Electrical Architecture for Critical Processes

The electrical architecture typically refers to a double radial power supply system for switchboards used in critical processes. These switchboards comprise two separate bus sections fed by two redundant sources, with each source being able to sustain the full load of the switchboard. In normal operation, the bus coupler between the two bus sections is kept open. Each bus section is loaded by motor loads and non-motor loads. Motor loads are motors that are connected to the bus by mean of direct-on-line, reversing, star-delta, or Dahlander-Lindström starters. Non-motor loads are static loads or motors fed through non-regenerative frequency converters.

Should either of these sources be disabled, the power can be reinstated to the de-energized bus section by closing the bus coupler. This operation is called the ‘transfer sequence’ and can be carried out in different ways. The transfer type that can be associated with this type of switchboard is referred to as ‘two out of three’ (2oo3) in the IEC standards or ‘main-tie-main’ in the NEMA standards and means that no more than two out of three circuit breakers can be closed at the same time during normal operation. This electrical architecture is shown in Figure 1.
By convention, ‘Source 1’ is designated as the ‘normal’ source in the rest of this paper, and ‘Source 2’ is referred to as the ‘replacement’ source.

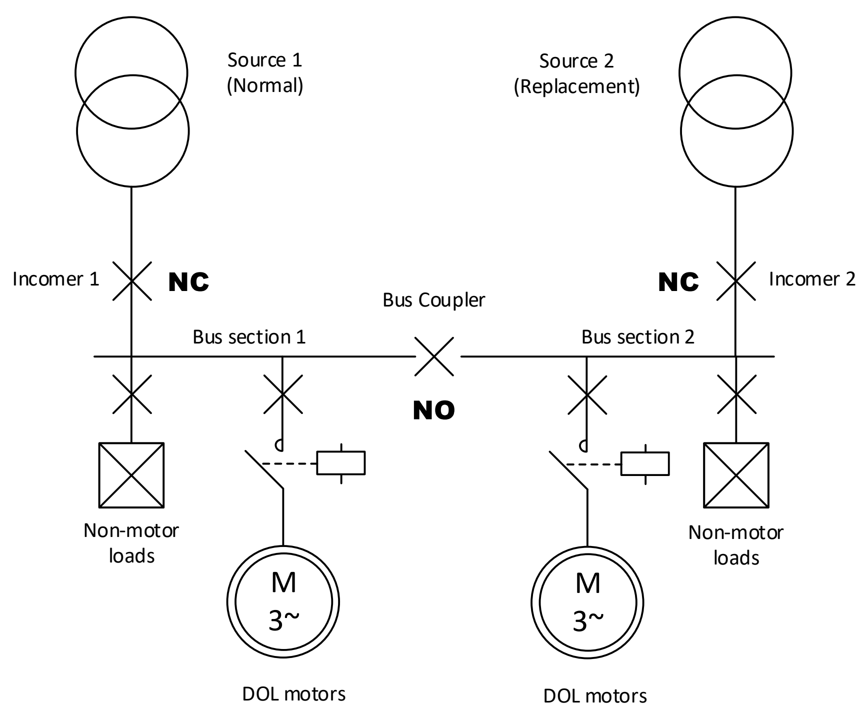


Figure 1

Typical Electrical Architecture with 2oo3 Source Transfer Capability

A variant of this architecture, without a bus coupler on the main busbar, is also possible. This is referred to as a 'one out of two' (1oo2) transfer in IEC or 'main-main' in NEMA and is depicted in Figure 2 below. It is less common than the aforementioned transfer type because it exposes the full switchboard to the risk of de-energization if the bus is disabled. Even though this variant is not considered in the rest of this document, it does not alter any of the characteristics or conclusions mentioned.

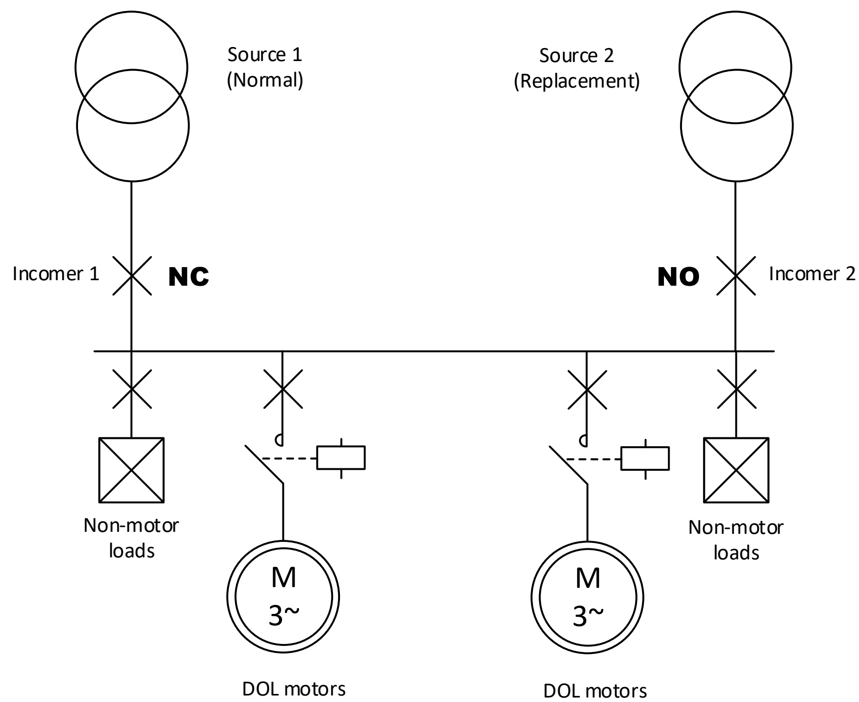


Figure 2

1oo2 Source Transfer Type

Usual Bus Transfer Methods

The transfer operation consists of disconnecting the bus from the normal source and reconnecting it to the replacement source in order to restore the power supply to the loads connected to the bus. The transfer operation takes place in the rated current range (In at 40 °C as per IEC 60947-2) of the incomer and bus coupler circuit breakers. This paper includes a brief discussion of the most common transfer methods and a more detailed description of the 'open transition simultaneous fast transfer', which highlights the interest of this solution to meet most transfer needs. An accurate characterization of the loads connected to the bus is advisable for the 'in-phase' and 'fast' transfer methods described to predetermine the voltage and frequency decay behavior of the bus during the transfer.

These methods are summarized in Figure 3 below:

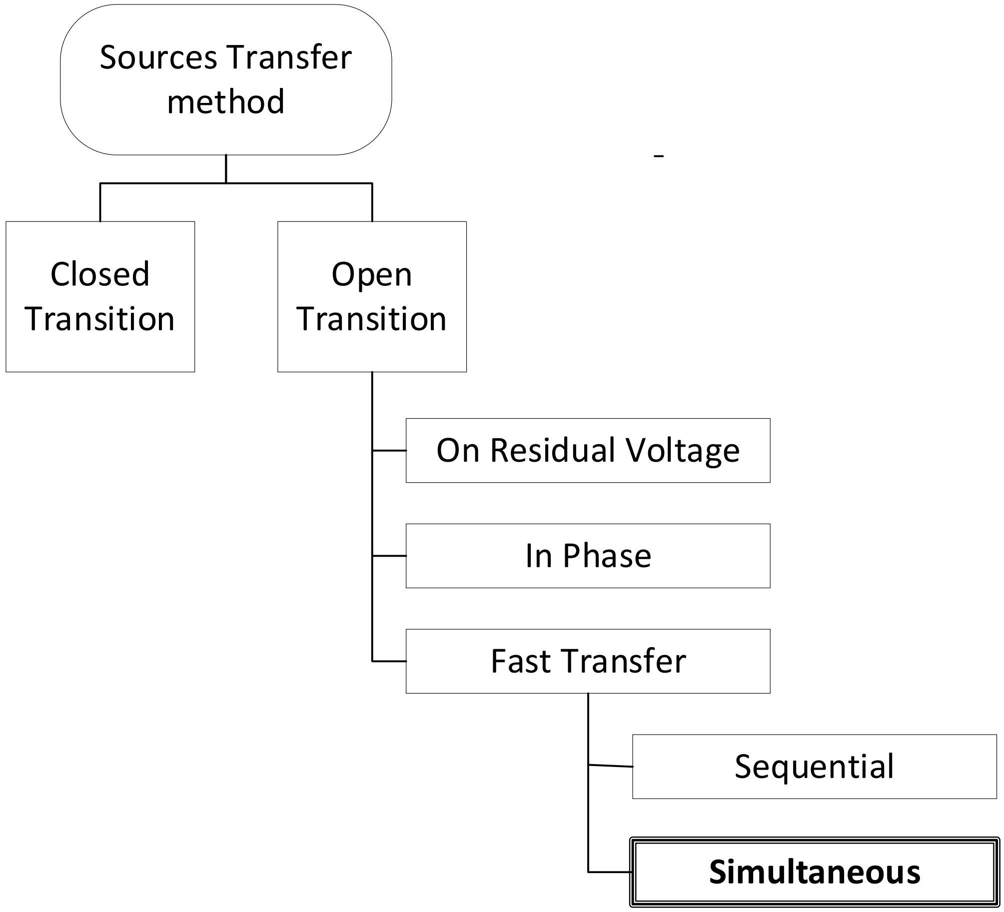


Figure 3

Different Transfer Methods

The following below shows the features offered by the main transfer system manufacturers:

	AARTECH SOLONICS LTD	ABB	BECKWITH ELECTRIC	SCHNEIDER	SCHWEITZER	SIEMENS
	BTS2000	SUE3000	M-4272	Easy FasTransfer	SEL 451	7VU683
Bus voltage monitoring	DYNAMIC	DYNAMIC	DYNAMIC	PREDICTIVE	DYNAMIC	DYNAMIC
Transfer performance	<2 CYCLES	1 CYCLE	1 CYCLE	<½ CYCLE	<2 CYCLES	<½ CYCLE
Number of controllable CBs	3	3	2	3	2	3
CB late closing protection	NO	NO	NO	YES	NO	NO

A ‘Dynamic’ system based on voltage monitoring involves a permanent line and motor bus voltage signal processing. This acquisition performs real-time motor bus and lines respective frequency, voltage magnitude, phase difference and rate of change calculations. It is mandatory for any ‘in-phase' transfer system.

A ‘predictive’ system relies on modeling of the loads, mechanical retarding torques, and inertias along with the motor magnetic field conservation to assess the fast transfer performance. This system considers that once the transfer has been initiated, the transfer duration is too short for the replacement line source to notably change in frequency and voltage, and for the motor bus voltage to decay and slow down significantly.

Standards

Numerous standards govern electrical components, equipment, and their installation. The following standards are specific to the transfer systems mentioned in this paper:

IEC 60947-6-1

According to this standard, the simultaneous fast transfer system described in this paper can be defined as manually operated transfer switching equipment (MTSE) or remotely operated transfer switching equipment (RTSE) where the transfer is initiated voluntarily either locally or remotely. It differs from automatic transfer switching equipment (ATSE), which is controlled through a certain operation and energy management logic. As such, ATSE devices monitor normal source availability and automatically switch to the replacement source with the capacity to start up a Genset when required.

ANSI C50.41-2012

This standard defines the electrical limits that are acceptable between the transferred bus residual voltage and the replacement source voltage for a safe transfer. It is used to assess the performance of the system.
This standard requires two conditions to be fulfilled within a time window of 10 cycles (200 ms @ 50 Hz):

(a) The phase angle between the transferred bus voltage phasor and the replacement source voltage phasor must remain below 90°.

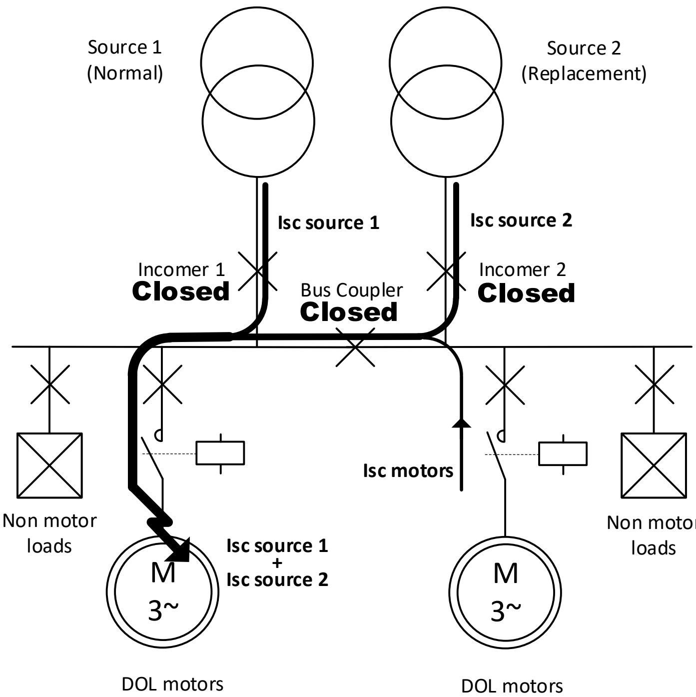
(b) The resultant voltage between the bus voltage phasor and the replacement source voltage phasor must not exceed the motor rated voltage by 133%.

Closed Transition Transfer Method

In the ‘closed transition’ transfer sequence, the normal and replacement sources are momentarily coupled together prior to the transfer by closing the bus coupler circuit breaker, providing that the two sources are in phase with the same voltage magnitude. The normal source is then disconnected by opening the corresponding circuit breaker. This method does not induce any voltage or frequency disturbance on the load-side supply, nor is there any disruption to the process or adverse overcurrent in the electrical distribution. The main drawback of this method relates to the sizing of the switchboard, the motor starters and the feeders that may be designed to withstand the prospective short-circuit current contributed by the two sources and the motors, as illustrated in Figure 4:

Figure 4

Cumulative Short-Circuit Currents



Although compliance with this constraint is not mentioned or required in IEC standards, it is nevertheless clearly stated in Sections 110.9 and 705.16 of the National Electric Code [1]. Therefore, many end-users operating critical processes still specify switchboard short-circuit withstand accordingly. Such a provision generally significantly increases the cost and size of the switchboards. The cost-effectiveness of the entire electrical system can also be affected as follows:

- Larger electrical rooms may be required to house switchboards with a larger footprint, involving higher costs in terms of real estate and dimensioning of building auxiliary systems such as air conditioning, fire prevention, and lighting.
- Larger cables may be required to satisfy a higher short-circuit current withstand requirement, especially with non-limiting protection devices, thereby increasing cabling costs.

Open Transition Transfer Methods

With an ‘open transition’ transfer sequence there is no overlapping between the normal and replacement sources, which allows the short-circuit withstand of the switchboard components to be dimensioned with respect to one source instead of two. This provides clear benefits in terms of cost and switchboard footprint. A noticeable effect occurs during the open transition transfer: thanks to the rotating mass inertia and residual magnetic field in the rotor, motors connected to the transferred bus contribute to maintaining the voltage and frequency on the bus before the transfer to the replacement source. During this time, their behavior can be assimilated to a single equivalent asynchronous generator [2] with a rapid decay in voltage and frequency. The presence of a capacitor bank on the bus section can help to maintain the voltage on the bus by bringing magnetizing energy to the induction motors during the transfer.

Static loads such as heaters, sub-distribution transformers, or motors on non-regenerative variable speed drives can also be connected to the busbar, but these loads absorb the energy delivered by the induction motors acting as generators and, in turn, increase the voltage and frequency decay rates on the bus.

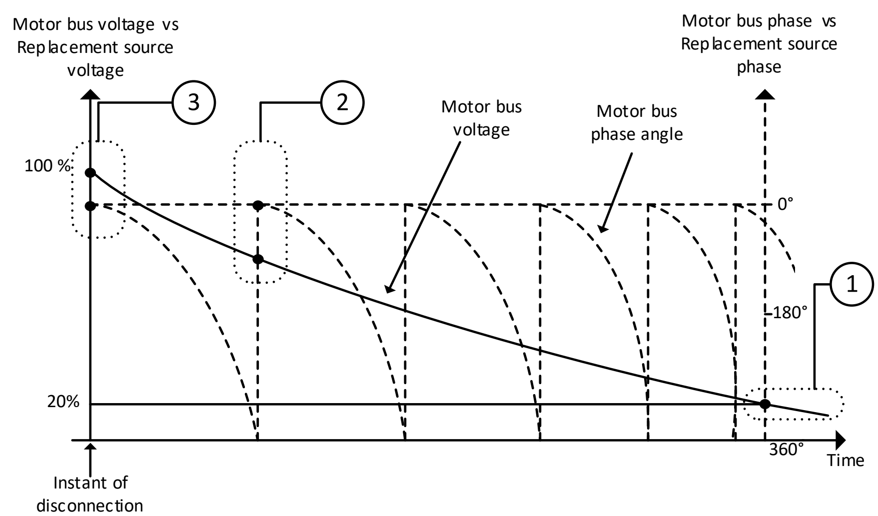
However, this method inherently leads to a temporary interruption in the power flow to the loads. Depending on the duration of this interruption, the following adverse effects can occur: disruption to the process implying motors to be stopped or reaccelerating (interruption of a few hundreds of milliseconds to a few seconds); risk of excessive stress on motors and nuisance tripping on uncontrolled out-of-phase reconnection to the replacement source (interruptions of a few tenths of milliseconds to a few hundreds of milliseconds).

There are three methods generally used for transferring a bus in an open transition transfer sequence.

These methods are depicted in Figure 5. They are: 'residual voltage' transfer ①, 'in-phase' transfer ②, and 'fast transfer' ③. The common feature of all three methods is that they do not allow a transfer in an electrical fault situation.

Figure 5

Bus Voltage and Phase as a Function of Time



①- Residual voltage transfer method: The reconnection of the motor bus to the replacement source is performed regardless of the phase difference between the motor bus and replacement source voltages, but only once the residual voltage present on the motor bus has dropped low enough to avoid a reconnection inrush current greater than the normal motor starting current. This voltage level can be controlled by a standard residual voltage relay (ANSI Device 27R), usually set to about 20-30%of the motor rated voltage. This method is safe and cost-effective but does have one drawback: the delay for the voltage to drop down to the preset threshold can last up to several seconds, thus jeopardizing the continuity of the process driven by the motors. A coordinated restart sequence motor by motor should therefore be implemented to avoid further disruption to the process. Alternatively, if all motors are reaccelerated together, special attention must be paid to the capacity of the electrical system to sustain such a load both thermally and dynamically.

②- In-phase transfer sequence: Motor bus and replacement source voltage waveforms are constantly monitored by a real-time acquisition control system. Reconnection to the replacement source is attempted when the phase shift between the motor bus voltage and the replacement source voltage becomes almost zero, resulting from the slip frequency of the transferred bus. Other conditions are also considered to allow initiation of this transfer: the residual voltage at the instant of reconnection must be generally no lower than 60-70%of the rated voltage, and the motor bus frequency decay rate must not be too high, in order to be compatible with the latency of the command chain (control system, circuit breaker reaction times). Such systems are extremely costly and complex and commissioning is often carried out by specialists. When reconnection occurs, the inrush current is normally kept below the natural motor starting current and the transient torque remains acceptable.

③- Fast transfer sequence: The transfer is initiated immediately upon request, provided that: (a) the normal source is in synchronism with the replacement source (ANSI Device 25); (b) both sources have the same voltage level; and (c) the bus to be transferred is connected to its source and there is no electrical fault (ANSI Device 50/51) on the bus. The performance of a fast transfer sequence can be assessed with reference to the ANSI C50.41-2012 standard.

The fast transfer sequence can be performed in two ways: ‘sequential fast transfer’ or ‘simultaneous fast transfer’.

Sequential Fast Transfer

Figure 6 depicts the typical time chart of a sequential fast transfer: The normal source circuit breaker (here the incomer) trips first. When confirmation of the open status of the normal source circuit breaker is acquired by the controller, a second order is issued to close the replacement source or bus coupler circuit breaker. The transfer time is the period when the transferred busbar is no longer fed by the normal source but is not yet fed by the replacement source. Additional mechanical interlocking can be used between the circuit breakers to prevent undesired paralleling of the sources.

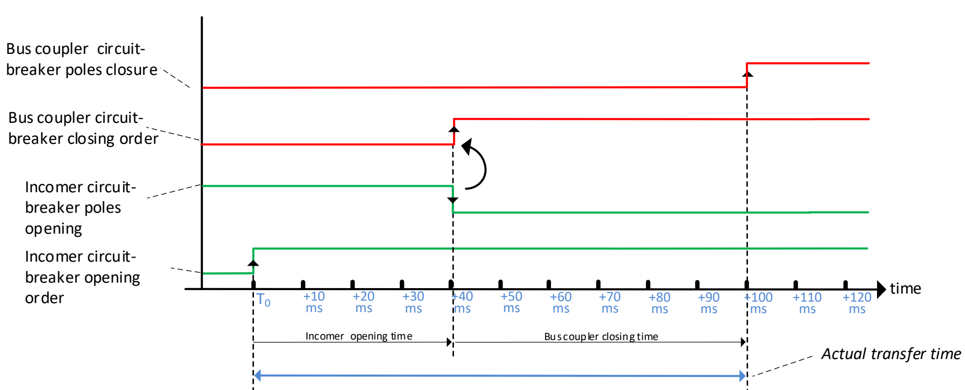


Figure 6

Sequential Fast Transfer Time Chart

The main drawback of a sequential fast transfer is that the total transfer time cannot be shorter than the sum of the latency values for each circuit breaker. This is typically 100ms for standard low-voltage circuit breakers, and slightly longer for medium-voltage vacuum circuit breakers. This transfer time can exceed requirements, especially in low-voltage applications, to ensure a satisfactory transfer performance according to the requirements of the ANSI C50.41-2012 standard.

Simultaneous Fast Transfer as an Efficient Alternative to the Other Methods

The time chart in Figure 7 depicts the sequence of a simultaneous fast transfer: The closing order for the replacement source or bus coupler circuit breaker and the opening order for the normal source circuit breaker are independently issued according to a differential time delay based on the constant latency of each circuit breaker. Therefore, the total transfer time can essentially be set by displacing the instant of the normal source opening order ① with reference to the fixed instant of the replacement/bus coupler closing order ②. On Figure 7, the adjustment has been set to obtain a simultaneous opening and closing of the relevant circuit breakers, resulting in a 10ms transfer time. However, even though it is easily possible to obtain a lower value, a shorter transfer time is not desirable for a real open transition transfer mode. The simultaneous fast transfer system transfer time is sufficiently short to avoid significant adverse effects due to voltage, phase, and frequency change between the motor bus voltage and the replacement source voltage during the transfer phase.

It must be mentioned that a mechanical interlock system cannot be used between the circuit breakers in this case.

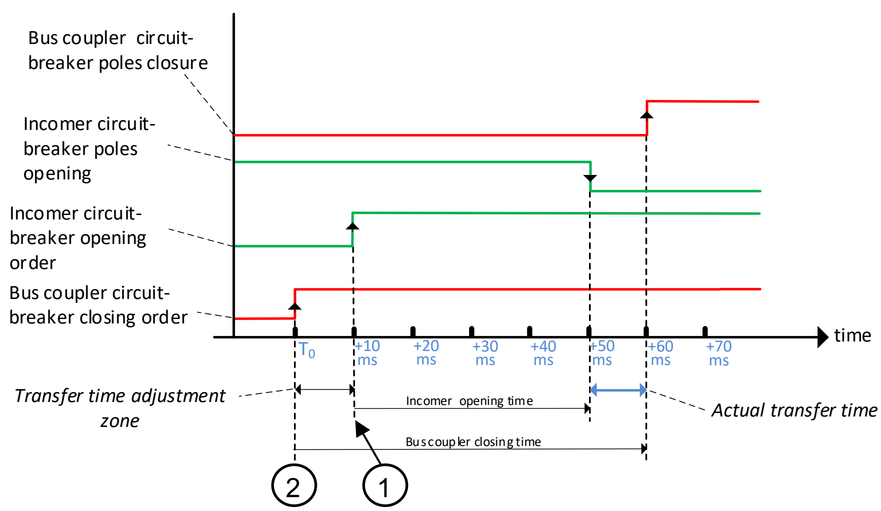


Figure 7

Simultaneous Fast Transfer Time Chart

As explained above, a simultaneous fast transfer offers excellent conditions for a source replacement, ensuring a smooth load transfer from one source to another because the bus voltage decay and phase shift can both be extremely low at the instant of the reconnection. The next section explains how motor characteristics and load inertia are important from this standpoint. This method generally exceeds the performance required by the ANSI C50.41-2012 standard.

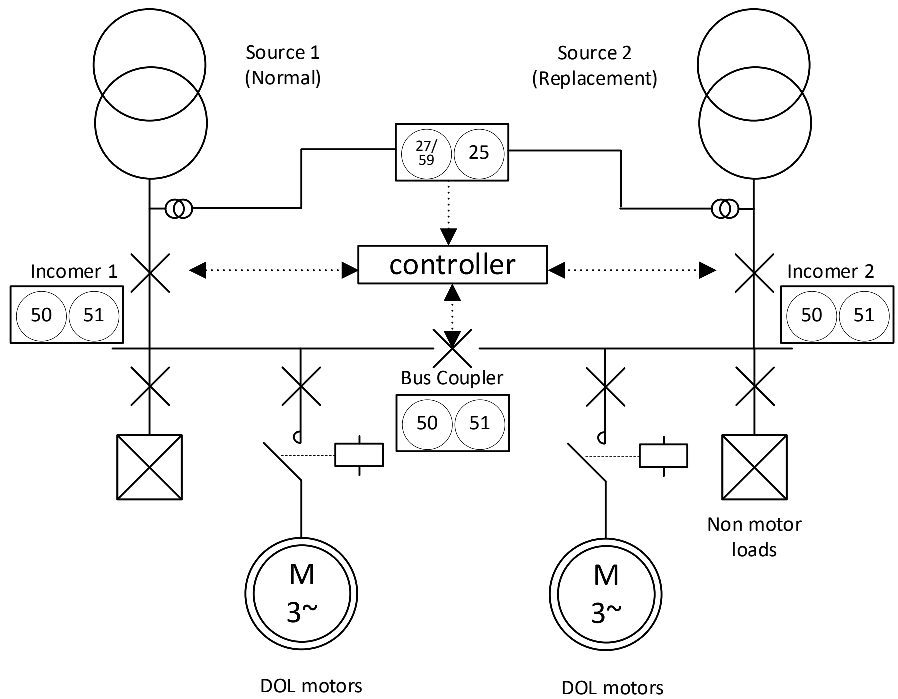
To be compatible with this performance, the controller must operate and monitor circuit breakers signals very quickly, typically in 1ms or less. Since no high-speed analog signal is required or processed, most standard controllers can be used for this purpose.

Figure 8 depicts the basic discrete inputs that are required by the controller to perform a simultaneous fast transfer: Voltage level concordance and synchro check signals between the sources on the one hand (ANSI device 27, 25), and no electrical fault signal on the circuit breakers (ANSI device 50, 51) on the other. No analog signal input is required. ANSI device 27 and ANSI device 25 relays are only necessary if the normal and replacement sources can have different frequency and voltage magnitudes.

The control and monitoring system is therefore reliable and simple; it does not require extended time for integration, parameter-setting, or commissioning thanks to the absence of external sensors and their calibration. The only calibration required in this kind of system is the accurate measurement of the operation and response times of the different components in the actuator control and monitoring chain, which can be performed automatically, thus dramatically simplifying and reducing the system start-up procedure.

Figure 8

Simplified View of Controller Inputs



Load Contribution

Characterization of the loads connected to the bus is of the utmost importance to be able to predict the capability of the transferred bus to maintain acceptable frequency and voltage decays during the transfer time. As a rule of thumb, and for a given real power to be transferred, it is recommended that at least 60%of this power is considered to consist of motor loads. It should be mentioned that no open transition system described above is better than another one if the dynamic conditions imposed by the loads leads to excessive voltage and frequency decay rate on the bus to be transferred. Therefore, prior to implementing any open transition fast transfer system, it is advisable to characterize the equivalent load that is connected to the bus. This characterization requires:
(a) the motor voltage decay rates to be aggregated as an equivalent motor, based on each motor's open circuit time constant characteristics;
(b) the moment of inertia of all motor rotors to be aggregated with the moment of inertia of their loads as an equivalent rotating mass;
(c) the magnitude of the aggregated retarding torque which(?)these loads apply to the equivalent rotating mass to be calculated as a function of time;
(d) this retarding torque to be converted to retarding power; and
(e) this power to be summed with all the static and non-regenerative load powers that could be connected to the bus. This methodology allows both the voltage decay rate and the spin deceleration rate to be assessed as a function of time to verify that this decay is compatible with the expected transfer performance.

Minimum and Maximum Transfer Time

The transfer time is selected within a time window that meets the following two criteria: a) a maximum transfer time that complies with or exceeds ANSI C50.41-2012 performances, and b) a minimum transfer time that allows the current flowing from the normal source into the transferred busbar to be interrupted on all three phases before being reenergized by the replacement source.
This latter requirement ensures a true open transition and eliminates the risk of a short-circuit current brought by the two sources in the event of a fault occurring at the instant of the transfer. The minimum transfer time can thus be as low as 10ms in low-voltage systems (≤ 1,000 VAC), whereas the zero-crossing constraint for current extinction in medium-voltage systems (> 1,000 VAC) requires a minimum transfer time of 15ms.

Actuator and Sensor Repetitiveness

In order to obtain expected performances in terms of control, monitoring, and fault management, the following mandatory conditions must be fulfilled by the whole system: a) the controller must have the capability to process the signals issued from and to the circuit breakers quickly, as mentioned in previous section, and b) the overall circuit breaker response time (internal trip and close mechanisms, poles, and position auxiliary contacts) must have a good repetitiveness, with a tolerance on the response dispersion time not greater than the controller process time, e.g. ± 0.5ms for a controller with tasks scheduled at 1ms. Special attention should also be paid to auxiliary contact bounce issues that can produce false time measurements if they are poorly processed by the controller and may impede the simultaneous fast transfer performance due to lack of accuracy.

Advanced Fault Monitoring

Circuit breaker monitoring is performed by the controller by comparing an expected response delay (with a tolerance) with the order the controller emits to the relevant circuit breaker. This monitoring allows fault treatment methods to be elaborated for the following cases:

	Case	Consequence	Severity	Occurrence	Countermeasures
1	Incomer CB fails to open	Fugitive coupling between the two sources when the bus coupler CB closes	Low	Unknown but expected to be very low	1- Permanent monitoring of trip coil circuit continuity 2- Monitoring of CB position and trip forcing on bus coupler CB in case of discrepancy
2	Incomer CB takes too long to open	Preset transfer time reduced Fugitive coupling between the two sources possible	Low	Unknown but expected to be extremely low	1- Routine CB maintenance program including annual exercise 2- Monitoring of CB position but no action
3	Bus coupler CB fails to close	Half of the switchboard motors decelerate and stop	Medium	Unknown but expected to be very low	1- Permanent monitoring of close coil circuit continuity 2- Monitoring of CB position and bus coupler CB close interlock in case of discrepancy
4	Bus coupler CB takes too long to close	Phase shift too high on motors resulting in excessive transfer overcurrent High mechanical stress	High	Unknown but expected to be extremely low	1- Routine CB maintenance program including annual exercise 2- Monitoring of bus coupler CB response by means of early movement detection: bus coupler CB re-opening counter-order if tolerance is exceeded

Case 4 requires specific fault treatment to protect the motors against adverse effects resulting in a potential out-of-phase closure. Causes of an unexpected delay in mechanism operation can result from the partial seizure or abnormal grease dryness of poorly maintained circuit breakers. Long periods of inactivity can also lead to such a fault. To achieve efficient motor protection, several conditions must be fulfilled together:
a) The circuit breaker must issue a very early signal (the earliest possible) to the controller indicating the mobile poles have started to close. This can be achieved by a specific auxiliary contact or any other means, providing it is fast and repetitive.
b) The circuit breaker closing mechanism must be designed in such a way that the re-opening order issued by the controller processing this fault always has priority over the closing movement in progress, notwithstanding the position of the mobile poles between their at-rest open position and their fully closed position. Air circuit breakers with dual-crank trip operating mechanisms are able to achieve this.
c) Depending on the instant the fault is detected and given the speed already acquired by the mobile poles that are in transit, it is possible for the mobile poles to have slight and very short contact with the fixed poles before reopening. Low-voltage circuit breaker poles and arc chute chambers can generally handle this situation without any trouble, but medium-voltage circuit breakers cannot, due to the risk of contact welding. Another protection strategy must be implemented for MV circuit breakers, such as automatically lowering the instantaneous tripping threshold and eliminating any delay on their protection relays immediately prior to and during a simultaneous fast transfer, then restoring their original setting once the transfer is complete.

Operational Result

Low Voltage Applications

The oscillogram in Figure 9 has been captured on a standard squirrel-cage 400 V induction motor operating at rated load. The mechanical load inertia is about 100%of the induction motor rotor inertia and its retarding torque characteristic is of the quadratic type.

The transfer time window is delimited by the dotted and dashed lines ① from the poles parting on the normal source circuit breaker ③ (dotted line) to the poles closing on the replacement source circuit breaker ④ (dashed line). This transfer time lasts 19ms. In this example, the current in the motor is actually interrupted about 6ms after parting of the normal source circuit breaker poles ②, with the current interruption between the two sources thus lasting 13ms.

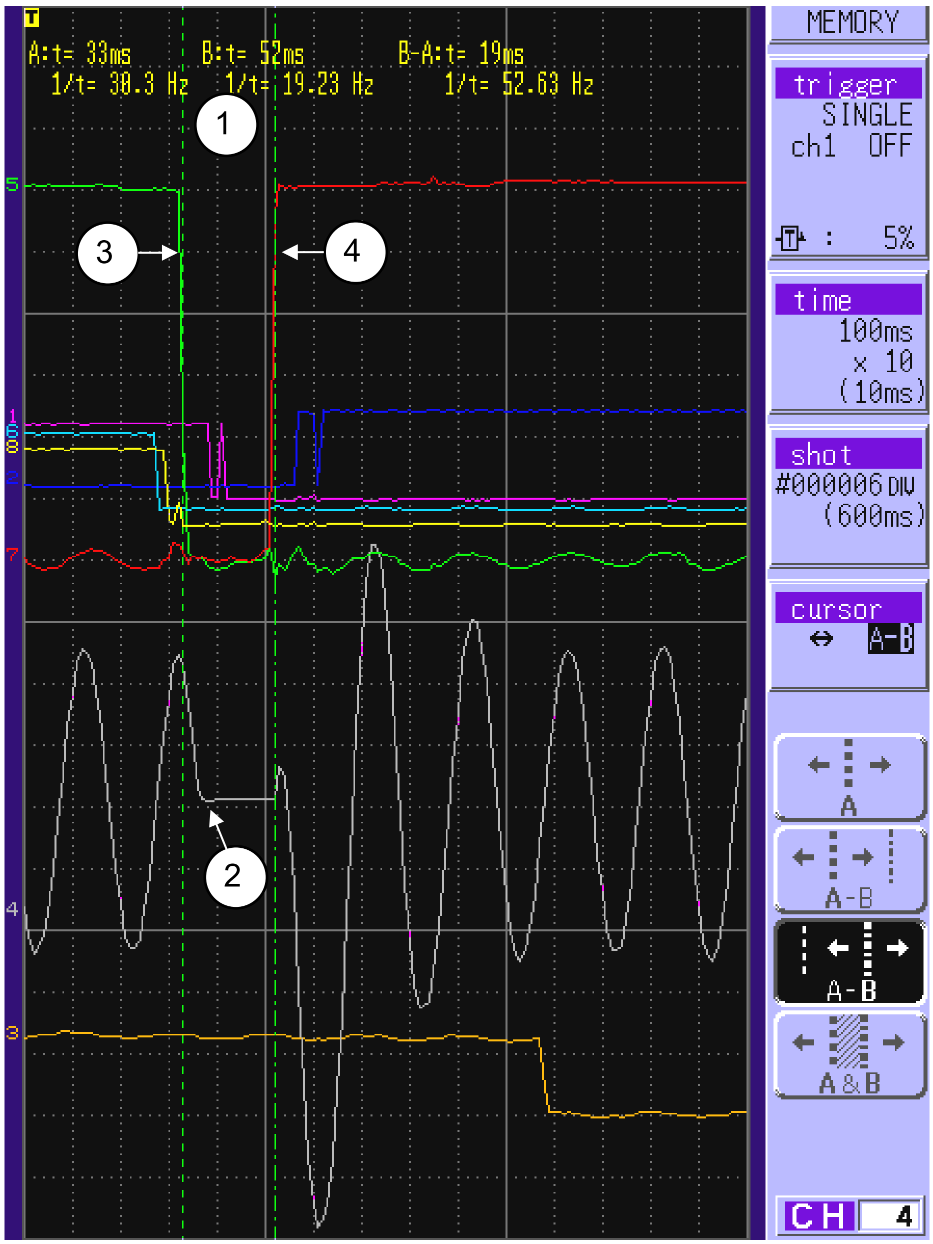


Figure 9

Typical 19 ms Fast Transfer

The lower part of this oscillogram (Figure 10) depicts the typical current waveform on one phase of the tested motor. Segment 1 displays the instantaneous motor current magnitude on one phase. Segment 2 displays the maximum instantaneous current in the motor for reacceleration of the motor and its load once reconnected to the replacement source. Several instants of disconnection have been tested to find the highest inrush current value. With a transfer time of 19ms, the inrush current ratio is about 2.8 times the rated motor current.

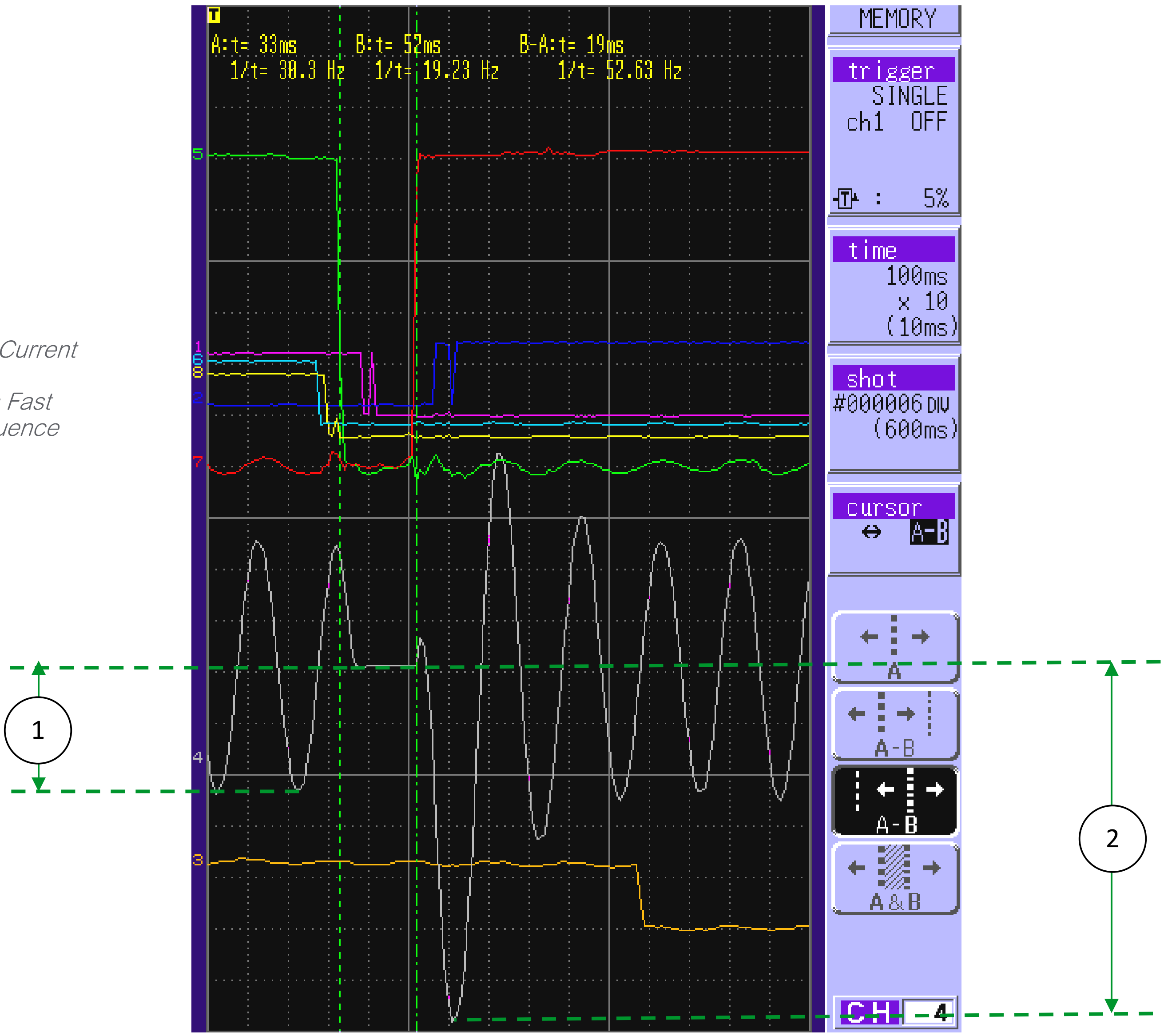


Figure 10

Motor Inrush Current on a 19 ms Simultaneous Fast Transfer Sequence

Medium Voltage Applications

In medium-voltage applications, the two-phase current zero-crossing delay and reignition time is considered to ascertain the current interruption on the motor bus. The waveforms 1 depict the three-phase rated current drawn by a load of 48 MW with 0.8 power factor lagging at 17,500 V. The transfer is carried out by a pair of vacuum circuit breakers. The transfer time 2 is still determined from the poles parting on the normal source circuit breaker to the poles closing on the replacement source circuit breaker. It is set at 19.5ms.

However, in this case, the current in the load is interrupted only once the phase 1 and phase 2 currents cross the zero-current axis, about 7ms (3) after the poles part on the normal source circuit breaker. Nevertheless, the current in the load is reinstated about 2.5ms (4) before the replacement source circuit breaker poles actually close, due to arcing current between the mobile and fixed poles, resulting from the loss of dielectric withstand of the insulating media (vacuum) when the mobile poles approach the fixed poles. It should be noted that a different insulating media such as SF6 and/or mobile pole traveling speed may modify this value slightly. As a result, the actual current interruption time between the two sources is about 10ms (5).

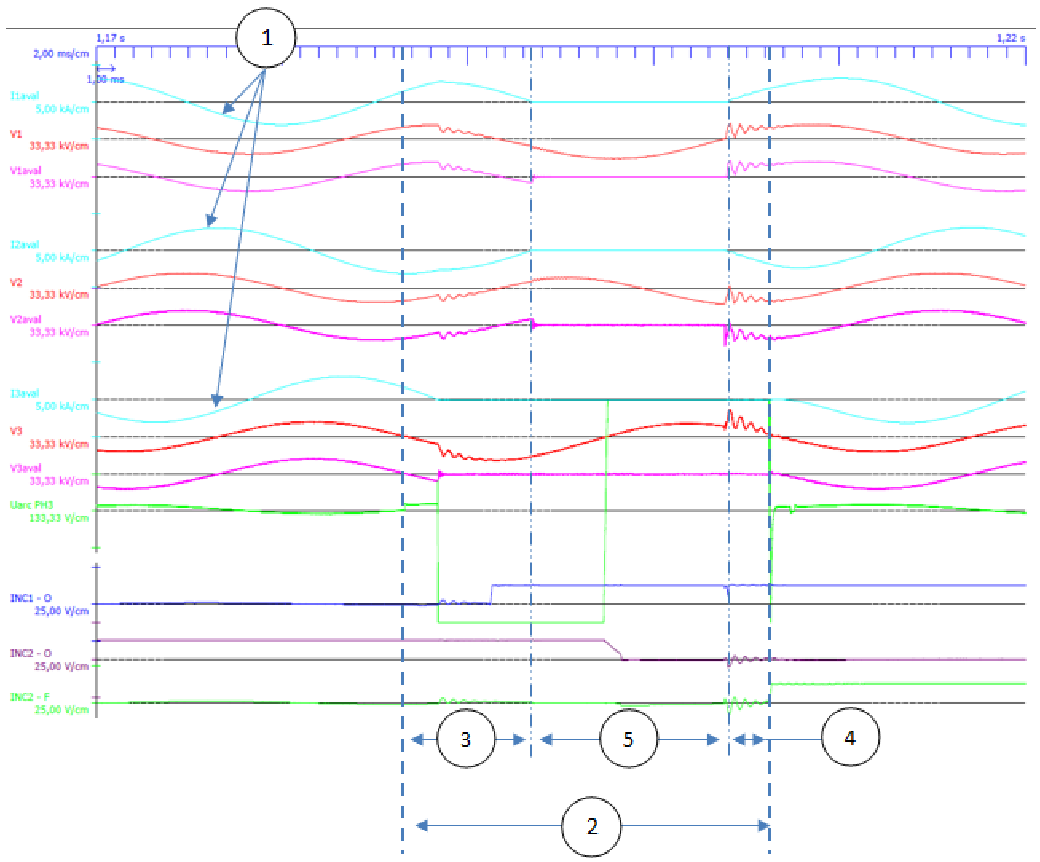


Figure 11

Transfer of 48 MW load at 17,500 V

Conclusion

To the extent that effective fault treatment is provided for abnormal late closing during a transfer sequence, the simultaneous fast transfer system is a simple, reliable, and very cost-effective solution for transferring a bus with DOL motors in 20ms or less, with no noticeable effect on process continuity or any need to oversize the entire electrical distribution system.

Bibliography

[1] National Electric Code, 2011

[2] Yuji AKIYAMA “Motor Residual Voltage”, Kanagawa Institute of Technology 1990

About the author

Jean-Luc Belletto graduated from the Jean Perrin School in Marseille (France) with a B.S. in Electrical Engineering in 1982. He has been employed by Schneider Electric for more than 30 years in various engineering in speed drives applications, power systems, and management roles. His current responsibilities in Schneider's Building & IT business include research related to power distribution equipment optimization for the oil and gas segment and technical support to regional front offices.

Contact us

For feedback and comments about the content of this white paper:
Motor Management Competency Center
motor.management@se.com