

Synchronous transfer control with SC9000 EP

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Overview

The Eaton SC9000™ EP drive has the ability to accelerate and transfer a motor to the utility bus reliably and repeatedly with minimum current and torque transients during the transfer. The SC9000 EP transfers from the adjustable frequency drive (AFD) to the utility bus and from the utility bus to the AFD with a closed transition.

This system helps maximize capital efficiency:

1. Operate multiple motors of different hp with a single drive
2. Starting an unloaded motor and transfer to bypass¹
3. Minimize utility disturbances during motor starting on a weak power system
4. Optimize process control by regulating motor speed based on demand
5. Reduce mechanical shock and wear by soft starting the motor and driven load

In addition, the Eaton SC9000 EP and Eaton's integrated control gear, double bus design, drive output isolation, motor select, bypass, and PLC control cabinet are close coupled under a common utility power bus with no external power cabling required, providing a more compact design for installation, maintenance, and troubleshooting.

Closed transition is also available with the SC9000 arc-resistant medium-voltage drive in conjunction with Ampgard® arc-resistant medium-voltage motor starters and is integrated into a single line-up.

This paper will review the Eaton SC9000 EP synchronous transfer:

- Sequence of operation
- Waveforms captured during motor load transition
- Limitations of open transition
- Typical system configurations

Sequence of operation

In the following example, the system is configured with an AFD per system, PLC per system, bypass, and motor select contactors for each motor. The AFD output isolation contactor feeding the adjustable frequency drive bus is optional and is shown in **Figure 1**. Synchronous transfer is abbreviated throughout this paper as 'sync' for brevity.

The basic principle is to adjust the AFD output voltage, frequency, and phase to match the utility bus. By matching these parameters, the motor can transfer to and from the utility in a seamless manner. In a sync up and sync down system, the AFD and PLC system is programmed to follow these general commands:

- Start / stop, hardwired (two-wire), per motor
- Sync up / sync down, typically hardwired (two-wire), per motor
- AFD speed reference via preset speed, fieldbus or analog input wired directly to the AFD controller

The start command for a specific motor is given by the customer PLC. The intent of the Eaton sync transfer PLC is to ensure contactors are operated in the proper sequence, indicate when the system is ready to start, provide the control signal hand-shake to the AFD controller, and annunciate incomplete sequence alarms.

For the example illustrated, the customer plant PLC/DCS/SCADA is referred to as "customer signal" and the Eaton PLC is referred to as "PLC." The AFD represented in all configurations is a fully integrated drive with isolation switch, power fuses, main input contactor, phase shifting isolation transformer, 24-pulse diode rectifier, DC link, and IGBT-based inverter.



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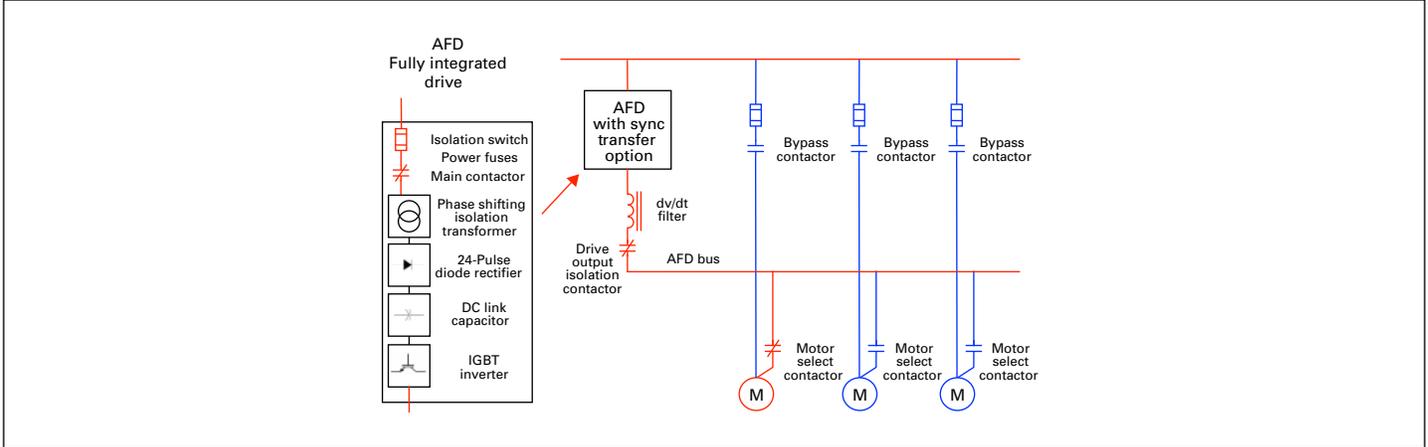


Figure 1. SC9000 EP integrated drive line-up and motor on AFD control

Start sequence

1. Customer sends a start signal to the PLC to start a specific motor
2. PLC closes appropriate motor select contactor
3. PLC sends run command to AFD controller
4. AFD pre-charges and closes main input contactor
5. AFD closes output isolation contactor
6. AFD ramps motor to reference speed

The motor is running on the AFD and follows the reference speed. PLC waits for next command.

Sync-up sequence

1. Customer sends a sync-up signal to the PLC to transfer motor to bypass
2. PLC sends sync-up signal to the AFD controller
3. AFD ignores speed reference and ramps motor at programmable rate
4. AFD locks output to match utility bus voltage, frequency, and phase
5. AFD sends sync acknowledgement to PLC
6. PLC closes bypass contactor
7. AFD detects closure of bypass contactor when AFD output current increases
8. AFD shuts off modulation (PWM off) to the inverter and opens output isolation contactor
9. PLC opens motor select contactor, removes run command and sync-up signal to AFD controller

The motor is running on bypass and the PLC waits for next command (**Figure 3**).

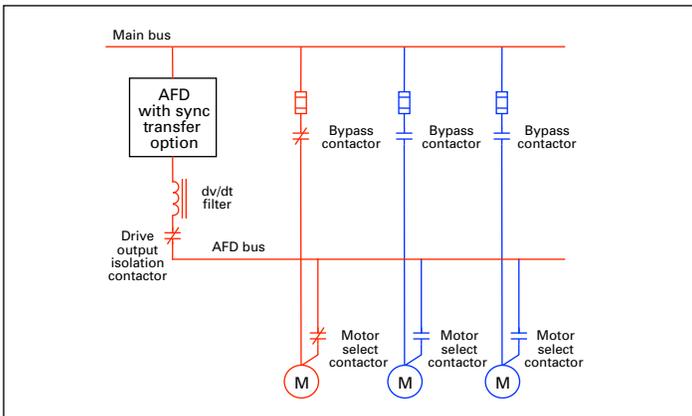


Figure 2. Sync-up and sync-down sequence

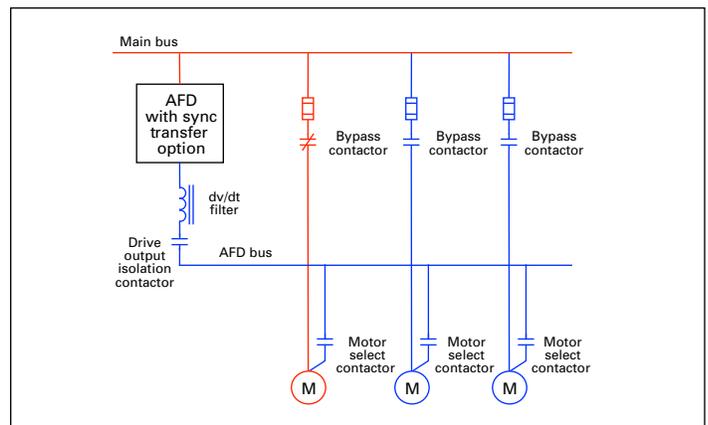


Figure 3. Motor running on bypass

Sync-down sequence

Note: See **Figure 2** and **Figure 3**.

1. Customer removes sync-up signal to the PLC to transfer to AFD control
2. PLC sends sync-down signal and run command to the AFD controller
3. AFD pre-charges and closes main input contactor
4. AFD ignores speed reference and locks output to match utility bus voltage, frequency, and phase. Inverter modulation is not yet enable (PWM off)
5. AFD closes drive output isolation contactor and sends sync acknowledgement to PLC
6. PLC initiates opening of bypass contactor and removes sync-down signal to AFD controller
7. AFD enables modulation (PWM on) and runs in parallel with the utility
8. Bypass contactor opens

The motor is running on AFD control and the PLC waits for the next command. The motor can be stopped or transferred to the utility bus again (**Figure 1**).

These sequences can be initiated for any of the motors. Systems are not limited to three motors; however, only one motor at a time can be on AFD control. Each system can be configured to start motors with different horsepower values; the drive must be sized to the largest motor and configuration layout may vary.

Closed transition waveforms

The following waveforms illustrate actual drive output and utility voltages/current taken from a loaded 4160 V, 1000 hp synchronous transfer system.

When the bypass contactor closes, the AFD controller detects the rise in current and shuts off modulation (PWM off). The transition is seamless (**Figure 4**).

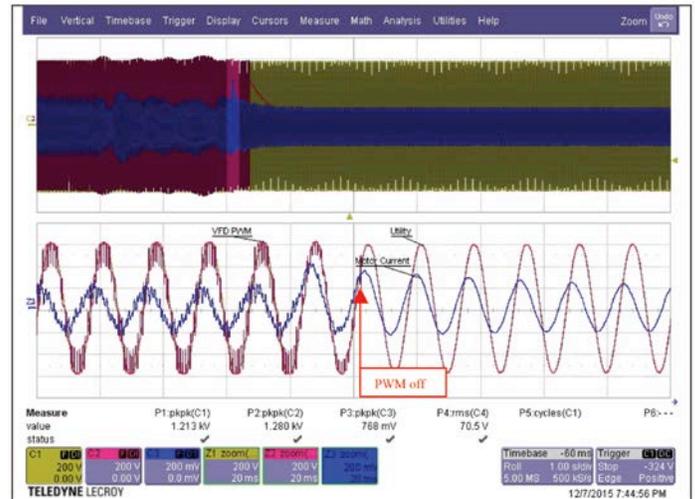


Figure 4. Sync-up drive and utility waveform

When the motor is operating on the utility bus, pure sinusoidal voltage and currents are observed. Once AFD enables modulation (PWM on), the utility and AFD output are paralleled momentarily. The bypass contactor opens and the motor is operated only on AFD control. The transition is seamless (**Figure 5**).

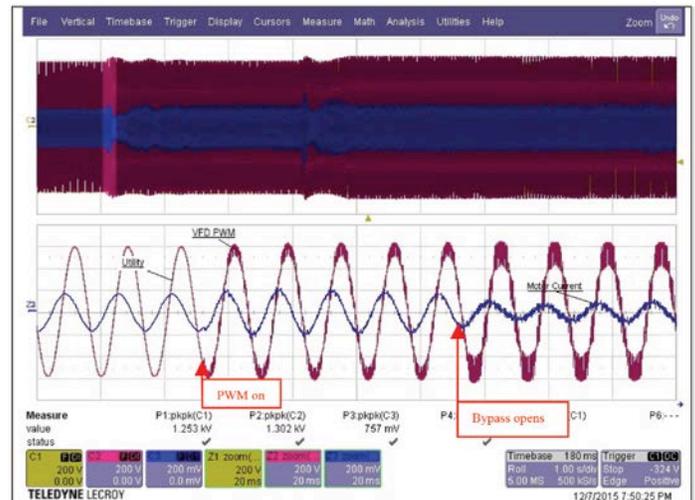


Figure 5. Sync-down drive and utility waveform

Limitations of open transition

The Eaton SC9000 EP provides true closed transition transfer from AFD to bypass and from bypass back to AFD control. This seamless transition eliminates mechanical shock and wear on the motor and driven load. Closed transition also eliminates current and torque transients observed in open transition transfer schemes.

During an open transfer from AFD to bypass, the actual contactor opening and closing timing is needed to ensure the open circuit duration is minimized. When an induction motor is open circuited, the back EMF and residual motor terminal voltage decays at a rate associated with specific electrical parameters of the motor (rotor resistance, leakage reactance, and magnetizing reactance). The rotor position drifts and phase difference, in relation with the utility phase, increases as the driven load slows the motor. The open circuit run-down rate is dependent upon the applied load torque.

In an open transition scheme, once the bypass contactor closes, a current and torque transient occurs. The current transient is associated with the difference in magnitude between motor terminal voltage and utility voltage. The torque transient is associated with the phase difference between the motor terminal voltage and utility voltage.² A large current transient may cause upstream protection relay tripping. Large torque transients may cause unnecessary mechanical wear to the system.

During an open transition from bypass to AFD control, the same transients are to be considered. The magnitude of the current transient is limited by the overload capability or current limit of the AFD. In a worst-case scenario, the voltage and phase difference will cause an overcurrent trip if the AFD controller is not fast enough to regulate the current.

During both modes of transfer, if the AFD is not designed to operate in true parallel mode, any deviation in contactor performance can result in unintended paralleling. Best case, the AFD controller trips; worst case, components within the AFD are damaged, resulting in costly process downtime during needed repairs.

Single motor application

1. Customer sends a start signal to the PLC to start the motor
2. PLC sends run command to AFD controller
3. AFD pre-charges and closes input main contactor
4. AFD closes output isolation contactor
5. AFD ramps motor to reference speed

The motor is running on the AFD and follows the reference speed. PLC waits for next command.

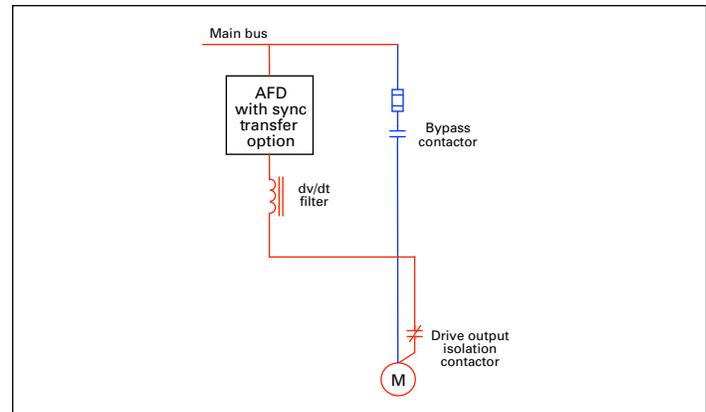


Figure 6. Motor running on AFD control

Sync-up sequence

1. Customer sends a sync-up signal to the PLC to transfer motor to bypass
2. PLC sends sync-up signal to the AFD controller
3. AFD ignores speed reference and ramps motor at programmable rate
4. AFD locks output to match utility bus voltage, frequency, and phase
5. AFD sends sync acknowledgement to PLC
6. PLC closes bypass contactor
7. AFD detects closure of bypass contactor when AFD output current increases
8. AFD shuts off modulation (PWM off) to the inverter and opens output isolation contactor
9. PLC removes run command and sync-up signal to AFD controller

The motor is running on bypass and the PLC waits for next command.

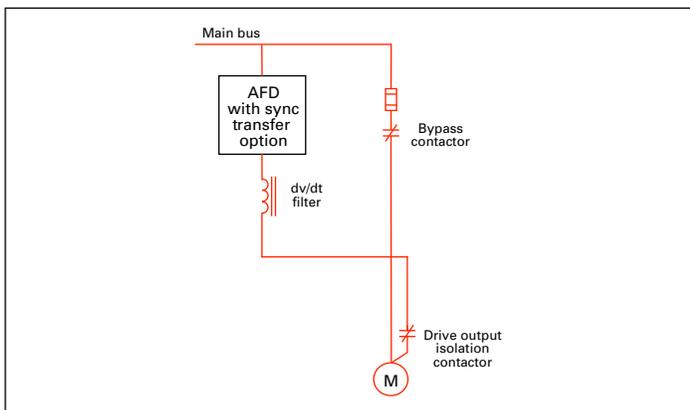


Figure 7. Sync-up and sync-down sequence

Sync-down sequence

1. Customer removes sync-up signal to the PLC to transfer to AFD control
2. PLC sends sync-down signal and run command to the AFD controller
3. AFD pre-charges and closes main input contactor
4. AFD ignores speed reference and locks output to match utility bus voltage, frequency, and phase. Inverter modulation is not yet enable (PWM off)
5. AFD closes drive output isolation contactor and sends sync acknowledgement to PLC
6. PLC initiates opening of bypass contactor and removes sync-down signal to AFD controller
7. AFD enables modulation (PWM on) and runs in parallel with the utility
8. Bypass contactor opens

The motor is running on AFD control and the PLC waits for the next command. The motor can be stopped or transferred to the utility bus again (**Figure 6**).

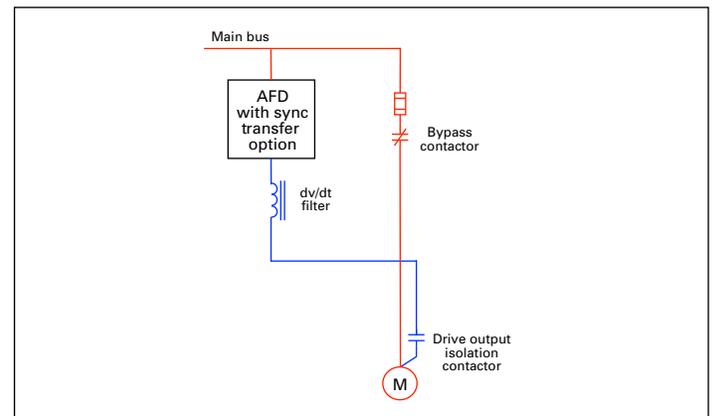


Figure 8. Motor running on bypass

Multiple motors, drives, and utility buses

Systems that require redundancy, multiple motor operating requirements, or multiple utility bus feeds can be configured as shown in **Figure 9**. In this scenario, when the bus tie and AFD tie are opened, the motor on either bus can be operated on the AFD or transferred to utility. If one of the utility feeds goes down, the bus tie and AFD tie can be closed, routing power to the other AFD and motors. This system can be configured to alternate AFD operation or default to one of the drives to control the motors. The PLC logic is programmed to operate the system in the required scenarios. A sync check relay (IEEE® device 25) is recommended for paralleling main utility buses.

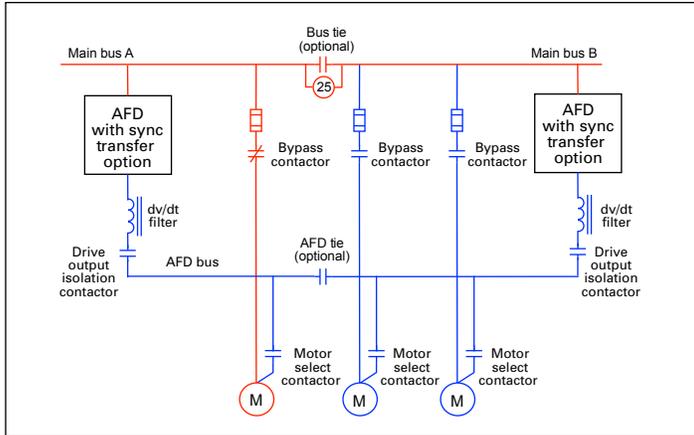


Figure 9. Multiple utility bus-feed configuration

If redundant drives are required with only a single utility feed, the bus tie and AFD tie can be omitted. The PLC logic can be programmed to alternate the drive starts to maintain even operation.

Alternatively, a reduced voltage soft starter (RVSS) is an option for backup operation. It is important to note, based on the motor load during RVSS starting, the thermal capacity of the RVSS may not allow immediate starting of another motor. The number of starts per hour and the time between starts are limited based on the motor manufacturers recommendations.

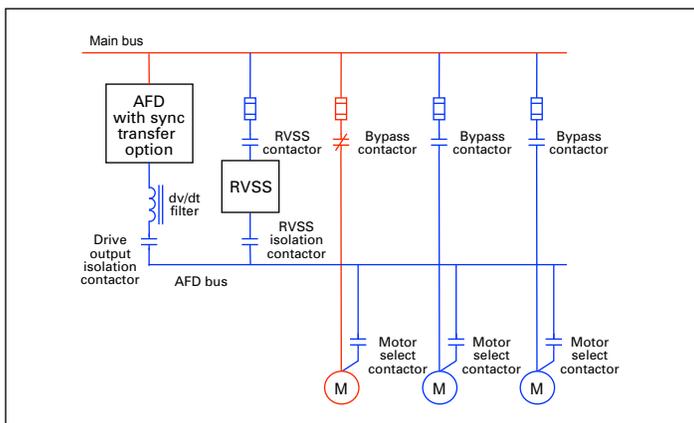


Figure 10. Multiple utility bus-feed configuration

Summary

The Eaton SC9000 EP closed transition provides added benefits to keep motor systems running reliably. The elimination of current and torque transients increases process uptime and reduces unnecessary motor and load wear. The elimination of contactor timing requires fewer control components, less testing time, fewer commissioning, and startup complexities. The integrated line-up provides flexible configurations, double power bus, optional redundancy, reduced cabling, and reduced footprint. The available medium voltage arc-resistant drive helps enhance safety, and minimize unplanned downtime and equipment damage while enabling synchronous transfer control.

Table 1. Synchronous transfer comparison

	Closed transition	Open transition
Contactor timing	None	Required
Torque transient	None	Typical
Current transient	None	Typical
Mechanical wear	None	Typical
Reliability	High	Medium

References

1. See Eaton white paper "Starting Duty Only Synchronous Transfer Systems."
2. Mulukutla, S.S., "A Critical Survey of Considerations in Maintaining Process Continuity During Voltage Dips While Protecting Motors with Reclosing and Bus-Transfer Practices," IEEE 1991.

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Publication No. AP020001EN / Z18085
July 2016



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