ECET 4530

Industrial Motor Control

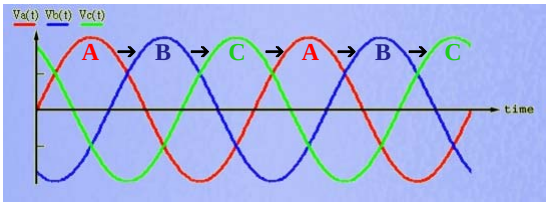
Directional Control
of
Induction Motors

Phase Sequence

The <u>phase-sequence</u> of a 3Φ supply is determined by the relationship of the phase angles of the supply's individual phase (or line) voltages.

A <u>positive-sequence</u> supply is defined such that its phase A voltage <u>leads</u> its phase B voltage by 120°, and its phase B voltage <u>leads</u> its phase C by 120°.

$$\tilde{V}_a = V\angle\phi$$
$$\tilde{V}_b = V\angle\phi - 120°$$
$$\tilde{V}_c = V\angle\phi - 240°$$



Phase Sequence

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A positive-sequence supply is defined such that its phase A voltage leads its phase B voltage by 120°, and its phase B voltage leads its phase C by 120°.

$$\tilde{V}_a = V\angle\phi$$
$$\tilde{V}_b = V\angle\phi - 120°$$
$$\tilde{V}_c = V\angle\phi - 240°$$

A negative-sequence supply is defined such that its phase A voltage lags its phase B voltage by 120°, and its phase B voltage lags its phase C by 120°.

$$\tilde{V}_a = V\angle\phi$$
$$\tilde{V}_b = V\angle\phi + 120°$$
$$\tilde{V}_c = V\angle\phi + 240°$$

Rotational Direction of a 3Φ Motor

The rotational direction of a 3Φ Induction Motor depends on the phase-sequence of the voltages used to supply the motor.

For example: If a positive-sequence 3Φ supply causes a specific 3Φ induction motor to develop a torque (rotate) in the CW direction,

Then a negative-sequence 3Φ supply will cause that same motor to develop a torque (rotate) in the CCW direction.

Reversing the Phase Sequence

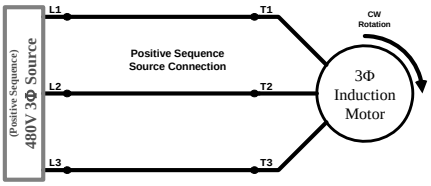
Note that, given the following sets of voltages:

Positive-Sequence	**Negative-Sequence**
$\tilde{V}_a = V\angle\phi$	$\tilde{V}_a = V\angle\phi$
$\tilde{V}_b = V\angle\phi - 120°$	$\tilde{V}_b = V\angle\phi + 120°$
$\tilde{V}_c = V\angle\phi - 240°$	$\tilde{V}_c = V\angle\phi + 240°$

Since: $V\angle\phi - 120° = V\angle\phi + 240°$ **and** $V\angle\phi - 240° = V\angle\phi + 120°$**,**
a positive-sequence source can be converted to a negative-sequence source by swapping lines B & C (or any other pair of supply lines).

Reversing the Phase Sequence

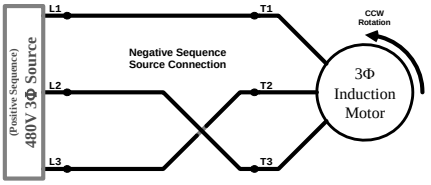
Thus, given the following positive-sequence source supplying a 3Φ Induction Motor that rotates in the CW direction:



$\tilde{V}_a = V\angle\phi$
$\tilde{V}_b = V\angle\phi - 120°$
$\tilde{V}_c = V\angle\phi - 240°$

Voltages seen at the motor's terminals.

the direction of rotation can be reversed by swapping lines B & C.

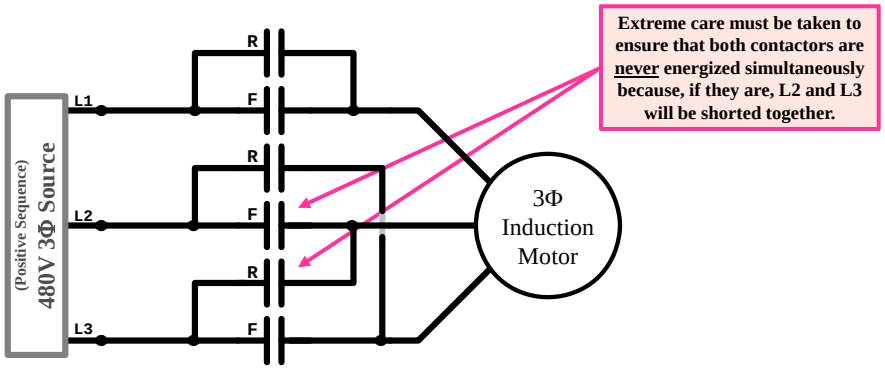


$\tilde{V}_a = V\angle\phi$
$\tilde{V}_b = V\angle\phi + 120°$
$\tilde{V}_c = V\angle\phi + 240°$

Voltages seen at the motor's terminals.

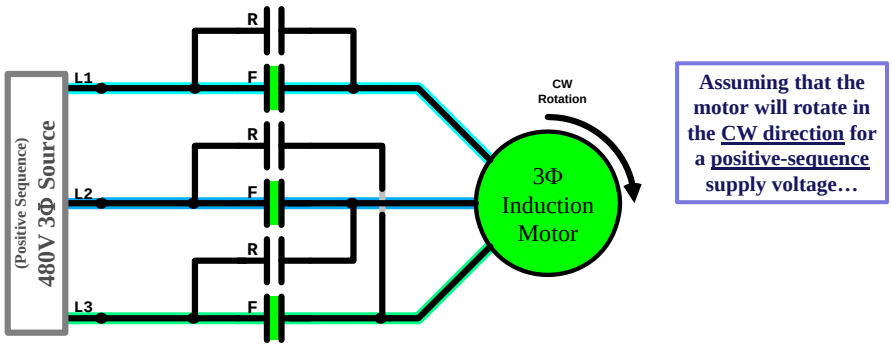
Directional Control of a 3Φ Motor

Directional control of a 3Φ Induction Motor can be achieved by utilizing two main contactors; one to supply a positive-sequence set of voltages to the motor, and the second to supply the motor with a set of negative-sequence voltages.



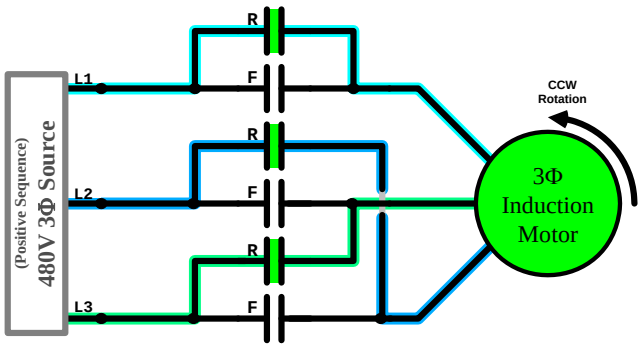
Forward Operation

When the "F" (Forward) contactor's field coil is energized, its main contacts will actuate (close), in-turn supplying the 3Φ Induction Motor with a positive-sequence set of voltages and causing the motor to rotate in the CW direction.



Reverse Operation

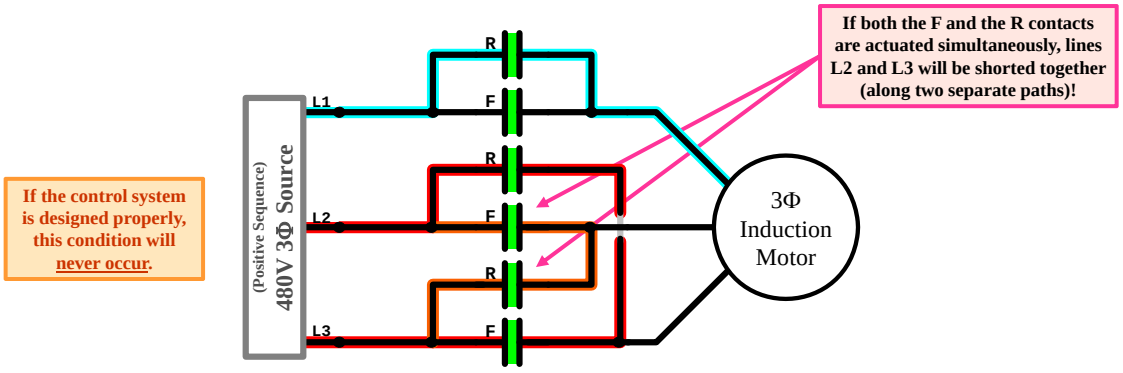
When the "R" (Reverse) contactor's field coil is energized, its main contacts will actuate (close), in-turn supplying the 3Φ Induction Motor with a negative-sequence set of voltages and causing the motor to rotate in the CCW direction.



Assuming that the motor will rotate in the CW direction for a positive-sequence supply voltage, then a negative-sequence supply will cause it to rotate in the CCW direction.

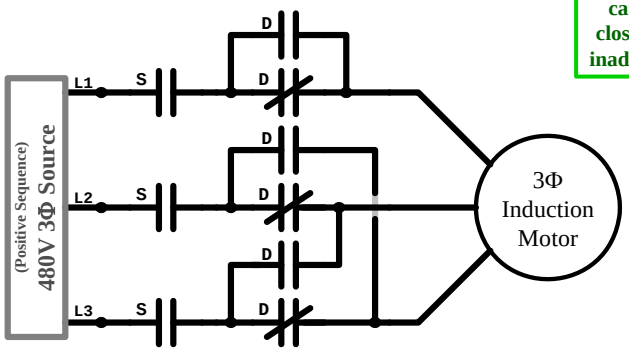
Dangerous Operating Condition

When using one contactor to energize the motor in the forward direction and a second to energize the motor in the reverse direction, extreme care must be taken to ensure that both contactors are never energized simultaneously!



Directional Control of a 3Φ Motor

Directional control can also be achieved by utilizing two main contactors; one to (start) energize the motor, and the second to determine the (direction) phase-sequence of the voltages supplied to the motor's terminals.

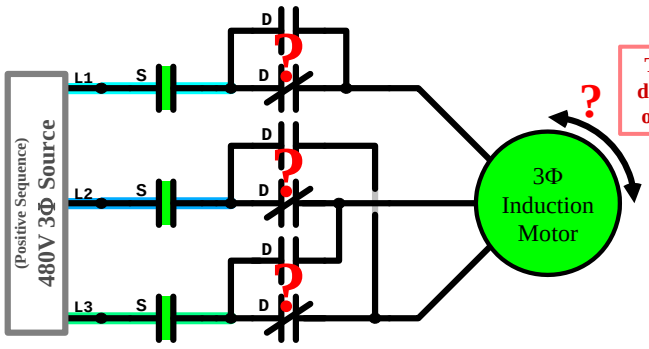


Since both sets of D contacts cannot be simultaneously closed, the supply cannot be inadvertently short-circuited.

But, large contactors typically only come with a set of main NO contacts, so this scheme may be difficult to realize for larger motors.

Directional Control of a 3Φ Motor

When the "S" (Start) contactor's field coil is energized, its main contacts will actuate (close), in-turn supplying the 3Φ Induction Motor with a set of voltages, the phase-sequence of which are determined by the state of the "D" contactor.

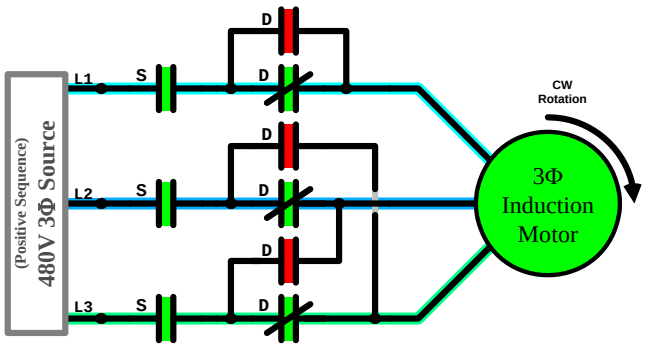


The direction will depend on the state of the D contactor.

Forward Operation

If the "D" (Direction) contactor's field coil is de-energized, then D's main contacts will be in their normal positions.

Thus, when "S" is energized, a positive-sequence set of voltages will be delivered to the motor by D's NC contacts.



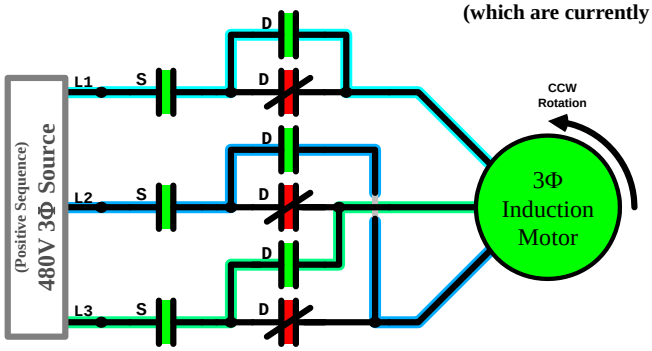
Assuming that the motor will rotate in the CW direction for a positive-sequence supply voltage…

Reverse Operation

If the "D" (Direction) contactor's field coil is energized, then D's main contacts will actuate.

Thus, when "S" is also energized, a negative-sequence set of voltages will be delivered to the motor by D's NO contacts.

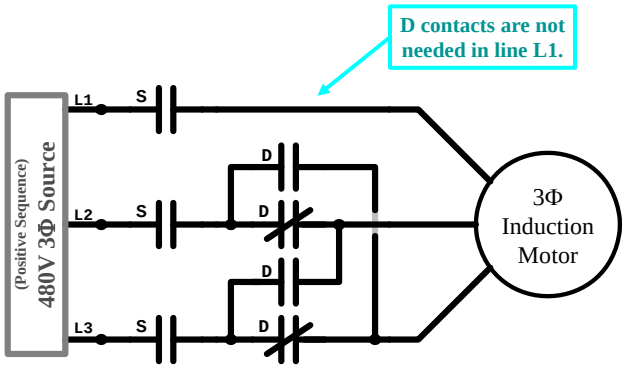
(which are currently actuated/closed)



Assuming that the motor will rotate in the CW direction for a positive-sequence supply voltage, then a negative-sequence supply will cause it to rotate in the CCW direction.

Directional Control of a 3Φ Motor

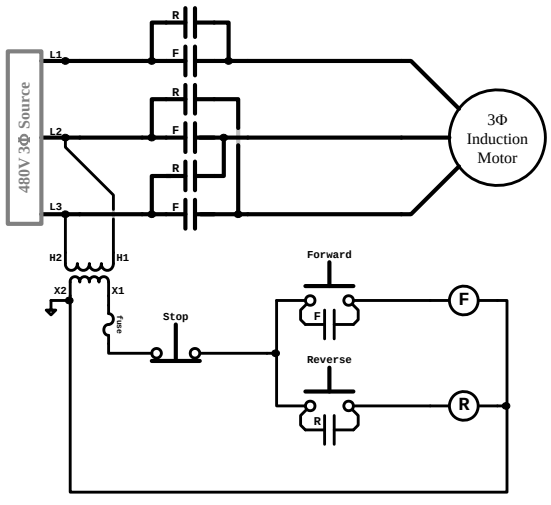
Note that, with this control scheme, the NO/NC "D" contacts associated with Line A are not required because contactor D's only function is to reverse supply lines B & C when the motor needs to rotate in the reverse (CCW) direction.



Directional Control of a 3Φ Motor

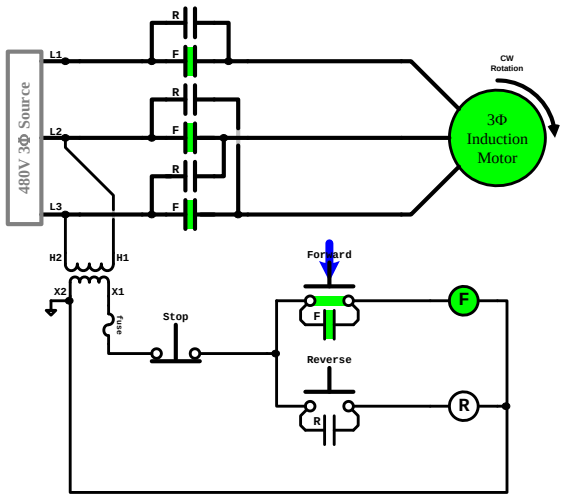
The figure shown to the right includes the components that are required to control the Forward and Reverse contactors.

Note that, although a single stop button is utilized, separate buttons are required to start the motor in either the forward or the reverse direction.



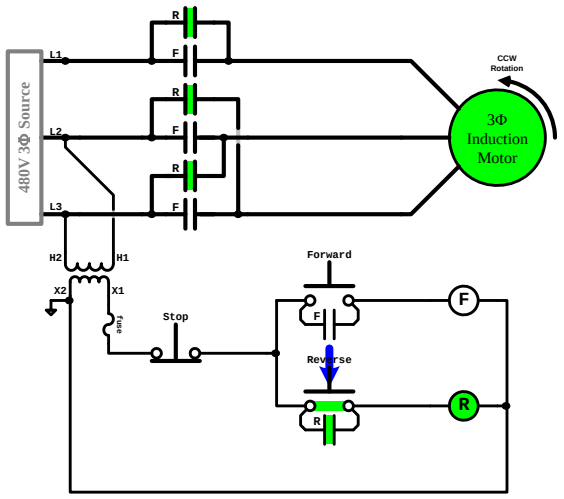
Forward Operation

When the "Forward" button is pressed, the field coil of the "F" (Forward) contactor is energized and its contacts will actuate, in-turn supplying the motor with a positive-sequence set of voltages and causing the motor to rotate in the CW direction.



Reverse Operation

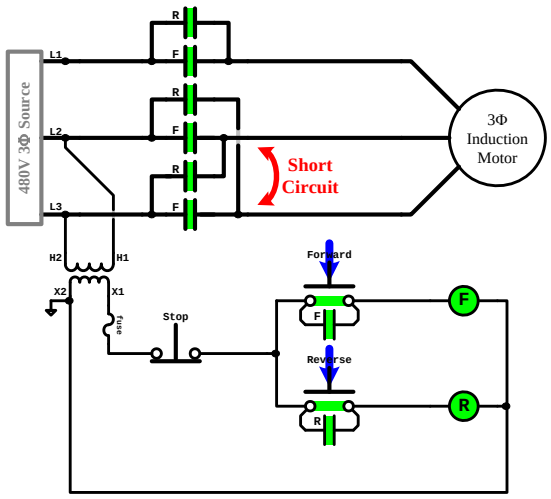
But, if the "Reverse" button is pressed, the field coil of the "R" (Reverse) contactor is energized and its contacts will actuate, in-turn supplying the motor with a negative-sequence set of voltages and causing the motor to rotate in the CCW direction.



Dangerous Operational State!!!

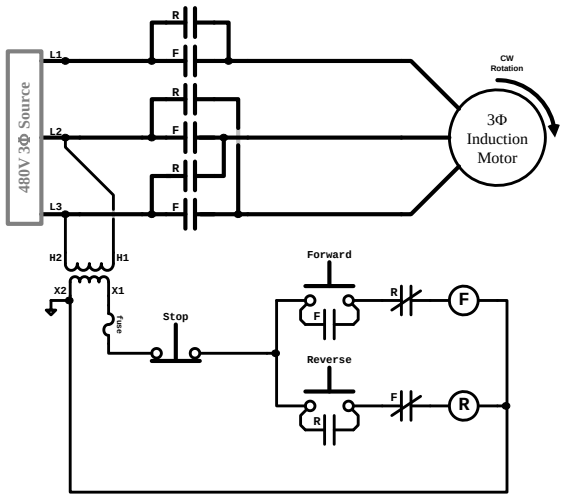
Note that, as shown, both the Forward and the Reverse field coils can be energized <u>simultaneously</u>.

If this occurs, then the "F" and "R" contacts will all actuate, causing the main "F" and "R" contacts to short-circuit lines B & C.



Safe Operation

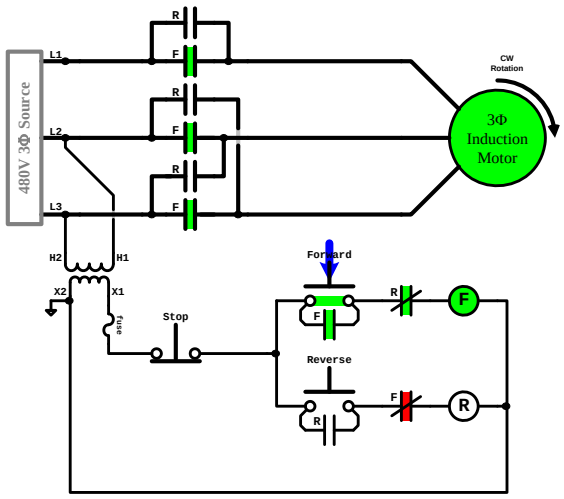
To prevent simultaneous activation of the field coils, a pair of NC contacts can be placed in series with the field coils.



Safe Operation

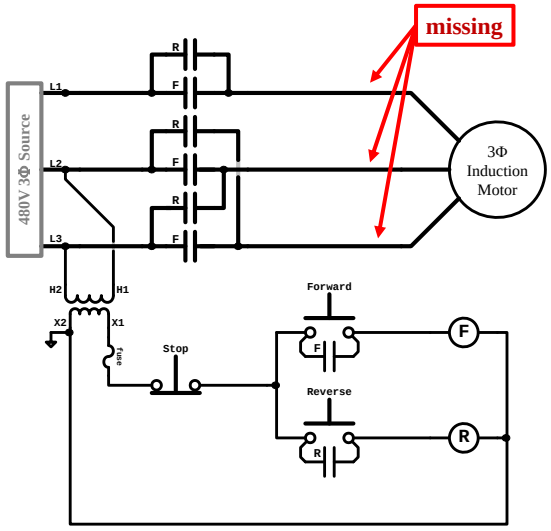
To prevent simultaneous activation of the field coils, a pair of NC contacts can be placed in series with the field coils.

If either field coil is energized, that field coil's NC contact will actuate (open), in-turn preventing the other field coil from being energized.



Forward/Reverse Motor Starter

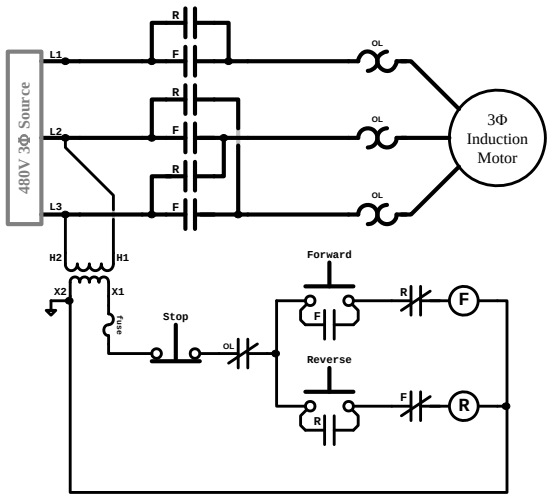
One typical component of a motor starter that has been missing up to this point is overload protection.



Forward/Reverse Motor Starter

One typical component of a motor starter that has been missing up to this point is overload protection.

Note that, to add overload protection, the relay's NC contact must be placed in series with the Stop button in order for the relay to be able to de-energize both contactors.



Forward/Reverse Reduced-Voltage Starter

Finally, what if the motor needs to be soft-started?

A series-resistance, reduced-voltage starting scheme can be employed.

This requires a timer, a set of starting resistors, and a third contactor, the main contacts of which will be used to ByPass the resistors.