ECET 4530

Industrial Motor Control

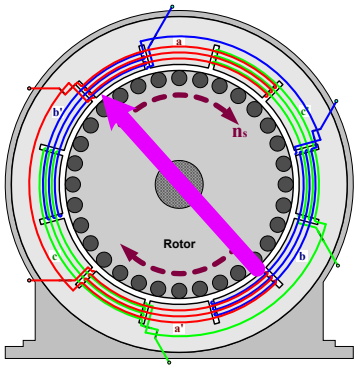
Directional Control
of
3Φ Induction Motors

1

Rotational Direction of a 3Φ Motor

When supplied with a balanced set of three-phase voltages, the **stator windings** of a 3Φ Induction Motor produce a **rotating magnetic field** that passes through the machine's rotor region.

The stator construction shown is that for a 2-pole motor, such that it contains one set of three-phase windings that are symmetrically-placed around the stator.



The speed at which the field rotates is referred to as the synchronous speed (n_s) of the motor and is a function of both the number of poles and the frequency of the voltages:

$$n_s = \frac{120 \cdot f_{elec}}{\#\ poles}$$

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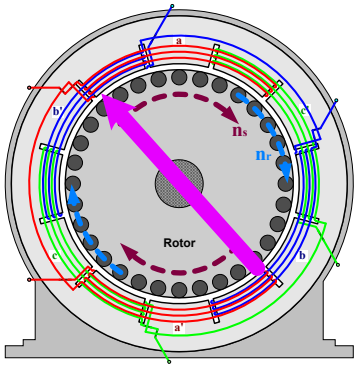
Rotational Direction of a 3Φ Motor

The **rotating stator field** induces a torque upon the rotor that tries to **accelerate the rotor** in the **same direction as the rotating field**.

Thus, the **rotational direction** of a 3Φ Induction Motor is determined by the **rotational direction of its stator field**.

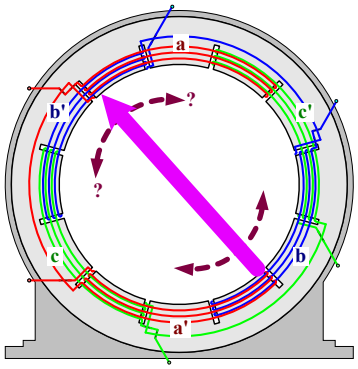


3

Rotational Direction of a 3Φ Motor

But the **rotational direction** of its stator field is affected by both:

- the **layout of the stator windings**, and
- the **phase sequence of the voltages** suppling those windings.



The windings shown are laid-out such that *winding-b* is rotated 120° CW from *winding-a*, and *winding-c* is rotated 120° CW from *winding-b*.

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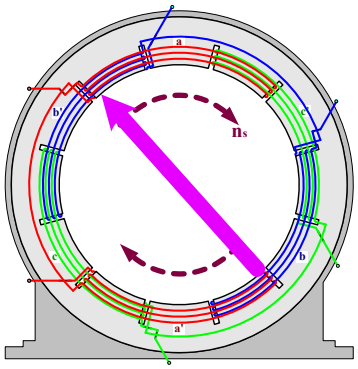
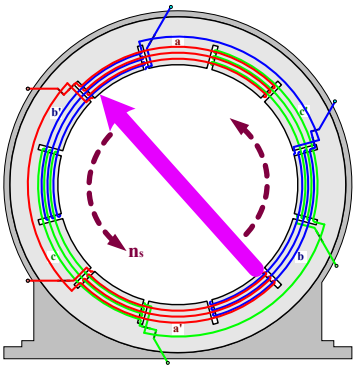
Rotational Direction of a 3Φ Motor

For example, with the windings oriented as shown, the field will:

- **rotate clockwise** when supplied by a **positive-sequence** set of three-phase voltages.
- **rotate counter-clockwise** when supplied by a **negative-sequence** set of three-phase voltages.





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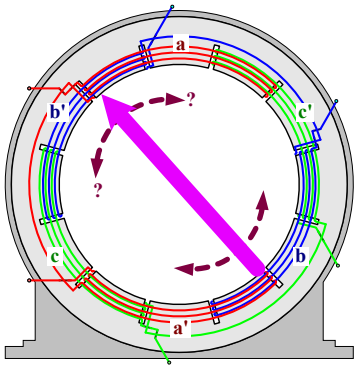
Rotational Direction of a 3Φ Motor

Thus, given a 3Φ Induction Motor, the windings of which have been configured in a specific manner, it is the **phase sequence** of the supply voltage that **determines the motor's direction of rotation**.



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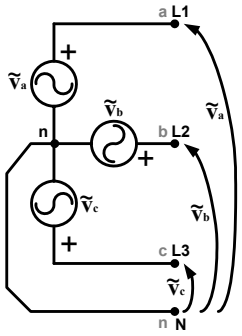
Phase Sequence

The **phase sequence** of a 3Φ supply is determined by the specific relationship between the phase angles of the supply's individual phase voltages (or line voltages).



Phase Voltages of a Y-connected 3Φ Supply

7

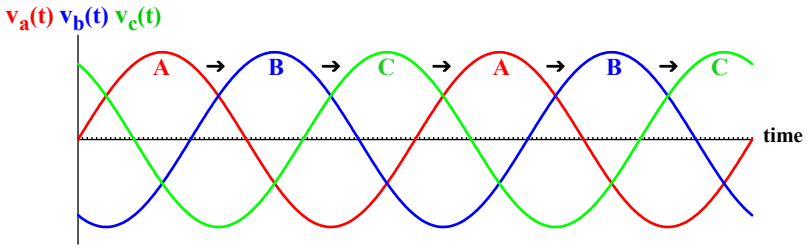
Positive Phase-Sequence

The **phase sequence** of a 3Φ supply is determined by the specific relationship between the phase angles of the supply's individual phase voltages (or line voltages).

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°.

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

decreasing angles



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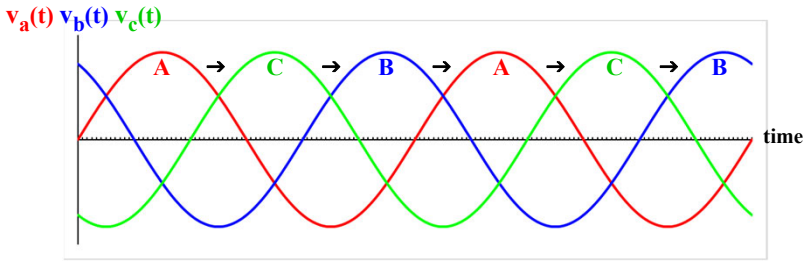
Negative Phase Sequence

The **phase sequence** of a 3Φ supply is determined by the specific relationship between the phase angles of the supply's individual phase voltages (or line voltages).

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°.

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

increasing angles



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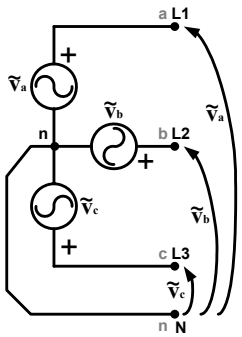
Phase Sequence from a Supply Panel

The actual **phase sequence** of a 3Φ supply is hard-wired into an electrical distribution system, such that the voltages available from line-terminals L1, L2, and L3 of an electrical supply panel will either have a positive or a negative sequence, and this cannot be changed without rewiring the supply panel.



Phase Voltages of a Y-connected 3Φ Supply

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Comparing the Phase Sequences

But note that phase voltage V_b of a positive-sequence supply is equivalent to voltage V_c of a negative-sequence supply, and that phase voltage V_c of a positive-sequence supply is equivalent to voltage V_b of a negative-sequence supply:

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

This occurs because rotating 120° CW on a polar plot (subtracting 120°) is equivalent to rotating 240° CCW on a polar plot (adding 240°), and vice-versa.

$$V\angle\phi - 120° = V\angle\phi + 240°$$

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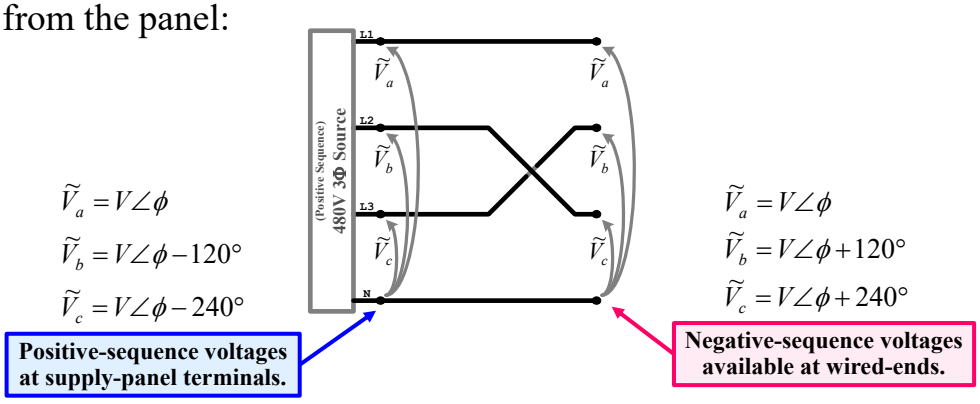
Reversing the Phase Sequence

Thus, if a **positive-sequence** set of voltages are available at the terminals of a supply panel, then those voltages can effectively be converted to a negative-sequence set of voltages **by swapping lines B & C** (or any other pair of supply lines) when pulling lines from the panel:



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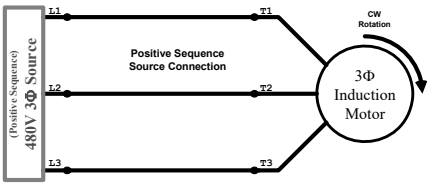
Reversing the Direction of a Motor

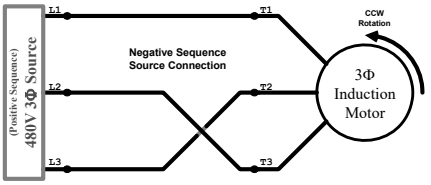
Based on this concept, given the following **positive-sequence** source supplying a 3Φ Induction Motor that rotates in the **CW direction**:



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

Voltages seen at the motor's terminals.

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



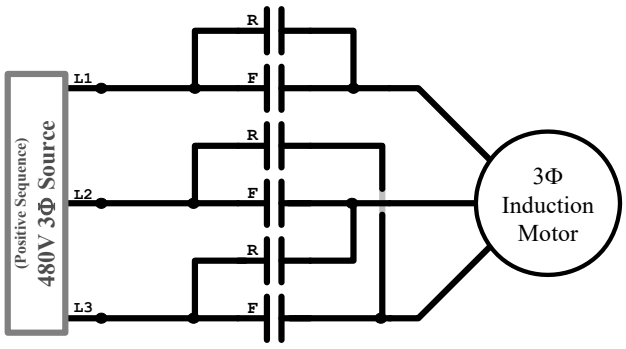
$$\tilde{V}_a = V\angle\phi$$
$$\tilde{V}_b = V\angle\phi + 120°$$
$$\tilde{V}_c = V\angle\phi + 240°$$

Voltages seen at the motor's terminals.

13

Directional Control of a 3Φ Motor

Directional control of a 3Φ Induction Motor can be achieved by using two main contactors; **one to supply a positive-sequence set of voltages** to the motor, and **the other to supply** the motor with **a set of negative-sequence voltages** (i.e. – swap two lines)**.**



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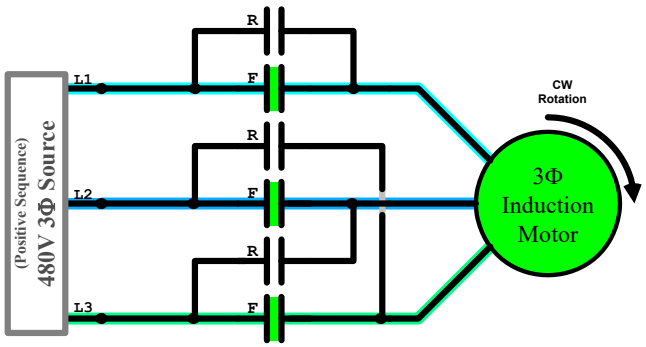
Forward Operation

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**.

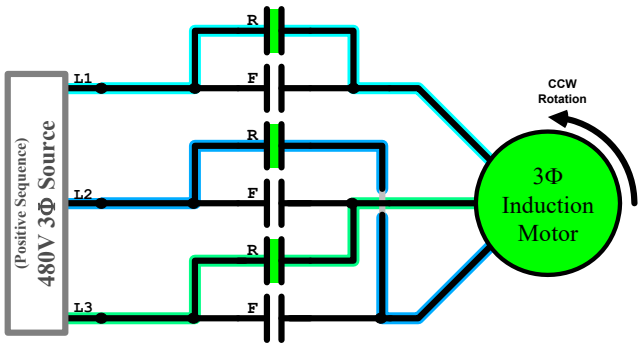


Assuming that the motor will rotate in the CW direction for a positive-sequence supply voltage…

15

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**.

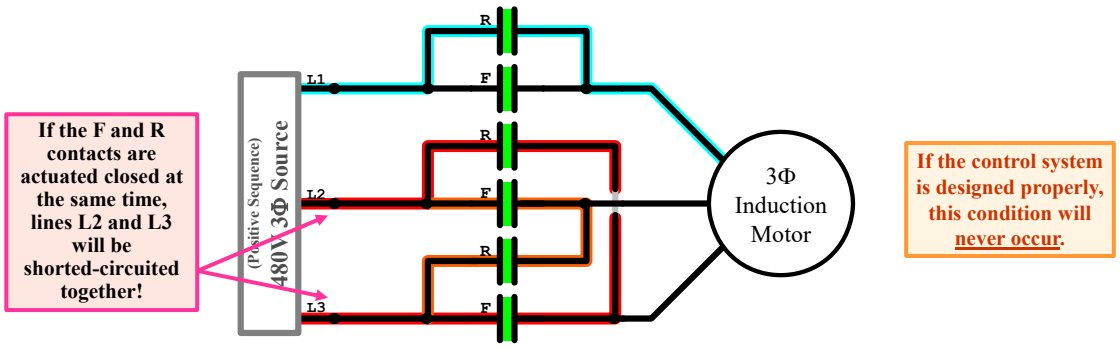


Assuming that the motor will rotate in the CW direction for a positive-sequence supply voltage, then a negative-sequence supply will cause it to rotate in the CCW direction.

16

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 sets of contacts (F and R) are <u>never</u> actuated at the same time**!



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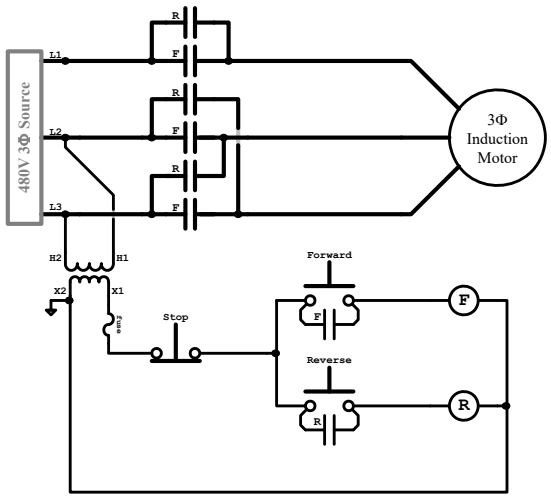
Directional Control of a 3Φ Motor

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

Although a **single stop button** is utilized, **two start buttons** are required:

- one to **start** the motor in the **forward** direction, and
- the other to **start** the motor in the **reverse** direction.

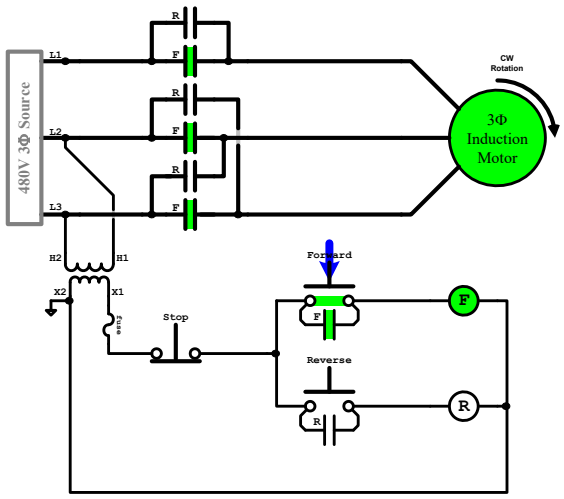


18

Forward Operation

When the "**Forward**" button is **pressed**:

- the **F field coil** (Forward contactor) is **energized**, actuating the **F contacts closed**, and
- when the **F** contacts close, the motor is supplied with a **positive-sequence** set of voltages and causing the motor to rotate in the **CW** direction.

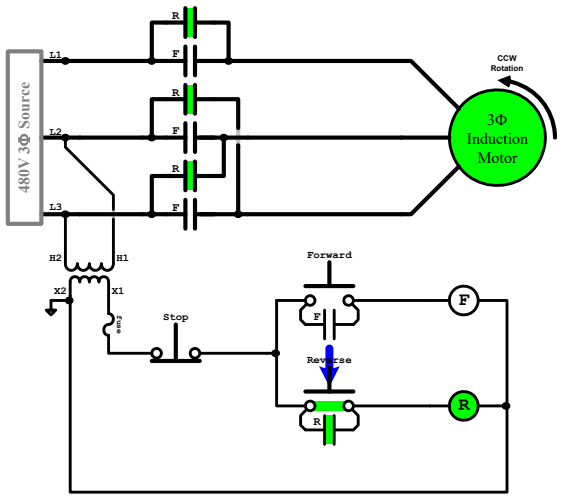


19

Reverse Operation

Or, when then the "**Reverse**" button is **pressed**:

- the **R field coil** (Reverse contactor) is **energized**, actuating the **R contacts closed**, and
- when the **R** contacts close, the motor is supplied with a **negative-sequence** set of voltages and causing the motor to rotate in the **CCW** direction.



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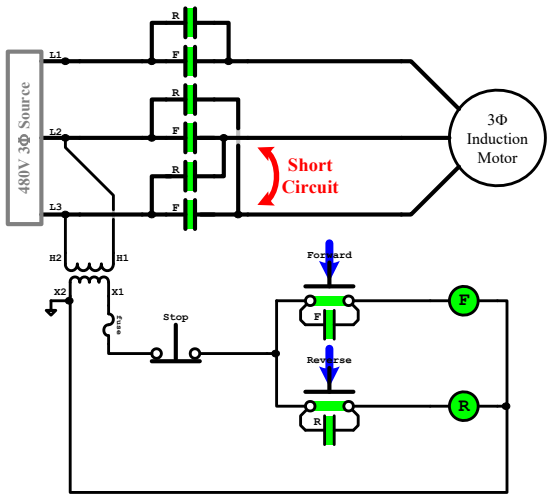
Dangerous Operational State!!!

Note that, as shown, both the **Forward** and the **Reverse field coils** can be **energized simultaneously**.

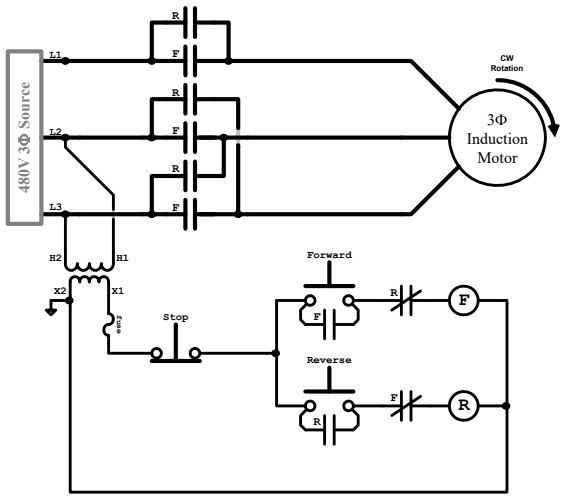
If this occurs, the **F** and **R contacts** will all **actuate** closed, in-turn creating a **short-circuit** current path between supply **lines B & C**.



21

Designing for Safe Operation

To prevent one field coil from becoming energized after the other is already energized, a pair of opposing **NC contacts** can be **placed in series** with each of the field coils.



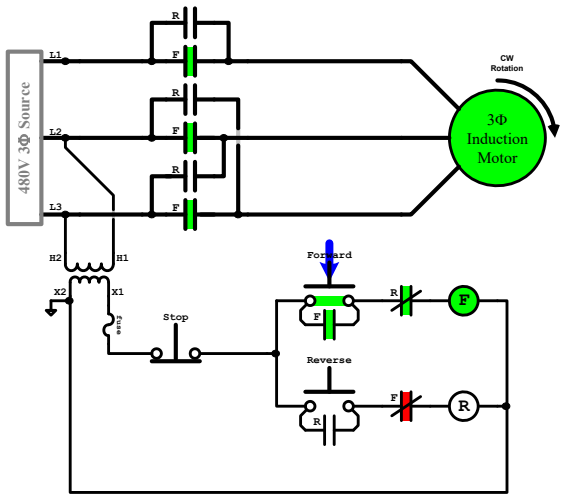
22

Designing for Safe Operation

To prevent one field coil from becoming energized after the other is already energized, a pair of opposing **NC contacts** can be **placed in series** with each of the field coils.

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

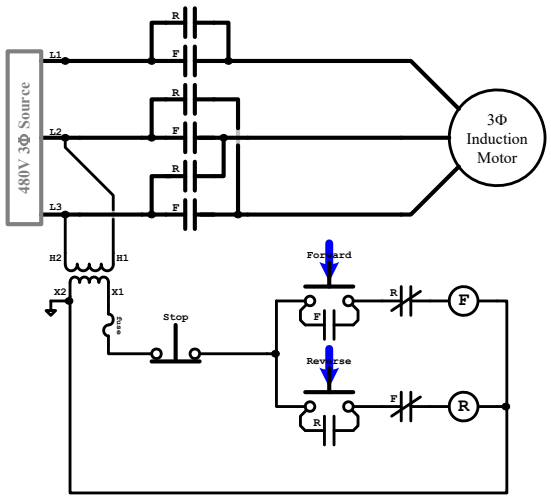
Will this always prevent a short-circuit condition?



23

Designing for Safe Operation

Although the addition of the opposing NC contacts will prevent a second field coil from being energized after the motor is started in one direction, this does **not** account for the **simultaneous** pressing of both the Forward and the Reverse buttons.



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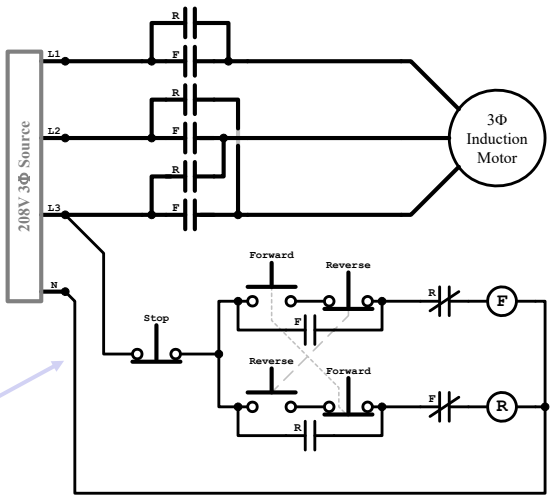
Designing for Safe Operation

Combination pushbuttons can be utilized in order to provide the necessary protection that will prevent both field coils from being energized if the **Forward** and **Reverse** buttons are pressed simultaneously.

Note that the control circuit in this figure is shown to be connected directly across one phase of a 208V 3Φ source instead using a transformer to step-down the voltage from a 480V 3Φ source.

This change was made to both simplify the figure and to better represent the circuit that would be constructed in the Q-215 lab.



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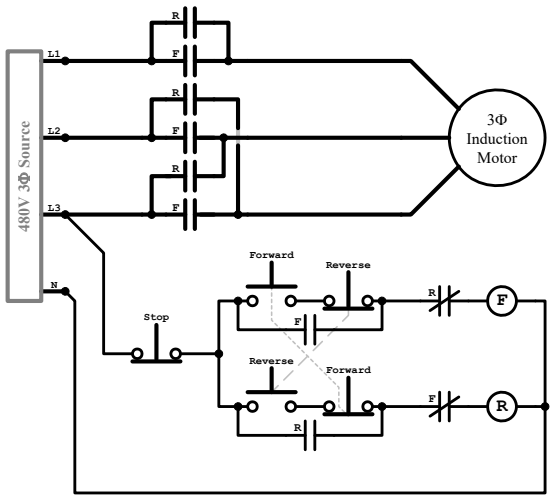
Designing for Safe Operation

Note that there are also special "**Reversing-Contactors**" available that effectively contain individual two contactors along with an interlock that will physically prevent both armatures from actuating simultaneously.



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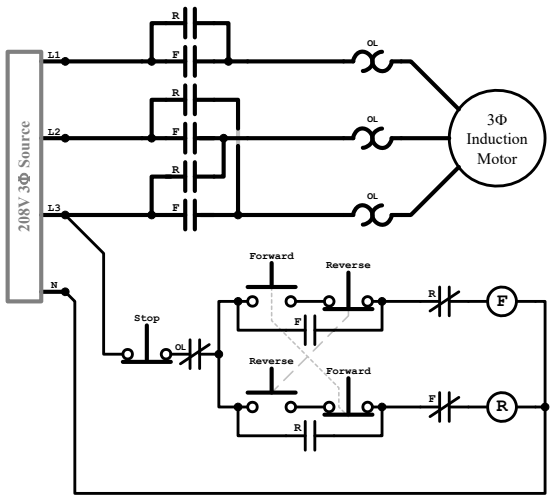
Forward/Reverse Motor Starter

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

To add overload protection, the **OL relay's NC contact** must be placed in **series** with the **Stop** button in order for the OL relay to be able to de-energize whichever field coil had been energized.



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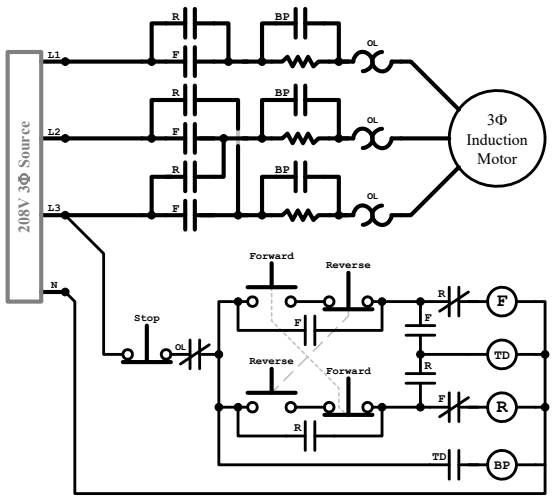
Reduced-Voltage Starter w/ Directional Control

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

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



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