Failure Modes and Effects Analysis: An Experience from the E-Bike Domain

Interview with our e-Bike expert - Eng. Marcello Minervini

1 Preliminary Question: Are the modeled faults realistic?

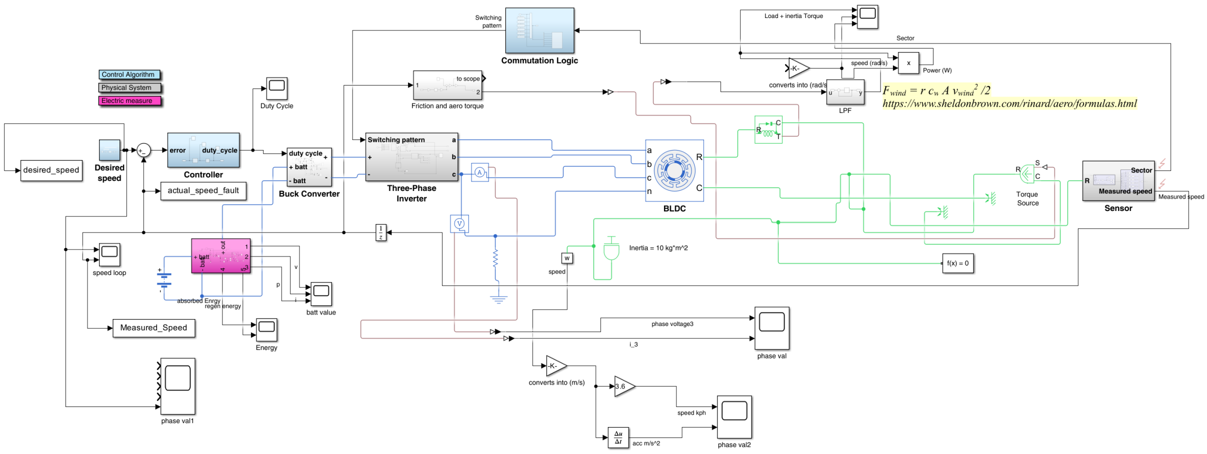


Figure 1: Model

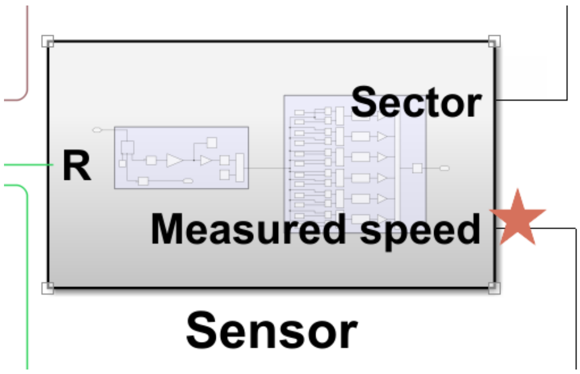


Figure 2: Speed Sensor

1.1 Fault F1 - Breakage of the speed sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency				•	
Criticality					•

1.2 Fault F2 - Noisy speed sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency		•			
Criticality	•				

1.3 Fault F3 - Amplification error in speed sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility	•				
Frequency	•				
Criticality	•				

1.4 Fault F4 - Delayed speed sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility	•				
Frequency	•				
Criticality			•		

1.5 Fault F5 - Speed sensor with constant value

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency				•	
Criticality					•

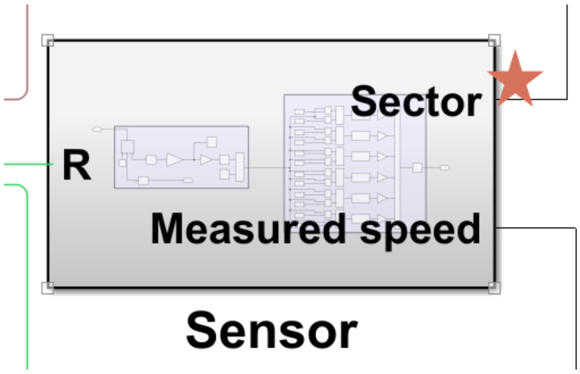


Figure 3: Sector Sensor

1.6 Fault F6 - Breakage of the sector sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency				•	
Criticality					•

1.7 Fault F7 - Noisy sector sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency		•			
Criticality	•				

1.8 Fault F8 - Amplification error in sector sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility	•				
Frequency	•				
Criticality	•				

1.9 Fault F9 - Delayed sector sensor

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility	•				
Frequency	•				
Criticality			•		

1.10 Fault F10 - Sector sensor with constant value

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency				•	
Criticality					•

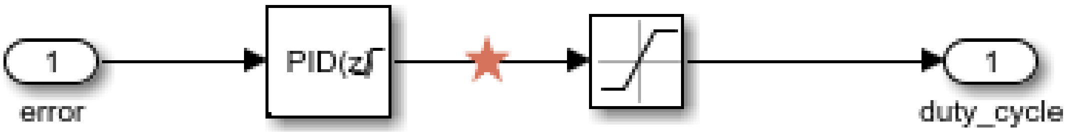


Figure 4: PID controller

1.11 Fault F11 - PID controller design error

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility			•		
Frequency		•			
Criticality					•

1.12 Fault F12 - Noise on the output of the PID

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency		•			
Criticality				•	

1.13 Fault F13 - Amplification on the output of the PID

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility				•	
Frequency		•			
Criticality			•		

1.14 Fault F14 - Inverted PID output

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility	•				
Frequency	•				
Criticality					•

1.15 Fault F15 - Constant output of the PID

For this fault, assign three separate ratings from 1 (low) to 5 (high), evaluating its plausibility, frequency, and criticality.

Parameter	1	2	3	4	5
Plausibility			•		
Frequency		•			
Criticality					•

1.16 Recommendations: Are there any behaviors that, in your opinion, have not been considered but are relevant?

Faults in the Three-Phase Inverter and the Buck Converter should be taken into account, specifically the failure of the MOSFET transistors, which causes the system to shut down. In fact, if even a single transistor in the Three-Phase Inverter fails, the system would stop functioning, or, in specific cases, it might continue to operate but incorrectly. In addition, it is important to note that the battery degrades over time, which can lead to changes in its characteristics. Finally, it should be noted that, in the event of a failure of the sector sensor, the MOSFETs would most likely fail as well.

2 Research Question 1: Are the fault models accurate?

2.1 Fault F1 - Breakage of the speed sensor

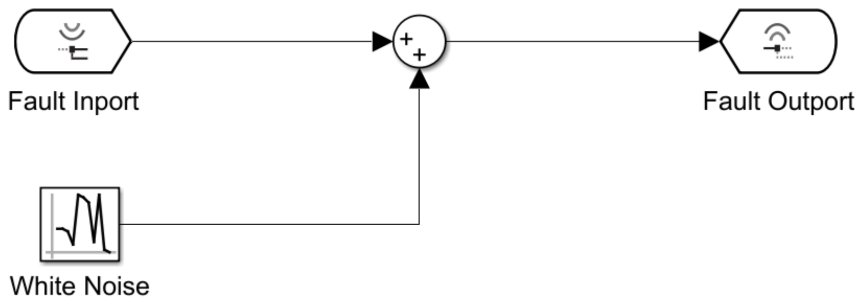
Is this fault implemented correctly?

- Yes

Justify your response.

- It may occur that, at very low speeds (e.g., 0 or 1 RPM), the memory of the speed sensor resets before a full rotation is completed.

2.2 Fault F2 - Noisy speed sensor



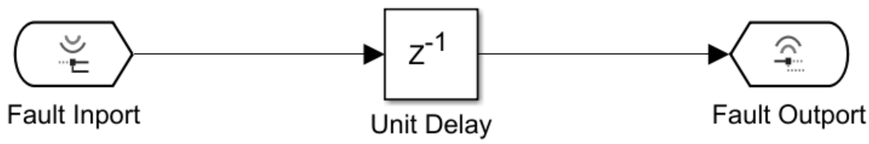
Is this fault implemented correctly?

- Yes

Justify your response.

- Noise may appear in the signal at high speeds.

2.3 Fault F4 - Delayed speed sensor



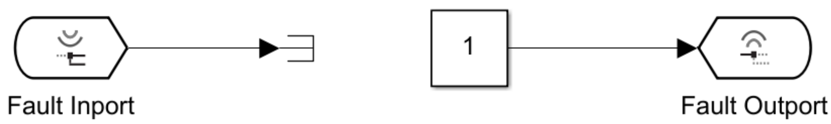
Is this fault implemented correctly?

- Yes

Justify your response.

- At low speeds, the sensor responds more slowly to changes.

2.4 Fault F5 - Speed sensor with constant value



Is this fault implemented correctly?

- Yes

Justify your response.

- It may occur in the case of failure of some internal component of the sensor.

2.5 Fault F6 - Breakage of the sector sensor

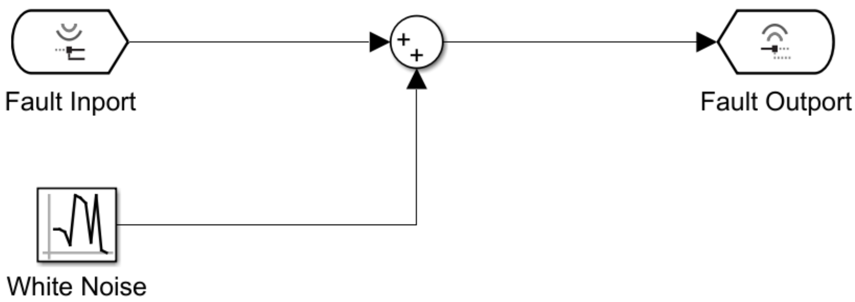
Is this fault implemented correctly?

- Yes

Justify your response.

- It occurs when the wires directly connected to the sensor are disconnected.

2.6 Fault F7 - Noisy sector sensor



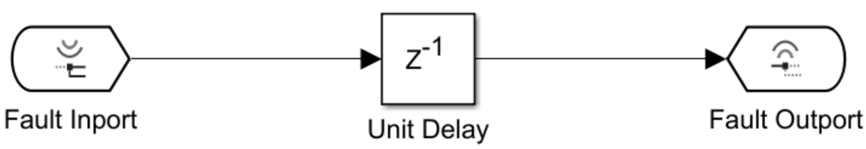
Is this fault implemented correctly?

- Yes, but with minor inaccuracies

Justify your response.

- The sector sensor is more resistant to noise since it is digital. However, at high speeds, collecting all pulses is more challenging because of increased sensitivity, so this fault may occur.

2.7 Fault F9 - Delayed sector sensor



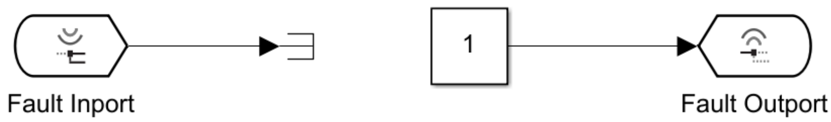
Is this fault implemented correctly?

- Yes

Justify your response.

- A slight delay in the signal may occur.

2.8 Fault F10 - Sector sensor with constant value



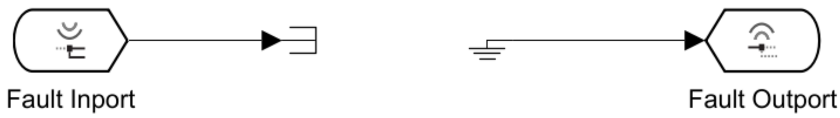
Is this fault implemented correctly?

- Yes, but with minor inaccuracies

Justify your response.

- It occurs when internal sensors within the sector sensor break.

2.9 Fault F11 - PID controller design error



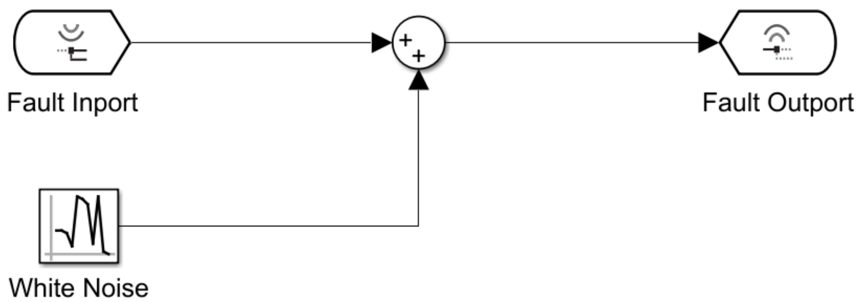
Is this fault implemented correctly?

- Yes, but with minor inaccuracies

Justify your response.

- This may happen because the PID output is zero or constant when the desired speed equals the measured speed.

2.10 Fault F12 - Noise on the output of the PID



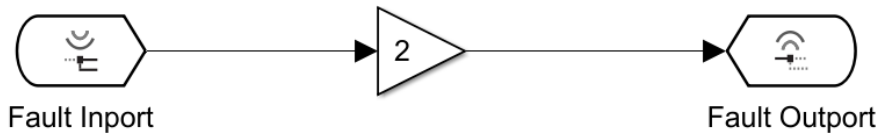
Is this fault implemented correctly?

- Yes

Justify your response.

- At very low or very high speeds, accuracy decreases, and noise appears in the signal.

2.11 Fault F13 - Amplification on the output of the PID



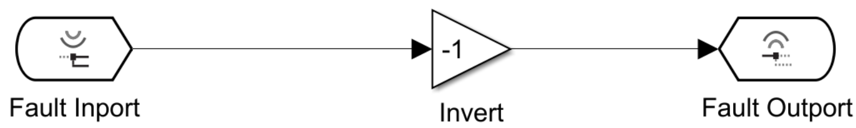
Is this fault implemented correctly?

- Yes, but with minor inaccuracies

Justify your response.

- It may occur even though the PID is highly robust against amplification faults.

2.12 Fault F14 - Inverted PID output



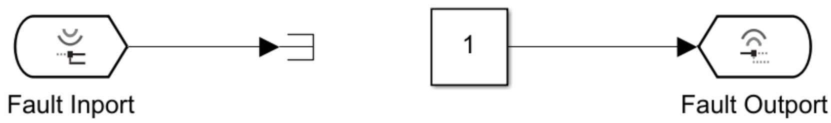
Is this fault implemented correctly?

- Yes, but with minor inaccuracies

Justify your response.

- It may occur, although only in rare cases.

2.13 Fault F15 - Constant output of the PID



Is this fault implemented correctly?

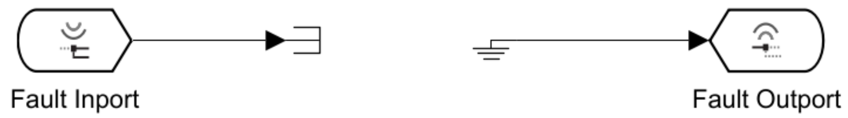
- Yes, but with minor inaccuracies

Justify your response.

- It may occur, although only in rare cases.

3 Research Question 2: Is FMEA useful for the electric bicycle project?

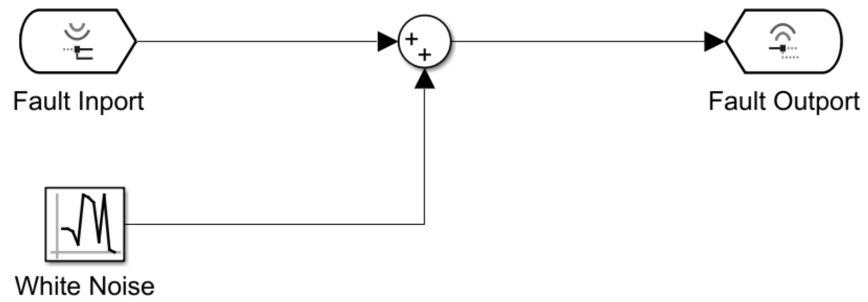
3.1 Fault F1 - Breakage of the speed sensor



What do you expect as the result of this fault?

- The controller, namely the PID, will instruct the motor to accelerate. Therefore, in the model, the duty cycle will have high values, and at least one of the three phase currents should also show high values (the same could occur in the battery current).

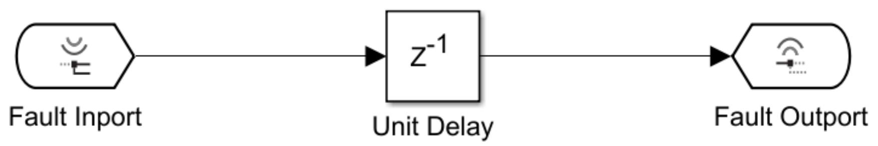
3.2 Fault F2 - Noisy speed sensor



What do you expect as the result of this fault?

- The PID output signal shows a not excessively strong oscillation.

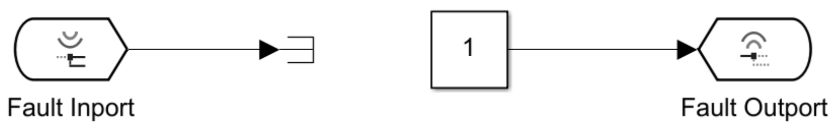
3.3 Fault F4 - Delayed speed sensor



What do you expect as the result of this fault?

- The sensor becomes slower in reading speed variations and, as a result, the PID takes more time to adjust the speed.

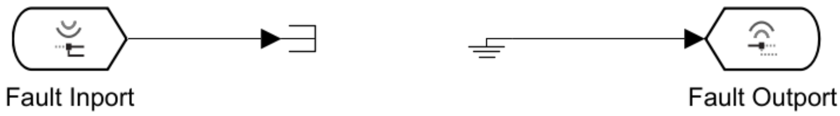
3.4 Fault F5 - Speed sensor with constant value



What do you expect as the result of this fault?

- If the actual speed is higher than the constant value to which the signal is frozen, the PID increases the duty cycle. Therefore, the system reaches a significantly higher speed than desired, because it keeps trying to match the measured speed to the desired one, even though this cannot happen since the measured speed is stuck at a constant value.

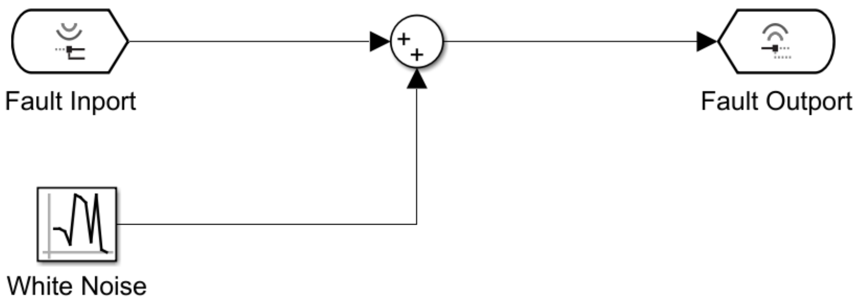
3.5 Fault F6 - Breakage of the sector sensor



What do you expect as the result of this fault?

- It cannot encode the value because it is not within the allowed range, which is 1–6.

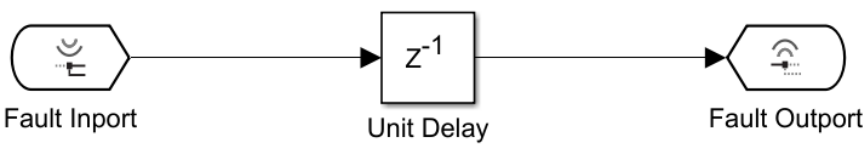
3.6 Fault F7 - Noisy sector sensor



What do you expect as the result of this fault?

- The sector sensor communicates the wrong sector in which the rotor is located, causing severe instability with extremely high currents and speed oscillations.

3.7 Fault F9 - Delayed sector sensor



What do you expect as the result of this fault?

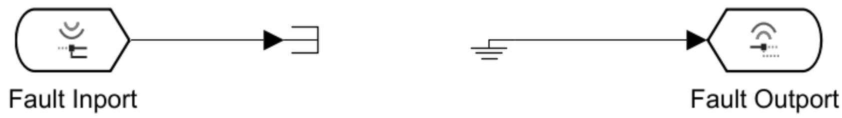
- The system stops because it receives the rotor's position in the motor sectors with delay.

3.8 Fault F10 - Sector sensor with constant value

What do you expect as the result of this fault?

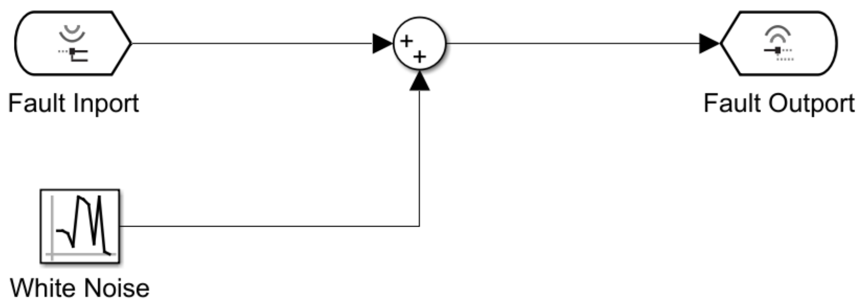
- In the system, the phase currents will reach very high values to the point that the motor starts braking the system until it comes to a complete stop. The higher the speed at which the fault occurs, the greater the damage caused. Thus, the higher the speed, the higher the current values.

3.9 Fault F11 - PID controller design error



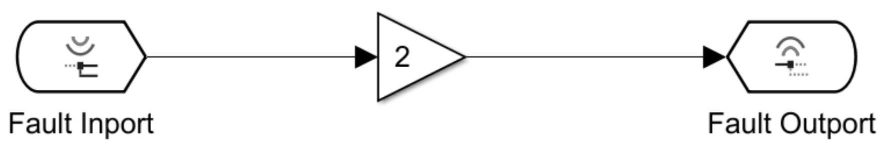
What do you expect as the result of this fault?
- The duty cycle drops to zero, and the motor slows down the system until it either stops completely or the fault disappears.

3.10 Fault F12 - Noise on the output of the PID



What do you expect as the result of this fault?
- An oscillation of the phase currents occurs, with continuous alternating increases and decreases, making them less regular.

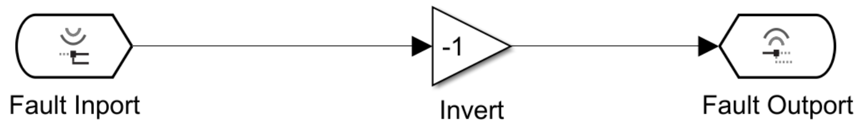
3.11 Fault F13 - Amplification on the output of the PID



What do you expect as the result of this fault?

- From the moment the PID reaches the value 0.5, it goes into saturation and keeps trying to accelerate even when it's not necessary.

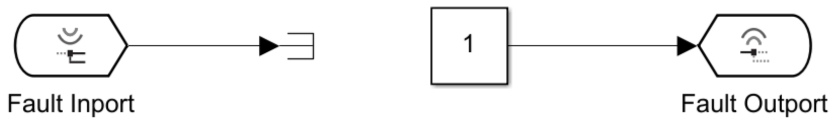
3.12 Fault F14 - Inverted PID output



What do you expect as the result of this fault?

- The fault is not detected because anything below zero is ignored due to saturation. Therefore, the signal is interpreted as zero, and the system slows down until it stops.

3.13 Fault F15 - Constant output of the PID



What do you expect as the result of this fault?

- The PID tries to accelerate the system as much as possible until an electrical equilibrium is reached—either when the current reaches its maximum value based on the applied voltage and the motor power equals the load power, or when the fault disappears.