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## 1. Understand the Voltage Architecture

Before troubleshooting any machine, answer:

- Where does power originate?
- What protects it?
- What distributes it?
- What consumes it?
- What controls it?
- What feedback confirms operation?

**Build a “Power Path Map”- Scott / Pawel???**

For every machine, document:

Step	Question
Source	Battery? Shore power? Generator? Converter?
Main Protection	Breakers, fuses, disconnects
Distribution	Power distribution modules, relays, CAN nodes
Regulation	DC/DC converters, power supplies
Control Voltage	24VDC? 12VDC? 120VAC? Ethernet PoE?
Loads	Solenoids, PLCs, cameras, relays, sensors
Return Path	Ground studs, chassis grounds, isolated returns

**Typical Heavy Equipment Control Voltages**

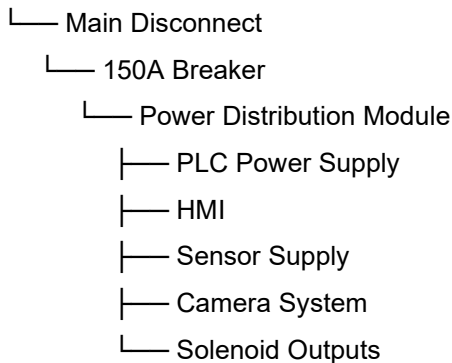
System	Typical Voltage
Mobile equipment controls	24VDC
Automotive-style modules	12VDC
PLC I/O	24VDC
Sensors	5VDC reference
Ethernet vision systems	PoE / 24VDC
Valve solenoids	12V or 24V
Industrial controls	120VAC / 480VAC

**Create a “Voltage Tree” – who can do this / programming ?? / Engineering?**

This becomes one of the most powerful diagnostic tools.

Example:

Battery 24V



If a downstream device fails:

- You immediately know upstream dependencies
- You know shared failure points
- You know what else should also be dead

## 2. Define Minimum and Maximum Voltages

Advanced diagnostics ask: "Is voltage within operational tolerance under load?"

### Example Voltage Standards Table -what is the voltage for our machines?

Component	Nominal	Minimum	Maximum	Failure Symptoms
PLC	24VDC	21.6V	28.8V	Random resets
Proximity Sensor	24VDC	18V	30V	False switching
CAN Module	24VDC	20V	30V	Communication loss
Camera	24VDC	22V	28V	Video dropout
Solenoid Coil	24VDC	20V	28V	Weak/no actuation
5V Sensor Ref	5V	4.8V	5.2V	Sensor drift

### Critical Concept: Voltage Drop Under Load

A circuit may show:

- 24V unloaded
- 14V loaded

This is one of the most common hidden failures.

Always test:

- Static voltage
- Dynamic voltage
- Loaded voltage

### Diagnostic Rule

If voltage drops:

- Check grounds first
- Then connectors
- Then crimps
- Then relays
- Then wiring resistance
- Then source capacity

### 3. Understand How Components Work Together, need:

- Functional logic maps
- Cause/effect chains
- Failure interaction charts

**Build Functional Sequence Maps - ??? Programming /**

**Example:**

Operator presses AUTO START  
 ↓  
 PLC sees switch input  
 ↓  
 PLC checks safety interlocks  
 ↓  
 Hydraulic enable relay energizes  
 ↓  
 Valve bank powers up  
 ↓  
 Pressure switch confirms pressure  
 ↓  
 Machine enters AUTO mode

Now ask:

What happens if each step fails?

**Failure Consequence Matrix**

Failed Component	System Result
Input switch	No start request
PLC input card	PLC never sees command
Safety relay	Hydraulic enable blocked
Pressure switch	System times out
CAN node	PLC loses feedback
Ground failure	Intermittent operation

**Critical Diagnostic Principle**

Never troubleshoot only the failed component.

Always ask:

1. What enables it?
2. What commands it?
3. What confirms it?
4. What shuts it down?
5. What depends on it?

## 4. What Can Be Bypassed — and What Cannot

Improper bypassing destroys machines and injures people.

A proper diagnostic program defines:

- Temporary diagnostic bypasses
- Controlled override conditions
- Absolute no-bypass systems

### Systems Often Allowed Temporary Diagnostic Bypass

(Under controlled service conditions only)

System	Possible Temporary Bypass
Pressure switch	Simulated signal
Level sensor	Resistor substitution
Input switch	Jumper
Relay output	Manual energization
Analog sensor	Signal simulator
CAN sensor	Known-good node

### Systems That Usually Must NOT Be Bypassed

System	Reason
Emergency stop	Personnel safety
Overspeed protection	Catastrophic damage
Brake interlocks	Runaway risk
Safety PLC outputs	OSHA/FRA exposure
Guard switches	Crush hazards
Fire suppression	Equipment loss
High-pressure shutdowns	Explosion/failure risk

**Best Practice: "Bypass Authorization Matrix"**

Create a chart:

Device	Allowed?	Conditions	Time Limit	Approval Required
Hydraulic pressure switch	Yes	Service mode only	Temporary	Technician
E-stop	No	Never	N/A	N/A
Door switch	Yes	Maintenance only	Temporary	Supervisor

This becomes extremely valuable for OEM liability protection.

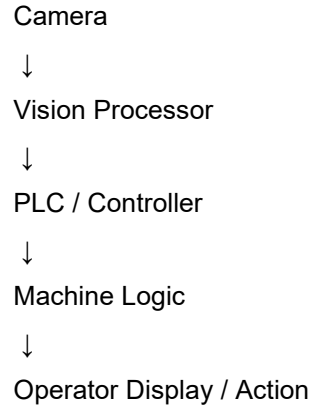
## 5. How Vision Systems Tie Into the Machine

Modern equipment increasingly integrates:

- Cameras
- AI detection
- Laser measurement
- LiDAR
- Position sensing
- Machine guidance

Vision systems are no longer “accessories.”  
They are part of machine control architecture.

### Typical Vision System Architecture



### What Vision Systems Usually Provide

Function	Example
Object detection	Rail obstruction
Alignment	Track geometry
Position verification	Tool placement
Safety zone monitoring	Personnel detection
Measurement	Wear analysis
Guidance	Autonomous positioning

### Common Vision Failure Modes

Failure	Result
Dirty lens	False negatives
Ethernet loss	No image
Voltage instability	Camera rebooting
Poor grounding	Image noise
Lighting failure	Detection loss
IP conflict	Offline cameras
Timing latency	Delayed machine response

### Critical Concept: Vision Is Usually “Advisory” or “Interlocked”

You must determine:

#### Advisory System

Vision informs operator only.

Failure result:

- Loss of visibility

No automatic shutdown

#### Interlocked System

Vision actively controls machine logic.

Failure result:

- Machine inhibited
- Auto mode disabled
- Safety shutdown

**Create "System Dependency Maps"**

**Example:**

Camera Failure



Vision processor loses target



PLC loses valid alignment



AUTO tamping disabled



Operator forced into manual mode

This is the type of logic mapping that separates advanced troubleshooting from guesswork.