At Living Web Farms
An introduction to simple electrical control systems

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Why Learn Controls?

These systems are everywhere! And they govern a lot of the systems that make us comfortable and productive. Why not learn this practical hands-on knowledge?

Required for diagnosing failures and more informed operation of:

- Heating systems
- Greenhouse Environmental
- Automobiles and Equipment
- Appliances, Power Tools
- Your specific application
About me:

I'm definitely not an expert! Merely someone who has learned ‘the hard way’ and wants to share the knowledge with the DIY oriented community - so you can make educated decisions about the technology that surrounds you.

Ex. 1 - Oven electronic control board - would you be able to diagnose a broken solder joint? That’s all it took to repair a $200 part, without waiting days for new parts to arrive in mail.

Ex. 2 - Used Hobart 180 welder - had issues with wire feed rate. Online communities helped me locate and replace a $5 transistor. Reconditioned welders sell for $550. I got mine for $105.
What we’ll cover today:

- Becoming familiar with circuits and reading wiring diagrams
- Working safely with electricity
- Using a multimeter
- Reading labels and nameplates
- Recognizing components: Switches, Relays, Transformers, etc.
- Maybe a little soldering practice?
- Discover a few common readymade controllers: Thermostats, Setpoint, Timers...
- See some operating control systems at the LWF Grandview Facility
- Become familiar with the vocabulary and supporting resources
- Gain confidence to do your own troubleshooting and repair work
Philosophy:
NOT going to cover:

- Complicated and inaccessible control programming
- Automation technology that replaces people
- Controls that make us more dependent farmers: wasteful, lazy, and unaware

We ARE going to cover:

- Systems that replace the most mundane, regular scheduled tasks
- Systems that help us stay safe, clean and productive
- Systems that can be shut down and manually operated
- Systems that help us become more resilient and creative people
Is there a PASSIVE option?
Control circuits: A Broad Definition:

Anything that uses electricity to first sense something and act on that information

Power Source -> Switch -> Load -> Ground
A Broad Definition:

Anything that uses electricity to first sense something and act on that information

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Schematics and Wiring Diagrams

- Visual representation showing layout of an electrical circuit
- Map for troubleshooting
- Tool for designing, modifying existing circuit
- Pictorial or Schematic often can look very different from each other
- I like to use both for my projects:
  - Schematics for designing and understanding function
  - Pictorial for installation
Ladder Diagrams - Schematic

Source: library.automationdirect.com
Switches
Switches

SPST - Single Pole Single Throw

SPDT - Single Pole Double Throw

DPST - Double Pole Single Throw

DPDT - Double Pole Double Throw
Switches: Normally Open and Normally Closed

Button Switch: Normally Open

Button Switch: Normally Closed

Normally Closed  N/C

Normally Open  N/O
Switches: Momentary (ON) and Latching ON

Screenshot: Mouser.com
The Three-Way Lighting Switch
Fun with switches

Can we have one temperature monitor look at 4 different sensors?
Fun with switches

SS44D04 Slide Switch

4P4T w/ 20 pins!
The Multimeter: Measuring Continuity

Measures whether two points are electrically connected: if there is *continuity*

Perform continuity test de-energized equipment

One of the most useful tests: diagnose breaks in wires, switch function, blown fuses, etc.
Part 2
Safety, Electrical Loads, Control Voltage, And Relays
Working Safely around Electricity

- Know your environment: Dry, Well-lit, Clean
- Be awake, be aware
- Always completely de-energize, it helps to be redundant.
- Lockout/Tagout - label switches when others are present
- Redundancy of testing equipment - use a voltage tester, AND a multimeter
- Observe safety warnings, switches, disconnects - esp. after re-energizing
- Beware capacitors hold a charge
- When testing live circuits, especially high voltage:
  - One-Hand - don’t make a circuit across your chest! Know your limits!
  - Insulate from ground - this is why you see fiberglass ladders
  - Use insulated tools
  - Safety glasses
  - Know your limits!
Know your load: Resistive loads

- Convert Electricity to light and/or heat via Electrical Resistance
- Examples: Conventional light bulbs and Heating Elements
- Need to know:
  - Voltage rating (V)
  - Current demand (A) or (I)
- Watts: Volts X Amps
The Multimeter: Measuring Resistance

Resistance is measured in Ohms (Ω)

Select Ohms, and select range

Use both probes and measure resistance between two points on circuit

1 or OL indicates out of range
How many Watts?

Ohms Law:
V=IR or R=V/I or I=V/R

V = Voltage (measured in Volts)
I = Current (measured in Amps)
R = Resistance (measured in Ohms)

120V rated bulb

Measured 18 Ohms
How many Watts?

Ohms Law:
V=IR  or  R=V/I  or  I=V/R

V= Voltage (measured in Volts)
I = Current (measured in Amps)
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120V rated bulb
18 Ohms resistance

Solve for 6.6 Amps
6.6 Amps x 120 Volts = 800 watt light bulb?
How many Watts?

Solve for 6.6 Amps
6.6 Amps x 120 Volts = 800 watt light bulb?

Resistance actually increases from measured 18 ohms to 240 ohms after it heats up

This 60W bulb actually uses .5 amps at 120 Volts.
Know your load: motors

- ‘Inductive’ Load
- Voltage
- Amperage
  - FLA
  - Surge/inrush current
  - SF amps
- Watts (Volts x Amps)
- Other:
  - Phase? Hz?
  - Intermittent duty?
  - Protected?
  - Reversible?
Fun with Switches: Motor Reversing

Figure 2: DPDT reversing switch circuit

Source: forum.allaboutcircuits.com
VFD: variable frequency drive

- Operate 3-phase motors from single phase source
- Primarily used for Speed control
- Reduced energy consumption when operating loads at lower speeds
- Controlled acceleration and torque
- Select a VFD that can tolerate motors max current under maximum torque demand
- Talk to an expert first
DC Power supplies
HON-KWANG
PLUG IN CLASS 2 TRANSFORMER
UL LISTED 69NO LR 68048

NOM
166
Made In China

MODEL NO: D12-50
INPUT: 120V 60Hz 15W
OUTPUT: 12VDC 500mA
AC Power supply

For the scope of this workshop:
120V AC, Single Phase power

Two ‘legs’ combine for 240V AC

Typ. Residential and small commercial power

Each circuit - lighting, outlets, etc is protected by an overcurrent device.
Is it live? Using a multimeter to check voltage

- Select AC or DC
- Set Range at slightly higher than what you expect to measure
- Reduce range if necessary for more accurate results
- DC - Red is +, Black is -
- AC - Red/Black doesn’t matter
- Probe between two points: typically between test point and known ground
- 1 or OL indicates out of range
Be Safe! Be Redundant!
Low Voltage Controls

Inherently safer because of lower voltages

Smaller wires: more economical, easier installation

Typical residential applications: doorbells! Thermostats

24Vac typical. NEC specifies 49V or less AC as ‘Low Voltage’

Further applications: specialty switches, timers, thermostats and humidity controls.. The list goes on!
Transformers

- Labeled by Primary and Secondary windings.
- 40 VA rated 24VAC ‘Doorbell’ transformers are very common for control voltage
- Pri: 120V, Sec: 24V
- We’ll use ‘Step-Down’ transformers
- Step-up transformers: microwaves, spark transformer
Relays!

- **Armature**
- **Spring**
- **Yoke**
- **Contacts**
- **Coil**
Fun with Relays
12VDC SOURCE
CONTROL CIRCUIT

RELAY 1
- N/O
- C
- N/C

RELAY 2
- N/O
- C
- N/C

RELAY 3
RELAY 4
- N/O
- C
- N/O
- C

RELAY 3 12VDC COIL
20A RATED

MOTOR 12VDC 6A
Solenoids, SSRs, Contactors: similar, but different

**Solenoid:** refers to electromagnetic action
Used in relays and valves
Source: Adafruit.com

**Solid State Relay:** functions same as mechanical relay, with no mechanical parts.
Reliable, fast, and capable of switching at much lower voltages
Source: sparkfun.com

**Contactor:** electromagnetic action, reserved for large load switching.
Typ. as large motor starter w/ modular design - add thermal, more contacts, 3-phase switching.
Source: Omega.com
Part 3

Circuit Protection and Ready-Made Controllers
Using a multimeter: recap

https://www.youtube.com/watch?v=SECWePatYjY
Using a multimeter: Measuring Amperage

‘Clamp’ meter is necessary for anything but the smallest current measurements

Select AC or DC, Select Range

Affordable AC clamp meters are common: very useful

Affordable DC clamp meters are harder to find: useful for troubleshooting battery systems: solar, auto, etc
Overcurrent Protection

- Protect people and equipment from fire and electric shock
- Designed to fail, when current exceeds it’s interrupting rating
- Built-in ‘weak link’

Select a fuse based on:

- Voltage Rating. System voltage must be less than rated voltage on fuse.
- Overload protection: ballpark 125% or 150% of normal operating current. Ex. 10A motor? Use 15A protection. ‘Fuse protects the wire” see: ’ampacity’
- Use Time delay fuses for inductive loads (motors, transformers, coils)
- Use Fast Acting fuses for resistive loads (heaters, incandescent bulbs)
- Interrupting rating: find an electrician. Err on the high side.
- Lesson learned? **Best to replace blown fuses w/ identical fuse or Get Help**
Wire Sizing: Ampacity

The Maximum current carrying capacity of a conductor (wire)

Larger wires: higher ampacity

Pay attention to the details:

Wire insulation

# of wires bundled together

Wire material: Cu or Al

Undersized wires means risk of Fire! Do not go this alone!

When doing repairs - replace with same wire or larger!

Pay attention to wire type: UV rated? Direct Burial rated?
‘Ready-made’ Controllers

Combine sensing element and relay switching for simple automated controls

Look for input voltage and amperage requirements

Look for ratings at switch: voltage, and maximum switching amps

Pay attention to environmental ratings: Can it be used in humid environment? Etc.

Electronic or mechanical action? Will it store presets if power goes out? - Pay attention to these details found in the spec sheet or brochure.

Following are a few of my low-cost favorites we use around Living Web Farms
PECO TF115-001

- Simple and Rugged, Affordable
- NEMA 4x housing: can be sprayed (not submerged) with water
- Operable at multiple voltages
- Bimetallic sensor req’s no outside power source
- Not very accurate, especially at low temps
- Great greenhouse thermostat
- SPDT operation:
  - Normally open and Normally Closed contacts
  - Switch for heating or cooling operation
Programmable Thermostats

- Typically powered with 24 volts
- More sophisticated operation
- May be multiple relays packed in there
- May offer remote temperature sensor
- Unconventional installation?
  - Pay attention to environmental ratings
  - Not likely to withstand humid environments over time
Setpoint Controllers: Ranco ETC-111000

- Single-Stage Temperature Control
- Comes in many voltage options
- Open on Rise (close on fall)
  - Heating applications: switch opens at setpoint point or above
- Close on Rise (open on fall)
  - Cooling applications: switch closes at setpoint or above
- Programmable Differential
  - Range where no action is taken
  - Overcome ‘short cycling’
  - Typically low mass heating systems have higher differential
- **Open on Rise (close on fall)**
  - Heating applications: switch opens at setpoint point or above

- **Close on Rise (open on fall)**
  - Cooling applications: switch closes at setpoint or above

*Figure 1: Setpoint and Differential Settings. Diagram indicates relay on and off points in either the heating or cooling modes.*
2 stage setpoint control: Ranco 211/212 series

2 relay outputs for operating two devices

Huge variety of applications

Still limited to single sensor
Humidistat

Similar operation as Thermostat, switching is usually based on **relative humidity** (temperature compensated).

Willhi WH1463: very cheap, pre-wired outlet

- 1%-100% Relative humidity, accurate to 1%
- Remote sensing option
- Humidify/Dehumidify option
Timers: TM-619 Programmable clock timer

- Up to 8 different programmable on/off settings
- Optional power sources: 12VDC, 24,120,240VAC
- Range from hours and seconds.
- Battery backup, retains programs and current time

Examples:

- Used to limit operation of humidity controlled ventilation fans in our solar kiln
- Used to operate compost tumbler: on for only 5 seconds, twice a day.
- Commonly used for animal feed dispensing, security, chicken coop door
Timers: Peltec 102

Repeat Cycle (recycle) timer

Single Relay, n/o and n/c contact

Universal input voltage in single unit

Separate programmable on and off time

Range from .1 seconds to 100 days

Example:

- Buzzer control on overheat/overflow alarm
- Spray bar control on germination trials
Specialty Controllers: some of my favorites

- **Differential Temperature controller**
  - Mostly used for solar heating applications
  - We use these for controlling pumps that draw heat from our storage tanks, in our biochar facility heating system.

- **PID**
  - For “continuously modulated control”
  - Common DIY applications are paired with resistive heating for constant temperature control

- **Honeywell R8184N**
  - Oil Burner ignition control: will shut down process in the absence of light (no flame)
  - We use these on our Pyrolysis oil burner mods

- **Rain Bird SMRT-Y Soil Moisture Sensor Kit**
  - Interrupts 24V signal to irrigation solenoid, if soil is already at a user-defined moisture setpoint
  - Simple, robust, and doesn’t require internet connections like other ‘smart’ irrigation controllers
Big League Controls: Microcontrollers, PLC + Beyond

Arduino Microcontrollers: electronics prototyping platform
Very Affordable components, huge network of online help
Programmable in C+ via open source Arduino IDE software

PLC: Programmable Logic Controllers
Workhorse of industrial automation
Typically proprietary hardware/software with ladder logic programming
AutomationDirect.com has affordable units with lots of training videos