Small Scale Renewable Energy Control Systems

Brent Crowhurst
Renewable Energy Program Coordinator
Falls Brook Centre, New Brunswick, Canada

Nordic Folkecenter for Renewable Energy

November 2006 - April 2007

Table of Contents

List of Figures

1. Battery Based System Control

1.1. Commercial dump load control products

Battery overcharge/discharge regulation is a feature built into many charge controllers and wind turbine controllers. The protection in many cases is insufficient to prevent battery and or turbine damage.

- The **Southwest Windpower AirX 400W turbine** has battery voltage regulation built into the electronics inside the turbine itself.
  see \\nfcserv\Ansante Delt\Windturbines\Small Windturbines\AirX page 22:

  > *4.1.2 Voltage Regulator*
  > *The AIR-X continually monitors the battery voltage and compares it to the regulation set point. The regulation set point is field adjustable, and is factory set to 14.1V (12V Turbine) or 28.2V (24V System). When the battery voltage rises above the set point, the turbine enters regulation mode. During regulation mode, the turbine automatically shuts off. It stops rotating, and no power is generated. Before entering regulation mode, the AIR-X will momentarily stop charging in order to get a true reading of the battery voltage. If the turbine was sensing a high voltage due to line loss in the system, this will be detected and the AIR-X will continue to charge. This process takes a fraction of a second and will not be visible.*
  >
  > *Once in regulation mode, the AIR-X will simply wait for the battery voltage to drop. Normal charging will resume when the battery voltage drops slightly below the fully charged level. For 12v turbines the turbine will resume charging at 12.75V (25.5V for 24V turbines). The AIR-X controller will blink the 10 times each second (fast blink) to indicate that it is in regulation mode.*
  >
  > ***NOTE:** Bad connections, undersized wires, and inline diodes will cause the internal regulator to not work properly. It is very important that the **AIR-X** can "sense" the proper battery voltage.*

- The **Bergey XL 1kW turbine** has a "slow mode" feature which uses a dump load resistor in combination with a pulse width modulation controller.

  See \\nfcserv\Ansante Delt\Winturbines\Small Windturbines\Bergey page 5:

  > *C. Slow-Mode Operation*
  > *As the battery bank voltage approaches the battery regulation voltage, the PowerCenter controller will first try to restrain this voltage by applying the optional Extra Load (or "dump load"). The Extra Load function diverts current from the battery to an air or water heater. If this measure is not sufficient, or there is no dump load in the system, the PowerCenter will slow the wind turbine and pulse the solar panels on and off to regulate the charge on the batteries. Slow-Mode prevents the wind turbine from operating without load once the batteries are full. This reduces noise and reduces the likelihood of blade flutter. Blade flutter is loud, short-term, blade vibration that can occur at very high rotor speeds or in severely gusting winds. Flutter will not hurt the system or endanger it, but it can be annoying. Most customers are unlikely to experience blade flutter.*

> *In Slow-Mode, the turbine will be slowed to approximately 130 RPM in low wind speeds, and as the wind speed increases, the operating RPM will be decreased. Maximum power in this mode is 120 watts and the power output will decrease as the wind speed decreases. The speed of the rotor will vary over a limited range as the PowerCenter adjusts turbine output current to maintain the battery voltage within a narrow range. If the load on the batteries increases, dropping battery voltage, the XL.1 will speed up so that it can deliver more charging current. If there is no load at all on the system, then the turbine will be brought to a very slow speed, approximately 20 RPM, and the solar panels will be disconnected completely.*

- The **Windtalker** series of turbines controller disconnects the turbine from the batteries when the battery voltage is over 14.1 V. New versions of the controller have and integrated dump load but their operation has not been verified at the Folkecenter.

- The **Proven** wind interface installed at the straw bale house has a control circuit board that turns on a series of relays depending on the battery level. Although the system currently only uses one of these relays to control a 1500W water heating element, the system could be wired such that multiple smaller loads were used to more closely track the wind turbine output and put less stress on the battery bank.

- The **Trace (now Xantrex) SW series inverter** installed at the straw bale house includes configurable relay control outputs which could be used to control a generator, enable a diversion load, or disable a load depending on battery voltage. This feature is not currently being used.

- The **Joker inverter** includes a low battery voltage disable feature which turns the inverter off when the battery voltage goes below 10.5 volts. This feature prevents serious damage to the batteries but is not sufficient to be used as a load control because this level of battery discharge should be avoided.

- The **Xantrex C series** of solar charge controllers can also be used for load or diversion control. A charge controller turns off when a voltage threshold is reached; a load/diversion controller turns on. This product is included with the industrial version of the Air X.

  See \\nfcserv\Ansante Delt\Winturbines\Small Windturbines\Xantrex page 8:

> *Diversion Controller*
> *The C-Series controller can operate as a Diversion Controller, also called a shunt regulator, to manage battery charging from alternative energy sources such as PV, wind or hydroelectricgenerators. A diversion controller monitors battery voltage and, when the voltage exceeds the settings for your charge stage (whether bulk or float), the power is diverted from the source (solar, wind, or hydro generator) to a "dump" load which will dissipate the excess power into heat.*
>
> *When used for this purpose, the C-Series controller varies an amount of battery voltage to a "dump load" in order to redirect the excess power generated from over-charging the batteries. This allows the charging source to remain under constant load to prevent an over-speed condition which could occur if the charging source is suddenly disconnected from the battery–as series regulators do.*
>
> *Consult your dealer for recommendations on diversion load type and regulator size.*

1.2. Commercial Relay based dump load control designs

Procure provides a simple design for a dump load controller (see Figure 1). The design uses a Carlo Gavazzi undervoltage monitoring relay (DUA52). This relay is useable in 12, 24, and 48 volt installations, has adjustable hysteresis, and is powered by the same supply that it measures. (i.e. no additional power supply other than the system batteries is required).

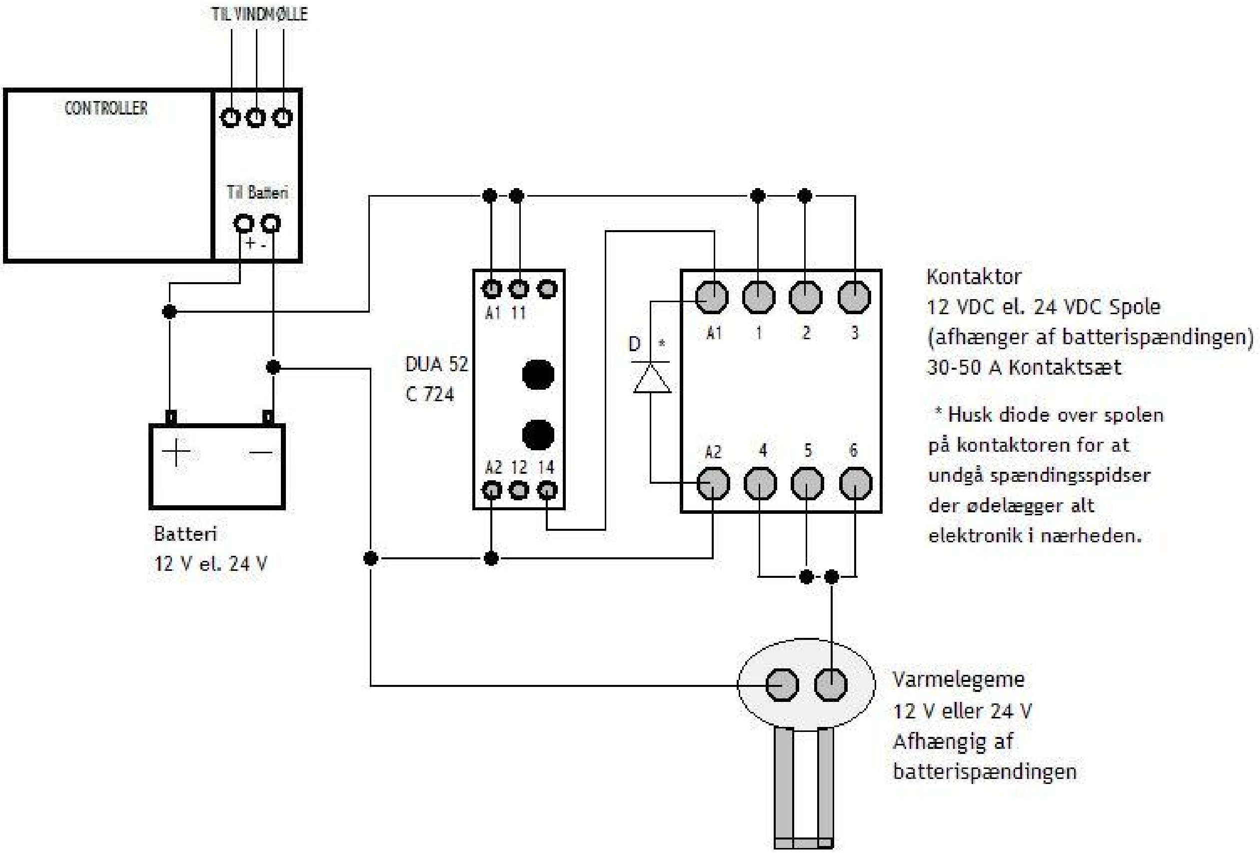

Figure 1: Procure Load Control Design

If a properly sized heating element is used this design can protect the batteries and provide some useful heat output. This design will not produce the optimal amount of heat output for all wind conditions nor is it able to be used without batteries.

1.3. Battery Voltage Dump Load Relay Control Circuit

A simple battery voltage dump load relay control circuit based on similar designs freely available on the internet was designed, tested, and built here at the Folkecenter. The design is based on the LM 358 operational amplifier. See Figure 2. The circuit includes variable voltage trigger point, voltage hysteresis, and built in time delay. The circuit should also include a large capacitor (>1000uF) between positive and negative to increase noise immunity (this capacitor is not shown in Figure 2). The prototype circuit is installed on the three turbine system in the SkibstedFjord training centre and controls an arc of light bulbs.

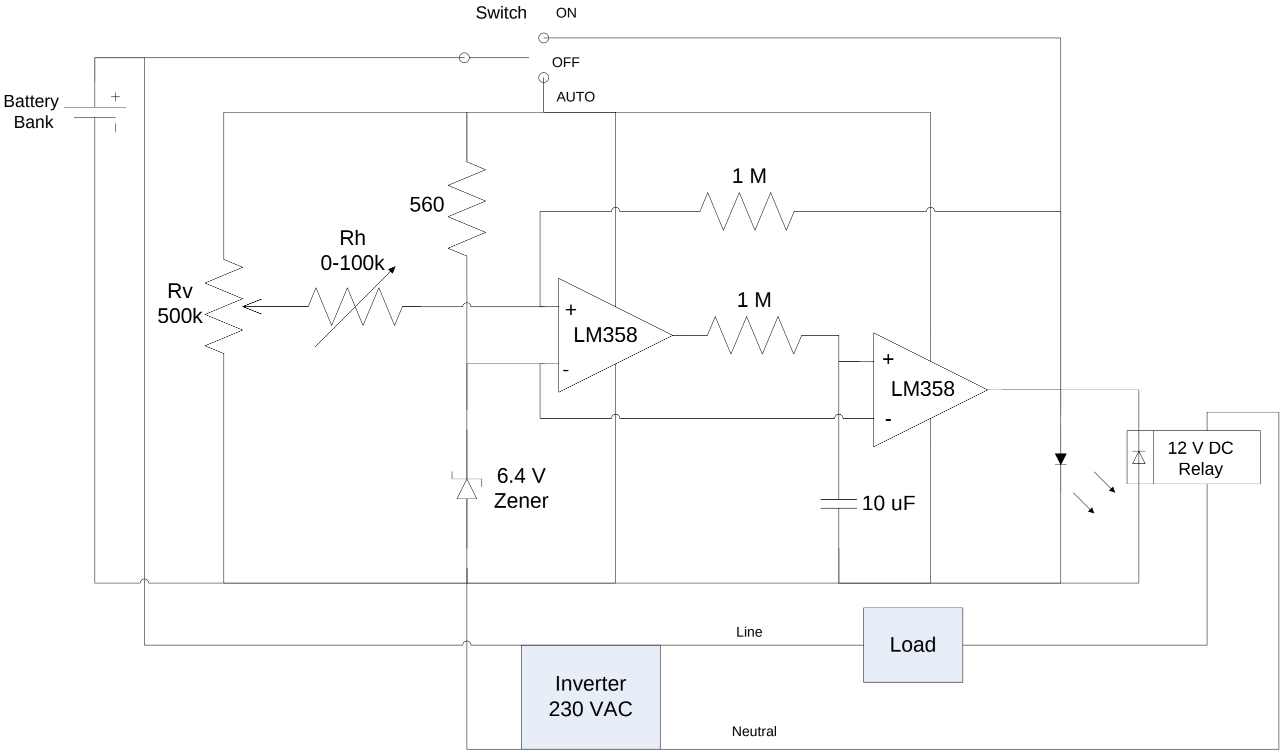

Figure 2: Basic Load Control Circuit

The circuit as shown works for 12 Volt battery applications but with a different sized Zener diode could be used for 24 Volt systems. An additional regulator would be needed for 48 volt systems. The circuit can be used to switch AC loads in conjunction with an AC power inverter. A DC load could also be switched using a contactor similar to the one shown in Figure 2 or a power transistor.

The design includes a switch (marked "switch" on diagram) that can select between ON (battery voltage applied directly to circuit output thus enabling the relay), OFF (battery voltage disconnected), and AUTO *relay controlled by load control circuit).

The circuit includes a potentiometer (Rv) to control the battery voltage level at which the relay will switch (on when battery is above this setting and off when below) and a variable resistor (Rh) to control the size of the hysteresis window (how far above the Rv set point the battery voltage must be before the relay is turned on and how far below the Rv set point the battery must be before disabling the relay).

The circuit also includes an RC delay between the operational amplifier stages to increase noise immunity and prevent the circuit from reacting to short bursts of wind or solar power output (i.e. the circuit will wait until the voltage has been over or under the set point for a few seconds before switching on of off the relay).

The circuit as shown in Figure 2 is driving a 12V DC relay model RTE24012 capable of carrying 8-10 Amps. When switching high power loads as additional high current contactor should be used.

2. Synchronous Wind Turbine Control

2.1. DC Direct Resistive Heating

2.1.1. DC Voltage Multiple Switched Resistor Power Control

A simple circuit for heating applications where no battery is required was developed from ideas initially conceived by Gregers Oddershede. The design is very simple in terms of component count and provides a good degree of maximum power point tracking (see Figure 3).

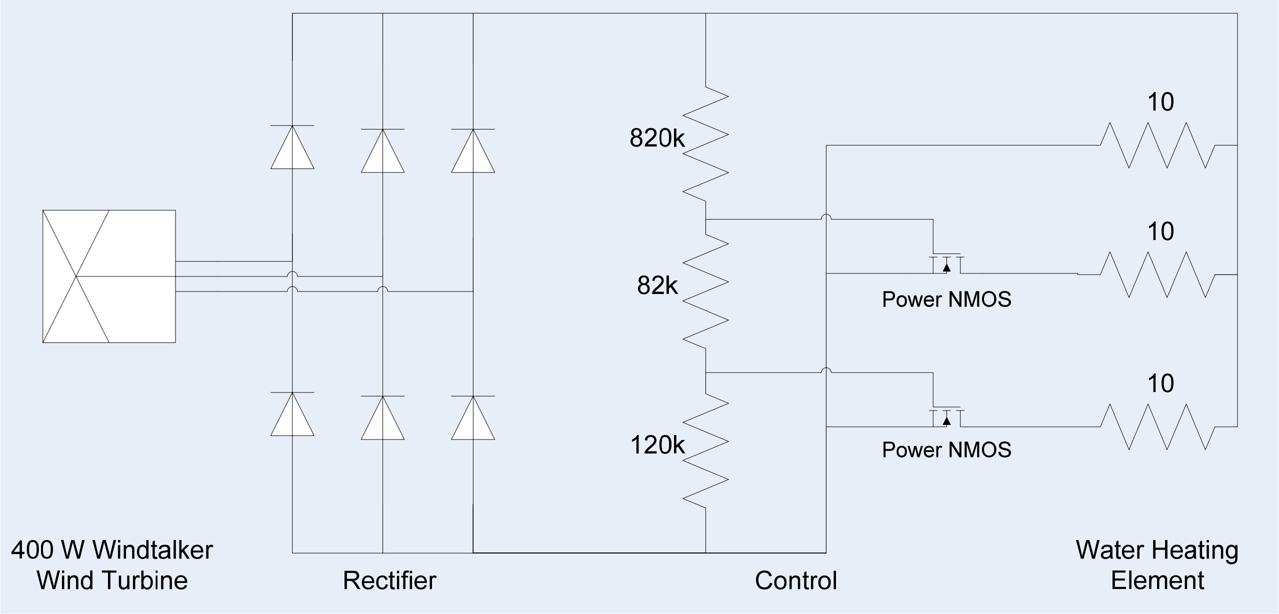

Figure 3: DC Resistor Control

The testing of this circuit was carried out using the windtalker 400W turbine. The control box for this turbine, although it contains a rectifier, could not be used because a battery is required for its proper operation. A set of three bridge rectifiers was used although in reality only six diodes are required for rectification of the turbine output to generate DC power.

The output of the rectifier connects to a simple control circuit made up of a resistor divider and two power NMOS transistors. The design is expandable if more water heating elements are available. The power NMOS devices turn on at 3 Volts Vgs (gate to source voltage). The resistor divider was sized based on extensive testing of the turbine connected to a range of resistive loads. The idea is that at low wind speeds both transistor will be off and thus the load on the turbine will be 10 Ohms. When the rectifier voltage output reaches 15 Volts the bottom transistor will turn on and the load on the turbine will be 5 Ohms (10 Ohms / 2). When the rectifier voltage output reaches 25 Volts the top transistor will turn on and the load on the turbine will be 3.3 Ohms (10 Ohms / 3). It is in this was that the control switches the load for near optimal power output.

The load tested was built using a broken water heater element. The resistance of each leg of this element is critical in the proper power maximization of this circuit. This is a problem s the resistance of the heating element is not standard except for high power water heaters. Water heater elements are also rarely sold by resistance but rather by voltage and power.

2.1.2. DC Voltage Single Resistor PWM Power Control

Many commercial controllers use Pulse Width Modulation (PWM) to vary the power delivery in DC systems. The idea is to deliver a pulse train to the load with varying duty cycle. In our application the duty cycle is controlled by the regulated DC output voltage of the turbine.

A possible circuit for PWM control of small wind turbines is shown in Figure 4. This circuit has not been tested and may require changes for proper frequency of operation. RL should be sized for maximum power output of the turbine. R1 and R2 should be sized such that Vmax*R2/(R1 + R2) is equal to the supply voltage of the operational amplifiers (12 Volts as shown in Figure 4) where Vmax is the regulated DC Voltage at maximum power output.

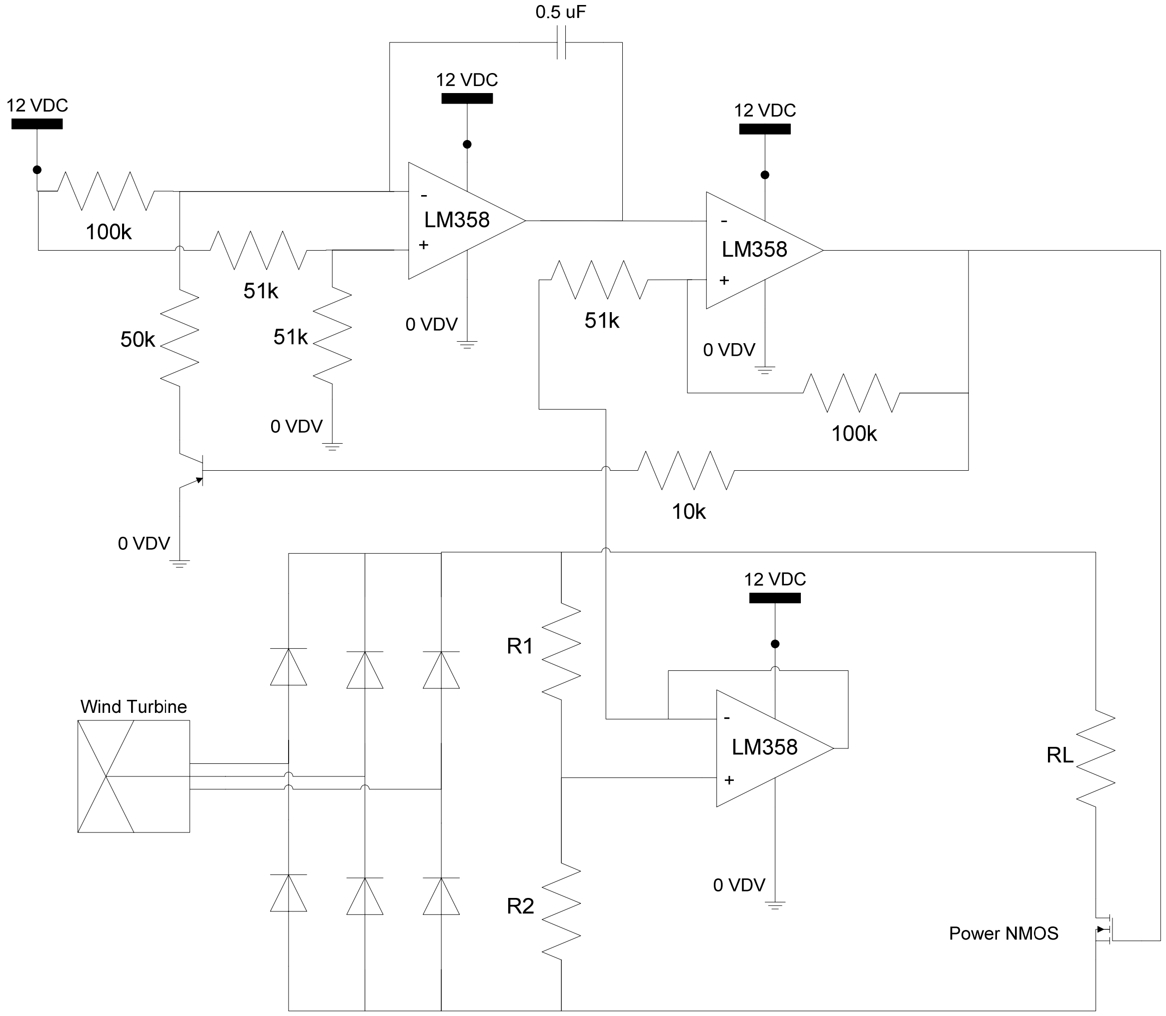

Figure 4: Pulse Width Modulation DC Control

Other supply voltages can be used within the specs of the LM358. A small battery, power supply, or regulator is required to provide this supply voltage to the circuit because the regulator output voltage range is too high for the amplifiers.

2.2. AC Direct Resistive Heating

2.2.1. AC Voltage Three Resistor Star-Delta Power Control

Testing has been done observing the effect of varying the configuration of a three resistor heating load connected directly to a 400W synchronous wind turbine. Switching from Star to Delta configuration has the effect of changing the load resistance experienced by the turbine by a factor of three. This property can be used for a simple two state AC heating control (see Figure 5).

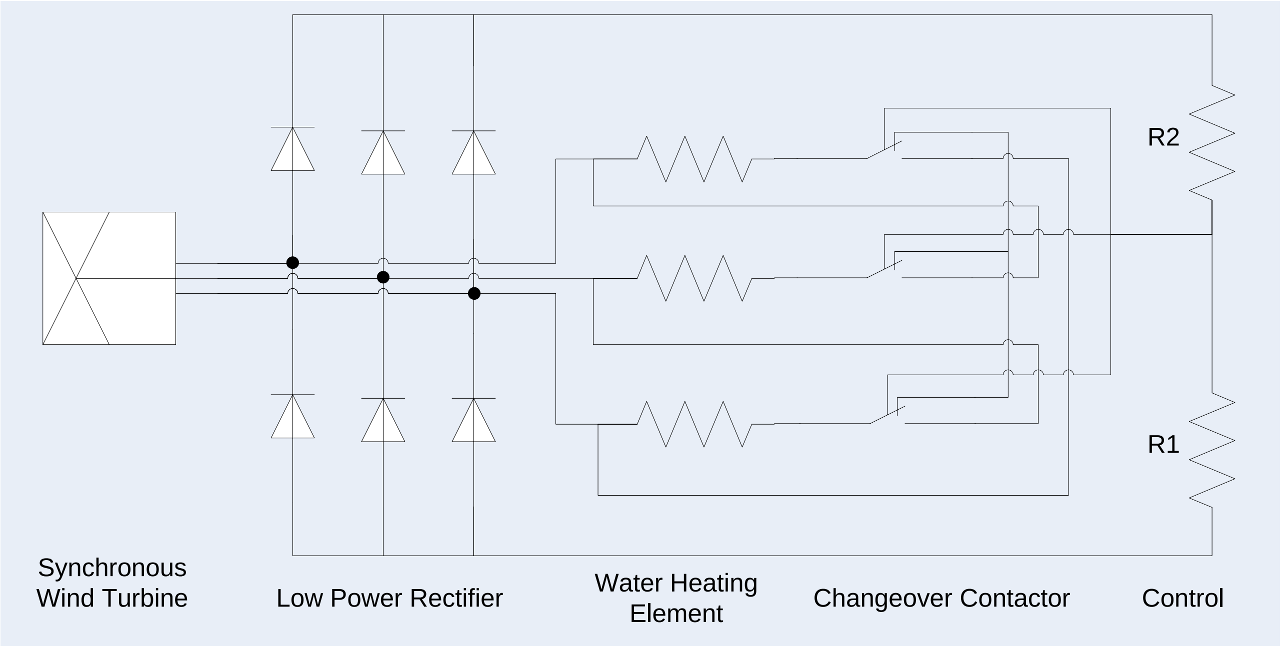

Figure 5: AC Star-Delta Power Control

The size of the heating element resistors and control resistors is dependent on the power and voltage of the wind turbine. Additional control elements may be required for proper operation of the switchover contactor.

2.2.2. AC Voltage Multiple Resistor Power Control

A strategy similar to the DC Voltage Multiple Resistor control could be used in an AC heating application however the number of resistors required would be three times greater. See Figure 6.

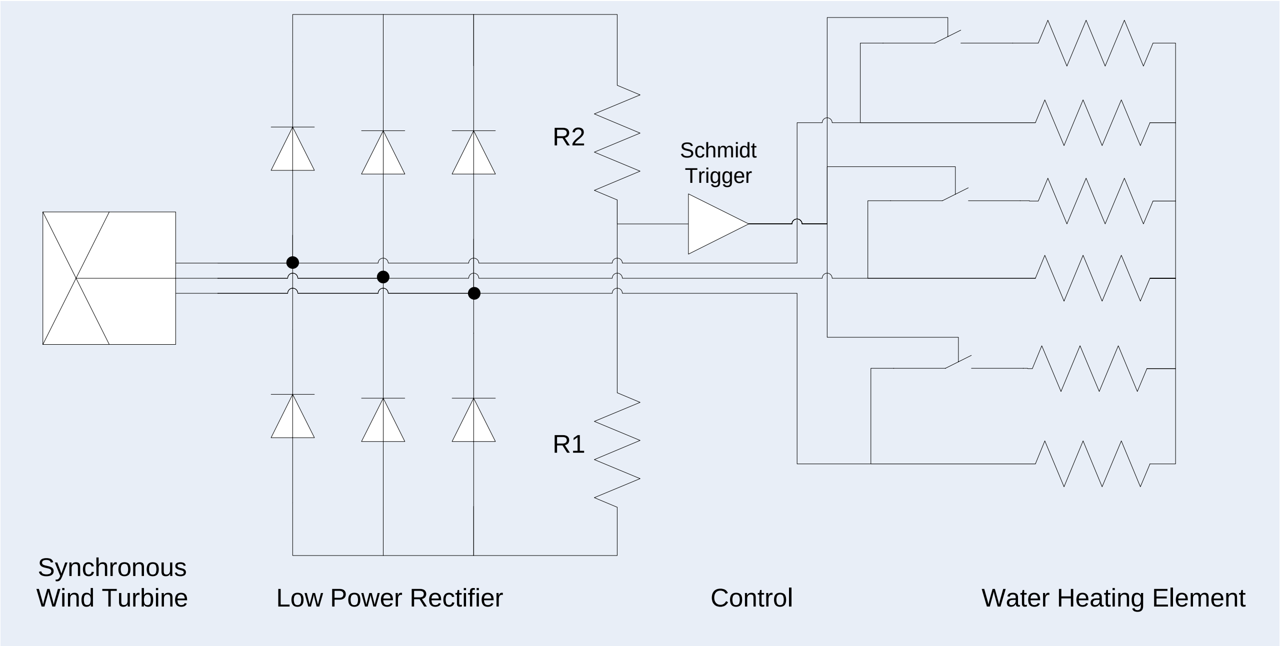

Figure 6: AC Multiple Resistor Heat Control

The example shown in Figure 6has the heating element resistors connected in a star configuration; delta configuration could also be used. The MOS transistors could be replaced by Insulated Gate Bipolar Transistors (IGBTs), or relays/contactors. Additional circuit elements may be required to protect the switching devices (transistors/relays) from high voltage levels.

2.2.3. AC Voltage Three Resistor SSR Power Control

A circuit for AC heating using a single three resistor water heating element has been designed (see Figure 7). The design uses a Zero Voltage Switching (ZVS) Solid State Relay (SSR) to selectively connect the turbine output to the load.

The enable input of the SSR is driven by a control circuit. The circuit varies the percentage of time the SSR is enabled depending on the voltage output of the turbine. Al low wind speeds the SSR is disabled and thus the turbine is disconnected from the load. At higher voltage output the SSR enable is pulsed with a 25% duty cycle square wave, at even higher voltage with a 50% duty cycle, even higher with a 75% duty cycle, and at full power the enable is held high effectively connecting the load directly to the turbine.

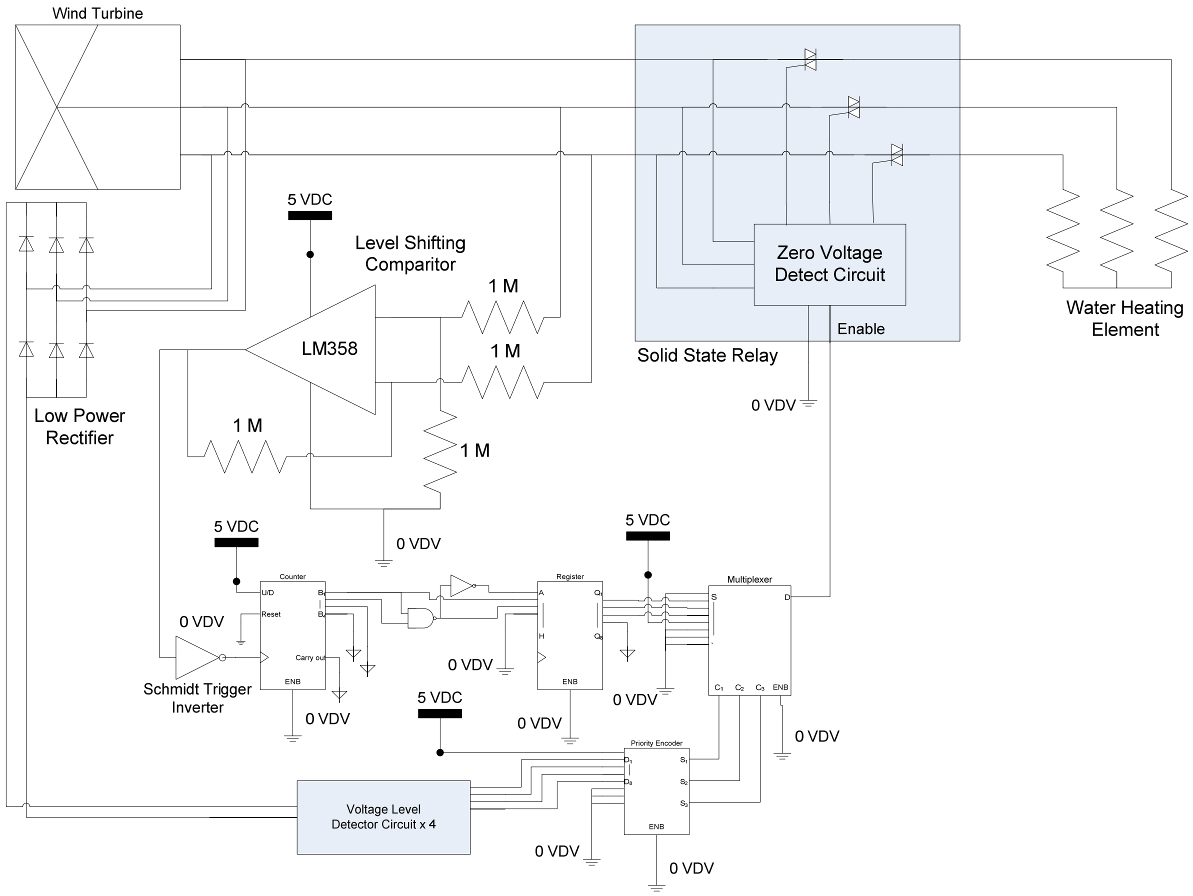

Figure 7: SSR Power Control

Proper operation of this circuit requires four Voltage Level Detector circuits which are individually tuned for optimal power output. Detector 1 will correspond with 25% power, detector 2 with 50%, detector 3 with 75%, and detector 4 with 100%. Measurements will need to be made of the turbine being used to see the rectifier output voltage at different wind speeds to determine optimal detector tuning. Possible circuits for the voltage level detector are shown in Figure 8 and Figure 9.

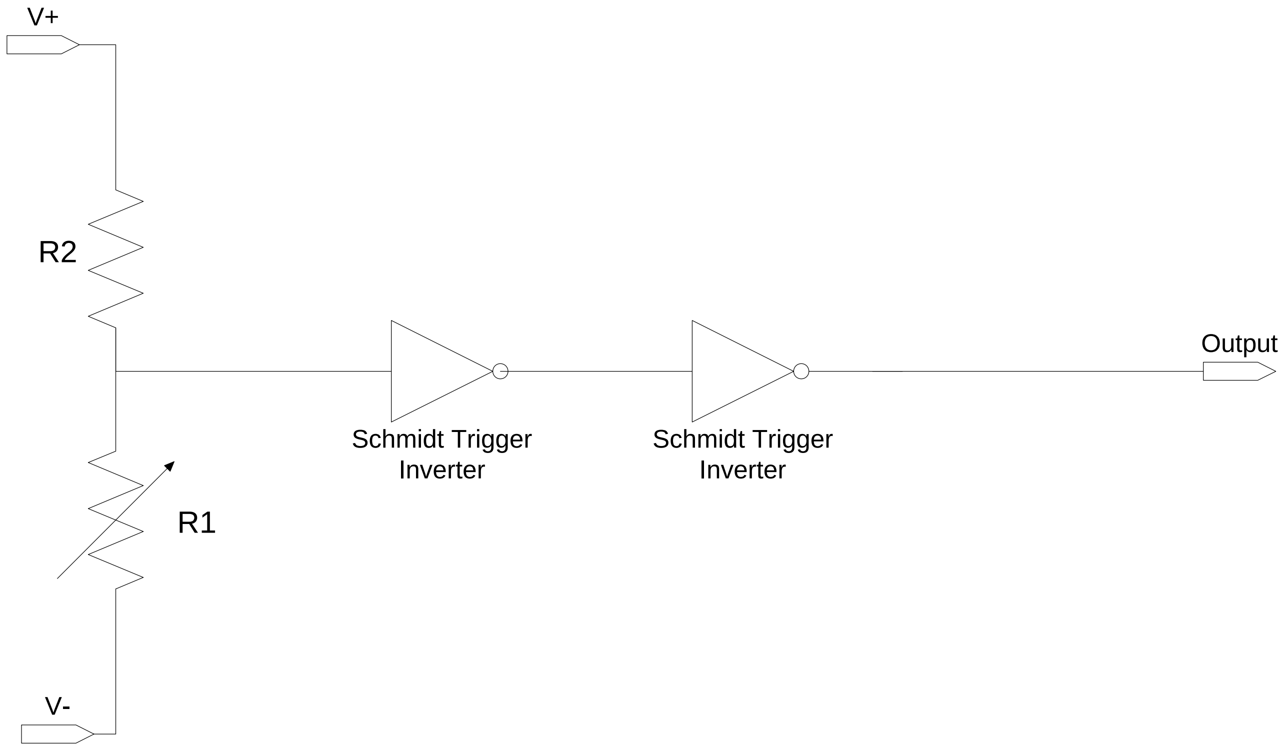

Figure 8: Voltage Level Detector 1

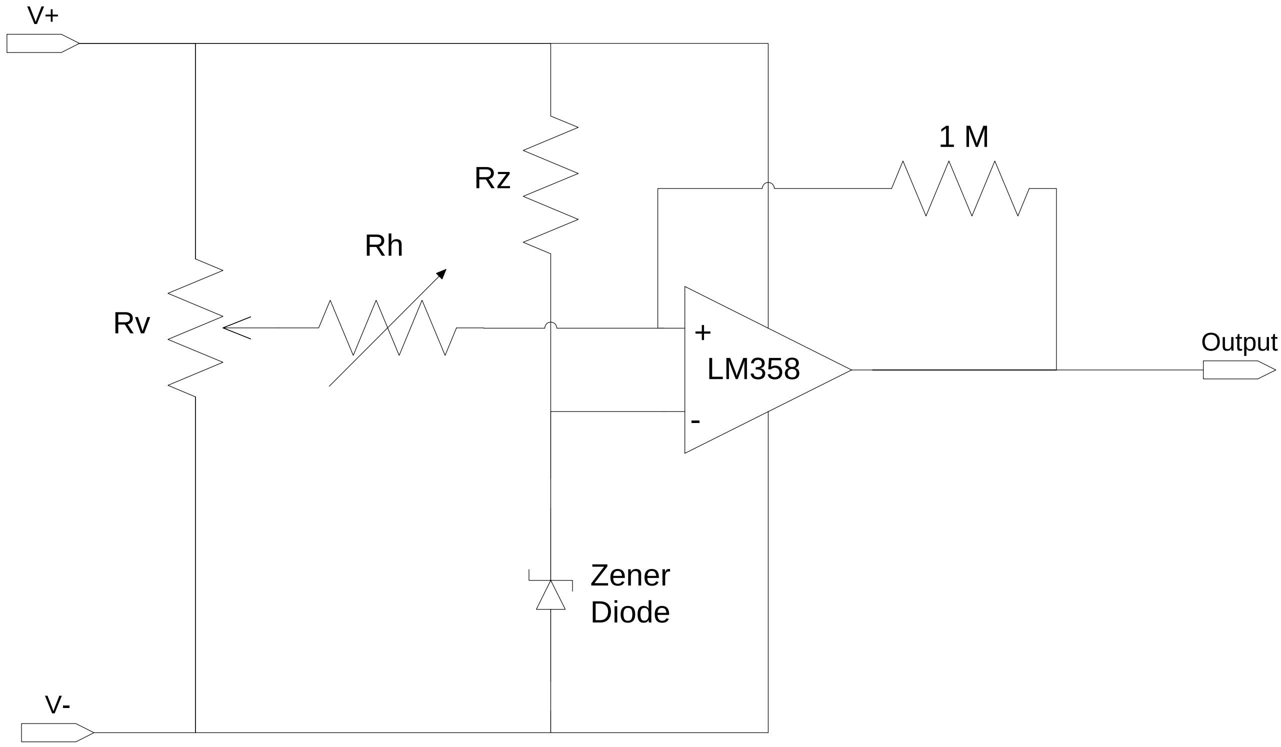

Figure 9: Voltage Level Detector 2

3. Asynchronous Wind Turbine Control

3.1. Stand Alone Systems

3.1.1. RC Load for stand alone heating system

Although not typical, an asynchronous wind turbine can be connected in the absence of a grid connection using an RC load. Stig Vindelow has some rule of thumb recommendations for sizing the RC load to match the generator being used. Stig.vindelow@paradis.dk. A star-delta controller similar to the one described in Section 2.2.1 may also be useful in this configuration.

3.2. Grid Connected Systems

3.2.1. Grid Connect Controller

Stig Vindelow’s Mini Net design uses a PR 2255 f/I converter as the main controller for his grid connected asynchronous turbine. The controller connects to a standard pulse generating RPM sensor mounted to the back of the generator (Stig uses an Aftaster 8341 which was recommended by PR electronics for his application) and has a relay output he uses to control the turbine’s main contactor.

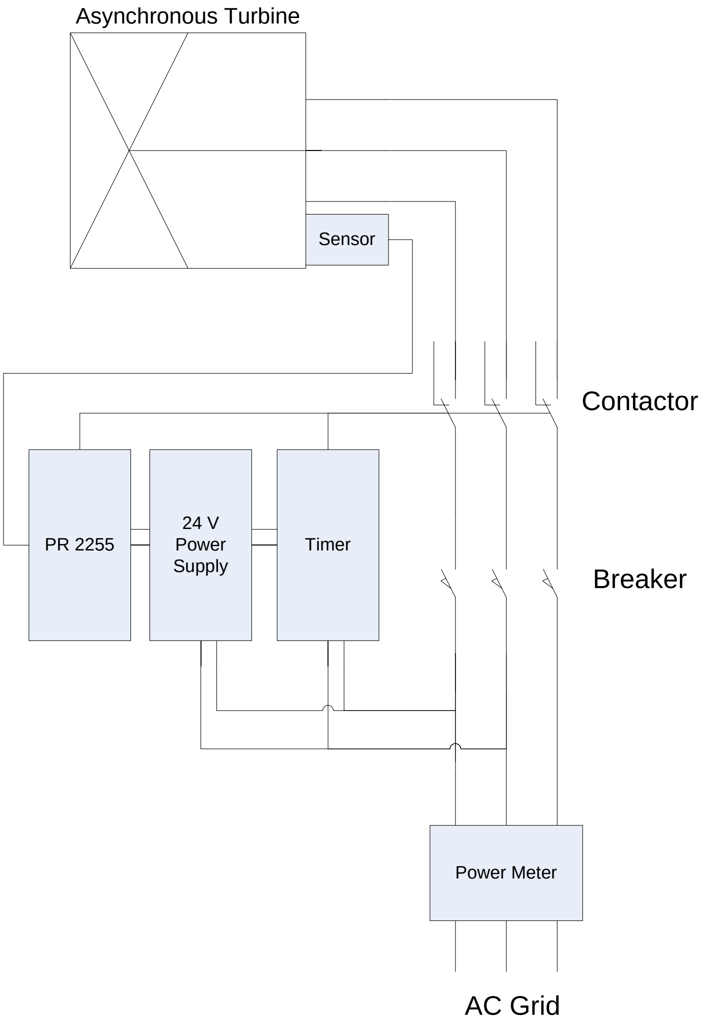

Figure 10: "Mini Net" Control Diagram

3.2.2. Generator start timer

Stig’s design also includes a timer circuit to periodically start the turbine in case wind speeds are sufficient for power production but not sufficient to overcome the static forces holding the rotor at rest.