2.2.3 Small Signal Outputs (Ground Relative to SCR Firing Board)

Signals originate on the SPI Board under the control of the Controller.

SCR Firing Board Enable	0 or 12 VDC
SCR Firing Drive	0.4 to 8 VDC

2.2.4 120 Volt Signal Inputs (Common is 120 L1, Signal presence is sensed when input is pulled to Ground potential.)

Signals come to the I/O Board and are opto coupled to the Controller.

Signal Description	Name	Indicator on for
Ground Fault	GFAULT	Ground Fault
Out of Balance	OBAL	Not Out of Balance
Blade Position	BPOS	Blades Back (Ready)
Main Breaker	MBKR	Closed
Brake Released	BMPR	* Released or Not Energized
Brake Set	BMPS	* Set or Not Energized
Over Temp	OTEMP	Temperature OK
Oil Level	OIL	Oil Level Low
Wear Switch		* BMPR and BMPS will be off if Wear Switch is Open.

2.2.5 120 VAC Output Drive Signals (Drive Level is 120 L1)

Signals originate on the Controller Board, and are opto coupled using 1 amp Solid State Relays on the I/O Board. Indicator lights show when the SSRs are activated, either by signal from the controller or by depression of the associated button on the I/O Board.

Signal Description	Name on I/O Board
Brake Solenoid Dump Relay	DUMP
Capacitor Contactor Relay	CAPS
200 KW Meter	200kW
Blade Snubbers Relay	SNUB
Yaw Drive Relay	YAW
Yaw Direction Relay	YAW D
Brake and Solenoid Relays	BRAKE
Warming Coil Relay	WARM
Main Breaker Trip Enable	

2.2.6 120/240 Volt Control Drives

Drives originate on the Relay and Breaker Panels.

Drive Description	Panel	Voltage
Yaw Power A	Relay	240 L1/L2
Yaw Power B	Relay	240 L2/L1
Snubber Power	Relay	240 L1
Warming Power	Relay	240 L2
Brake Motor Power	Relay	120 L1
Solenoid Power	Relay	90 VDC
Capacitor Contactor	Relay	120 L1
Firing Board Power	Breaker	120 L1
Main Breaker Trip	Breaker	Neutral

2.3 Electrical Integrity

2.3.1 Isolation

Electrical Isolation is important for proper function and reliability of the Controller. Isolation is accomplished using two stages of optocouplers for all Digital I/O and single stage for frequency related inputs and SCR control. Also, the Controller is insulated from the Swing Door by a rubber gasket.

2.3.2 Transient Suppression

Transient Suppression reduces the chance of damage to small signal components in front end circuits. The SPI and I/O Boards use Tranzorbs profusely to accomplish this necessary function.

2.3.3 Noise Immunity

Both Electrical Isolation and Transient Suppression contribute to the Noise Immunity in this system. In addition, small signal interfaces between boards as well as etch paths on boards are kept as short as possible. RPM and Windspeed signals are brought to the SPI Board using shielded twisted pairs. The other analog signals from the Nacelle are filtered heavily on the I/O Board or by using digital techniques in software. AC Digital Input signals are relatively slow and are filtered on the I/O Board and again on the Controller Board.

2.4 Peripherals

Peripherals are referred to here as all control and sensing devices which are used in the control system. A rudimentary knowledge of these is helpful in understanding the Control System both from technical and philosophical standpoints.

2.4.1 SCR System

All Generator current flows through and is controlled by the SCRs. These are large thyristor devices which are fired by the SCR Firing Board. This is a special, self contained system which is enabled and to some degree, driven by outputs from the SPI Board. Power for the Firing Board comes from the Brake Solenoid Relay RY2 which is mounted on the Relay Panel. Since RY2 can only be energized when the Controller has energized the brake circuit and concurrently the Brake Position Switch is in the released position, the SCRs can only be fired when the Brake is released and all systems are "Go." The purpose is to insure that no sort of accident can cause the Generator to be motored against the Brake.

In general, the SCRs will be phase fired at a large angle (low voltage) when then RPM is < 1805 (input power is low) and the drive signal from the SPI Board is low. A small angle (approaching zero) will occur as input power increases or the drive signal increases. The Controller will issue a high drive signal at the time of tie on if acceleration is higher than 100 RPM/Sec or in normal run if power reaches 80 KW. A low drive signal will be issued when measured power drops below 40 KW.

2.4.2 Yaw Motor

The Yaw Motor is a 240 volt 3 phase induction motor. Two of its legs are driven from the Yaw SSRs RY4 and RY5 on the Relay Panel. The third leg is connected to Tower Common. The mechanical relay RY8 on the Relay Panel swaps the two drive voltages 240 L1 and 240 L2 which supply RY4 and RY5 when yaw direction needs to be reversed.

2.4.3 Blade Snubbers

The Blade Snubbers contain large electromagnets which hold the blades in a pitched down position while the machine is running. They are connected in series and powered by 240 L1 from RY3 on the Relay Panel. A full wave diode bridge mounted on the hub of the blades converts this voltage to DC. When energized, these coils draw a little less than 1 amp. The diode bridge and the snubber release circuit is located on the inner door of the unit control cabinet.

2.4.4 Brake System

The Brake is a large disk brake on the generator shaft capable of stopping the machine in any wind condition. It is released when RY1 on the Relay Panel energizes the Brake Motor which pulls the spring loaded pads away from the disk with a rotating a lever arm. When this arm reaches the desired position a micro-switch is depressed which removes drive voltage from the input to RY1, stopping the motor and energizing RY2 which applies power to the solenoid power supply which is located on the Relay Panel. This activates the solenoid clutch which latches the motor in the released position. The solenoid power supply provides filtered 90 VDC. When power is removed from the brake system it takes about 15 seconds to bleed down enough for the solenoid to release the brake motor so that this amount of time will elapse before the brake will set. This allows the blades to have pitched up completely and slowed down before the brake is applied in a power outage situation. The brake solenoid power supply has a relay located on the I/O Board which the controller can activate when necessary which immediately bleeds the filter capacitors and causes timely brake activation in emergency situations.

2.4.5 Capacitors

Power Factor Correction Capacitors are installed in the 480 volt side of the Main Transformer Cabinet. A contactor mounted near them connects them in a delta fashion to the 480 volt secondary. This contactor is energized by RY7 on the Relay Panel when power factor correction is needed.

2.4.6 Warming Circuit

When certain humidity and temperature conditions exist, it becomes necessary to warm the Generator slightly to avoid condensation in the Stator Windings. Warming is only used when the Generator is not on line and only when temperature sensors indicate that the generator may be below the dew point. To achieve this, Warming Coils are embedded in the Stator Windings which can be energized by 240 L2 from RY6 on the Relay Panel. There are two Warming Coils, each of which provide about 100 Watts.

2.4.7 Blade Status Switches

Blade Position is sensed by two micro switches, one in each blade. These are wired in series so that if either is open the circuit will not be completed. When both switches are closed, the controller receives the indication through the I/O Board that the Blades are back and ready to run.

2.4.8 Brake Status Switches

Brake Motor Position is sensed using the same micro switch that controls drive voltage to the Brake Motor and Brake Solenoid Relays (RY1 and RY2). Common for the micro switch comes through the Wear Switch from Tower Common. Two signals are generated: Brake Released and Brake Set. Below is a truth table showing status indicators:

Conditions			Signals	
Brk Pwr	Wear Sw	Brk Pos	Brk Rel	Brk Set
Off	Closed	X	On	On
On	Closed	Set	Off	On
On	Closed	Released	On	Off
X	Open	X	Off	Off

X = Don't Care

2.4.9 Temperature Switch

An Over Temp switch is potted into the stator coils of the Generator as a protective device. This switch is normally closed. This means that it will open if the Generator get too hot. The controller senses this indication through the I/O Board.

2.4.10 Oil Level Switch

Oil level in the Gear Box is sensed using a level sensor. This switch is open when the Oil Level is OK. The controller senses this indication through the I/O Board.

2.4.11 Vibration Sensor

The Vibration Sensor is a switch with a weight on it which can be activated from any direction. It is normally closed meaning that an Out of Balance condition will cause the switch to open momentarily in a periodic fashion. The controller senses this indication through the I/O Board.

2.4.12 Wind Direction Flag

Wind Direction relative to the Nacelle orientation is detected using a rotating flag which is mechanically connected to a potentiometer. This flag acts as a voltage divider and provides a signal from +5 to -5 VDC. Power for this flag comes from the I/O Board. The signal is conditioned on the I/O Board and multiplexed to the Controller.

2.4.13 Wrap Potentiometer

Wrap Angle of the Umbilical Cable is sensed using a linear potentiometer connected to a screw drive which rotates with the Nacelle relative to the Tower. This potentiometer acts as a voltage divider and provides a signal from +5 to -5 VDC. Power for this pot comes from the I/O Board. The signal is conditioned on the I/O Board and multiplexed to the Controller.

2.4.14 Temperature Sensors (Analog)

Three Temperatures are sensed in the Nacelle. These are:

Generator Temp (A)
Gear Box Temp
Ambient Temp

These sensors are each an LM34 (National Semiconductor).Power for these sensors comes from the I/O Board. The signals are conditioned on the I/O Board and multiplexed to the Controller.

2.4.15 Voltage Sensors

Two Voltages are monitored by the Controller. These are:

Transformer Voltage	Line to Neutral	ϕA	≈ 277
Generator Voltage	Line to Line	$\phi A - \phi B$	$\approx 90\text{-}480$

These voltages are reduced to small signal level using small PTs mounted in the Control Cabinet. The signals are conditioned on the I/O Board and passed on to the Controller.

2.4.16 Current Sensors

Two Currents are monitored by the Controller. These are:

Generator Current	ϕA	0 to 400 Amps
Generator Current	ϕC	0 to 400 Amps

These currents are reduced to small signal level using small CTs mounted on the CT Board in the Control Cabinet. Wires from the Main 400:5 CTs are passed through these small CTs. The signals are conditioned on the I/O Board and passed on to the Controller.

2.4.17 RPM Transducer

For RPM detection, a 56 tooth spline or gear on the generator shaft is used with a magnetic sensor detecting the passing teeth as an input to the SPI Board. When properly connected to the SPI Board this sensor generates a fairly sinusoidal wave form of about 6 to 9 volts at 1800 RPM. The voltage becomes lower as RPM drops. This signal is conditioned and opto coupled on the SPI Board before passing it directly to the Controller which accurately counts time between teeth.

2.4.18 Anemometer (Windspeed Sensor)

For Windspeed detection an Anemometer with a magnet and a Hall-Effect Sensor is used. Power for the sensor comes from the SPI Board. The square wave signal is conditioned and opto coupled on the SPI Board before passing it directly to the Controller which counts number of half revolutions per second.

2.5 Controller

The HSC11 Controller is the "Brains" of the Control System.

2.5.1 CPU

The controller uses a Motorola MC68HC11 microprocessor as its CPU. This device incorporates the following internal features to provide efficient operation of the control system:

*	COP	CPU Operating Properly Timer Insures that Program continues to run normally.	0.5 Seconds
*	SCI	Serial Communications Interface Enables external communication with the Controller for remote control and data retrieval.	2400 Baud
*	SPI	Serial Peripheral Interface Provides high speed communications with the SPI Board.	500 KBaud
*	A/D	Analog to Digital Conversion Used for monitoring Analog Signals	9 Bits
*	PA	Pulse Accumulator Used for monitoring Windspeed	

* ICF Input Capture
  Used for monitoring RPM

2.5.2 Memory

There is 16K of program space (EPROM), 32K of data space (RAM), and 16K of parameter storage space (write protected RAM). Both RAMs are battery backed up for data retention during power outages.

2.5.3 Digital Inputs (8)

Digital Status Inputs are received by opto couplers and passed to the CPU as a single byte in memory.

2.5.4 Digital Outputs (8)

Digital Output is handled by using reed relays. These are each addressed as a single bit of a single byte in memory. Before this byte can be written by the CPU a security code must be written to an enable latch. This significantly reduces the chance of erroneous output levels.

2.5.5 Analog Inputs (8)

The analog input signals are conditioned by the first stage. They are then multiplexed through to an absolute value circuit before being sent to the A/D Convertor in the CPU. A sign bit is also generated which is sensed by the processor.

2.5.6 Time of Day Clock

A TOD Clock chip is used to keep track of date and time. This chip is backed up by the on board Lithium Battery. It is addressed by the CPU as 16 bytes in memory.

2.5.7 Display

The Display has 2 lines of 24 characters each. It is an LCD with module with its own controller on board. This device is addressed by the CPU as 2 bytes in memory.

2.5.8 Keypad

The keypad is a series of 4 by 4 membrane switches. The CPU addresses it through one byte in memory.

2.5.9 Power Supply

Three voltages are generated by the on board Power Supply. These are +5 volts, +10 volts and -10 volts. A battery located on the I/O Board will supply power so that all three voltages can be maintained for approximately 30 seconds following a power outage. This allows the CPU to monitor conditions until the Generator RPM has dropped to a safe level. If necessary, the Controller can cause the Brake to set immediately.

2.6 Control Support Components

2.6.1 SPI Interface Board

The SPI Board performs the following functions:

* RPM Sensor Signal Conditioning
* RPM Sensor Presence Verification
* Anemometer Signal Conditioning
* KWH Meter Pulse Coupling
* Nacelle Analog Signal Multiplexer Addressing
* Brake Solenoid Voltage Dump
* SRC Firing Board Enable
* SRC Firing Board Analog Drive
* Opto Isolation of all Signals to & from Controller
* Level Shifting for RS-232 Serial Port
* Fiber Optic Interface

This board uses high speed opto couplers for the signals which need the speed such as the RPM, Windspeed, and SPI Circuits and normal opto couplers for the slower signals including Brake Dump and KWH Pulses. The SPI Board has its own power supply which receives low voltage AC from a transformer on the I/O Board. This power is then returned to the I/O Board for a few of its functions. These voltages are basically equivalent to those on the Controller but are completely isolated from the Controller. A battery located on the SPI is capable of maintaining the +5 and +10 volt rails for about 30 seconds in case of a power outage for the same reasons referenced in the Controller discussion.

The SCR Enable and Drive circuit is completely isolated from both these supplies and receives its power from the SCR Firing Board. A D/A Convertor is driven from an SPI chip with the 8th bit being used as the enable bit. The output of the D/A applies a variable voltage to the Signal Hi input of the Firing Board.

LEDs on the SPI Board indicate operation of the following:

Windspeed	Blinks when pulses are received
RPM	Appears solid on when Generator is turning
RPM Fail	On if Sensor wire is open or shorted
KWH	On half the time, Off half the time

2.6.2 I/O Interface Board

The I/O Board performs the following functions:

* Rectification and level shifting of AC Input Signals
* Level shifting and conversion of Digital Outputs
* Signal Conditioning of all Analog Signals
* Multiplexing of Nacelle originated Analog Signals
* Visual indication of AC Input Stati
* Visual indication of Digital Output Drives
* Manual operation Digital Output Drives (Push Buttons)
* +/- 5 volt Power Supplies for Analog Sensors
* Opto Isolation of Digital Signals to & from Controller

This board uses opto isolators for the Digital Inputs and small solid state relays for the Digital Outputs. These Inputs and Outputs are defined in detail in the I/O Signals discussion above. LEDs are used as indicators to show status of each input and each output. Analog inputs are protected using Tranzorbs. Voltage and Current signals are piped directly through to the Controller while the Yaw, Wrap and Temperature Signals are multiplexed into 2 Analog signals which are sent to the Controller.

2.6.3 Fiber Optic Interface Board

The Fiber Optic Interface performs the following functions:

* Modem Interface	RS232
* Inter-Turbine Interface	RS422
* Controller Communications Interface	TTL/Fiber Optic
* RTS simulation	
* Power Supply for the Modem	
* Level Shifting for the different modes	

The Fiber Optics used here is a plastic duplex system in which all the optics are contained in the connectors which terminate the ends of the cable. There are no optic elements on the board. The turbines are connected by 3 shielded twisted pairs. These act as Power and Communications transmission lines in an RS422 Full Duplex system. Wire designations are as follows:

Pair A	Modem Transmit	———————>	Controller Receive
Pair B	Modem Receive	<———————	Controller Transmit
Pair C	+12 Volts (Both Wires)		
Shields	Ground		

Only one Turbine in a group will have a modem and a power supply. The Fiber Optic Link is to isolate all control system components (especially the Controller) from the phone lines and from other Turbines.

2.6.4 Relay Panel

The Relay Panel functions to give the Controller control over the mechanical actuating devices in the Wind Turbine System. This is accomplished mainly through the use of Solid State Relays (SSRs). SSRs are used because they are reliable and noise free, both at the input since there is no inductive kick when they are turned off and at the output because they continue to conduct until the current zero crossing. These are 250 volt, 25 Amp rated SSRs with a 250 Amp surge rating. The following is a list of the Relays on the Relay Panel:

RY1	Brake Motor	┐ Only one can operate at
RY2	Brake Solenoid	┘ a time.
RY3	Blade Snubbers	
RY4	Yaw Motor (Phase A)	┐ Both of these are ener-
RY5	Yaw Motor (Phase B)	┘ gized simultaneously.
RY6	Warming Circuit	
RY7	Capacitor Contactor	
RY8	Yaw Direction	Mechanical Relay - DPDT

The Solenoid Relay actually energizes a Power Supply which operates the Brake Solenoid. This Power Supply provides approximately 90 VDC to the Solenoid when it is holding the Brake. It has the characteristic that the 90 volts comes on very rapidly when the Solenoid Relay is energized but takes about 15 seconds to drop to a voltage low enough for the Solenoid to release when the Relay is turned off. This Power Supply is located on the Relay Panel.