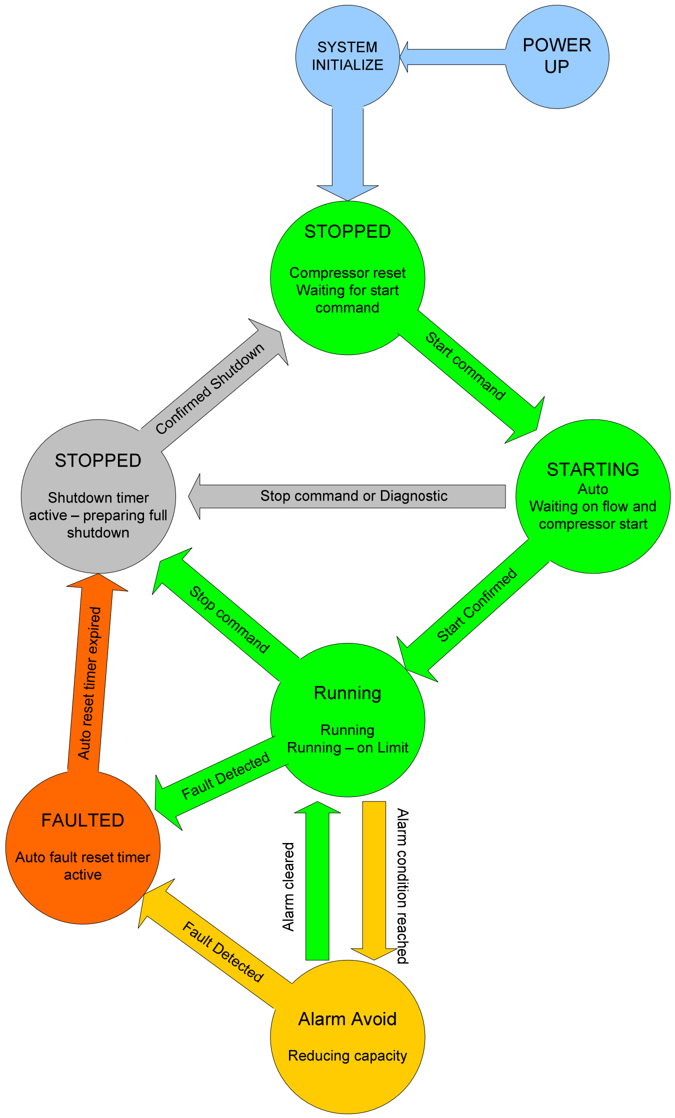
General sequence of operation overview:

The graphical chiller control system is responisible for providing demand to compressors, staging on and off compressors, control of electronic expansion valves, control of load balance valves, alarm condition avoidance and fault detection/shutdown.

In order to run the chiller the following field installed inputs must be made:

- DI-1 BAS enable – Start command
- DI-2 Chilled water flow proof
- DI-3 Condenser water flow proof (Bridge DI-3 if air cooled chiller)

For physical wiring locations of inputs see “Control wiring diagram – Field connections” section of submittal



SYSTEM INITIALIZE
POWER UP
STOPPED
Compressor reset
Waiting for start command
Start command
Confirmed Shutdown
STOPPED
Shutdown timer active – preparing full shutdown
Stop command or Diagnostic
STARTING
Auto
Waiting on flow and compressor start
Start Confirmed
Stop command
Auto reset timer expired
Running
Running
Running – on Limit
Fault Detected
FAULTED
Auto fault reset timer active
Alarm cleared
Alarm condition reached
Fault Detected
Alarm Avoid
Reducing capacity

Air Cooled Chiller Cycle Description

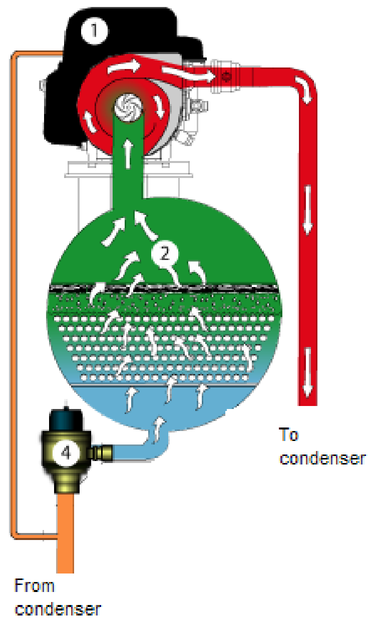
Controls – Cooling cycle operation:

When the SMARDT chiller control system is set to "HVAC_COOL" mode indicating the chiller is to be used to control the leaving chilled water temperature to some desired value the following description of operation is true:

EVAPORATOR

When the chiller is operated in cooling mode the condensed liquid refrigerant exits the electronic expansion valve and enters the bottom of the flooded evaporator where it is evenly dispersed along the length of the evaporator by the use of a distributor plate. Liquid refrigerant inside the evaporator at low pressure then makes contact with the copper tube the buildings water runs through and exchanges heat to the refrigerant vaporizing it at the suction pressure of the compressor.

The vaporized refrigerant gas is then drawn to the top of the evaporator through the mist eliminators (mist eliminators inhibit minute liquid particles entrained in the vapor refrigerant from entering the compressor) as a result of the lower density of the vapor and the suction of the compressor. The vapor refrigerant enters the compressors inlet passing through the inlet guide vanes (pre-rotation vanes) where the angle of incidence of the vapor refrigerant hitting the first stage impellor is altered allowing a higher compression efficiency for a given compressor rotor speed.

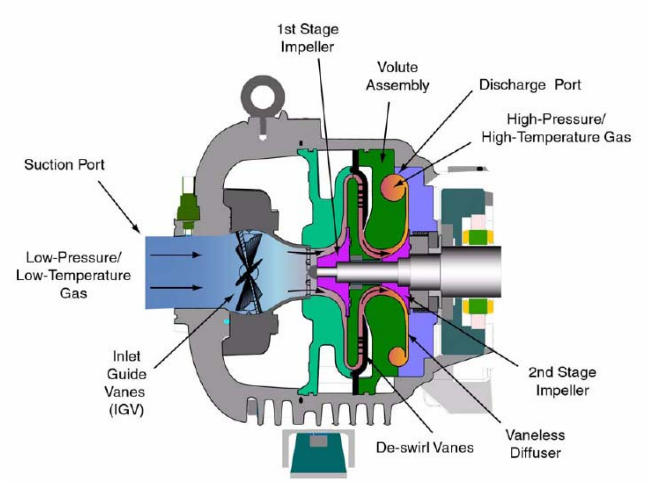


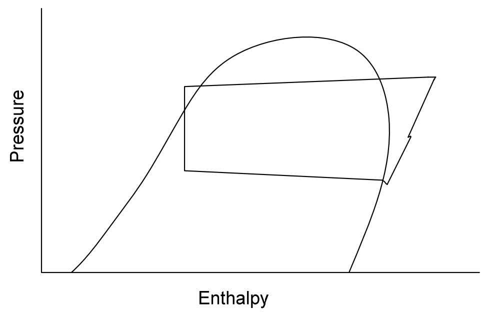
COMPRESSOR

SMARDT Inc oil free chillers exclusively use Turbocor™ variable speed magnetic bearing compressors on all chillers. All of the Turbocor compressors are a two stage design meaning the compression of the vapor refrigerant takes place through two impellors (see figure 1.1).

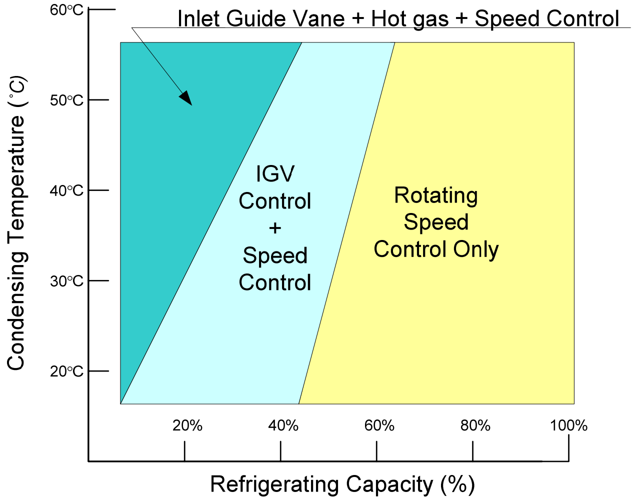
The refrigerant enters the suction side of the compressor as a low-pressure, low-temperature, super-heated gas. The refrigerant gas passes through a set of adjustable inlet guide vanes (IGV) that are used to control the compressor capacity at low load conditions. The first compression element that the gas encounters is the first-stage impeller.
The centrifugal force produced by the rotating impeller results in an increase in both gas velocity and pressure.

The high-velocity gas discharging from the impeller is directed to the second stage impeller through de-swirl vanes. The gas is further compressed by the second stage impeller and then discharged through a volute via a vane-less diffuser. (A volute is a curved funnel increasing in area to the discharge port. As the area of the cross-section increases, the volute reduces the speed of the gas and increases its pressure.) From there, the high-pressure/high temperature gas exits the compressor at the discharge port.





Capacity control on SMARDT chillers is achieved by varying the speed, inlet guide vane position and number of compressor operating. Figure X.X provides a graphical representation of the centrifugal compressors response to demand and operating conditions.



CONDENSER

Superheated refrigerant from the compressor enters at the top of the condenser coils where is make a number of passes along the length of the condenser. As the refrigerant is moving through the tubes in the condenser heat is constantly been removed from the refrigerant and dissipated to the air moving across the coil surface.

The SMARDT chiller control system varies the amount of air flow through the condenser either by staging on and off fixed speed fans or by driving the speed up and down of variable speed fans (VFD fans on high efficiency premium units only). The amount of fans required on/off or the speed is determined by monitoring the outside air temperature via the sensor connected to Temp input #5 and the saturated condenser refrigerant temperature.

During normal air conditioning operation (ambient above 35°F) the fans will be operated to provide the best energy balance between compressor power and fan power. At lower than 35°F ambient the fans will modulate down to maintain a minimum condensing pressure that is required to provide pressure difference from the liquid refrigerant line to the suction side of the system in order to establish refrigerant flow through the compressors motor cooling circuit.

HOT GAS VALVE CONTROL
The hot gas valve provides the following functionality:

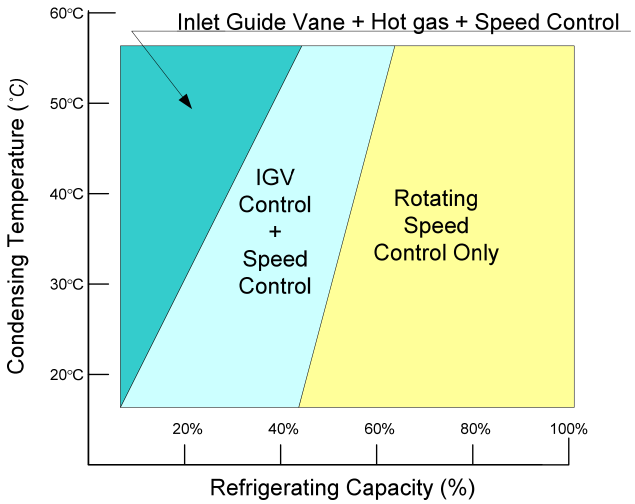
- Capacity control at low load.
- Assisted pressure ratio relief for starting new compressors.
- Head pressure relief for heat pump and air cooled chillers operating above design conditions.

Low Load Capacity Control Functionality
Hot gas control of leaving water temperature is a last resort method of control when speed control and inlet guide vane control is no longer an option. The hot gas valve control uses the compressors *IGV%*, surge. Choke and actual rpm to determine when to use the hot gas valve for capacity control.

The set point for the hot gas control is a differential temperature below the leaving temperature set point. By using a differential temperature the hot gas control set point automatically adjusts with a change in supply temperature set point for the chiller such it is easy to implement along side set point reset strategies.

As the chart below shows the hot gas valve is only used once the compressor(s) have used up all speed control and *IGV* control envelope. If the chillers capacity must be increased and the hot gas valve is open the hot gas valve will be closed before adjusting compressor demand.

It should be noted that hot gas capacity control of SMARDT air cooled chillers only takes place when the last compressor is operating; the chiller control system makes best use of compressor staging before resorting to hot gas control. Under normal air conditioning loads where the outside air temperature and the heat load applied to the chiller are closely related it is not uncommon for the hot gas capacity control valve never to be used.



Assisted Pressure Ratio Relief

Hot gas bypass assistance is required to help start new compressors whenever the pressure ratio across the check valve of the compressor to be started exceeds 2.4:1, the value of 2.4 has been determined from lab and field testing.

Some of the major reasons for requiring pressure ratio relief when turning on another compressor on a refrigerant circuit where other compressors are operating:

- Avoid rapid rotor displacement which is a weakness of all centrifugal compressors without pressure ratio unloading. High dynamic forces impact bearings significantly. Benefit of magnetic bearings is they can shutdown before surface impact occurs thus suffering no damage.
- Instability as the compressor overcomes the system pressure and begins to open the discharge check valve
- Dangerous to hold in ramp up condition with no flow for too long.
  - All energy placed into compressor has no where to go resulting in high internal temperatures.
  - Large sudden amperage spikes on inverter can be dangerous due to low thermal inertia on IGBT's. The higher the head that must be overcome the higher these spikes are.

Control Strategy

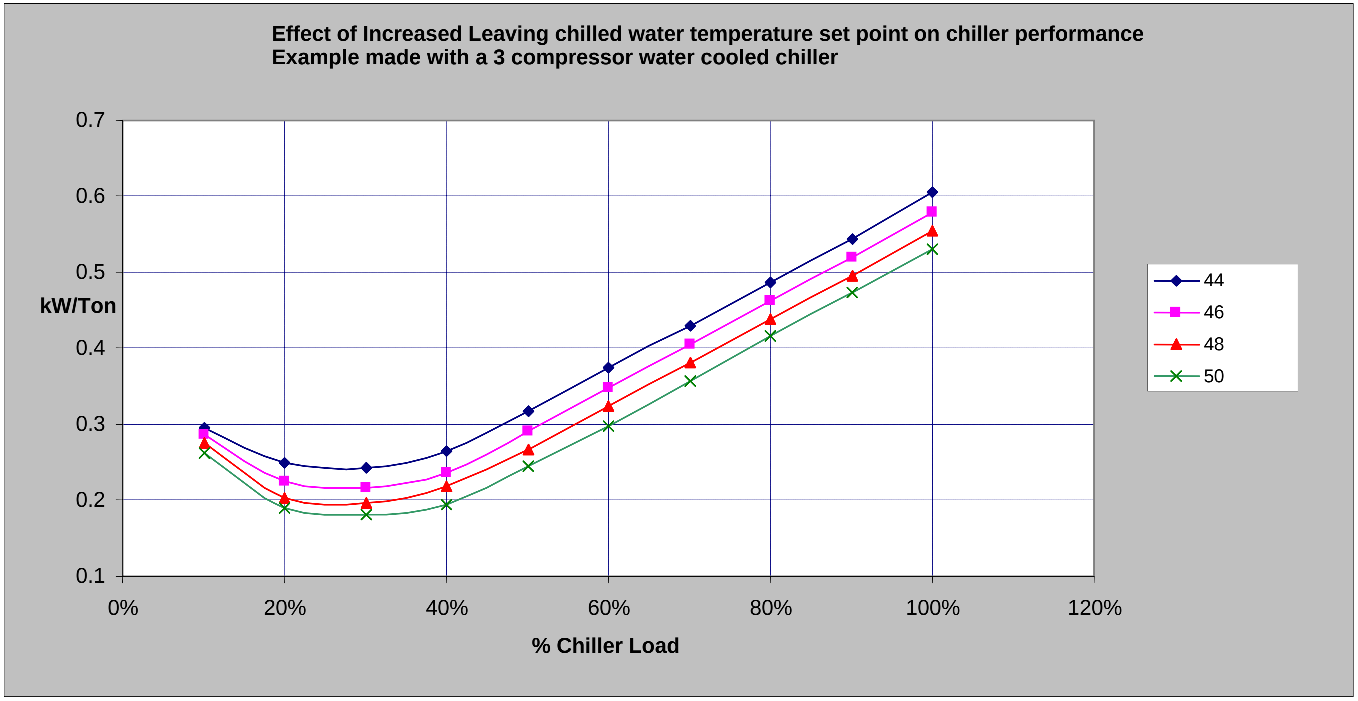
The assisted hot gas bypass start up is enabled whenever the chiller enters the "STAGE UP" mode and the pressure ratio calculated from the highest discharge pressure and lowest suction pressure of all compressors online is above a configured limit (default 2.2).

If hot gas pressure ratio assistance is required the hot gas valve is forced open at 1% per second until the pressure ratio is reduced below the limit at which time the next compressor is enabled to start. Once the new compressor has started and is running within 10% speed of the other compressors the hot gas valve is closed slowly at a rate of 0.5% per second.
Hot gas bypass assistance is required to help start new compressors whenever the pressure ratio across the check valve of the compressor to be started exceeds 2.4:1, the value of 2.4 has been determined from lab and field testing.

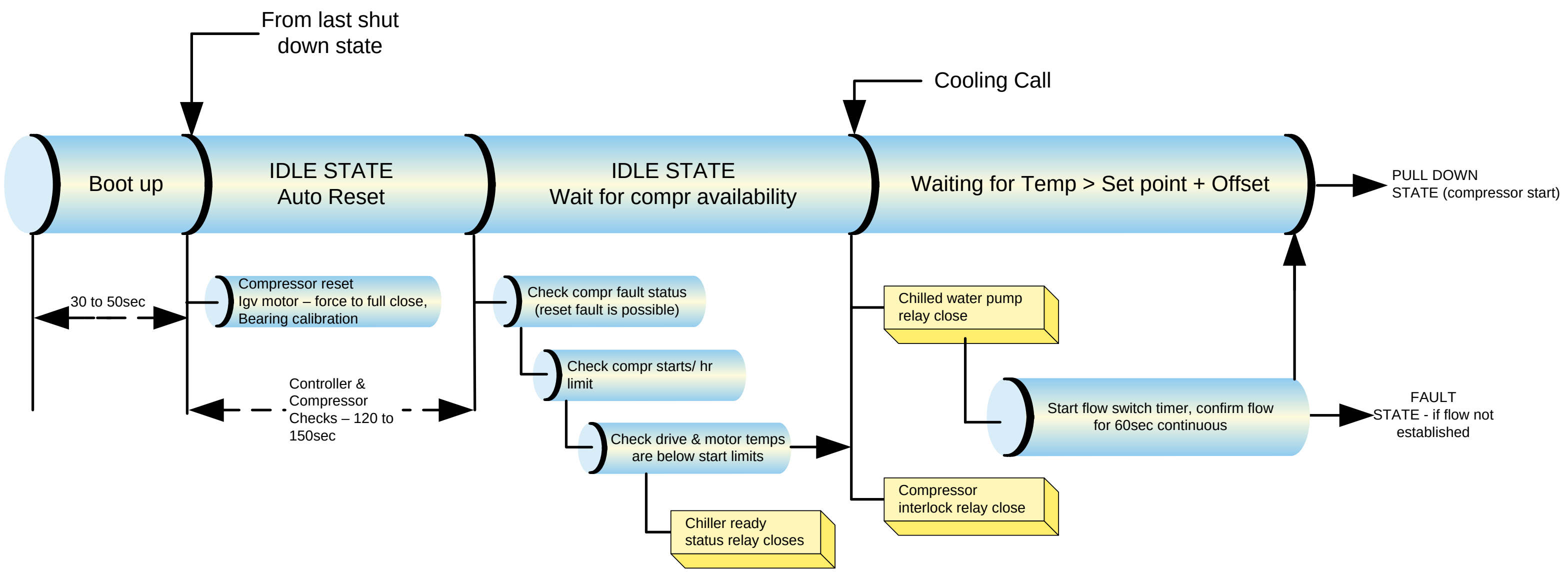
Return water control

Occasionally SMARDT chillers are selected to provide return water temperature control in a plant instead of supply chilled water control. Return water temperature control allows the leaving chilled water set point to automatically float with the actual building load. Running higher leaving chilled water temperatures permits a higher chiller performance – an efficiency increase of approximately 3% per °F increase in set point is possible (see chart below).

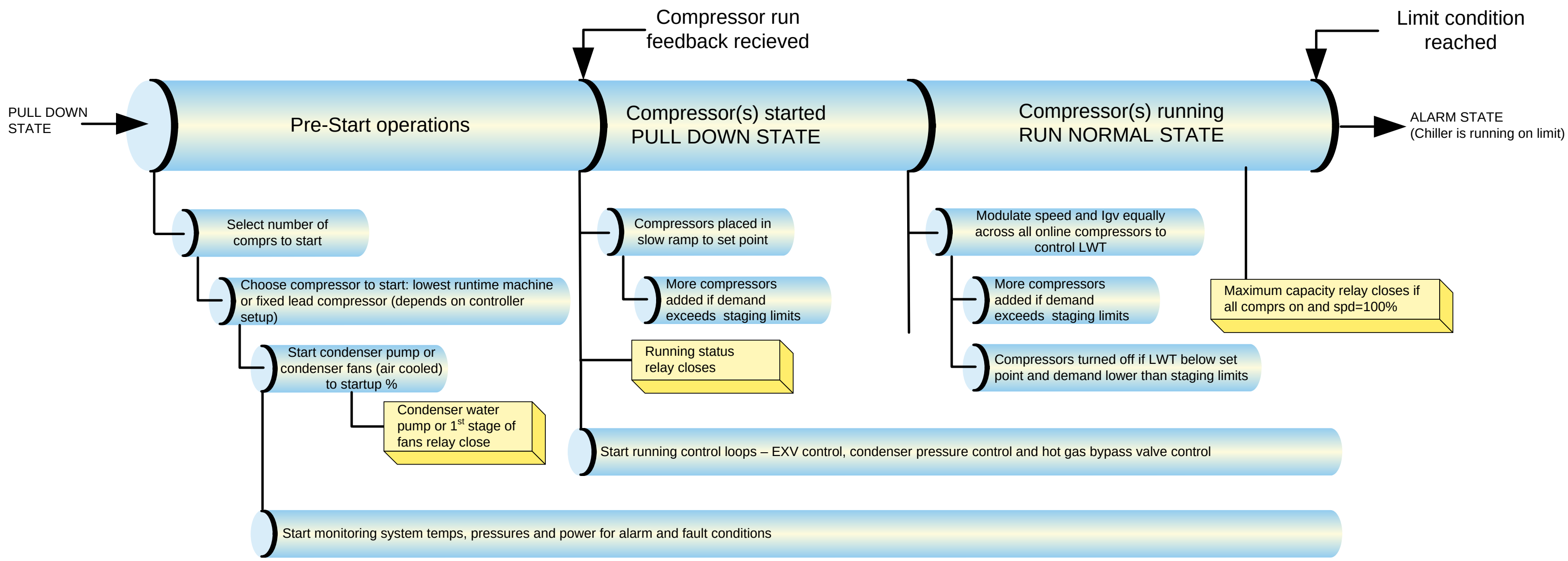
Selecting "HVAC_RET" mode in the chillers graphical touch pad interface will enable control from return water temperature, all alarm and fault trip points are active in this mode – extra care must be taken when selecting a return water temperature to run to avoid driving the chiller into low suction pressure or low leaving chilled water faults. SMARDT Inc suggests a set point from 50°F to 60°F.


Effect of Increased Leaving chilled water temperature set point on chiller performance
Example made with a 3 compressor water cooled chiller
kW/Ton
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0%
20%
40%
60%
80%
100%
120%
% Chiller Load
44
46
48
50

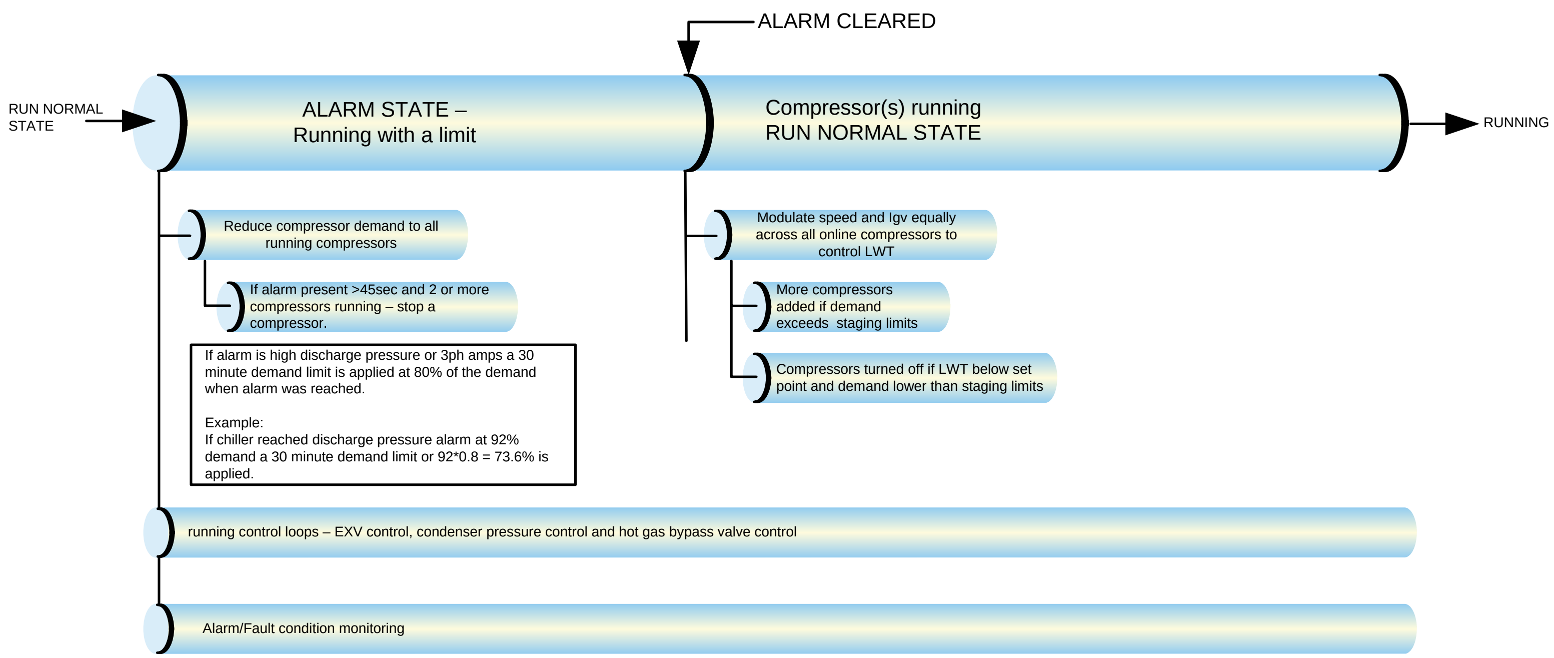
Chiller Sequence of operation: Power up to running:



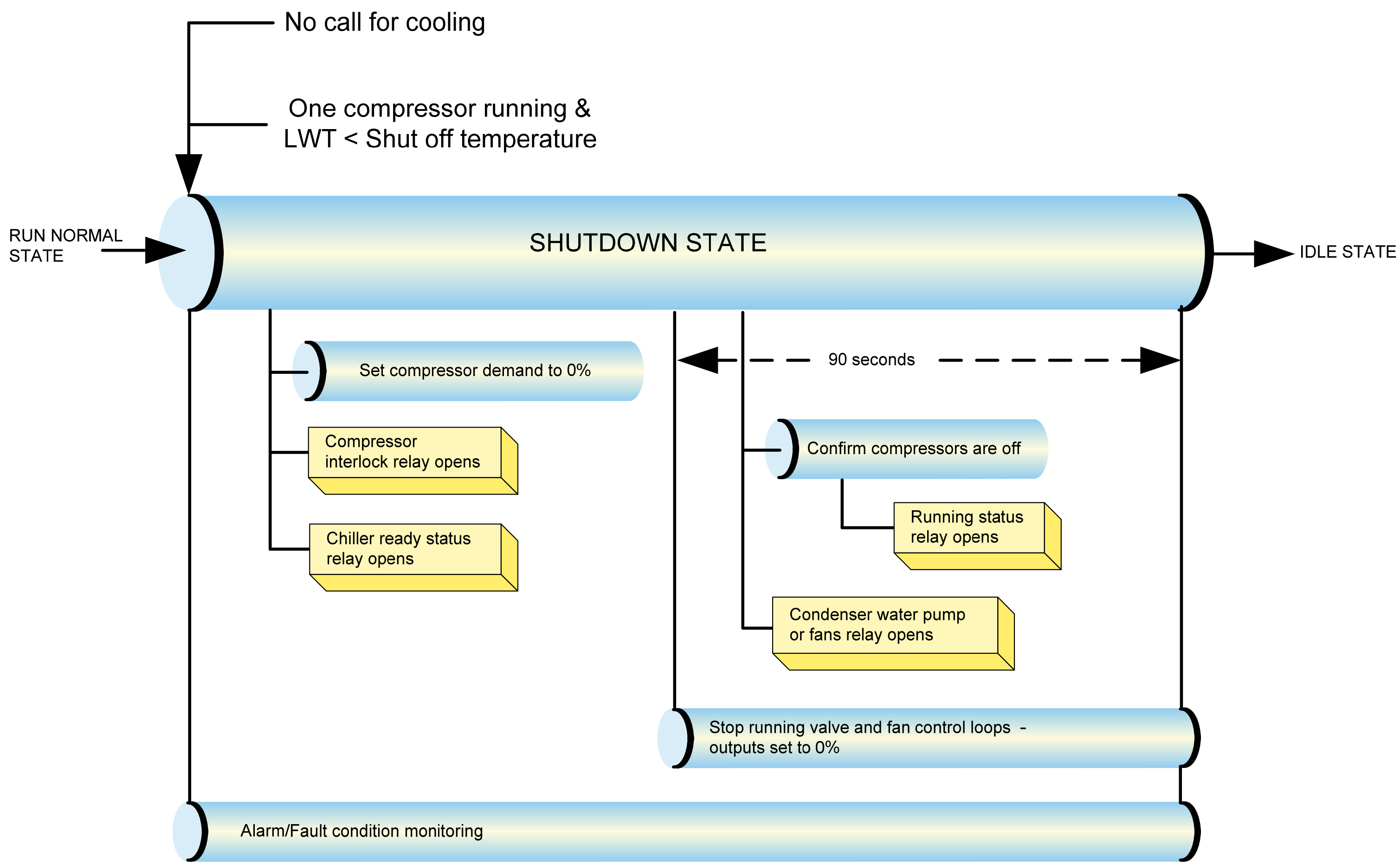
Chiller Sequence of operation: Temperature Pull down and normal running:



Chiller Sequence of operation: Running with an alarm limit (fault avoidance):



Chiller Sequence of operation: Normal shut down:



Chiller Sequence of operation: Abnormal shut down (fault present):