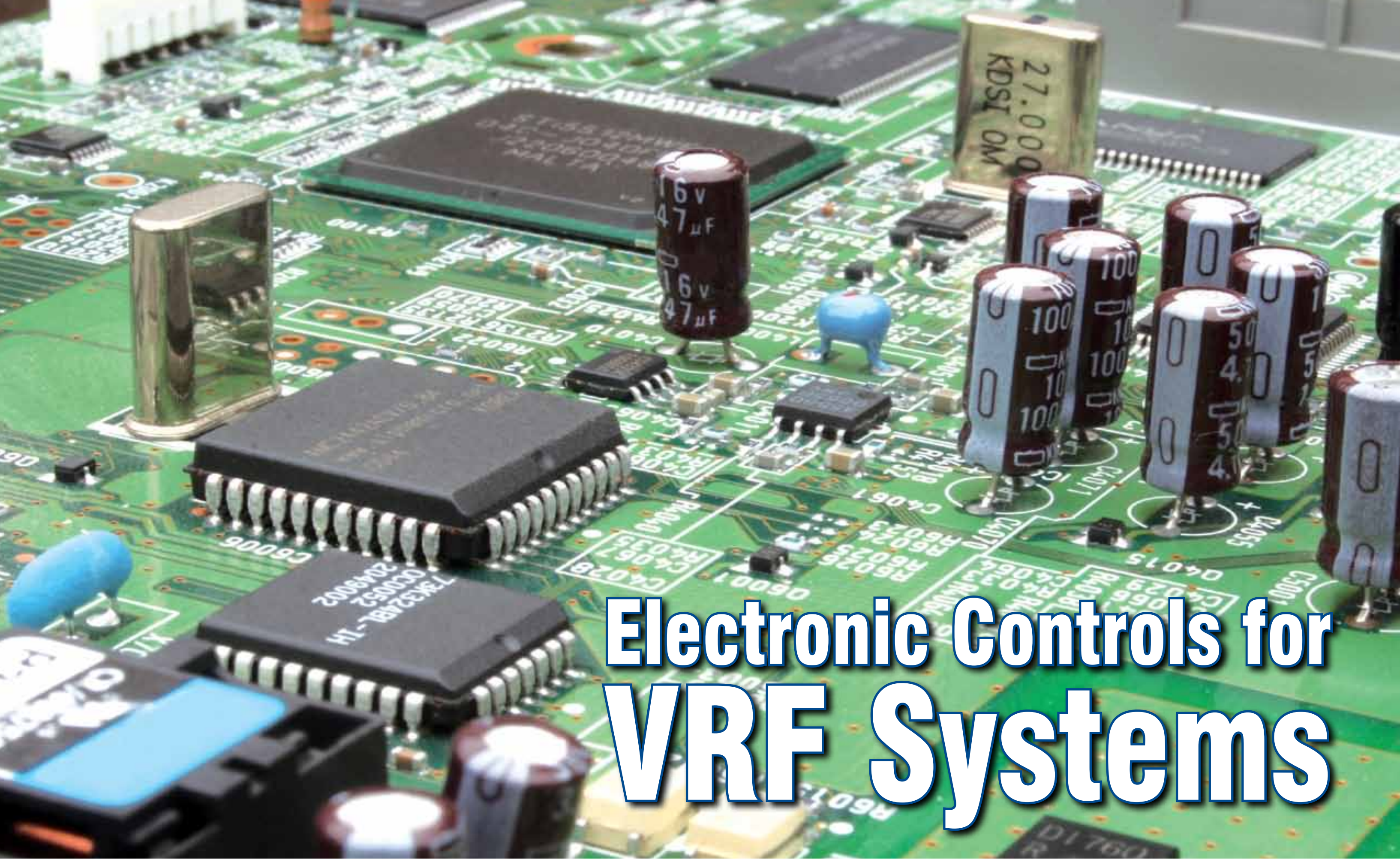


Electronic Controls for VRF Systems

By Arup Majumdar
Director Marketing
Emerson Climate Technologies Asia Pacific, Hong Kong

Part 3

The April-June 2008 and July-Sept. 2008 issues carried the first and second part of the series of articles on VRF systems, their evolution, advantages and details of the technology. This is the third part that covers the way the electronic controller works in a VRF system. The fourth article will focus on the challenges faced by designers when applying VRF for tall buildings. The fifth and final part will look at advances to the VRF technology and discuss leading technologies employed to improve system efficiencies and heating performance.

This is the 3rd article in the series explaining the VRF technologies. In the first article, I explained how the Copeland Scroll works and the principle behind the operation of the Digital Scroll technology. I concluded the article by explaining some of the key advantages of the Digital Scroll technology. In the second article, I provided a more detailed analysis and comparison between the DC inverter and Digital Scroll. I discussed the challenges of measuring the energy efficiency of VRF systems and talked about the advances that are happening on the Digital Scroll platform – namely, equipping the Digital Scroll compressor with enhanced vapor injection technology. In this article, I am going to explain how the electronic controller works in a

---

About the Author

Arup Majumdar has a B. Tech in mechanical engineering from the Indian Institute of Technology, Kanpur and an MBA from the Indian Institute of Management, Ahmedabad. Arup has been instrumental in introducing the Digital Scroll technology to multiple OEMs spread across Asia, Middle East, Europe and North America and establishing this technology as a strong alternate to the incumbent Japanese inverter. He has been awarded the Emerson Technology Award for his contribution to establishing this technology globally. Arup is a regular speaker on modulated technologies in various industrial forums globally and has written several technical articles on this topic.

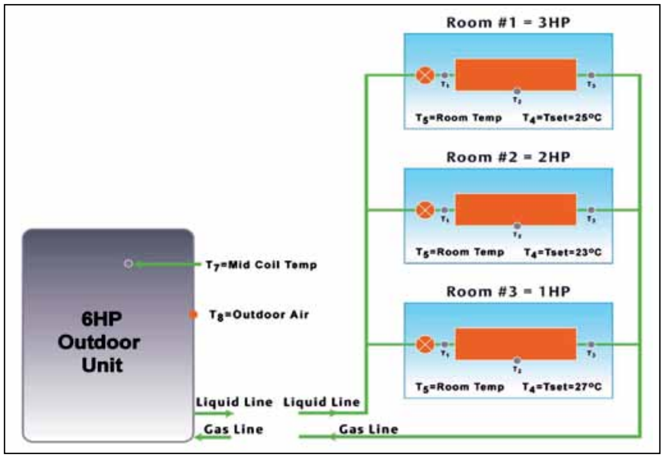


Chart 1: A/C system configuration

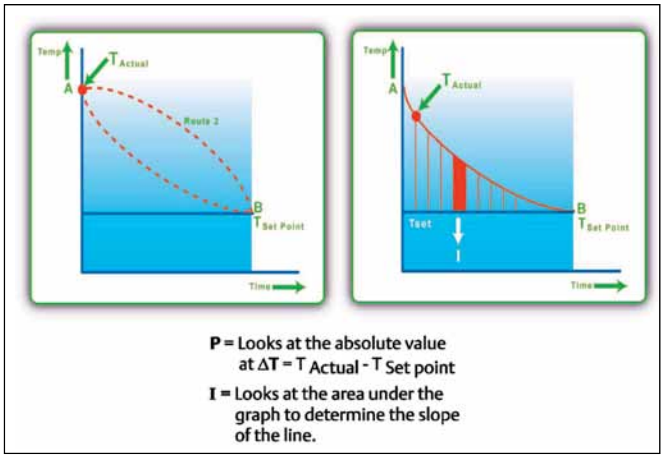


Chart 2: PI logic explanation

VRF system. System design engineers have always been confronted with a very complicated logic to drive the VRF systems due to the various parameters that need to be managed – so in this article, I will try to explain the control logic in very simple terms.

System and Application Configuration

We will use the following system configuration to explain the controller function (*Chart 1*): The system comprises one outdoor unit of 6HP with one Digital Scroll compressor and two outdoor fans of 2 speeds each, threessss indoor units of 3HP, 2HP and 1HP that are installed in three separate rooms. The system is cooling only as most systems sold in India are cooling only and we can keep the discussion simple by eliminating the 4 - way valve control and the defrost cycle etc.

Objective of the Controller

This configuration has three rooms and so there can potentially be three different room temperatures that are demanded by three separate end users. For example: the 3HP installed in the living room has a set point of 25°C, the bedroom #1 with 2HP has a set point of 23°C and the bedroom #2 with 1HP has a set point of 27°C.

The objective of the controller is to ensure that room temperatures are quickly pulled down from whatever levels they are at to the desired set temperature. Once the desired set temperature has been achieved, the controller has to ensure that the room is maintained precisely within a band of 0.5°C. All these temperature targets have to be achieved at the lowest possible energy consumption and so the controller has to ensure that the system pressures are maintained optimally at all operating conditions.

Measurement of System Parameters and Location of Sensors

In order to ensure optimal system performance, the system parameters have to be measured at various points in the system. Ideally, we would like to measure pressures and temperatures at various points in the refrigeration circuit. Measurement of temperature is easy, as it requires only a thermistor which is very cost effective. Measurement of pressure is more challenging and expensive as it needs pressure transducers. In this article, we will explain how the entire system parameters can be measured and controlled quite effectively by using thermistors only. That not only reduces the system cost but also makes the system simpler.

The sensor locations are shown in *Chart 1*. In each indoor unit, there are five sensors. Three sensors are mounted on the evaporator coil to measure refrigerant temperature. Sensor T1 is mounted at the coil inlet, sensor T2 is mounted at the coil middle and sensor T3 is mounted at the exit of the coil. Two sensors measure the air temperature. Sensor T4 measures the set point temperature that has been set by the user and sensor T5 measures the actual room temperature by sensing the return air temperature.

In the outdoor unit, there are three sensors. T6 is mounted on the compressor discharge tube to measure the discharge temperature. T7 is mounted on the outdoor coil middle to measure the condensing temperature and T8 measures the outdoor air temperature.

Step 1: Room Cooling Demand Calculation by PI Logic

The first step in the process is to determine the room cooling demand. As mentioned before, user #1 has set the room at 25°C, user #2 has set at 23°C and user #3 has set at 27°C. Let us assume that before the machines are turned on, the rooms are hot and all are at 30°C. Delta T is defined as:

ΔT = Actual room temperature – set point temperature

continued on page 86

continued from page 84

By this definition, ΔT (room #1) = 5°C, ΔT (room #2) = 7°C, ΔT (room #3) = 3°C. As mentioned earlier, the job of the controller is to reduce these deltas to zero as soon as possible.

Let us now introduce the concept of PI (proportional integral) logic. PI logic concept is shown in *Chart 2.*

The P part of the equation looks at the instantaneous ΔT and tries to determine the absolute delta that needs to be bridged. However to reach from point A to Point B, the temperature slope can either be Route 1 or Route 2 as shown in the left graph in *Chart 2*. If the room load is very heavy and there is not enough capacity, the drop in temperature can be slow and so the curve would look more convex from the bottom. However, if the room demand is light and there is a lot of capacity, the room can be pulled down to the set point temperature faster and the curve is more concave. The "I" part of the equation tries to capture this slope. So every 5 seconds, the thermistor tries to find the ΔT. Summation of the ΔT for each 5 seconds interval is done for 50 seconds and by the end of the 50 seconds, the summation of the previous 10 intervals of 5 seconds gives the area under the curve. So if the room temperature is falling slowly, the area under the curve is larger and if the room temperature is falling sharply, the area under the curve is smaller.

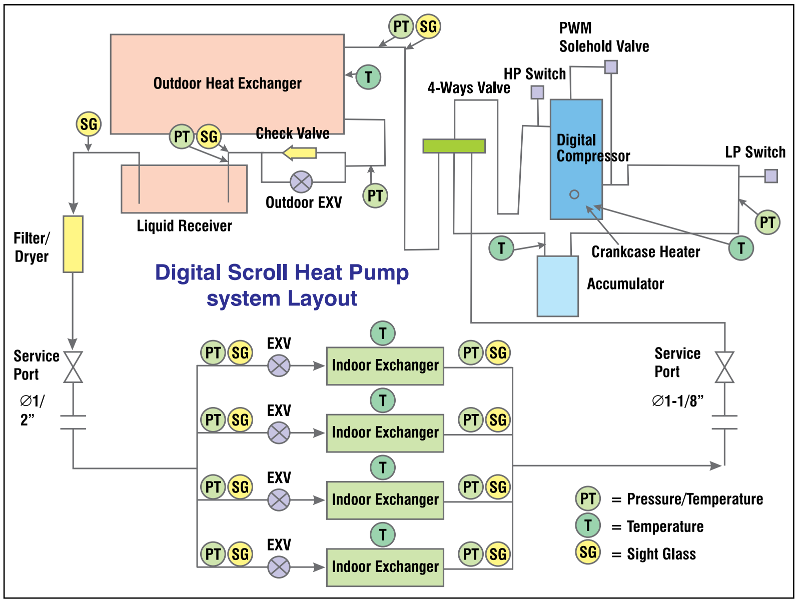


Chart 4: Mechanical architecture of A/C System

Adding the P and I component together (and knowing what is the indoor unit HP) provides the total demand that needs to be satisfied in each room.

Step 2: Summation of Cooling Demand

So at the end of 50 seconds, the main outdoor controller sums up the individual cooling demand from each of the three rooms and determines what is the total cooling capacity required to satisfy the aggregate demand. For this exercise, let us assume that the demand in room #1 is 2HP, the demand in room #2 is 1.5 HP and the demand in room #3 is 0.5HP

Total cooling capacity required = 2HP + 1.5HP + 0.5HP = 4HP

Step 3: Variable Compressor Capacity Determination

The outdoor controller then makes a calculation that the 6HP compressor has to deliver 4HP cooling capacity in total. That means that the Digital Scroll compressor has to modulate to 4HP/6HP = 66% of its full load capacity. As explained in the previous articles, the Digital Scroll works on the principle of loading and unloading of scrolls. A 66% capacity requirement, with a cycle time of 10 seconds translates to the following:

Loading time = 6.6 seconds, Unloading time = 3.4 seconds.

Once this is determined by the controller, for the first 6.6 seconds no signal is sent to the compressor solenoid valve (which ensures that the scrolls are engaged and the compressor is pumping to 100% capacity). In the next 3.4 seconds, a 220V signal is sent to the

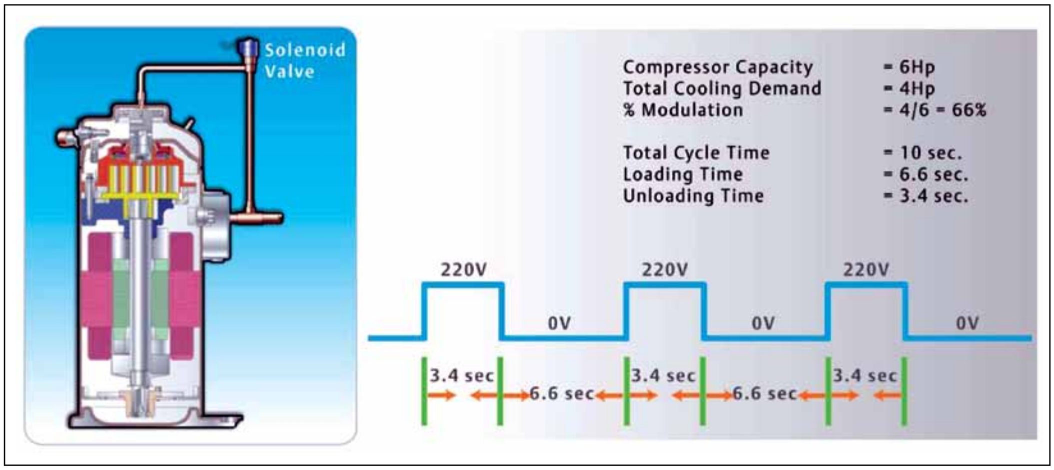


Chart 3: Loading & unloading of scrolls

continued on page 88

continued from page 86

solenoid valve that lifts the fixed scroll and stops the pumping/compression process in the compressor (0% capacity). This series of periods of full compression (6.6 seconds) and no compression (3.4 seconds) ensures that the compressor is delivering 66% capacity and this is enough to satisfy the aggregate room demand. This concept is shown in *Chart 3*.

Step 4: Refrigerant Distribution

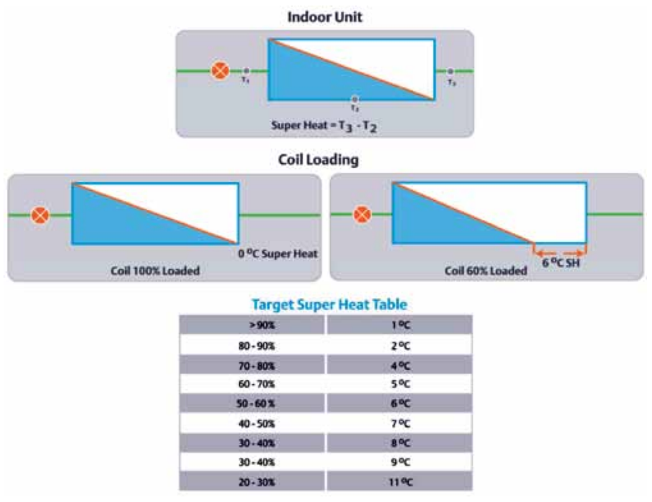
The next step of the process is how to distribute this 66% capacity (or 4HP) in the right proportion to each of the indoor units so that the room demand is accurately satisfied. While the compressor is delivering this 4HP capacity, there are pressure fluctuations that are happening in the condenser due to the periodic loading and unloading. However, the liquid receiver downstream of the condenser acts like a buffer tank and collects all the liquid that is coming out from the condenser. The presence of the liquid receiver ensures that the pressure downstream of the receiver is a constant value. This is important as we have to ensure that a constant stream of liquid is fed to the expansion device to prevent any electronic expansion valve malfunctioning and also eliminating hissing sound. *Chart 4* shows the typical heat pump layout and the location of the liquid receiver that ensures a steady stream of liquid refrigerant to the electronic expansion valve.

Once the liquid moves out of the receiver, the refrigerant distribution control to each indoor unit in the right amount is determined by the electronic expansion valve.

Step 5: Electronic Expansion Valve Operation

The expansion device in a VRF system is the Electronic Expansion Valve (EXV) and there is one such device in each indoor unit. Normally the EXV's are located in the indoor unit but there are some OEMs who have systems where the EXV's are located in a distribution box that is kept on the outside of the building. For this exercise, we will assume that the EXV is located in each of the indoor units.

The electronic expansion valve has a stepper motor and it typically has steps of upto 480. A 12V/24V signal has to be given to the stepper motor to make it turn and consequently open or close the opening of the expansion device. In a typical EXV, there are 480 steps. This means that to fully open the EXV, it has to be turned 480 steps. The closing specification is normally 60 steps +/– 30 steps. This means that the EXV can completely close anywhere between 30 and 90 steps. The speed of rotation of the stepper motor is typically 30 steps per second and this means that it takes about 16 seconds to ensure that the EXV is completely open.



Target Super Heat Table

>90%	1°C
80-90%	2°C
70-80%	4°C
60-70%	5°C
50-60%	6°C
40-50%	7°C
30-40%	8°C
30-40%	9°C
20-30%	11°C

Chart 5 : Superheat and coil loading

The next question is how does the EXV know how much to open or close in order to distribute the right amount of refrigerant to the three indoor units. This is done through superheat control and let me explain that in the following section.

Step 6: Superheat Calculation

In an indoor coil, the best way to measure superheat at the evaporator outlet is to put a pressure transducer at the coil outlet and measure the suction pressure and also use a thermistor to measure the suction temperature. From the suction pressure, the saturated suction temperature can be calculated and the superheat is:

Superheat = Actual outlet temperature – saturated suction temperature

At the outset, we said that we will only use thermistors in the system and not pressure transducers. The easiest and probably the most accurate way to measure superheat by only using thermistors is to put one thermistors at the center of the coil and one thermistor at the coil outlet. The thermistor at the mid coil is a good proxy for the saturated suction temperature. So for the case we are considering, the superheat in indoor unit 1 = T3 – T2. So anytime the controller wants to know the superheat in any of the three indoor units, it looks at the delta between the coil outlet temperature and the mid coil temperature.

So the question is: how does the EXV know how much superheat to control for each of the three indoor units and for that we need to look at what is the target superheat in each of the three rooms in this exercise.

continued on page 90

continued from page 88

Step 7: Indoor Unit Loading and Target Superheat

Let us first explain the principle of coil loading. If we take a 3HP evaporator coil, we can safely assume that it will deliver its full capacity of 3HP if there is enough refrigerant fed to the coil. To simplify the explanation, let us say that the coil is 100% loaded when the superheat is 0. Which means that to get 3HP out of this indoor unit, we would need only that much refrigerant fed to the coil, that would result in a zero degree superheat. It means that by the time the refrigerant is leaving the coil, it has just all turned to gas. *Chart* 5 explains this concept.

If we want to get less capacity from a 3HP coil, then we have to feed lesser amount of refrigerant to the evaporator and that would in turn increase the superheat. So we can make a table of Coil Loading versus superheat. *Chart* 5 shows an example of such a correlation. This chart shows that a 50% coil loading means that we have to ensure that the superheat is 7°C. And this is the concept of target superheat.

For the example of this case, the indoor coil loading are as follows:

Indoor #1 = 2HP/3HP = 66% loading
Indoor #2 = 1.5HP/2HP = 75% loading
Indoor #3 = 0.5HP/1HP = 50% loading

Each of these coil loadings translates to a target superheat. So the target superheat for each of these three indoor units are (refer *chart* 5)

Target superheat for Indoor unit #1 = 5°C
Target superheat for Indoor unit #2 = 4°C
Target superheat for indoor unit #3 = 7°C

Step 8: Expansion Valve Control

The controller looks at the actual superheat and also looks at the target superheat and then gives a signal to the EXV to close or open. In case the actual superheat is more than the target superheat, the EXV will open to divert more flow of refrigerant to that particular indoor unit and decrease the amount of superheat. In case the actual superheat is less than the target superheat, the EXV will close in order to choke the flow of refrigerant to that particular indoor unit so that the superheat can be increased. So the formula for expansion valve control is:

If actual superheat > target superheat, open EXV
If actual superheat < target superheat, close EXV

This opening and closing is done at the rate of 30 steps per second. When the system is started, there is a start up sequence for the EXVs. The EXVs all go in the closing direction for 16 seconds to ensure that the system knows the starting point of the EXV motor. And then the EXV moves to somewhere in between fully close and fully open – like 220 steps and the system is started up. At the end of every 50 seconds, a signal is sent to each of the EXV's to ensure that they are closing or opening to divert the right amount of refrigerant to each indoor unit to satisfy the room demand.

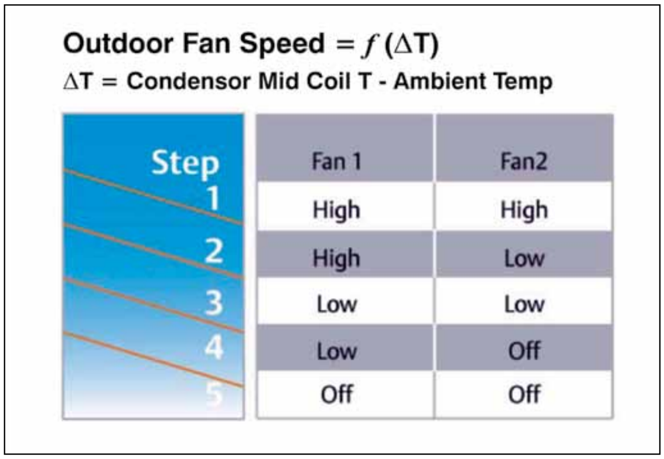
Step 9: System Optimization – Outdoor Unit Fan Control, etc.

The outdoor unit has two fan motors and they consume quite a lot of power. It is important to identify the conditions under which the fan speed can be reduced in order to save energy. The parameter to control is:

ΔT = Outdoor mid coil temperature (T7) – ambient temperature (T8)

Chart 6 shows the various speed zones that can be used in fan speed control.

As the ΔT starts increasing, the fan speed goes up and as the ΔT starts reducing the fan speed goes down. Since there are two fan motors with dual speeds, five combinations can be used for the combined fan speed output (shown in *Chart* 6)

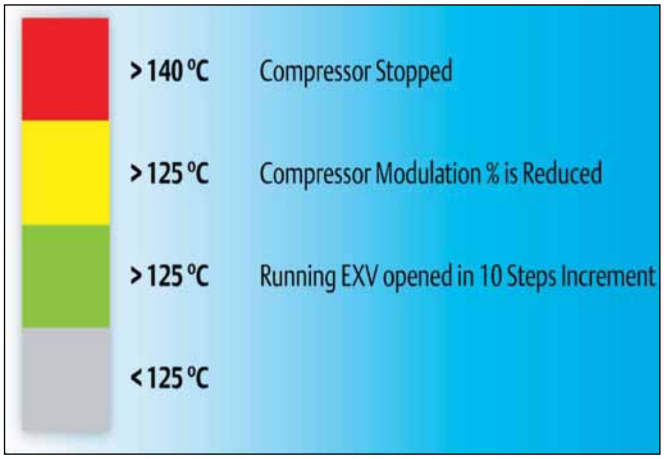


Outdoor Fan Speed = $f(\Delta T)$

ΔT = Condensor Mid Coil T - Ambient Temp

Step	Fan 1	Fan2
1	High	High
2	High	Low
3	Low	Low
4	Low	Off
5	Off	Off

Chart 6: Outdoor fan motor speed control



🟥	>140 °C	Compressor Stopped
🟨	>125 °C	Compressor Modulation % is Reduced
🟩	>125 °C	Running EXV opened in 10 Steps Increment
⬜	<125 °C	

Chart 7: Discharge temperature protection

continued on page 92

continued from page 90

When the system goes down on capacity, the condensing pressures start going down too and it is important to maintain a right differential pressure so that adequate flow velocity is maintained through the expansion device. When the load goes down, reducing the fan speed helps to push up the discharge pressure to a level that ensures optimal system performance.

Step 10: Safety Functions

Safety is a very important consideration in a multi evaporator VRF system. For this particular application, there is only one a/c unit that is serving the entire space and if this machine breaks down, the a/c for the entire space is shut down. So the objective of the control function is not only to protect the system from abnormal operation but also to ensure that the compressor and the system can be operated as long as possible (so that some a/c is provided) before it is shut down due to some malfunction.

There are several safety protections in a VRF system and here is a partial list of some important ones:

a. Low pressure protection
b. High pressure protection
c. Discharge temperature protection
d. Reverse rotation prevention
e. Loss of phase protection
f. Over current protection
g. Short cycling protection
h. Coil freeze protection
i. High ambient protection

In this article, we will explain one of the safety features in detail: Discharge temperature protection. In this protection scheme, there are four operating zones: safe, green, yellow red. For this case, we will take some representative temperature values to explain the concept as shown in *Chart 7*

Safe zone: Discharge temperature < 125°C

Green and Yellow zone: 125 < Discharge temperature < 140°C

Red zone: Discharge temperature > 140°C

Following is a typical example of how the controller can work:

Safe zone: temperature measurement is done every three seconds and as long as temperature is less than 125°C, no action is taken.

Green zone: > 125°C and sampling every two minutes. Open all running EXV by 10 steps and set counter to 1. After two minutes, open EXV by further 10 steps and set counter to 2. After ten minutes check counter and if > 2, then go to yellow zone.

Yellow zone: The sampling time is changed to ten minutes. The compressor modulation is reduced by 15% every ten minutes. If the compressor capacity goes below 10%, the compressor is stopped. If the temperature starts falling, the mode goes to the safe zone.

Red zone: The sampling time is now set at three seconds. If the temperature starts going up, the compressor is shut off.

As can be seen from the above logic (which is just a representative case), the objective is to run the compressor as long as possible and provide cooling as long as possible to the a/c space, without causing damage to the system.

Start Up and Shut Down Sequence

Since there are several control elements in a VRF system, there is a systematic procedure to start up and shut down a system. We will not go into the detailed technical sequence but some of the parameters that have to be adjusted during the start up process are: how much should the expansion valve open in each indoor unit, what is the time duration the compressor is off before it is turned on, what is the position of the indoor louvers, what is the sequence of indoor and outdoor fan speed etc.

Hardware: Master Slave Architecture

The indoor controller and outdoor controller form a "master-slave" control system architecture. Under this system architecture, the indoor unit controller only collects all information from user (e.g. set temperature, fan speed … etc) and environment (e.g. coil temperature, room temperature … etc) and aggregate this information to a specific indoor command format. This indoor command is then sent out to the outdoor unit controller via a dedicated communication link. The outdoor unit controller processes the data from the indoor unit, and determines the optimized operating condition of the indoor unit. Then the outdoor unit sends back an outdoor command to indoor unit. Finally, the indoor unit controller executes the outdoor command (e.g. open EXV, louver swing … etc) with its hardware.

Conclusion

The control algorithm for the VRF systems are complex and this article has only provided a simplistic overview of what exactly goes on in such a system. There are more variables that need to be controlled and this flexibility allows for better system optimization as well as enhanced protection to the system. The controller is key to efficient operation of the system and the system designer has to consider all the aspects of design simplicity and reliability in the controller design. ❖