Technical Note 155

Cooling tower controls with ACH580

Multi-cell operation with intelligent drive control

Cooling towers are an efficient method of rejecting heat for HVACR condenser loops. To save energy, fans installed in the cooling towers can be controlled from a variable frequency drive (VFD) rather than running full speed. With the ACH580 series of drives, the cooling tower operation can be integrated into the drive's control system using PID loops, digital and analog I/O points. As a further efficiency for multi-cell tower applications, the drive's Intelligent Pump Control (IPC) feature can be used for staging additional fans with system demand as well as rotating operation. While the IPC feature uses the word "pump" in its definition, IPC works great for multi-cell cooling towers. IPC is essentially intelligent drive process control where the drives communicate directly to each other without the need for a separate controller. For the sake of this technical note, one can consider the IPC to be Intelligent Process Control. This technical note will cover the wiring for cooling tower sensors input, command outputs, safety interlocks, the programming parameters for analog and digital I/O, internal process PIDs and the IPC feature.

Traditional open loop cooling tower designs would stage the cooling fan on and off as loop temperature feedback required more evaporative cooling through the tower media to meet the setpoint. Tower cells or fans would be sized to meet the full load capacity of the condenser loop on design day conditions. On most other days, the system would be oversized for rejecting heat from the condenser loop. Two or more smaller cells could be used to stage on one then another to meet the loop temp setpoint. Variable speed drives can now be used to control the fan speed of single or multi-cell tower to further reduce the energy required during partial load conditions.

With multiple independent drives and fans, there is also redundancy if one cell were to have a failure or need to be offline for maintenance. The ACH580's IPC provides features to program lead-lag operation for multiple drives and cell fans. IPC can also be set to limit or allow a set number of cell fans, up to a maximum of eight, to run in parallel depending on demand. Some or all drives can be the master or lead drive with the other set to be follower, lag or standby fans. Each drive set as master will share the PID information and settings to control connected fans. Rotation for the fans can be set to even runtime of the individual fans, balancing the wear for each cell, IPC settings allow for defined duration, scheduled rotation, or a maximum stationary time so the fan, motor and gearbox do not remain inactive.

In this example, the drives will be configured as a direct digital controller (DDC) for a multi-cell cooling tower. Integration with a Building Automation System (BAS) is also possible using optional fieldbus adapters but will not be covered in this paper. Programming will assume motor data has already been entered and first startup is complete. The following example uses North American (imperial) units though the drive supports global (SI) units as well.

Programming changes

For this application example, the parameters listed are changed from the drive's HVAC default values. To complete this programming, keypad menu navigation to the parameter groups is listed first followed by the parameter number, name and new value. The Primary Settings menu navigation is referenced for adjusting several other settings and text fields. Options are available to use the control panel and navigate to the parameter's menu. An advanced control panel with Bluetooth can link to the Drivetune mobile app available for download.

The recommended programming method will be the PC based software Drive Composer using a USB cable to connect with the drive's control panel. This software provides access to the Adaptive Programming described below. Downloads are available here for both the free Entry version and trial Pro version.

https://new.abb.com/drives/software-tools/drive-composer

Multi-cell open loop cooling tower

For the cooling tower represented in Figure 1, the drives will be setup for condenser loop supply or tower leaving water temperature control using *Process PIDs* (group 40, 41). When enabling IPC, the PID loop and analog input parameters will be synchronized to master drives to simplify programming and ensure they are consistent. Condenser loop return or tower entering temperature will be monitored for status. Outdoor air temperature and relative humidity will be used to monitor the outdoor conditions to enable basin heating *Supervision* (group 32). A basin water level sensor with high and low levels will be used to open the make-up water valve and alarm if below the low limit. A vibration switch will be wired as a safety start interlock.

Intelligent pump control (group 76) will be configured for 3 cells/fans and all capable of being master. Rotation will be based on *Even Wear*, which will enable the motor/drive with the lowest number of running hours to an adjustable amount of wear imbalance. This will help prevent any fan from sitting stationary too long causing potential mechanical issues. A schedule will be created with *Timed functions* (group 34) to enable rotation between the cells for use with IPC if that is preferred over even wear to control when the rotation occurs. Summer and winter seasons will be scheduled to switch setpoints and IPC operation.

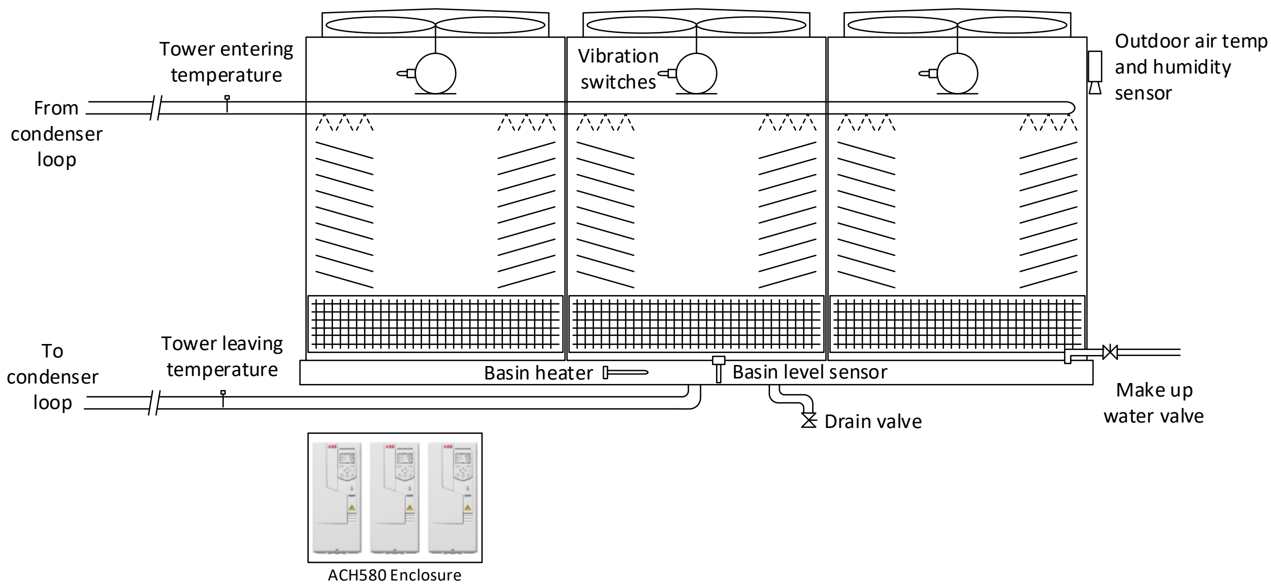
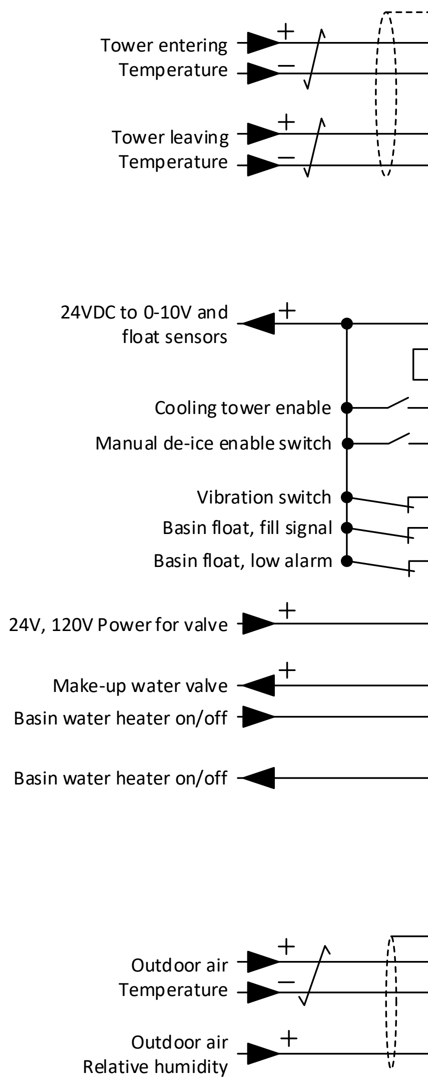


Figure 1: Flow diagram, multi-cell open loop cooling tower

Cooling tower wiring diagram

Figure 2 represents the wiring terminations on the drive for analog and digital I/O. The CAIO-01 extension module is installed to increase the drive's capacity for monitoring and controlling analog signals. The temperature ranges shown are for common immersion mounted temp sensors and outdoor air temperature/humidity sensors used for HVACR applications. Control power circuits will be run to the drive for RO1 to energize the make-up water valve. RO2 will enable a single phase or 3-phase contactor to power an electric basin heater.

While the drive is capable of reading temperature inputs of RTDs or thermistors, this example use sensors that output 0-10 V. For instructions to setup and scale an RTD input, refer to ABB Technical Note 153. This will allow for each drive to be a redundant master with IPC, sharing the sensor feedback for each drive. If you prefer sensors with 4-20 mA signals, it is recommended to use an analog signal splitter to share the sensor values to all drives for true redundant operation. Water level switch inputs and drive outputs to the make-up water valve and basin heater should be paralleled with relay contacts for redundancy.



X1	Reference voltage and analog inputs and outputs	
1	SCR	Signal cable shield (screen)
2	AI1	**Temperature Scaled, 0-10 V, 20-120 °F**
3	AGND	Analog input circuit common
4	+10V	Reference voltage 10 VDC
5	AI2	**Temperature Scaled, 0-10 V, 20-120 °F**
6	AGND	Analog input circuit common
7	AO1	Output frequency: 0-10 V
8	AO2	Motor current: 0-20 mA only
9	AGND	Analog output circuit common
X2 & X3	Aux voltage outputs and programmable digital inputs	
10	+24V	Aux voltate output +24 VDC, max 250 mA
11	DGND	Aux voltage output common
12	DCOM	Digital input common for all
13	DI1	**Stop (0) / Start (1)**
14	DI2	**Ext2 in2 source (Direction)**
15	DI3	Not used
16	DI4	**Start interlock 1 (1 - allow start)**
17	DI5	**RO1 - Basin float, fill command**
18	DI6	**External Event 1 - Warning, Basin Htr Disable**
X6, X7, X8	Relay Outputs	
19	RO1C	**RO1 source: DI5 (Basin float)**
20	RO1A	Not used
21	RO1B	**RO1 source: DI5 (Basin float)**
22	RO2C	**RO2 source: Supervisor 1 (water temp)**
23	RO2A	Not used
24	RO2B	**RO2 source: Supervisor 1 (water temp)**
25	RO3C	Not used
26	RO3A	Not used
27	RO3B	Not used
CAIO-01	Extension module programmable analog inputs and outputs	
80	SHD	Signal cable shield
81	AI3 +	**Temperature Scaled, 0-10 V, -40-140 °F**
82	AI3 -	Analog input circuit negative
83	SHD	Signal cable shield
84	AI4 +	**Humidity Scaled, 0-10 V, 0-100%**
85	AI4 -	Analog input circuit negative
86	SHD	Signal cable shield
87	AI5 +	Not used
88	AI5 -	Analog input circuit negative
90	SHD	Signal cable shield

* Valve actuators will require separate 24V power source from signal to not overload the 24V aux output of the control board

Figure 2: Wiring diagram for ACH580, multi-cell open loop cooling tower with IPC

Tower leaving water temperature control
To enable the tower control, default programming is when DI1 closes to start the drive. Alternatively, this enable can be over a communication network such as BACnet or left always enabled, allowing the tower fan to start as soon as the leaving temperature requires with PID loops and sensor feedback continuously monitored.

An immersion temperature sensor installed in the tower leaving water loop or basin will be setup in *Standard Analog Inputs*; scaled for output type and temperature range depending on your specific device. HVAC default programming is for AI2 to be used as feedback for *Process PID 1 and 2* to control the tower fan. As leaving water temperature increases above the setpoint, fan speed will increase to draw more air through the tower increasing the evaporative cooling. As feedback returns to setpoint the tower fan will slow down to maintain a minimum speed to meet setpoint. PID gains provided are starting values and will need to be adjusted during the commissioning process to verify the PID outputs can maintain desired loop temperature setpoint.

The *PID Sleep* function will allow the drive to stop the fan when feedback is below setpoint and fan speed has reached a minimum for an adjustable delay time when evaporative cooling is sufficient to meet loop heat rejection. Tower entering temperature will be setup for AI1 and can be used for monitoring or sending data to a BAS. A *Timed Function* will be used to start and end the winter season. This will be set to select between *Process PID 1 and 2* to adjust setpoints, deadbands, gains, or sleep/wake delays that vary between summer and may not be applicable during winter conditions. For more information on *Timed Functions*, refer to ABB Technical Note 156.

Menu > Parameters > Complete List > **12 Standard AI** *(tower leaving temperature)*

- 12.25 AI2 unit selection: V
- 12.29 AI2 scaled at AI2 min: 20.0
- 12.30 AI2 scaled at AI2 max: 120.0

Menu > Parameters > Complete List > **28 Frequency reference chain** *(PID speed control)*

- 28.11 Ext1 frequency ref1: PID
- 28.15 Ext2 frequency ref1: PID

Menu > Parameters > Complete List > **30 Limits**

- 30.13 Minimum frequency: 25.0 Hz *(adjust to manufactures requirements)*

Menu > Parameters > Complete List > **34 Timed functions** *(season schedule)*

- 34.10 Timed function enable: Enabled
- 34.11 Timer 1 configuration: Mon, Tues, Wed, Thurs, Fri, Sat, Sun, Season 1, Season 2, Season 3
- 34.12 Timer 1 start time: 00:00:00 *(midnight)*
- 34.13 Timer 1 duration: 01 00:00 *(1 day)*
- 34.60 Season 1 start date: 1.1 *(January 1st)*
- 34.61 Season 2 start date: 5.1 *(May 1st)*
- 34.62 Season 3 start date: 11.1 *(November 1st)*
- 34.100 Timed function 1: Enable Timer 1

Menu > Parameters > Complete List > **40 Process PID set 1** *(summer)*

- 40.07 Process PID operation mode: On
- 40.08 Set 1 feedback 1 source: AI2 scaled
- 40.16 Set 1 setpoint 1 source: Internal setpoint
- 40.19 Set 1 internal setpoint sel1: Selected
- 40.21 Set 1 internal setpoint 1: 85 °F
- 40.31 Set 1 deviation inversion: Inverted (Fbk – Ref)
- 40.32 Set 1 gain: 4.0
- 40.33 Set 1 integration time: 60.0 seconds
- 40.43 Set 1 sleep level: 25.0 Hz *(adjust to above min frequency, summer only)*
- 40.47 Set 1 wake-up deviation: -2.0 °F
- 40.57 PID set1/set2 selection: Timed function 1
- 40.79 Set 1 units: °F *(°C also available)*

Menu > Parameters > Complete List > **41 Process PID set 2** *(winter)*

- 41.08 Set 2 feedback 1 source: AI2 scaled
- 41.16 Set 2 setpoint 1 source: Internal setpoint
- 41.19 Set 2 internal setpoint sel1: Selected
- 41.21 Set 2 internal setpoint 1: 85 °F
- 41.31 Set 2 deviation inversion: Inverted (Fbk – Ref)
- 41.32 Set 2 gain: 4.0
- 41.33 Set 2 integration time: 60.0 seconds
- 41.36 Set 2 output min: 25.0 Hz
- 41.79 Set 2 units: °F *(°C also available)*

To access Drive name and Set time clock with Drive Composer, right click the drive in the left navigation tree and select System Information, see Figure 3. Setting the time will be used for the Timed Functions as well as time stamps in the event log.

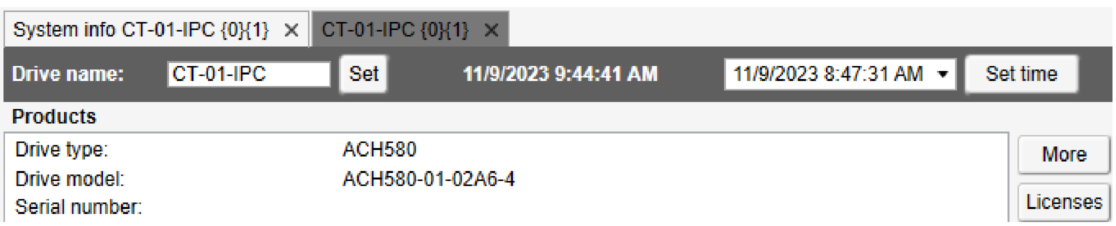


Figure 3: System information from Drive Composer

Make-up water and low level alarm

The make-up water valve can be directly controlled from a basin float, but in this example the drives will be set to monitor the status of a two level water sensor which can provide data on usage as well as alarm status to the operator or BAS. The sensor height will need to be adjusted such that when below the high level, the drive will open the make-up water valve. *External Event 1* will be used to provide a message on the control panel that the make-up valve is open. If the basin water level drops to the low level, *External Event 2* in the drive will provide another warning of low level, attention required, while still keeping the make-up water valve open. Editing the custom text fields is quicker with the Drivetune app or a Text Editor is available with Drive Composer Pro.

Menu > Parameters > Complete List > **10 Standard DI, RO**

- 10.24 RO1 source: Other > 10.01 DI status > DI5 (-1, inverted)

Menu > Parameters > Complete List > **31 Fault functions**

- 31.01 External event 1 source: Other > 10.01 DI status > DI5 (-1, inverted)
- 31.02 External event 1 type: Warning
- 31.03 External event 2 source: Other > 10.01 DI status > DI6 (-1, inverted)
- 31.04 External event 2 type: Warning

Menu > Primary settings > Advanced functions > External events > **External event 1**

- Label: Make-up water valve
- Instruction line 1: Valve open to fill basin

Menu > Primary settings > Advanced functions > External events > **External event 2**

- Label: Basin water level low
- Instruction line 1: Service required

Outdoor temperature, relative humidity

To monitor outdoor ambient conditions, the drive will read both outdoor air temperature as well as relative humidity. These values can be passed to a BAS then used to calculate either outdoor wet bulb temperature or enthalpy. We will also use these values in *Supervision* to determine when to enable the basin heater or could be used for motor pre-heating.

Menu > Parameters > Complete List > **15 I/O extension module**

Install CAIO-01 extension module then power up drive to auto-detect

- 15.59 AI3 scaled at AI3 min: -40.0 *(degree F)*
- 15.60 AI3 scaled at AI3 min: 140.0 *(degree F)*
- 15.69 AI4 scaled at AI4 min: 0.0 *(% humidity)*
- 15.70 AI4 scaled at AI4 max: 100.0 *(% humidity)*

Motor heating, control condensation

If continuous operation is not required or some cell fans may stage off, motors may collect condensation as the motor cools causing failures. Motor *Pre-heating* can be enabled to keep the motor warm and prevent condensation forming. This can be set to always activated so the pre-heating will enable as soon as the drive stops the motor. Another option would be to add an Adaptive Programming block to compare OA temp to setpoint and enabled the pre-heating input source. A *Supervisor* or *Timed Function* could also be set to activate pre-heating when required. The percentage of DC current used to heat the motor can also be define as current (amps) or kilowatts (kW).

Menu > Parameters > Complete List > **21 Start/stop mode**

- 21.14 Pre-heating input source: On
- 21.15 Pre-heating time delay: 60 seconds
- 21.16 Pre-heating current: 0%
- 21.35 Preheating power: 0.10 kW
- 21.35 Preheating unit: Power

For more information on motor pre-heating see ABB Technical Note 074: Motor heating.

Basin heating

As outdoor air temperature drops and if the tower is off for an extended period, perhaps overnight, water in the tower basin may begin to freeze. Basin water can be heated to maintain flow in the condenser loop until the tower entering temperature rises to prevent freezing in the tower. The drives will close a relay output to enable a basin heater when outdoor air temperature is below an adjustable setpoint and the basin water is not below the low level limit. The heater will remain enabled until the outdoor temperature rises above an upper setpoint, if the basin water level drops too low, or emptied after shutdown. To require both of these conditions, *Supervision 1* and a simple Adaptive Program will be used to enable the basin heater, see Figure 4.

Menu > Parameters > Complete List > **12 Standard AI** *(Tower entering temperature, monitoring)*

- 12.19 AI1 scaled at AI1 min: 20.0
- 12.20 AI1 scaled at AI1 max: 120.0

Menu > Parameters > Complete List > **32 Supervision**

- 32.05 Supervision 1 function: Low
- 32.07 Supervision 1 signal: Other = P.15.59 *(AI3 scaled)*
- 32.09 Supervision 1 low: 42.5 *(enable below 40 °F)*
- 32.11 Supervision 1 hysteresis: 5.0 *(disable above 45 °F)*

Menu > Parameters > Complete List > **96 System**

- 96.70 Disable adaptive program: No

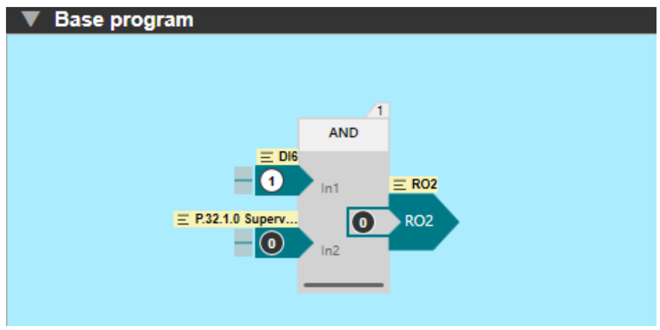


Figure 4: Basin heater enable output

De-icing with reverse fan direction

Keeping the tower water temperature above the wet-bulb freezing temperature with a basin heater may still be insufficient to prevent ice forming on the exterior of the tower, reducing air flow and allowing more ice to form. Using a drive to control the tower fan on each cell provides the opportunity to reverse the fan direction and move warm interior air of the tower out through the media to melt ice that has formed. IPC will use *Ext2 commands* so this source will be selected. The *Start interlock 1* text can also be set to indicate on the control panel the vibration switch has tripped if ice has formed on the fan blade.

Menu > Parameters > Complete List > **19 Operation mode**

- 19.11 Ext1/Ext2 selection: EXT2

Menu > Parameters > Complete List > **20 Start/stop/direction**

- 20.06 Ext2 commands: In1 Start; In2 Dir
- 20.08 Ext2 in1 source: DI1 *(tower enabled when closed)*
- 20.09 Ext2 in2 source: DI2 *(forward when open, reverse when closed)*
- 20.21 Direction: Request
- 20.42 Start interlock 1: DI4
- 20.47 Start interlock 1 text: Vibration trip

Intelligent Pump Control

With a multi-cell tower, energy usage can be reduced by staging on fans at lower speeds before ramping up one fan and then another. As an example, if each fan has a 10 HP motor and the system cooling required is down to 50%, Fan 1 runs at 60 Hz and Fan 2 runs at 30 Hz. This will require 100% of Fan 1 horsepower equal to 10 HP and 12.5% of Fan 2 horsepower equal to 1.25 HP, for a total of 11.25 HP. This is the cubed relation of fan speed to power from the Affinity Laws. Now, if all 3 fans are set to 30 Hz, the tower will still provide 50% cooling capacity and require 1.25 HP from each fan totaling only 3.75 HP.

IPC is a control feature available within the drive to manage a rotation and staging of multiple drives with varying demand. While labelled for pumping in the parameter names, this feature is suitable for cooling tower fans as well. This can tie together with the tower leaving temperature PID programmed above to stage on each cell at adjustable drive frequencies. With Adaptive Programming, IPC parameters will be adjusted depending on *Timer Function 1* for the summer and winter season, see Figure 5. For example, in summer the minimum number of motors allowed will be 1 so at low cooling demand, the fans can be staged off if less than minimum speed is needed. While in winter, all 3 fans will be required before all fans stop to ensure ice doesn't form on one or more cells.

For more information on IPC, see the ACH580 firmware manual or this configuration (application) guide:
[ABB Intelligent Pump Control (IPC) configuration guide]

Menu > Parameters > Complete List > **76 Multipump configuration**

- 76.21 Multipump configuration: IPC
- 76.25 Number of motors: 3
- 76.26 Min number of motors allowed: 1
- 76.27 Max number of motors allowed: 3
- 76.30 Start point 1: 26.0 Hz
- 76.31 Start point 2: 26.0 Hz
- 76.41 Stop point 1: 25.0 Hz
- 76.42 Stop point 2: 25.0 Hz
- 76.55 Start delay: 10 seconds
- 76.56 Stop delay: 10 seconds
- 76.70 PFC autochange: Even wear
- 76.72 Maximum wear imbalance: 24 hour
- 76.101 IPC parameter synchronization: Enabled

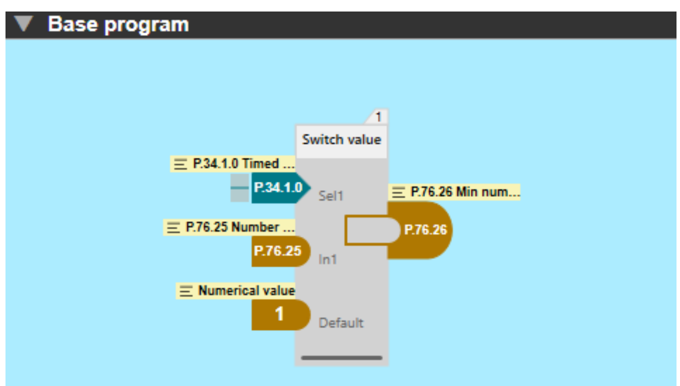


Figure 5: IPC min number of fans adjusted for summer/winter season

If the cooling tower sizing is such that one or more cells will be followers, used for standby or backup operation, IPC provides the option to rotate the master and follower drives on an adjustable *Even wear* interval for each motor. Master drives will synchronize the PID settings regularly to ensure if a drive fails or is temporarily offline, the next master will continue to run without interruption. *Even wear* has been set to 24 hours so that any fan having a greater difference in runtime from the other fans will become the master and run if only one fan is required. If the end-user prefers a scheduled rotation for observation or maintenance, these parameter changes can be made to setup that scheduling.

Menu > Parameters > Complete List > **34 Timed functions** *(Scheduled rotation)*

- 34.10 Timed function enable: Enabled
- 34.14 Timer 2 configuration: Tues, Season 1-4
- 34.15 Timer 1 start time: 09:00:00
- 34.16 Timer 1 duration: 00 00:01
- 34.101 Timed function 2: Enable Timer 2

Menu > Parameters > Complete List > **76 Multipump configuration**

- 70.70 PFC autochange: Timed Function 2

Conclusion

To simplify the integration of cooling towers into HVACR condenser loops, the controls sensors, outputs and programming can be packaged within the tower itself. The ACH580 series of drives with several extension modules allow the Direct Digital Control (DDC) to be part of the tower fan variable frequency drive. Integration with Building Automation Systems can be as simple as communication cabling instead of field installed control components and commissioning. Implementing multi-cell towers with functions such as IPC further increases potential energy savings.