Automated Fault Detection and Diagnostics (AFDD) for RTUs

BETTER BUILDINGS ALLIANCE

Overview

Packaged rooftop units (RTUs) provide heating, ventilation and air conditioning in 2.1 million commercial buildings, serving over 60% of the commercial building floor space in the U.S. RTUs consume over 2.6 quads of energy annually, and even a small improvement in efficiency can lead to significant reductions of energy consumption and carbon emissions.

An important component of improving RTU efficiency and maintaining persistence of operation is through automated fault detection and diagnostics (AFDD), which can be deployed in conjunction with advanced control packages to reduce energy consumption.

What is AFDD?

Advanced RTU controls provide significant improvement in RTU part-load energy efficiency. A field study jointly funded by the U.S. Department of Energy (DOE) and Bonneville Power Administration completed in FY12 showed an average electricity reduction of 57%. However, just deploying advance controls does not ensure persistence of operations. To ensure persistence, there is a need for AFDD.

Typically, RTU diagnostics on both the air-side and refrigerant-side have been deployed offline by collecting data from the RTUs that are integrated to a building automation system or using a retrofit package. However this method is costly, and of limited use as most RTUs do not install all necessary sensors. Both advanced RTU controls and AFDD are integrated on a single controller, allowing an integrated solution to be easily programmed into the controller with very little incremental cost increase.

In 2014, DOE funded Pacific Northwest National Laboratory (PNNL) to develop and integrate AFDD methods for both air-side and refrigerant-side fault detection and diagnostics with one of the leading advanced RTU controllers sold in the market today. The work also included testing and validating the integrated solution in the field. The field demonstrations showed reliable fault diagnostics on the air-side, though additional hurdles must be overcome to effectively deploy refrigerant-side diagnostics.

External view of the Kent, WA office where five RTUs were used to validate and test the embedded diagnostic algorithms.

AFDD with Advanced RTU Controls Field Test Results	
Installation and Maintenance	Air-side and refrigerant-side AFDD was successfully integrated with advanced RTU controllers. All sensors (except the mixed-air temperature sensor) required to conduct air-side AFDD are available on the RTU controller, meaning the cost to add air-side diagnostics is minimal. However, additional sensors are needed for refrigerant-side diagnostics, and locating these sensors in the correct location to measure the parameters turned out to be a challenge.
Overall Performance	Air-side diagnostics ran as anticipated, and successfully drew attention to problems with sensors, outdoor air flow, and others in the test RTUs. Refrigerant-side faults were artificially introduced into test RTUs, and the AFDD algorithms successfully identified charge and condenser-fouling faults.

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Diagnostics

Seven air-side AFDD algorithms were developed, deployed and tested on the advanced RTU controller for detecting and diagnosing faults with RTU economizer and ventilation operations using sensors that are commonly installed for advanced control purposes. The algorithms utilize rules derived from engineering principles of proper and improper RTU operations:

- Compare discharge-air temperatures with mixed-air temperatures for consistency
- Check if the outdoor-air damper is modulating
- Detect RTU sensor faults (outdoor-air, mixed-air and return-air temperature sensors)
- Detect if the RTU is not economizing when it should
- Detect if the RTU is economizing when it should not
- Detect if the RTU is using excess outdoor air
- Detect if the RTU is bringing in insufficient ventilation air.

In addition to the air-side diagnostics, refrigerant-side diagnostics were also deployed on the advanced RTU controller. These included: 1) low and high refrigerant charge, 2) condenser fouling and 3) liquid line restriction. Both the air-side diagnostics and the refrigerant-side diagnostics were validated by comparing the outputs from the embedded diagnostics with the output generated by offline analysis.

Testing and Validation

The refrigerant-side testing was conducted on five RTUs at an office building in Kent, WA and on four RTUs at a grocery store in Phoenix, AZ. The air-side diagnostics were tested on the same five RTUs in Kent, WA and 2 RTUs on a retail store in Seattle, WA. The field tests were conducted in the summer of 2014 (June through September).

The monitoring plan consisted of collection of data (both raw sensor and diagnostic output) at each RTU at 1-minute intervals, storing it locally on the controller on the roof, and streaming the data in real-time to the Cloud for further analysis. The cellular network was used to upload data from each site to the Cloud.

On both the air-side and the refrigerant side, the AFDD algorithms were successfully integrated with the advanced RTU controllers, operated as expected and successfully diagnosed faults.

Results

The project has shown that air-side and refrigerant-side AFDD can be easily integrated with advanced RTU controllers. With the exception of the mixed-air temperature sensor, all other sensors required to conduct the airside AFDD are readily available on the RTU controller because they are needed for the advanced control operations. Therefore, the incremental cost of adding air-side diagnostics is minimal.

Although integration of refrigerant-side diagnostics on to the RTU controller is possible as shown in this project, there are a number of additional sensors that are needed to deploy the refrigerant-side diagnostics. In addition to the cost of these sensors, locating the sensors in the correct location to measure the parameters turned out to be a challenge. Because temperature sensors were being used as proxies (to estimate pressure indirectly) for pressure measurements, mounting these sensors in the right location is critical; otherwise, the uncertainty in the measurement will be high. Accommodating additional sensors also means either increasing the input/output capability of the advanced RTU controller or adding another controller to handle the additional sensors, which increase the cost of deployment significantly.

Learn More

Learn more and view the full RTU Embedded Diagnostics: Automated Fault Detection and Diagnostics Development, Field Testing and Validation report at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23790.pdf. Many of the algorithms can be downloaded from https://github.com/VOLTTRON/volttron/tree/2.x/Agents/PassiveAFDD.

To take advantage of other advanced RTU technologies, join the Advanced RTU Campaign (ARC). ARC is an initiative supported by the DOE that encourages commercial building owners and operators to replace their old RTUs with more efficient units or to retrofit their RTUs with advanced controls.