Off-Grid Electrical Cabinet Dehumidifier

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I. Introduction

A. Objective

THE utility Ameren Illinois is interested in reducing corrosion, specifically on spare electrical cabinets in isolated areas. These cabinets are not in climate controlled environments, and they do not have access to a low voltage power supply. The central need is to have an off grid, autonomous system that regulates the environment of these cabinets to prevent corrosion on exposed electrical terminals. Ameren has begun acquiring parts for this project: two solar panels, a micro wind turbine, batteries, an electrical heater, and a hygrometer. The system set up is in need of efficiency and system control optimization.

Our goal is to improve the system in three ways: efficiency, reliability, and transparency. For efficiency, we plan to accomplish this through designing a better charging process, specifically switching from Pulse Width Modulation (PWM) to a Maximum Power Point Tracking (MPPT) process. The idea is to adjust the input voltage (from the solar panels) to the DC-DC converter to match the battery's charging capability (which in turn increases current) to maximize the wattage. For the reliability of the system, we propose adding a dehumidifier and the necessary control logic that will trade off with the heater to best regulate the relative humidity. Finally, with regard to transparency, we want to take the locally available hygrometer (and thermometer which we plan to add) data and transmit it while periodically recording humidity and temperature.

B. Background

Electrical cabinets are an inherent part of any substation, and they are prone to corrosion. Specifically, oxide corrosion, or rust, is an electrochemical reaction that occurs when water is exposed to certain kinds of metal [1]. Most metals can experience surface corrosion at humidities above 80%[7]. This commonplace process puts a heavy financial burden on electrical utilities. A study done by the National Association of Corrosion Engineers estimated that in 2013, utilities spent nearly $27.7 billion due to corrosion related maintenance [2]. The process of corrosion is accelerated by humid conditions, when water can more easily condense on electrical equipment. Preventing corrosion is important from both a financial and reliability standpoint, as the Electrical Power Research Institute of the United States estimates that "more than half of all unplanned power outages are due to corrosion" [2]. Therefore, preventing corrosion is a worthwhile endeavor, even on these spares.

Electric heaters prevent corrosion by decreasing the relative humidity, meaning that the air can hold more moisture without condensing. However, their ability to do this is hampered at higher temperatures in the summer when hot, humid air can't be effectively made hotter. Therefore, the incorporation of a dehumidifying system that exchanges control with the heater is necessary to be able to take moisture out of the air at higher temperatures.

The PWM process is a standard way to charge batteries. However, it's efficiency at higher wattage is not nearly as high as the MPPT. The Assam Don Bosco University found that for a higher wattage system above 200W, the MPPT was 30% more efficient than PWM [3]. The set up that Ameren proposes will have a 600W capacity, making the switch to MPPT to conserve power even more desirable. This is especially relevant during the winter months when the average solar panel wattage over a day is much lower.

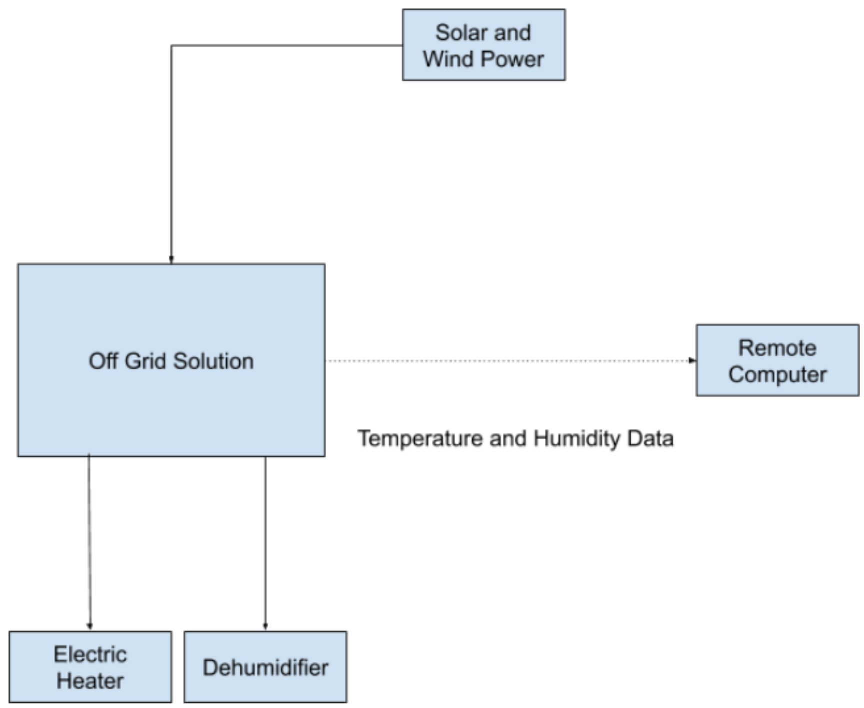

Fig. 1: Physical Design Diagram

C. *High-Level Requirements List*

- The electric heater must keep all condensation off of exposed electrical terminals for at least a 5 day period (ideally indefinitely), keeping humidity below 80%.

- The battery must have the capacity to run the dehumidifier and electric heater each for three hours a day for two days to account for a hypothetical situation of no wind and no sun for two days. This is 1350Wh or 112.5Ah on a 12v battery.

- Obtain, store, and communicate temperature and humidity data both inside and outside of the cabinet to within 3 significant figures to Ameren once per hour.

II. Design

A. *Block Diagram*

This system should capture more than 2500Wh of energy on average daily assuming a 17% turbine and 22% solar capacity factors. Even with minimal losses throughout the system, that will provide enough energy to meet our requirements for running the corrosion protection system. The dehumidifier and electric resistive heater when working in tandem will then be able to keep humidity levels at or below our listed standards. It will also capture enough data for the end user to know how well the system is working.

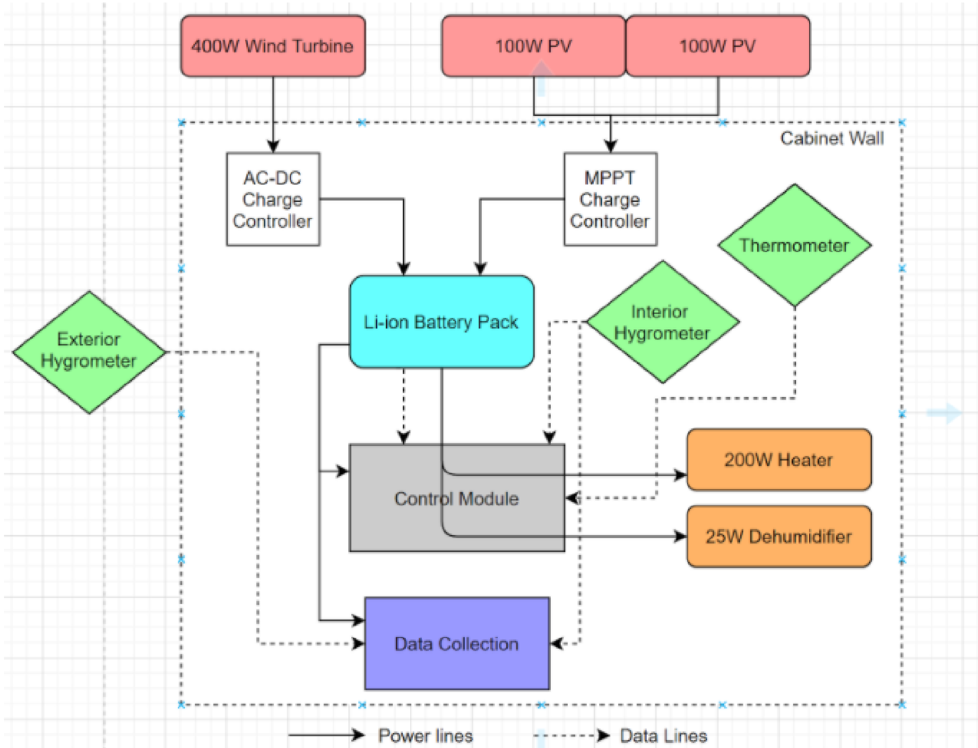

Fig. 2: High Level Diagram

B. Functional Overview

Wind Turbine

A 400W wind turbine should run at about 17% capacity in this area and will add energy to the system the most at nighttime, as that is when average wind speeds peak (source: ECE 333). This should cover a large portion of the system's energy needs, especially at crucial times when the solar panels do not. Hence the health and lifetime of the battery should be improved. Its electric power will run through a rectifier circuit and charge controller (same piece of equipment) to level off the voltage ripple and charge the battery packs with a steady DC current.

Solar PV

The photovoltaic panels will likely provide the most constant baseline power to the system with a total 200W at a predicted 22% average capacity. Its charge controller will be DC-DC, but we plan on maximizing the energy transfer efficiency by implementing a Maximum Power Point Tracker circuit to keep the panels running at the optimum position. This type of controller automatically adjusts the voltage level of the panels to maximize the IV characteristics and therefore power output.

Li-Ion Battery Pack

This battery pack must be compact enough to fit in the excess cabinet space along with the rest of our system electronics. Yet, it must store enough energy to keep the system running through nights without wind and days without sun. For that reason we believe a battery pack made from lithium ion cells is necessary. Lithium ion is the most energy dense and readily available form of storage we have.

Climate Sensors

The interior hygrometer is what actually controls the running of the dehumidifying system (whether it be the heater or miniature dehumidifier). It measures relative humidity of the air inside the cabinet, which is the main factor in determining how much the exposed Ameren electric equipment terminals will be corroding. This information is transferred to the control module indicating when the heater or dehumidifier need to be turned on or off.

The exterior hygrometer is present purely for data recording purposes. It will essentially measure the success our system has at lowering the humidity around the sensitive equipment by providing the outdoor reference.

The temperature sensor is another input into the control module which dictates whether the system will run the dehumidifier or the heater. If the temperature is below approximately 6°, the dehumidifier risks freezing around the coils, and therefore must be shut off.

Control Module

This is by far the most complex component of the system and will require the bulk of our attention. The high level requirements of this module are to take in climate data from inside the cabinet and decide whether to turn on the heater, dehumidifier, or both. It also then must be given switching control abilities somewhere in the power lines from the battery pack to the loads. We may also have to incorporate additional control to ensure that the battery is never completely depleted.

Data Collection

This block's purpose is to communicate how well our system is working to the user. It will record both outside and inside humidities and temperatures and store them on-device to be read on site or sent via RF to the nearest available Ameren site for data collection.

C. Block Requirements

Sensing Subsystem: Exterior hygrometer, Interior hygrometer, Thermometer

The interior hygrometer is necessary to trigger a reduction in relative humidity, that is, when it measures a humidity of 80% or greater. This works in conjunction with the thermometer to decide whether to turn on the heater if the temperature is below 60° or the dehumidifier if it is above that temperature. The exterior hygrometer is important to use for comparative purposes, to ensure the solution we design is working effectively compared to an outside environment.

Requirements

- The two hygrometers and thermometer must run at 12V (to connect to the battery) or else without their measurements relative humidity will not be lowered.
- The hygrometers must have precision within 1% and the thermometer within 1° to ensure dehumidifying or heating occurs when required.
- The hygrometers and thermometer must be able to continuously export data for use in the control module and data capture device.

Power Subsystem: 400W Wind Turbine, 2 100W PV, AC-DC Charge Controller, MPPT Charge Controller, Li-on Battery Pack.

This whole subsystem is necessary if this is to be an off-grid solution. The turbine and solar panels provide power at times when natural sunlight and wind are present, and the charge controllers convert that power into a steady form which is usable to run the system and charge the battery. The battery is necessary to store power and release it when necessary.

Requirements

- The two charge controllers must be able to output 12V for charging the battery.
- The battery must have the capacity to run the dehumidifier and electric heater each for three hours a day for two days to account for a hypothetical situation of no wind and no sun for two days. This is 1350Wh or 112.5Ah on a 12v battery (Ameren already has a 12V 170Ah lithium-ion-phosphate battery).

Control Module Subsystem: State Machine

This is the computer which will direct every part of the system and be the interface between power releasing from the battery and the components which do the desired task.

Requirements

- Turns on dehumidifier when there is enough battery power and the temperature is at least 60°F, the humidity is above 80%, and the battery has enough power (10v)
- Turns on heater when the temperature is less than 60°F, the humidity is above 80%, and the battery has enough

power (10v)

While the requirements are simple, this will likely be the most difficult part of the project. Our initial idea is a finite state machine that works in a manner presented by figure 3. However, it will likely become significantly more complicated as we work out physical and computational bugs in the system.

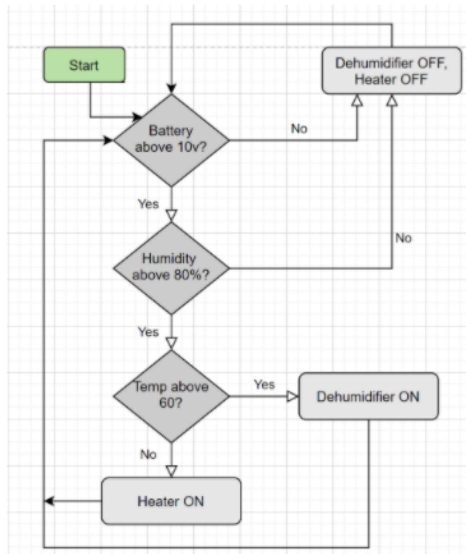

Fig. 3: Control Module Flow Chart

Relative Humidity Reduction Subsystem: 200W Electric Heater, 25W Dehumidifier
These devices provide the main functionality of this project. The electric heater and dehumidifier are intended to prevent exposed metal terminals from condensating and therefore corroding. This is done either by removing moisture from the air or raising the internal temperature of cabinet which reduces relative humidity.
<u>Requirements</u>
- Heater must produce at or near 200W of thermal heat
- Dehumidifier must reduce humidity in small space (380ft3)
- The dehumidifier must be installed such that it automatically drains condensed water, without the need of a person to empty it.

Data Communication Subsystem
This module is intended to communicate data to Ameren that shows how safe their equipment is. We have decided to do this by presenting them with the inside and outside relative humidities of the cabinet. This both lets them know that the interior is not corroding (or when it may be at risk for it) and when the system is or isn't working properly.
<u>Requirements</u>
- Interior and exterior hygrometer data is recorded
- Temperature data is recorded
- An Ameren coworker has the ability to read this data with relative ease.

D. Risk Analysis

The battery pack is the most likely to fail. The size and cost constraints make it difficult to get a large enough battery. Also if the battery does last many charge-discharge cycles without causing system failure, it will be damaging to the lithium material and reduce its energy capacity for future cycles. As with all batteries, eventually this will

cause system failure. Our goal is to stretch its lifetime as long as possible.
We believe we are tackling this by incorporating a battery voltage requirement before any devices are admitted to be turned on. This will occasionally cause the system to not function as intended, but we believe the added lifespan of the battery pack and the system as a whole is worth it.

III. Ethics and Safety

One of the principal ethical considerations in our project is the necessity to remain transparent with Ameren of the product that is being developed and delivered. To be in accordance with section 1.3 of the ACM Code of Ethics [5] as well as section 7.8.3 of the IEEE Code of Ethics [4], the specifications and capabilities of our project must be accurately stated. Failure to communicate product specifications accurately and precisely may result in severe consequences such as water-induced corrosion hindering functionality of electrical equipment.

Further, the intention of this product is to be used on spare electrical cabinets that may serve as a backup for maintaining components vital to the operation of critical infrastructure related to public safety. As such, the need to communicate the product clearly becomes relevant to section 7.8.1 and section 7.8.9 of the IEEE Code of Ethics where "the safety, health, and welfare of the public" becomes "paramount" [4] as well as section 1.2 of the ACM code of ethics [5]. Misrepresentation of the product due to poor communication and presentation may therefore present a public safety risk.

A lithium ion battery pack was chosen as it is generally the safest, most reliable, and widely available source of energy storage that meets the energy density requirements needed for our project [6]. However, any usage of a rechargeable lithium ion battery pack may serve as a source of potential hazard. Especially considering the remote conditions of the intended usage of our product, maintenance and repair may not be feasible in an expeditious manner given the event of unexpected failure in the lithium ion battery. For the above reasons, our project seeks to maximize the efficiency and lifetime of the battery.

The usage of remote transmission of data may serve as a serious source of ethical concern. Any computing device that transmits data wirelessly may be subject to malicious cyber attacks. In the event of this product being used to maintain spare equipment for critical infrastructure, a malicious cyber attack may have catastrophic consequences. In accordance with section 7.8.1 and 7.8.9 of the IEEE Code of Ethics [4] and section 2.9 of the ACM Code of Ethics [5], any system which is responsible for the remote transmission of data will be kept discrete from systems concerning the functionality of the product.

IV. References

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