Power Demand Response System

Team 21 - Antonio Martinez and William Widjaja
TA: Evan Widloski

1. Introduction

1.1 Objective

Stability of the grid is an increasingly difficult problem with the introduction of renewable energy sources. From a 2018 study on consumer energy management, 68% (up 3% from 2016) of residential consumers are very concerned about climate change and their carbon footprints while 7 in 10 businesses say their customers are demanding that a certain percentage of their electricity comes from renewable sources (up 9 points from 2017) [1]. It is clear that there is a growing demand by both consumers and businesses for an increase in renewable energy sources. The problem is that these renewable energy sources, wind and solar, are not stable and hard to predict in terms of energy output. Each new source creates another point which must be balanced against the demand. Therefore, a system of energy management must be put in place in order to maintain balance. Traditionally, energy is balanced from the perspective of the utility company. However, it is possible to balance the grid strictly from the demand side while still having monetary incentivisation.

Implementing demand response systems requires significant coordination of a large number of varying loads drawing power from the same grid. By developing a centralized means of communicating to loads on the grid, a utility company could make the consumer side demand more predictable, lowering the total capacity required and passing the economic benefit on to the consumers who participate. We aim to develop this communication system to vary the effective duty cycle of several loads on the grid and coordinate the demand to reduce the peak load.

1.2 Background

In 2015, the California Public Utilities Commission ordered its state's investor-owned utilities to adopt time-of-use (TOU) rates by 2019 [2]. This method of energy management has consumers being charged more during peak demand hours and rewards consumers who limit their energy during said hours. This alleviates some of the stress put on the power grid, but it also creates expensive pricing. It is still up for debate how beneficial this TOU method is compared to other ways of managing power consumption such as tier-rates where consumers pay prices dependent on how their

usage compares to overall average usage. These methods all share a dependance on the consumer to consciously and actively manage their own consumption.
Instead, with our functioning communication system, consumers may one day be able to opt-in to have their utilities be effectively controlled from the demand side.

1.3 High-level requirements

- Signal successfully sends across grid (from power source) to appliance.
- Signal decodes properly at appliance.
- Each additional appliance gets correct duty cycle signal, and power is altered properly at the load.

2. Design

Each successful load connected to our system depends on three separable sub-systems. These are the supply site scheduling, the communication module and the demand site controller.

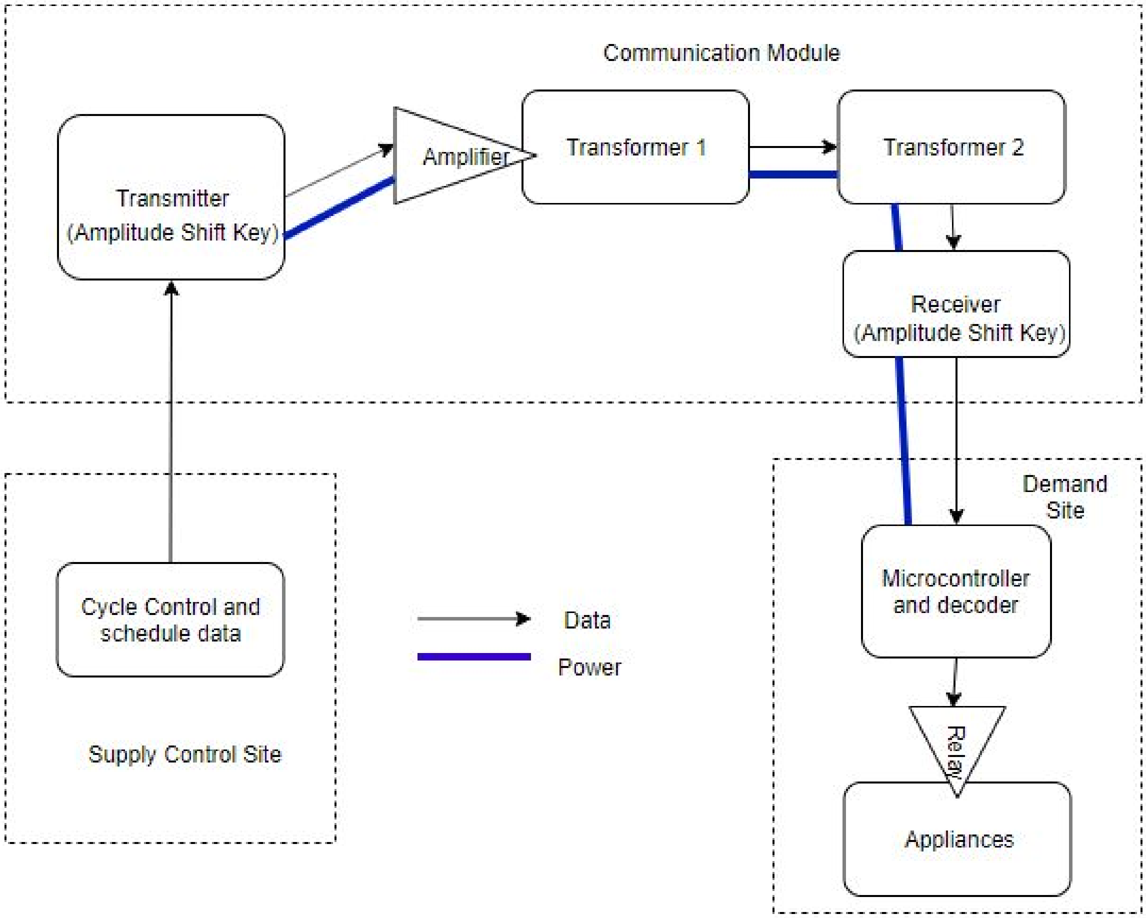

Figure 1. Block Diagram

Functional Overview

2.1 Supply Control: The initial control is a series of signals which will eventually control all loads on the grid. It also ensures there is enough power on the grid for the sum of all cycles it governs.

2.2 Communication Module: This module will send signals across the power line from utility line to load devices.

2.2.1 Transmitter: The transmitter will contain an amplifier and oscillator which sends an amplitude shifted data signal, S, onto the power line on a carrier signal. As its name suggests, it moves the data from the utility substation onto the grid.

2.2.2 Transformers: The two transformers act as a coupling circuit which converts the energy of the carrier signal from transmitter to receiver. This is a pipe for the data.

2.2.3 Amplitude-shift keying (ASK): This algorithm changes the amplitude of a carrier wave to represent digital data. The logical "1" is represented by sending a carrier wave with a constant frequency and constant amplitude for a "bit duration" which could be any amount of time T (in seconds). If a signal value is 1, then we transmit the carrier signal. Else, default to transmitting a value of 0. The frequency and phase values of the carrier remain constant throughout.

- Each amplitude will encode the same number of bits in T seconds.
- We then decide what each of the bits mean for the controller at the receiver end.
- The clocks are synchronized across the whole system and govern the measurement of T and the transmission record.

2.3 Demand Site:

2.3.1 Receiver: A receiver filters the signal through a series of high frequency and IR filters.

2.3.2 Microcontroller: This uses the ASK to convert the signal, then opens or closes the relay for the load.

2.4 Block Requirements:

2.4.1 Cycle Control: A software function which must correctly output the available power and the current duty cycle schedule of all loads as some data type like an array, map or list.

2.4.2 Transmitter (and ASK): Must send a signal which does encode information using a type of wave modulation. Tentatively, a 2-bit signal with a bit duration T = 4 seconds should be readable from the transmitter.

2.4.3 Amplifier: Must produce gain of 20 V/V or greater without clipping.

2.4.4 Transformers: Must not have energy losses that exceed 30% from transmitter to receiver if probed with an oscilloscope. (Or if the energy loss is greater, increase amplification proportionally at the amplifier within reason).

2.4.5 Receiver (and ASK): Must decode the information from the transmitter correctly, at least in an ideal situation where the transmitted signal is perfect/directly in communication with the transmitter. For example, if 1011 is transmitted, 1011 should be received.

2.4.6 Microcontroller at appliance: Must store correct bit representations as intended by transmitter/receiver and properly control the relay switch with those signals.

2.4.7 Relay: Must respond to a signal with no more than 5 s delay.

2.4.8 Other: All signals made by the system must be under 500 kHz by U.S. law. No radio waves in free space if unshielded wiring is used.

2.5 Risk Analysis:

Because our communication system is designed to send information from distant power sources to the devices they are powering, we must keep in mind the propagation of higher frequency signals across a power line. For this reason, we must look into appropriate frequencies to send information. Another potential issue deals with our signal processing; amplitude shift keying is vulnerable to the same things as amplitude modulation, including atmospheric noise and distortion. Our biggest challenges will come from the sending and gathering of information.

3. Ethics and Safety

Due to the nature of our project as a communication system, there is a need for proper security of the information being sent. Our project is designed to eventually help dictate the usage of compliant consumers, so it is our responsibility to come up with a secure method of sending data and be transparent with our understanding of how secure the system is. In compliance to the IEEE Code of Ethics and the ACM Code of Ethics and Professional Conduct [3][4], we will hold the security and safety of users paramount in our development of this project to exemplify the specific codes 1.1,1.3, 1.6, and 1.7. Note that we do not restrict ourselves to these only these codes but are stating that these codes are more relevant to the nature of our project. We do not foresee any ethical dilemmas created by our project. The system is intended to be used by consumers properly educated of what our communication system does and how it is intended to control their consumption. It will not be marketed or sold to consumers who would suffer compromises to their health from the rate limited use of electricity, such as a person on hospice.

Lastly, we will be careful to follow all lab procedures described by the ECE 445 guidelines and will not hesitate to ask questions or express concerns to faculty and classmates during the process of building this project. As partners, we will hold each other accountable to follow all codes of ethics especially in holding high standards of competence, conduct, and ethical practice, knowing and respecting existing rules pertaining to laws in the power and communications industry, and assisting each other during this project development, and to support each other in following these codes.

References

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