INDUSTRIAL DEMAND MANAGEMENT SYSTEM

case study of a coal mine

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The Premise

- Demand-Side Management is the idea of strategically controlling the customer's electrical loads in order to reduce its maximum electrical power demand (measured in kilowatts). This results in significant economic savings for the customer.

- Ideally, this should be done without reducing facility productivity in any way resulting in a win-win situation.

Incentive

- Power bill consists of two primary Charges:
  - Kilowatt-hour (kWh) energy charge: based on the total energy usage for the month
  - Demand charge: based on maximum power draw during the month

kWh Energy Charge
\+ Demand Charge
= Monthly Power Bill

Incentive

- This system focuses on reducing the demand charge of the bill, which is often over half of the total monthly power bill for large industrial customers
- Energy providers also benefit from demand management because they don't have to allocate as much resources to the customer if their demand is lowered

Demand Charge Calculation

- Energy usage for the customer is averaged and stored over every 15-minute period; this is multiplied by 4 to arrive at demand value for that particular time period
  - [kW*hr] / 0.25[hr] = kW
- The demand charge is arrived at by multiplying the highest power demand value in a month by the *Demand Rate*

Potential Savings

- The facility in question has a demand rate of $7.72/kW

- If demand can be lowered by average of 1500 kW per month (10% of total):
  - 1500 * 7.72 = **$11,580.00** per month, or
  - 11,580 * 12 = **$138,960.00** per year

Background of the Coal Mine

- The Montana coal mine for which this system is developed has a total load of about 15000 kW

- Most of the load (80%) is large inductive (motor) loads

Background of the Coal Mine

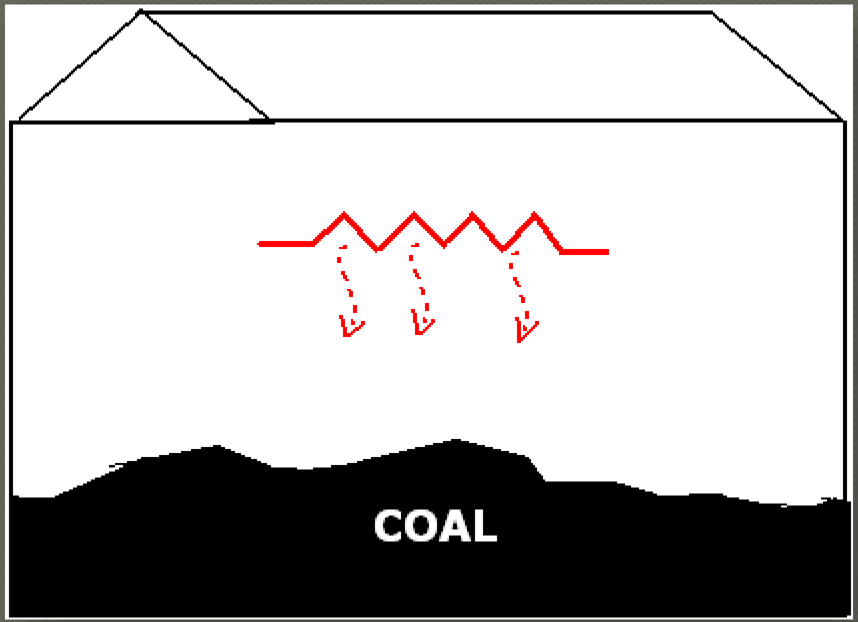
- Inductive loads:
  - Conveyors
  - Draglines
  - Electric shovels

Background of the Coal Mine

- Heat Loads: Resistive
  - Electric heat accounts for approximately 3000kW (20%) of coal mine's load

Background of the Coal Mine

- Electric Heat
  - Large coal storage facilities require heating in order to keep coal and water pipes from freezing in cold weather

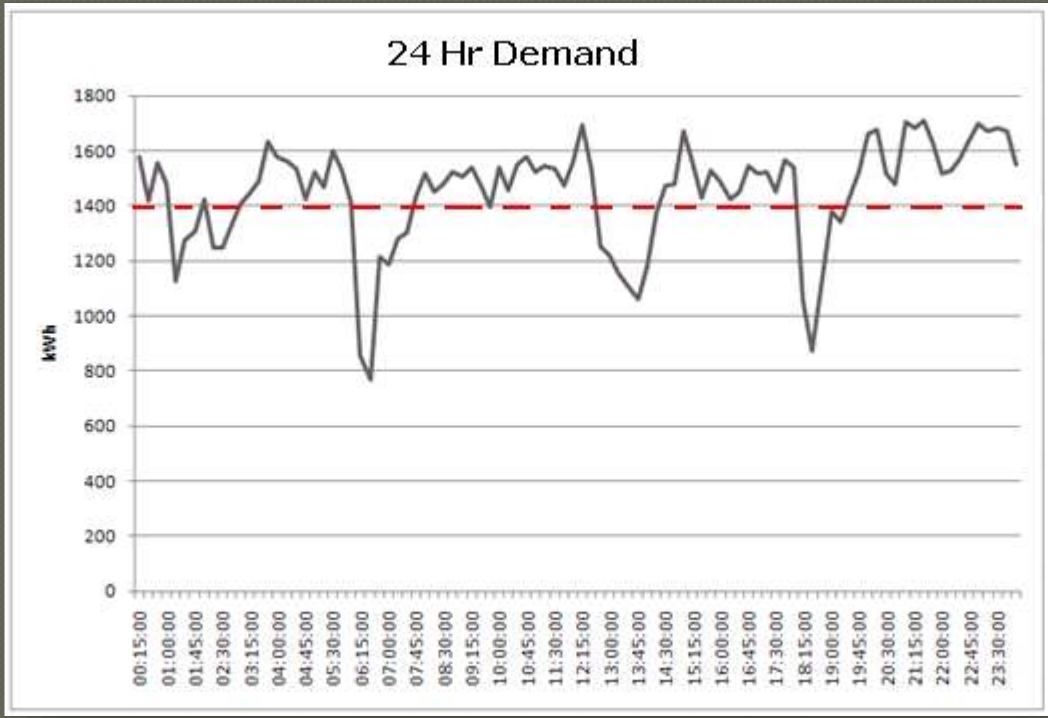


Coal Mine Demand Control

- Electric motors must be free to turn on and off as they are needed
- Heat loads, however, can be controlled to run during periods of low demand to bring temperature up and turned off during high demand; the large thermal mass of the air will keep the temperature at an acceptable level until it can be powered back on

Coal Mine Demand Control

- Typical daily demand curve and target value (red)

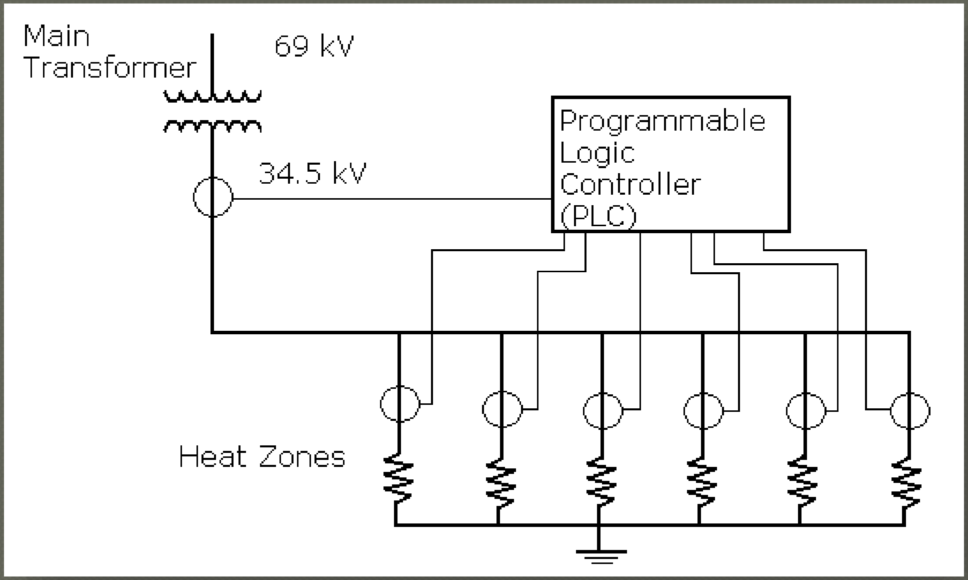


Coal Mine Demand Control

- Coal mine has 5 major heat zones
  - Storage buildings
  - Truck wash facility
  - Crusher buildings
- Each zone can be closely controlled individually

Coal Mine Demand Control

- The power is constantly monitored by a power meter at the main transformer and input to the PLC
- Heat loads are controlled by PLC



Coal Mine Demand Control

- Active power is monitored at the transformer
- If power increases beyond a preset peak demand threshold, heat loads begin to shed in a particular sequence
- Heat load is then ramped back on if total power usage reduces below demand threshold

Coal Mine Demand Control

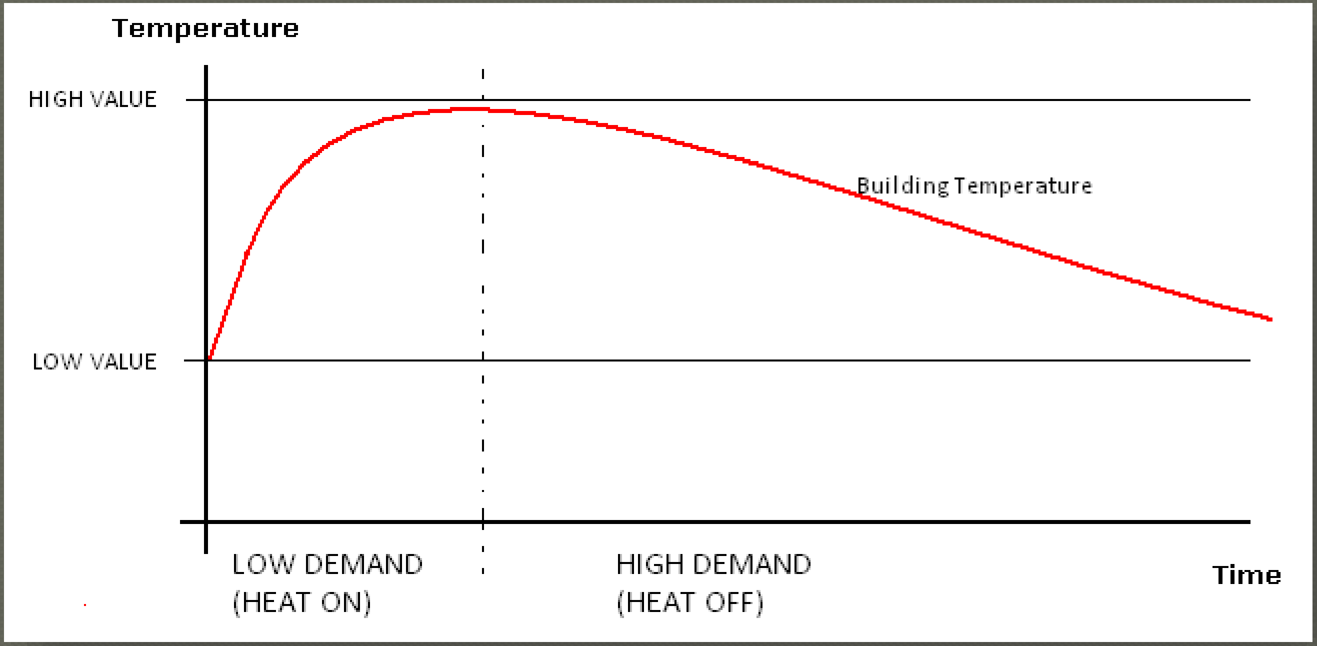
- Temperature is constantly monitored by the PLC
- If temperature falls to a critical value (within 5 degrees of 50 deg F) heat must be powered on and peak demand threshold will be increased to allow buildings to stay within temperature range
- This allows temperature maintenance to take precedence over demand reduction

Coal Mine Demand Control

- Heat loads have two important thermostat limits: low value and high value
- Low value for off state: switches loads back on if approached
- High value for on state: should be higher than normal to allow extra thermal mass to form and increase cooling times (i.e. allow buildings to heat as much as possible during low demand)

Coal Mine Demand Control

Temperature Behavior under demand management



Coal Mine Demand Control

State Table

State 1= All On
State 21 = All Off

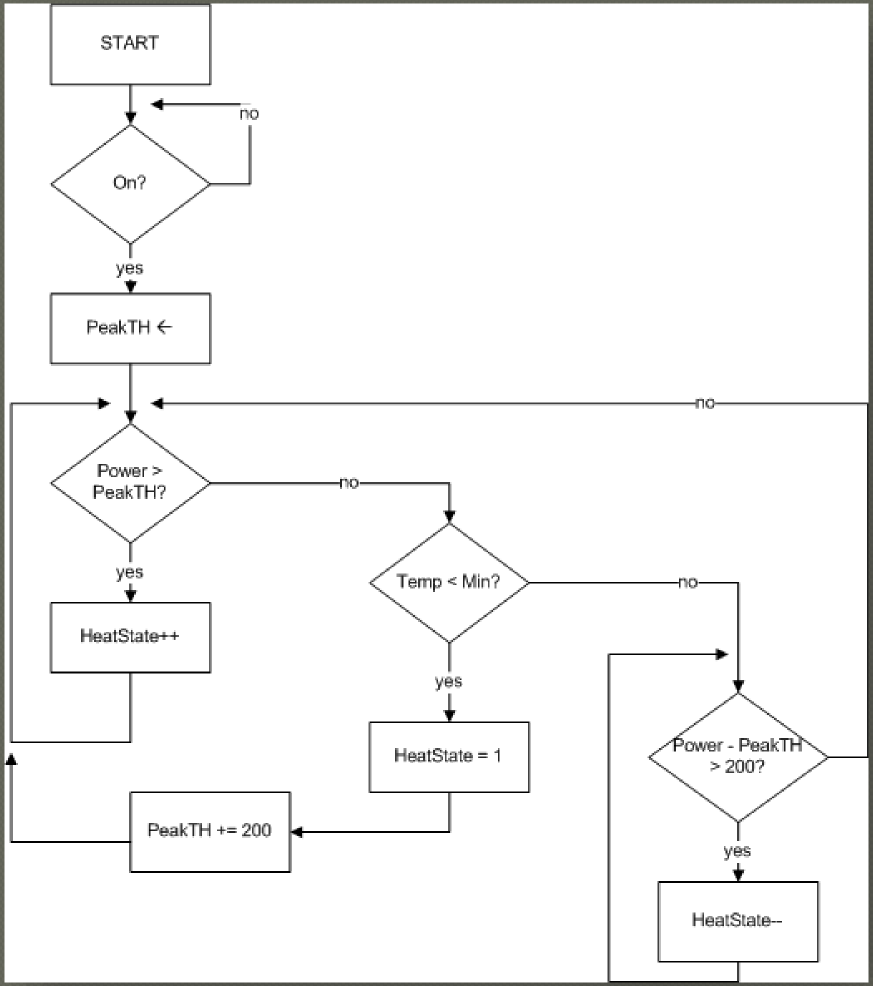
Reduced by ¼ steps

Should be ordered such that the highest priority areas are switched last

	1	2	3	4	5	Total Pwr [kW]
1	1	1	1	1	1	2987
2	1	1	1	1	0.75	2818.25
3	1	1	1	0.75	0.75	2649.5
4	1	1	0.75	0.75	0.75	2470.25
5	1	0.75	0.75	0.75	0.75	2320.25
6	0.75	0.75	0.75	0.75	0.75	2240.25
7	0.75	0.75	0.75	0.75	0.5	2071.5
8	0.75	0.75	0.75	0.5	0.5	1902.75
9	0.75	0.75	0.5	0.5	0.5	1723.5
10	0.75	0.5	0.5	0.5	0.5	1573.5
11	0.5	0.5	0.5	0.5	0.5	1493.5
12	0.5	0.5	0.5	0.5	0.25	1324.75
13	0.5	0.5	0.5	0.25	0.25	1156
14	0.5	0.5	0.25	0.25	0.25	976.75
15	0.5	0.25	0.25	0.25	0.25	826.75
16	0.25	0.25	0.25	0.25	0.25	746.75
17	0.25	0.25	0.25	0.25	0	578
18	0.25	0.25	0.25	0	0	409.25
19	0.25	0.25	0	0	0	230
20	0.25	0	0	0	0	80
21	0	0	0	0	0	0

Coal Mine Demand Control

System Flow Chart



Demand Management Modeling

- In order to model the system described, I designed and built a scaled down system based on the coal mine (scale 10^5:1)
  - Similar load characteristics
  - Switches loads based on power usage

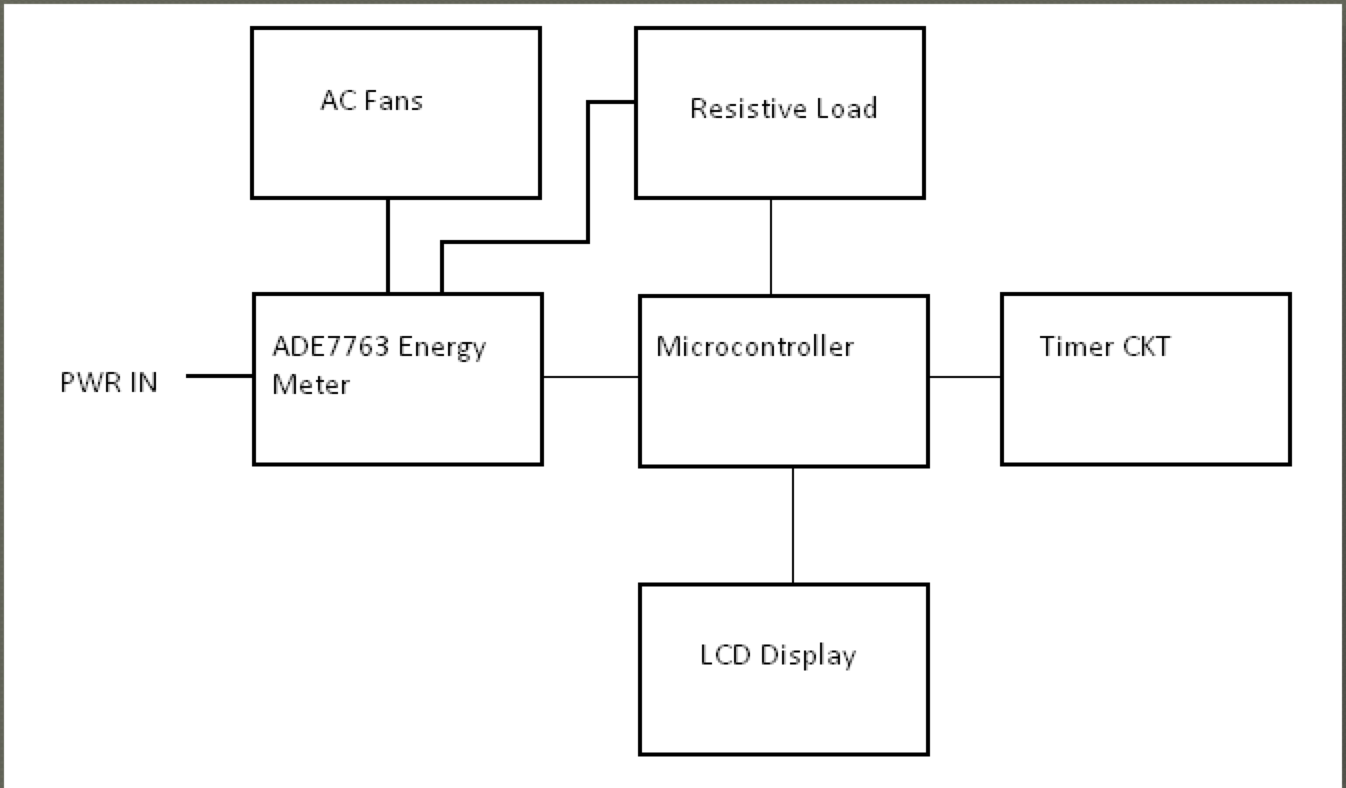
Demand Management Modeling

- Total = 135 Watts
- 110 Watts (~80%) Inductive load
  - AC fans

- 25 Watts (~20%) Resistive load (heat)
  - Power resistors
  - 4.5 Watts each

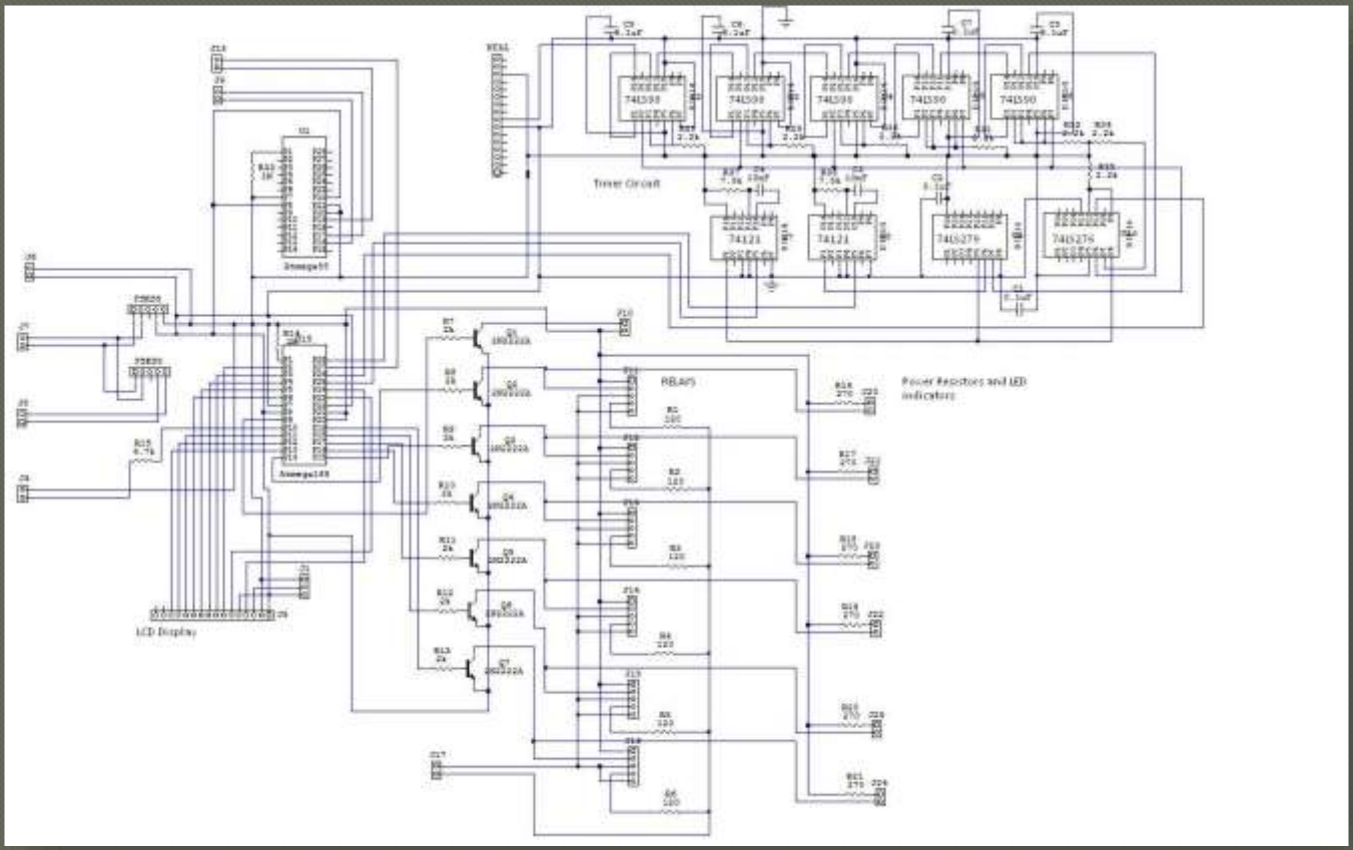
Demand Management Modeling

- Block Diagram



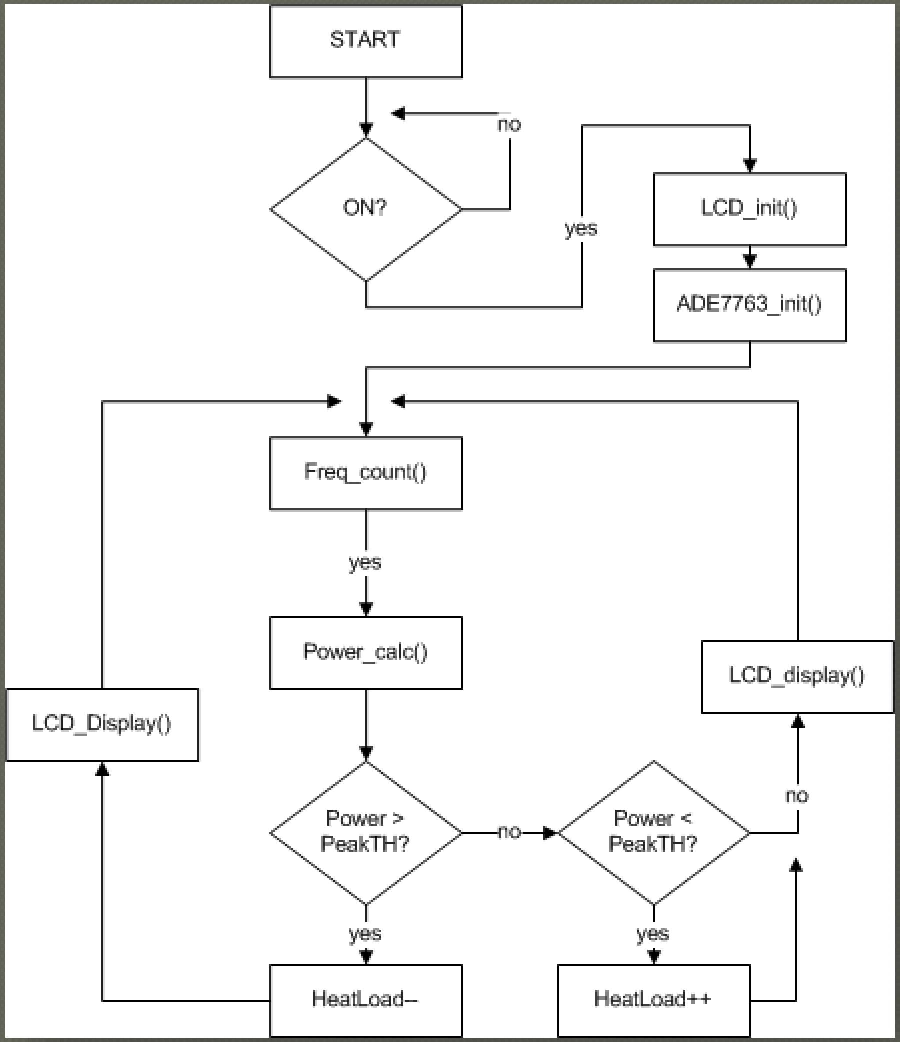
Demand Management Modeling

- Circuit Diagram



Demand Management Modeling

Flow Chart

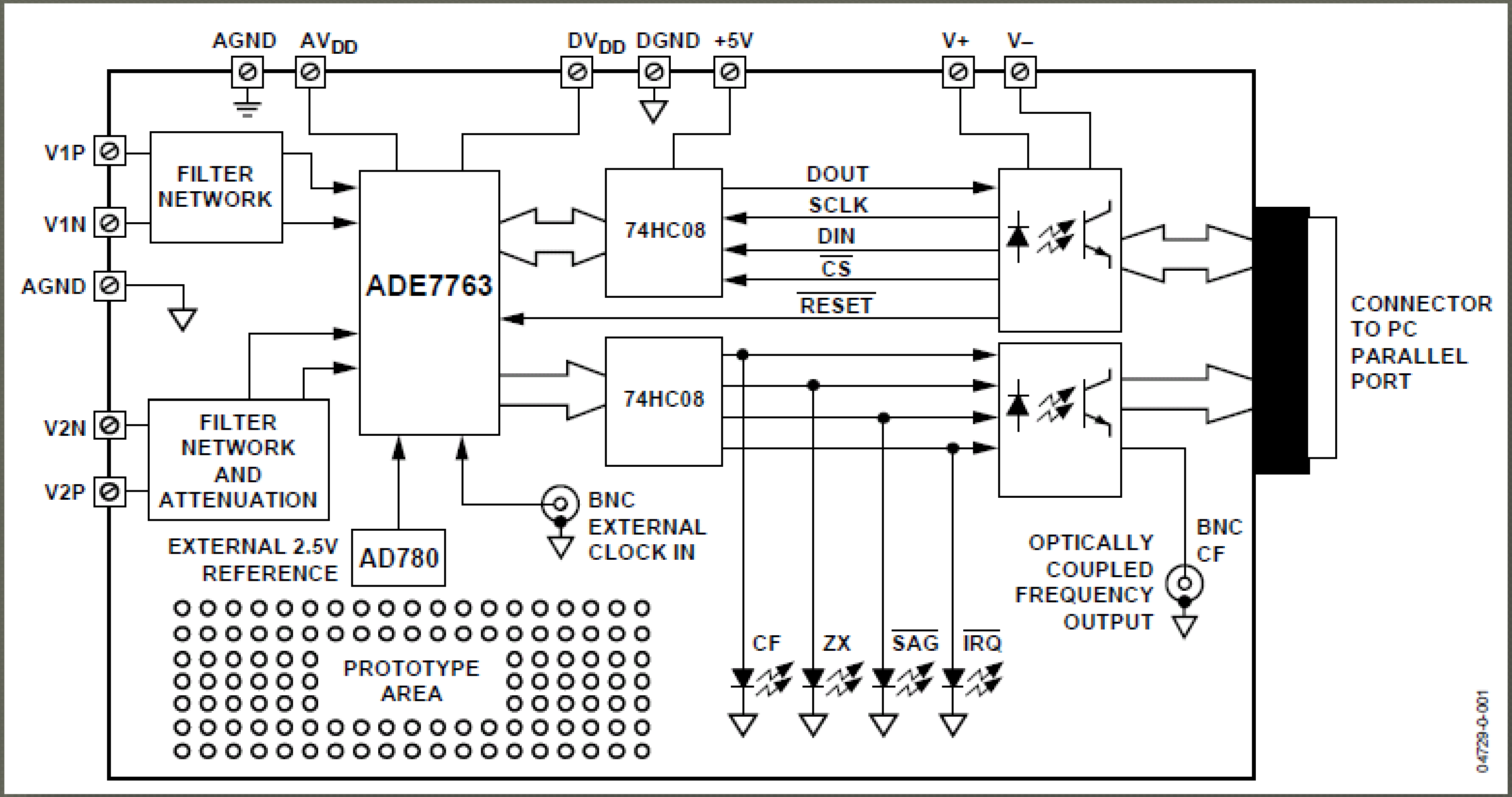


Demand Management Modeling

- ADE7763
  - Energy metering IC: Voltage & current inputs
  - Current input from Current Transformer with 3 turns
  - Voltage input directly through voltage divider
  - Current input: Current Transformer
  - Output: Calibration frequency proportional to active power
  - Arrived at power calculation through testing

Demand Management Modeling

- ADE7763 Evaluation Board Block Diagram



Demand Management Modeling

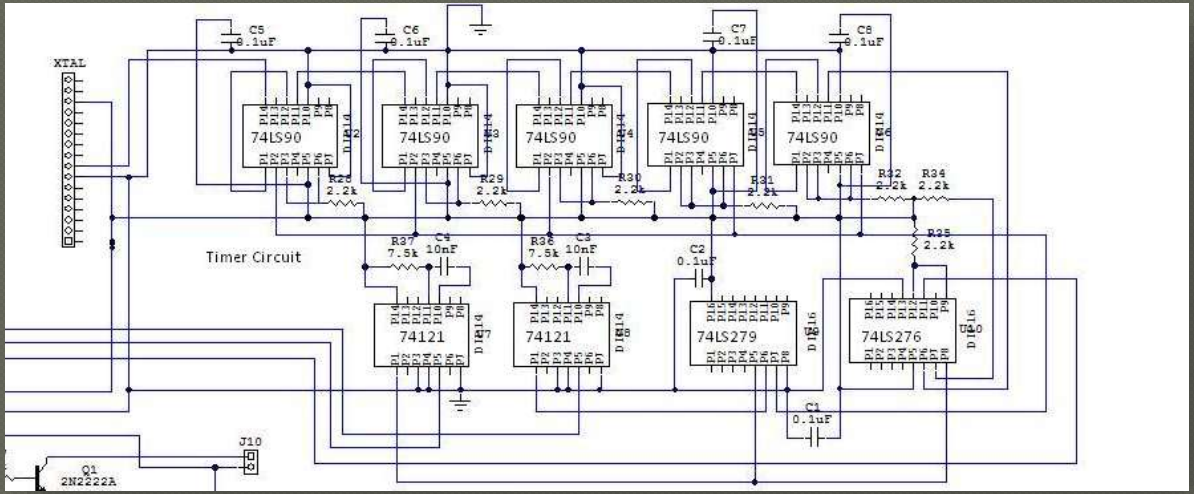
- Atmega168 Microcontroller
  - 16 kilobytes flash memory
  - Runs LCD display
  - Calculates power based on ADE7763 frequency
  - Switches heat loads based on active power in order to keep power usage within a given tolerance
    (+-5% of 100 Watts)

Demand Management Modeling

- Timer Circuit
  - Designed by Dr. Legowski
  - Gives 100ms reference pulse used to accurately measure frequency of ADE7763
  - Activated by single pulse
  - ADE7763 pulses are counted while timer circuit input is high (100 ms) gives 0.1*freq
  - Multiply by 10 to get real frequency
  - Deactivated by single pulse

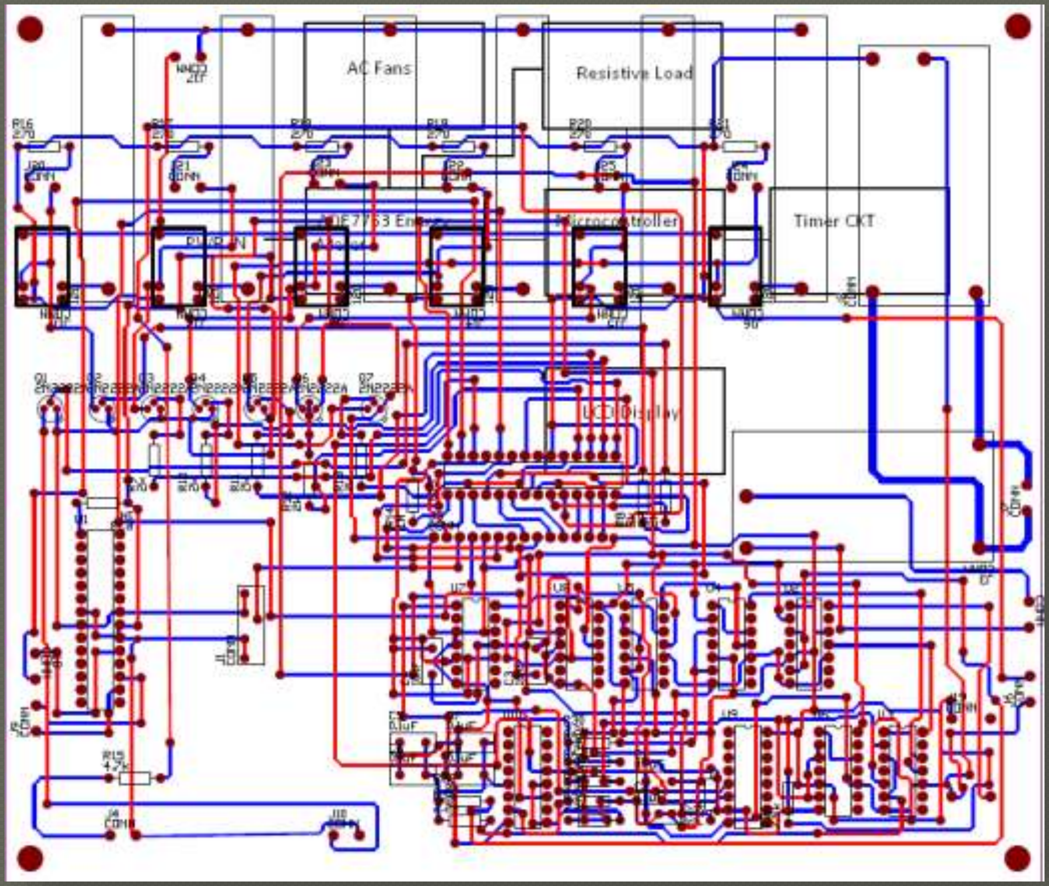
Demand Management Modeling

- Timer Circuit Diagram
  - 5 decade counters
  - Two monostables
  - S-R Latch and JK flip flop



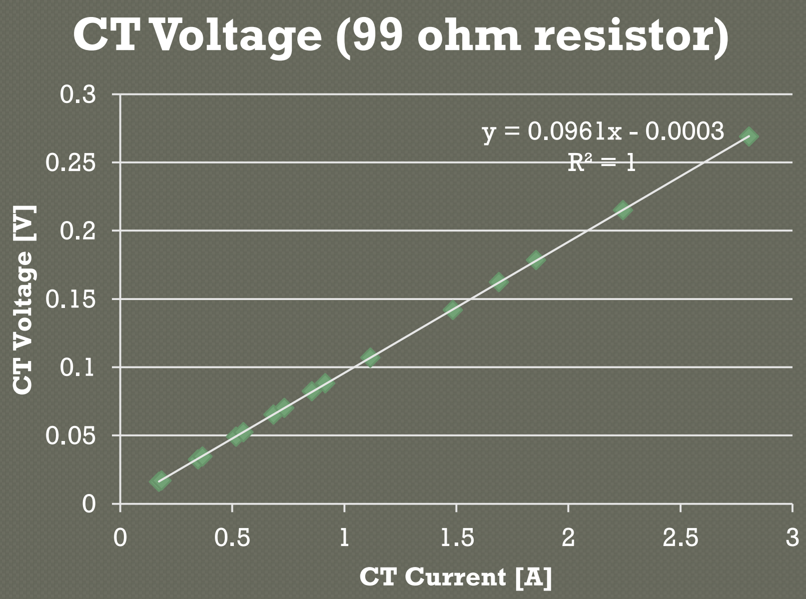
Demand Management Modeling

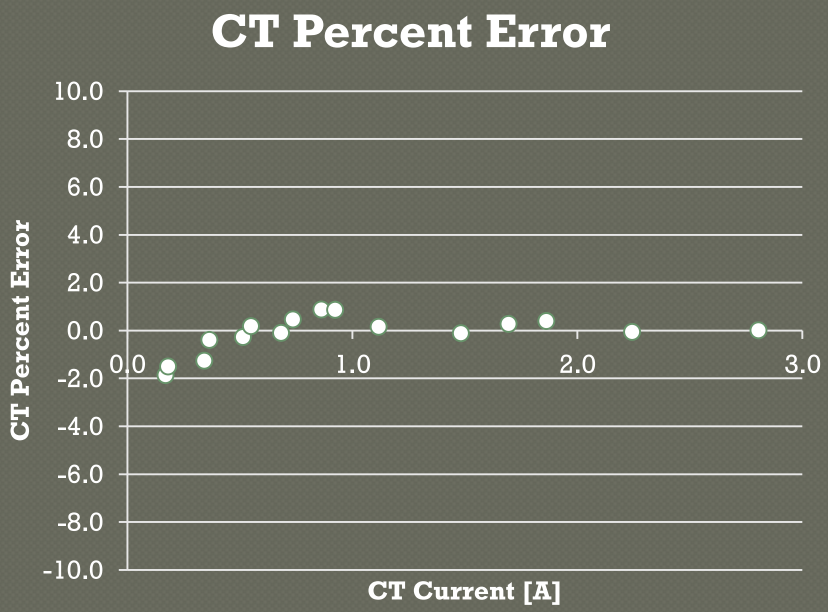
- Printed Circuit Board



Testing

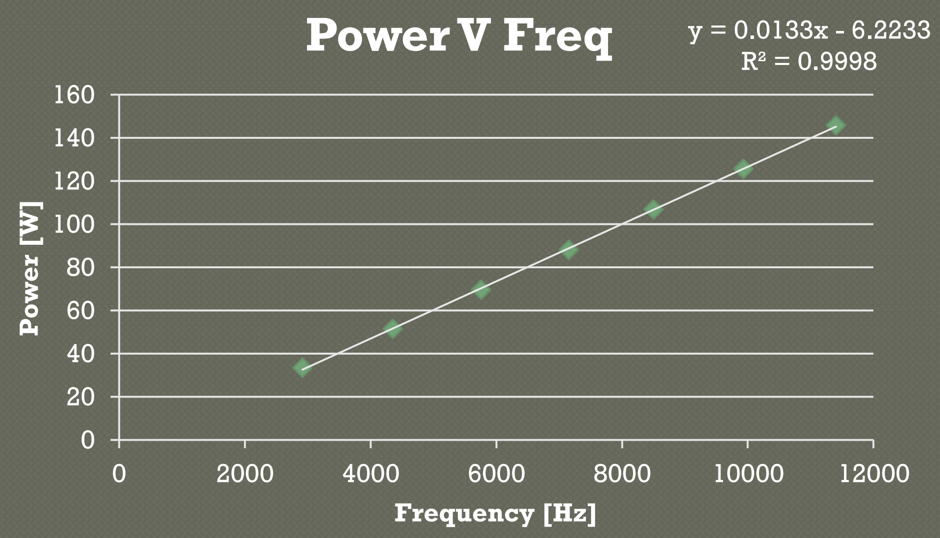
- Current Transformer
  - High degree of consistency: +-2%





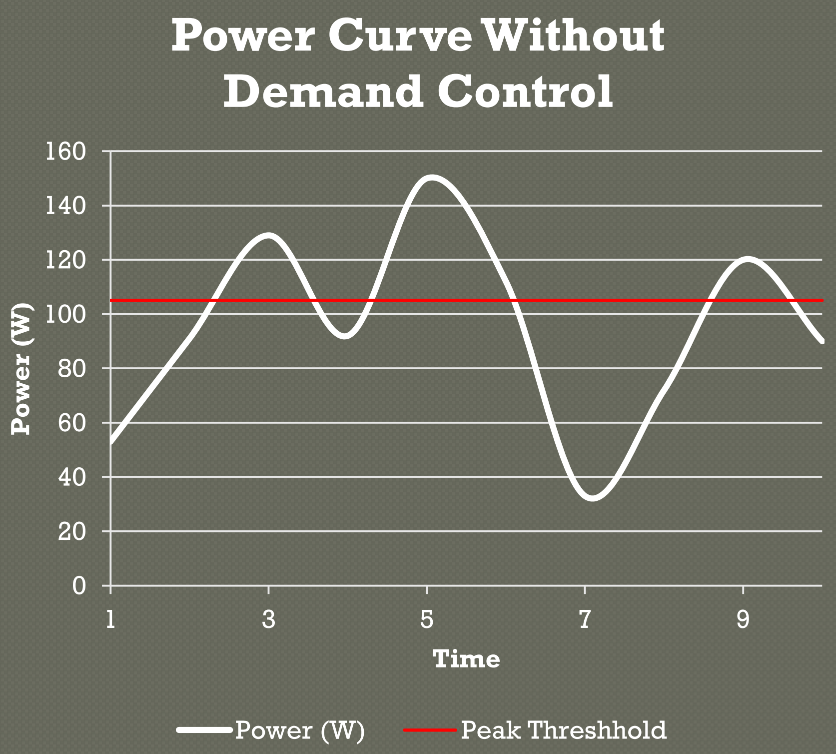
Testing

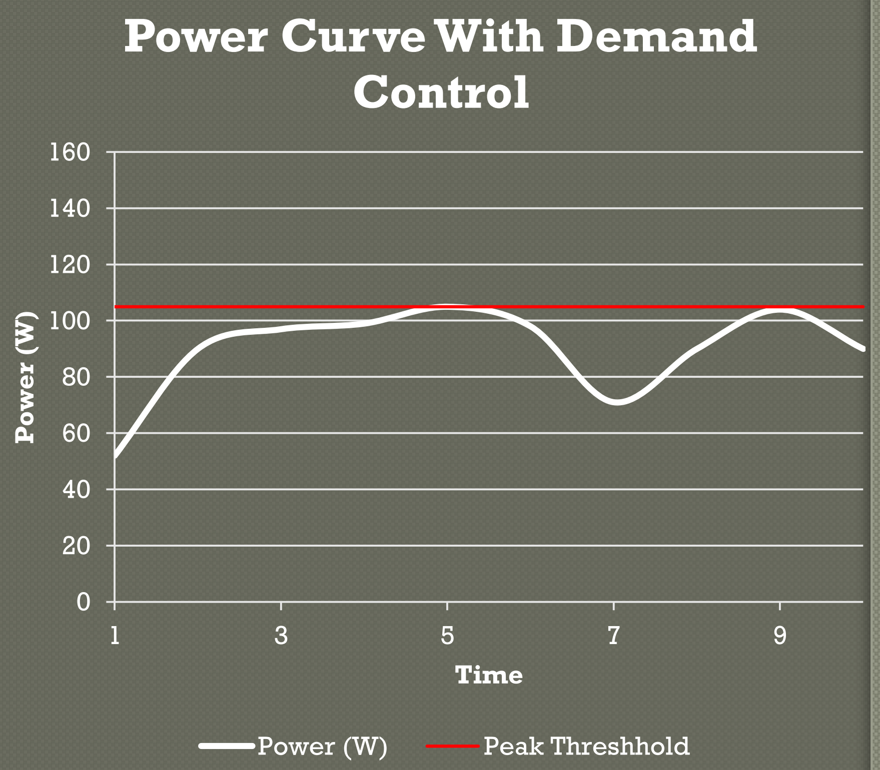
- ADE7763
  - Power v. calibration frequency testing to arrive at power calculation formula
  - Highly consistent performance
  - Measured power by measuring voltage and Current RMS values and phase difference with oscilloscope



Testing

- Final Project testing





Energy: 897 Wh
Demand: 150 W

Energy: 851 Wh
Demand: 105 W

Conclusions

- Demand management is an area of large potential savings
- A coal mine with electric heat is an ideal application of this system
- Modeling gives a scaled down demonstration of how system should work

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