

Intelligent Power Grid Simulation Hardware Design

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Abstract

Presently power distribution companies implement various decentralized systems that require human control interface. These systems are historically susceptible to inefficiencies, failures and human error as seen in recent years. The growing consensus among our elected leaders to put our country on a path to energy independence demands a more intelligent power distribution grid in addition to traditional green initiatives. A smart power distribution grid will allow consumers to better utilize small scale generation techniques and will help provide a more economically viable solution.

Key words: energy independence, power grid, intelligent power distribution

Overview:

We propose a simplified automated centralized system to handle the decisions controlling power flow, generation and real time billing. The problem was divided into the following four subsystems: system integration, demand, billing and generation. The subsystems each handle a specific duty in the system. The demand subsystem monitors demand, generates a load projection and decides which portion of the load to shed if needed. The billing subsystem calculates cost to the consumer by looking at current load level and delivery cost. The generation subsystem decides which generation sources at what level to use to meet the projected demand. The system integration subsystem controls information flow throughout the entire system. It generates the enable bits that turn on each individual subsystem, compares load level to generation level to determine if load shedding is needed and generates the current time period. The interconnections between the various subsystems are shown in Figure 1. Information travels in the direction of the arrow

and the message bit length is defined by the number in parentheses.

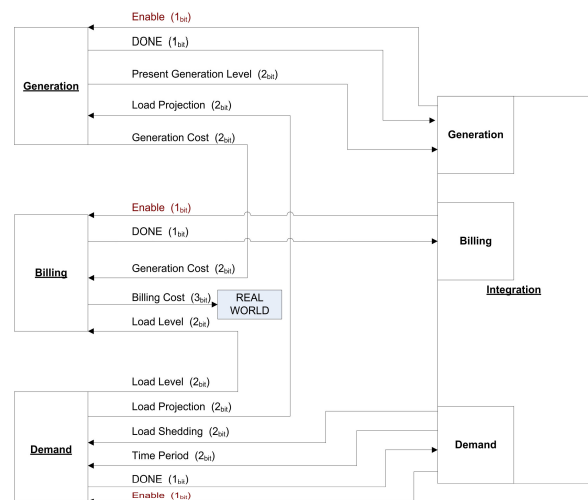


Figure 1: Smart Energy Grid System Overview

1. System Integration Subsystem

The main task of the system integration subsystem is to pass an enable bit to each subsystem when it is their turn to update. It determines if load shedding is required because the load level exceeds the generation level, and then calculates how much load should be shed. The final task of the system integration block is to calculate time period before it loops back to the beginning. Each day is broken up into four time periods, midnight to 6am, 6am to noon, noon to 6pm and 6pm to midnight.

There are eight inputs: Start, Demand Done, Billing Done, Generation Done, Load Level MSB, Load Level LSB, Generation Level MSB and Generation Level LSB. There are seven outputs: Demand Enable, Billing Enable, Generation Enable, Time Period MSB, Time Period LSB, Load Shed MSB and Load Shed LSB. Signals generated at this level but only used internally are: Integration Enable and Integration Done. Figure 1 details where each of the input signals originated and where each of the output signals travel to.

1.1 Enable Bit Calculation

The enable bit calculation is performed by monitoring the done bit of each subsystem starting with the demand block. All done bits are normally high, except for when an enable bit has been received by the subsystem. The done bit then is set low by the specific subsystem and is not set high again until the subsystem has completed all of the internal calculations and updated its output lines. The system integration subsystem monitors the done bit for transition back to high and once it does it moves to the next subsystem block. When the system starts up it begins with demand, then billing, then generation, then system integration and back to demand. It operates in a continuous loop.

The inputs are Start, Demand Done, Bill Done, Generation Done and Integration Done, these inputs are used to calculate the enables for each circuit. Each done bit is passed through an OR gate with the Done bit for the system that is two subsystems ahead of the subsystem that is currently enabled. The output is used as the enable on a D-Latch with the input to the D-Latch coming from the previous subsystem enable bit. The output of the D-Latch is put into an AND gate with the inverted input of the done bit for the next subsystem to calculate the next subsystems enable bit. The outputs of this circuit are: Demand Enable, Bill Enable, Generation Enable and Integration enable.

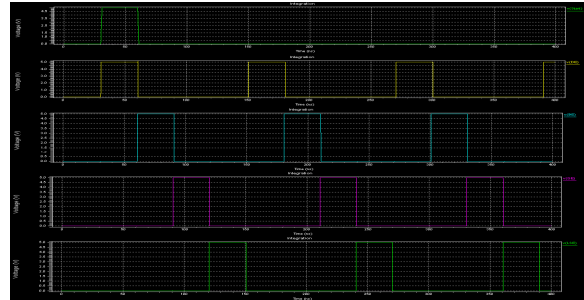


Figure 2: Enable Bit Progression

Figure 2 above shows the enable bit progression. The top plot is a start signal that is sent to the system to get the system started. From there the system progressively loops through the cycle from demand to system integration as can be seen by the enable bits. The second plot is the enable bit for the demand subsystem, the third is the enable bit for the billing subsystem, the fourth is for the generation subsystem and the fifth and last plot representing the enable bit for the system integration subsystem.

1.2 Load Shedding Calculation

The load shedding calculation is done by subtracting the load level calculated by the demand subsystem from the generation level calculated by the generation subsystem. A cascaded full subtractor is implemented to perform the binary subtraction. The subtraction is performed using two's complement binary addition. To do this the subtrahend (load level) is inverted and then bitwise subtracted from the minuend (generation level). If at the end of the cascaded chain of subtractors a borrow bit is needed then load level exceeds the generation level and load shedding must be performed. If no load shedding is needed then the output Load Shed bits remain at zero. If load shedding must be performed the result of the two's complement subtraction is converted back to a positive number by inverting the result and adding one. This is done in cascaded adders.

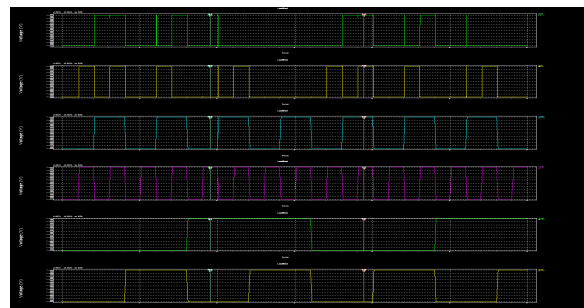


Figure 3: Load Shed Operation

Figure 3 details the bit progression that determines if load shedding is needed. The plots from top to bottom are Load Shed MSB, Load Shed LSB, Load Level MSB, Load Level LSB, Generation Level MSB and Generation Level LSB. The bottom two plots represent the minuend, the middle two the subtrahend and the top two the result with only if load shedding was needed. If load shedding was not needed then the result is zero, load shedding is not needed when generation level exceeds the load level.

1.3 Time Period Calculation

The time period calculation is done by implementing a four bit counter using T-Flip Flops. The input is the Demand Enable bit, this serves as a clock signal since it will increment every time the system has run through one complete loop. The T-Flip Flops then divide the system loop frequency by two, the number of T-Flip Flops determines how many times the signal has been divided. In our case we implemented four T-Flip Flops and used the last two outputs as our time period output. We were left with a two bit representation for time period. This setup results in our system looping eight times for each time period. It is easily scalable by increasing the number of T-Flip Flops to lengthen or shorten the time period.

1.4 Done Bit Calculation

The done bit calculation was a unique problem. There were several cases to be mindful of, the case when no inputs change therefore no outputs would change, the case when inputs change and outputs change and the case when inputs change but no outputs change. The first problem was each input and output line had to be monitored for change, to do this a change cell was created. Each data line gets its own change cell to individually monitor for bit change from the previous enabled state. The change cell accepts both the given subsystem enable bit as well as the data to be monitored. This is fed into two D-Latches set up to monitor current and last state. The outputs of the D-Latches are fed into an XOR gate which outputs a high if there is a change and a low if there is no change. The results of all the inputs are fed into a NOR gate and the results of all the outputs are fed into an OR gate. These results are then fed into both a NAND and OR gate, the results of which are fed into an OR gate to raise our done flag upon calculation completion.

2. Demand Subsystem

Demand monitoring (DM) will provide two outputs dictating load projection and present power consumption. If present power consumption exceeds a specific limit, a decision from system integrator will permit load shedding. Once a decision is made to reduce consumption, DM will make a judgment as to what load are important and specific a priority. Load on high priority (life threatening and other uninterruptible loads) will be subjected to less reduction as opposite to lower priority (such as street lights, parks and non volatile loads). In determining a load projection, several inputs will be compared against. Inputs include season, weather condition and time of day. Demand system block diagram is show below in Figure 4. The system activates once an enable command is given form the system integrator. In retrospect, a done command will be send to the system integrator to acknowledge that demand monitoring has perform all of its tasks.

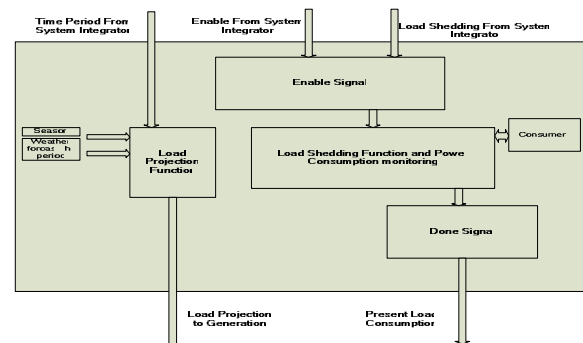


Figure 4: Demand Monitoring Block Diagram

2.1 Load Projection Function

This function will predict required power. The incorporation of season, time of day and predicted weather forecast can contribute to desired level of system confidence. It has been demonstrated [2] that temperature (weather) and time of day has a profound effect on the power consumption. These findings can play a role in developing a system which uses past history as a weight sum to predict load consumption based on weather forecast, season and time of day. The correlation is captured in the Load Projection definition. Based on historical data two states were outlined as extremities. These states were the highest level expected at 7pm to 10pm; represented by 11_b and the lowest level expected was 3am to 6am; represented by 00_b . However, to more fully utilize the 2-bit data structure four states were chosen to be implemented.

Additional requirements were derived from figure 5 which summarize data [1] about the consumption level in the United States as it relates to time of year (season). This data also correlates with figure 1 load projection requirement inputs.

Season	months	Kilowatts(billion)			Average
		2006	2007	2008	
Spring	March-May	881	898	904	894
Fall	June-August	922	971	933	942
Winter	Dec-Feb	922	949	983	951
Summer	June-August	1092	1091	1088	1090

Figure 5: Energy Information Administration Yearly Electrical Power

2.2 Load Shedding Function

Load shedding is performed by receiving information from the system integrator. Depending on the level of power reduction needed, the prioritizer will initiate power reduction, beginning with less life critical consumers. The order of reduction would begin with items such as street lights, move to residential consumers and ultimately shut down all non life critical systems such as; hospitals and security systems. Once this request is complete a done signal will be sent to the system integrator. Upon request, load level will be continuously available. In case the consumer consumption level goes above an extreme condition an internal power protection will provide relief. This protection will monitor consumer load level and will have an AND gate logic function, only when the situation becomes extreme (11) then will it shed to stabilize. This will be performing by a 2 x 4 Decoder with an enable/disable command [3].

2.3 Determining Load level

Load level determination is a necessity in today high power demanding environments to provide real time consumption. This can help alleviate the strain on systems in the event that a system becomes unstable. This oscillatory behavior can be caused by a hot summer day or failure at a local utility or power source. Although these monitoring systems have issues related to transferring the consumption level over power line communication due to noise, transformer isolation and impedance problems [4]. Much improvement in research and legislative support can provide a reliable system. [1]

In this portion of the system function, the system will assume that information is providing in a real time digital form. In a broader perspective, this system can

be implemented on a zip code to city monitor level with each system providing summation to their local utilities stations. Determine power consumption level will be a summation of commercial, residential and industrial areas. Its function will be performed by implementing a full adder.

3. Generation Subsystem

This function will look at the different sources of power and decide which is best for the load requirement from the Demand phase. The predetermined sources to be considered are Fossil fuels, Nuclear and Hydro energy as the input sources. Hydro is the least expensive in the group, Nuclear is the next expensive, and Fossil is the most expensive. The cost of energy is the main determining factor when it comes to the power sources selected. There are many other factors, such as power output capabilities and readiness of the energy source. Before the source is selected, Demand phase will send a signal giving a 00_b, 01_b, 10_b or 11_b, which will indicate the level of power generation needed. A 00_b will indicate a stand-by state and a 11_b will indicate the highest level of power needed.

The way the generation portion of the power grid will work is as follows: (a) the signal will be received from the demand portion of the power grid identifying what the current power level is needed. If the power level is high, then the system will remain static. If the power level is low, then the three input sources will engage and a decision will be made as to which source will be used. (b) An internal decision will compare a few variables of the three sources and determine which is best to proceed with. (c) After that decision is made on the best source, the current generation level is sent to Integration. (d) An Enable signal is sent to generation by integration to start the generating process. When Present Generation Level and Delivery Cost are populated and internal computations are performed, a "Done" signal is sent, when generation is complete.

If we go back to part (b); the internal decision will have to consider the following variables: (i) the cost of the power source, (ii) delivery capability to meet the load that is demanded, (iii) a clock to see what source was used last, this is to ensure the system does not repeat itself.

3.1 Load Projection & Present Generation Levels

Generation will receive the Load Projection Level from Demand. This will be two bits. A 2-to-4 decoder will analyze the load level needed with the Enable always High. Two bits are sent from the Generation subsystem to the Integration subsystem. This will indicate which power source has been selected and how much power is being generated. Either; Hydro, Nuclear or Fossil will be used. After further consideration of energy sources, any one source can be used and any number of sources can be used. A Full Adder was incorporated with D-Latch's.

3.2 Generation Cost

Generation Cost is determined by many factors which drive the cost of energy. The time of day is a critical factor in that it determines peak and off-peak pricing. The source, in itself, for example Hydro or Fossil comes with many costs' built in. Generation cost is the cost to make the electrical energy. Other deciding factors are the cost of transmission of the energy, maintenance of the energy producing facilities and the cost of the raw materials, to name a few. The information comes from the decision made after the source of power is selected and the factor's mentioned above are accounted for. A 2-to-4 binary decoder is modified to send the most significant bit and least significant bit to the Billing subsystem.

4. Billing Subsystem

The billing subsystem will determine the total cost of energy. Knowing the delivery cost and the load level, the total cost to produce that energy is determined. Delivery cost is a 2-bit number representing the cost to produce a unit of power. The scale is as follows. 00_b = low, 01_b = medium low, 10_b = medium high, and 11_b = high. Load level is a 2-bit number representing the amount of power being consumed by the end-user. This number uses the same scaling factor as delivery cost. Understanding possible permutations of the system an adder was chosen as a practical computational method. For example; the billing cost for a high delivery cost and a low load level can equal a low delivery cost and a high load level combination. Figure 6 shows a truth table representing the possible permutations.

The billing sub-system is provided a 1-bit enable from the Integration subsystem. While enabled, no other subsystem is able to post calculated results. The enable is also used to help determine if the subsystem inputs and/or outputs have changed. If

the inputs have not changed the done flag is raised immediately because there will be no need to perform calculations on the same data. Likewise, the change in inputs and change in outputs are monitored to determine when the DONE bit should be set. The DONE bit tells the Integration subsystem "I am" complete and the next subsystem may begin.

Delivery Cost	Load Level	Billed (Binary)	Billed (decimal)
00	00	000	0
00	01	001	1
00	10	010	2
00	11	011	3
01	00	001	1
01	01	010	2
01	10	011	3
01	11	100	4
10	00	010	2
10	01	011	3
10	10	100	4
10	11	101	5
11	00	011	3
11	01	100	4
11	10	101	5
11	11	110	6

Figure 6: Billing System Truth Table.

5. Conclusion

Hardware of the simplified automatic subsystems were successfully designed and tested. The system was able to make decision to control power flow generation and real time billing. The subsystems consisting of integration, demand, billing and generation were designed and integrated into one centralized system. The smart power distribution grid will allow consumers to better utilize small scale generation techniques and help to provide a more economically viable solution.

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