Smart Power Generation & Distribution

A Smart City Application

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ESE 527: Design of Smart Systems

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Abstract

This report explores the development of a smart energy generation and distribution system simulation using AnyLogic 7.3. A literature review discusses the motivation for creating a smarter generation and distribution system in order to provide energy to power a smart city. The ultimate goal of this simulation is to minimize the cost for an electric utility company to purchase energy resources while still meeting the energy demands of a smart city. The increased efficiency of a smart city would evidently reduce energy consumption and therefore reduce energy costs. The energy generation and distribution system focuses on different forms of energy generation for efficient and economical use. The different methods of energy generation modeled are: wind energy, geothermal energy, hydraulic energy, nuclear energy, solar energy, and thermoelectric energy. The smart generation technique will focus on maximizing throughput of the generation plant with minimal resource and cost utilization.The aforementioned sources of energy will be simulated using agent based modelling and each source will be modelled to have different costs. Additionally, feedback from the cities about their current power utilization and modifying supply and generation rates will be monitored for distribution.The simulation will be run with different types of load schedules and its performance in each situation will be compared.

Introduction

Developing and sustaining the infrastructure of smart cities requires a large amount of energy, especially off the electric grid. Smart cities promise to increase energy efficiency through improved lighting and transit systems. Our smart generation and distribution system aims to minimize the cost of generation by optimizing the purchasing of different forms of energy. This smart energy saving model is a System of Systems that interfaces with two other models, smart lighting and smart transit, together these systems are combined to form a large scale smart city model.

This model supports the implementation of a smart grid to sustain the energy needs of a smart city. The key component of this model is the incorporation of all forms of energy generation sources in the cost calculation. The current literature discusses how electricity generation from renewable sources need to increase in order to achieve sustainable energy for all by 2030 [1]. Many countries have already begun to add more renewable energy to the grid as it has become more technically and economically feasible [1]. This phenomena along with the increased trends, as described by the American Planning Association, of developing and sustaining smart cities supports the importance of adopting a smart generation and distribution system.

There are various trends that motivate the desire of transforming current cities into smart cities. According to the American Planning Association (APA), the trends that have led to the development of smart cities include rapid urbanization of the world's population [2]. Additionally, paradigm shifts in the way people live, work, and play has contributed to the proliferation of information and communication technology which have been adopted by various businesses and homeowners. APA describes five factors being the sources of trends for the development of smart cities: political, technological, social, financial, and environmental trends. Political trends refer to consumers demanding more transparency and accountability from city governments, corporations, and non-governmental organizations. Technological trends allude to the decrease in costs associated with computing and communication technology all of which has led to the rise of "Big Data" and cloud based computing. As a result, software and hardware based sensors are being installed to form smart cities. For example, buildings are incorporating renewable energy to power integrated control systems, infrastructures such as smart grid energy transmission networks are becoming more automated. Transit systems are also incorporating sensor based systems for technologies such as real-time route data for public transport. Personal use of smartphones, watches and location based services is another example of a trends that impact smart cities. Environmental trends is one in which this project is mostly concerned with. The understanding of social responsibility to preserve our environment has influenced the demand for transitioning to a carbon-neutral energy supply system [2]. Thus resulting less dependance on fossil fuels with more sustainable alternatives such as wind, solar, and geothermal energy.

Creating a smart generation and distribution system would benefit electric utility companies by allowing them to minimize the cost of energy which would impact the all trends associated with smart cities as previously mentioned. Utility companies would be able to implement a smart generation and distribution system in their control centers by incorporating an automated program that calculates the minimum amount of energy necessary to meet the energy demands of a smart city. The energy sources used are: wind energy, geothermal energy, hydraulic energy, nuclear energy, solar energy, and thermoelectric energy. The system will easily adapt to price changes and in cases when a power plant is down.

This system will ensure that energy supplied is reliable and cost effective not only for the utility companies but for the consumers living in the smart city. In order to deploy this system, the power plants, distribution centers, and the city transmission lines as well as smart meters need to be in constant communication over a secure network. This will ensure that data is up to date and available in real time. Currently companies such as NextEra Energy are installing cyber physical systems such as routing computers on their distribution lines to detect changes in power demands which can be to load shedding or a unpredicitve faults in power lines. A similar plan should be adopted for the purpose of connecting the three systems of generation, distribution, and the smart city itself. Utilities must begin to implement more smart grid technologies such as Automatic Metering Infrastructure that allow them to monitor and control distributed renewable generation in individual homes and businesses. Additionally, the utilities should include services of installing and monitoring distributed generation sources, similar to how SolarCity does. Added services and monitoring technologies would result in financial benefits from investing in a smart generation and distribution system. In order for all these systems to be enacted utility regulators must place financial incentives the reward smart grid, generation, and distribution investments [1].

System Objectives & Design

The objective of our project is to develop a smart power distribution system that optimizes the power purchased by a utility by minimizing cost while still meeting the demand of a smart city. This system would build upon current practices to sustain a smart grid. The system aims to provide a catalyst for creating a smart grid system for a smart city. It models the generation of six different power plants: fossil fuel, nuclear, thermal, solar, wind, and hydro. The maximum attainable power is noted for each plant and used to minimize the cost of to the utility company that purchases each energy source.Illustration 1 is a flowchart graphically describing the code used in the Main of the Anylogic simulation. Illustration 2 is the pseudocode for the cost minimization that occurs at the distribution center. Finally, Illustration 3 demonstrates the pseudo code for modeling each power plant. A monitoring display provides the system operator with the best strategy for purchasing the optimal amount of energy from each plant in order to meet the smart city's power demand. The display can simulate various scenarios such as an increase price of an energy source or a plant going offline due to a malfunction or maintenance. The monitoring display is shown in Illustration 4.

The cost minimization model is agent based. In this block, the cost of each resource and its maximum output available is used along with the load power demand of the city to calculate the most cost effective alternatives to be allocated for each resource. The proposed strategy will only be accepted if the demand for power is met. Currently, the values energy costs and power demand are stored in a database that is accessed by the code to perform the calculation [3][4]. The data can be updated to reflect the current and historical data for any city.

In order to ensure the functionality of this model, sensors would need to be installed in each plant indicating the maximum amount of power available this information would then need to be relayed to the distribution center which would then consolidate the information with the power demand data collected by the utility's smart meters. Implementing this smart generation and distribution system would only be feasible for a utility that both generated and distributes its own power because a conflict of interest would be lessened if the utility is responsible for all facets of power services.

Cost of power generation by source quantity :

In electrical power generation, the distinct ways of generating electricity incur significantly different costs. Calculations of these costs at the point of connection to a load or to the electricity grid can be made. It is measured by the the **levelized cost of electricity** (**LCOE**) which is a measure of a power source which attempts to compare different methods of electricity generation on a comparable basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the minimum cost at which electricity must be sold in order to break-even over the lifetime of the project.

Cost Factors :

While calculating costs, several internal cost factors have to be considered.[1] (Note the use of "costs," which is not the actual selling price, since this can be affected by a variety of factors such as subsidies and taxes):

- Capital costs (including waste disposal and decommissioning costs for nuclear energy) - tend to be low for fossil fuel power stations; high for wind turbines, solar PV; very high for waste to energy, wave and tidal, solar thermal, and nuclear.
- Fuel costs - high for fossil fuel and biomass sources, low for nuclear, and zero for many renewables.
- Factors such as the costs of waste (and associated issues) and different insurance costs are not included in the following: Works power, own use or parasitic load - that is, the portion of generated power actually used to run the stations pumps and fans has to be allowed for.

To evaluate the total cost of production of electricity, the streams of costs are converted to a net present value using the time value of money. These costs are all brought together using discounted cash flow.

Calculation to be used :

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

It : investment expenditures in the year t

Mt : operations and maintenance expenditures in the year t

Ft : fuel expenditures in the year t

Et : Electrical energy generated in the year t

r : discount rate

n : expected lifetime of system or power station

Calculations often do not include wider system costs associated with each type of plant, such as long distance transmission connections to grids, or balancing and reserve costs. Calculations do not include externalities such as health damage by coal plants, nor the effect of CO_2 emissions on the climate change, ocean acidification and eutrophication,ocean current shifts. Decommissioning costs of nuclear plants are usually not included (The USA is an exception, because the cost of decommissioning is included in the price of electricity, per the Nuclear Waste Policy Act), is therefore not full cost accounting. These types of items can be explicitly added as necessary depending on the purpose of the calculation. It has little relation to actual price of power, but assists policymakers and others to guide discussions and decision making.[*citation needed*]

These are not minor factors but very significantly affect all responsible power decisions:

- Comparisons of life-cycle greenhouse gas emissions show coal, for instance, to be radically higher in terms of GHGs than any alternative. *Accordingly, in the analysis below,carbon captured coal is generally treated as a separate source rather than being averaged in with other coal.*
- Other environmental concerns with electricity generation include acid rain, ocean acidification and effect of coal extraction on watersheds.
- Various human health concerns with electricity generation, including asthma and smog, now dominate decisions in developed nations that incur health care costs publicly. A Harvard University Medical School study estimates the US health costs of coal alone at between 300 and 500 billion US dollars annually.[32]
- While cost per kWh of transmission varies drastically with distance, the long complex projects required to clear or even upgrade transmission routes make even attractive new supplies often uncompetitive with conservation measures (see below), because the timing of payoff must take the transmission upgrade into account.

The resources availability also depends on a lot other environmental factors like climate change, lack of transportation, etc.. For our existing model, we have tried a crude approach to relate the fuel quantity value with the cost of generation. Keeping the maximum cost as the one obtained from the database relating to the plant with the maximum capacity. This relates to maximum quantity of 152 units. A relation is used to model the quantity with the cost as:

Cost = -0.5*Quantity + 77

This gives a simple relation showing how when the quantity of the resource decreases, the cost of generation increases to take care of the rising demand.

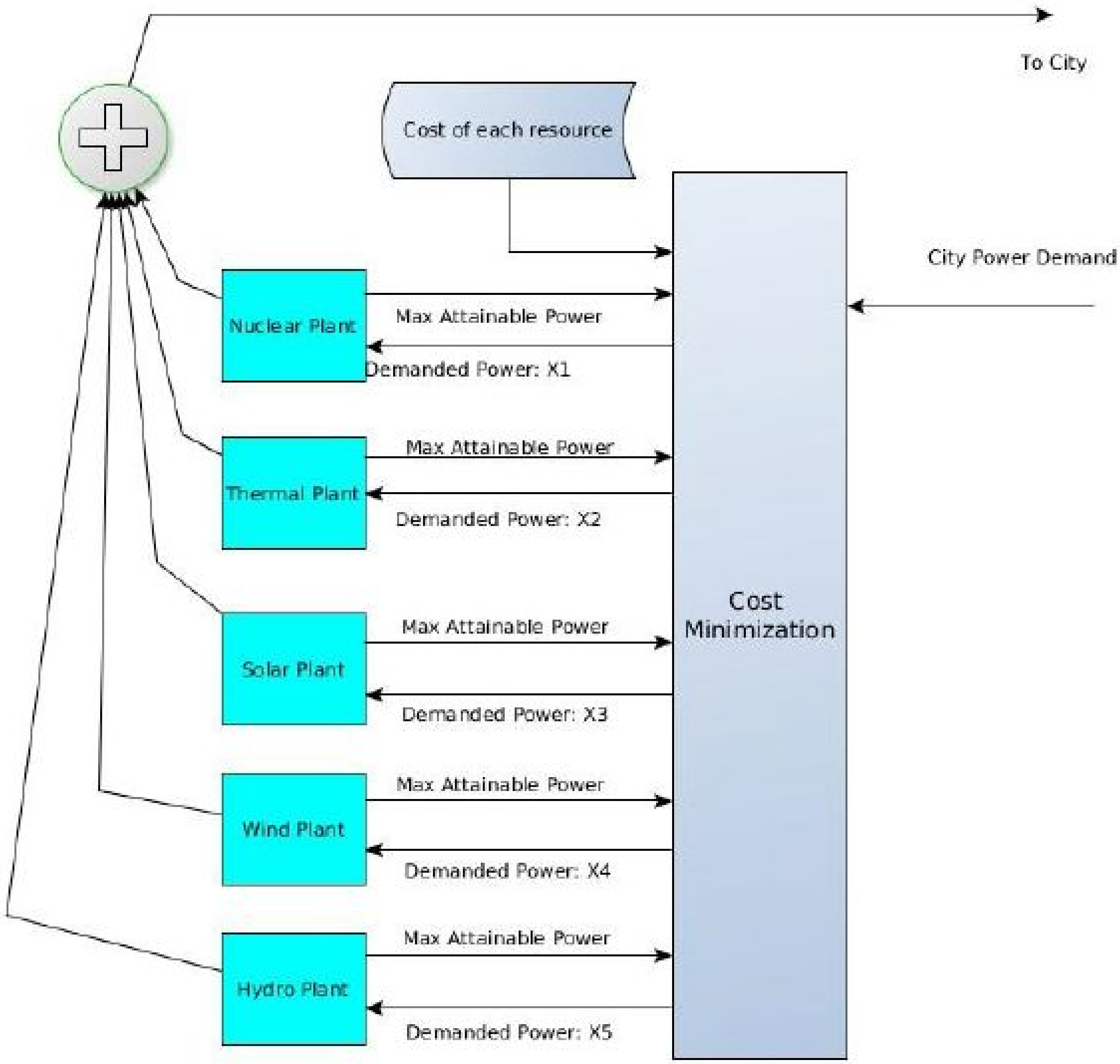

Illustration 1: Main Flowchart

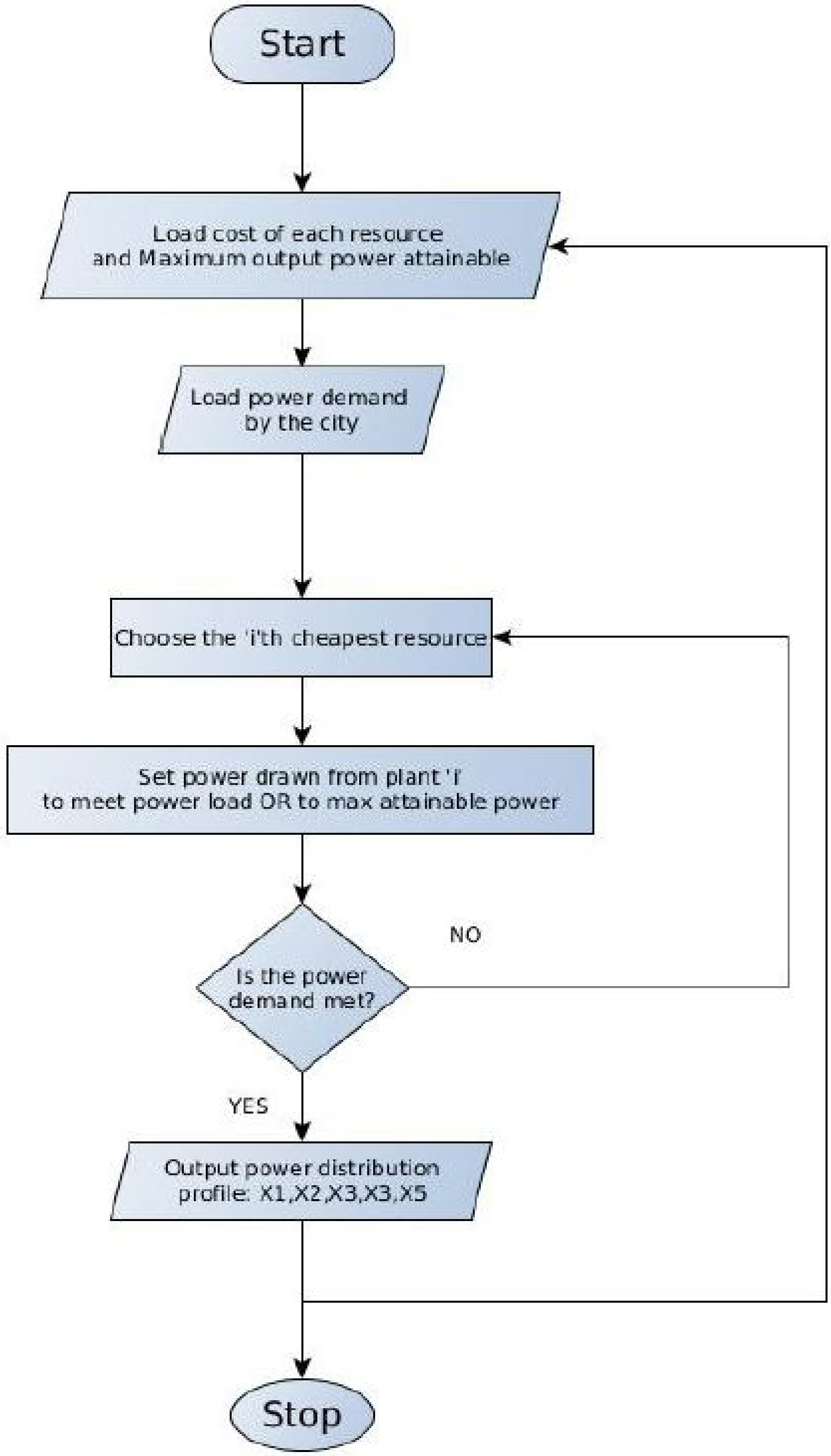

Illustration 2: Cost Minimization

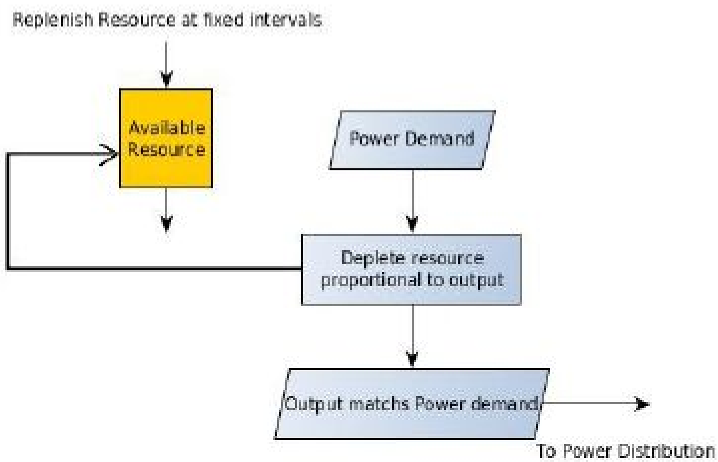

Illustration 3: Plant Model

Illustration 4: Control unit display

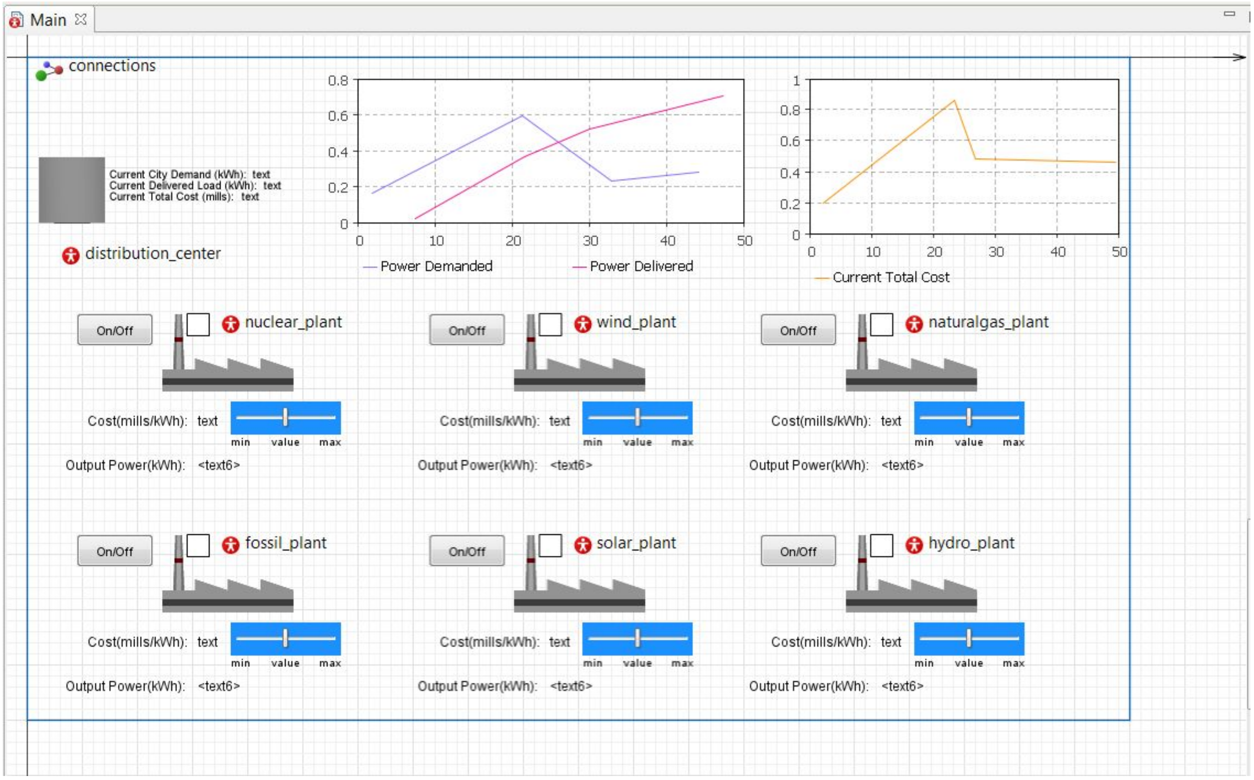

Illustration 5: AnyLogic Main

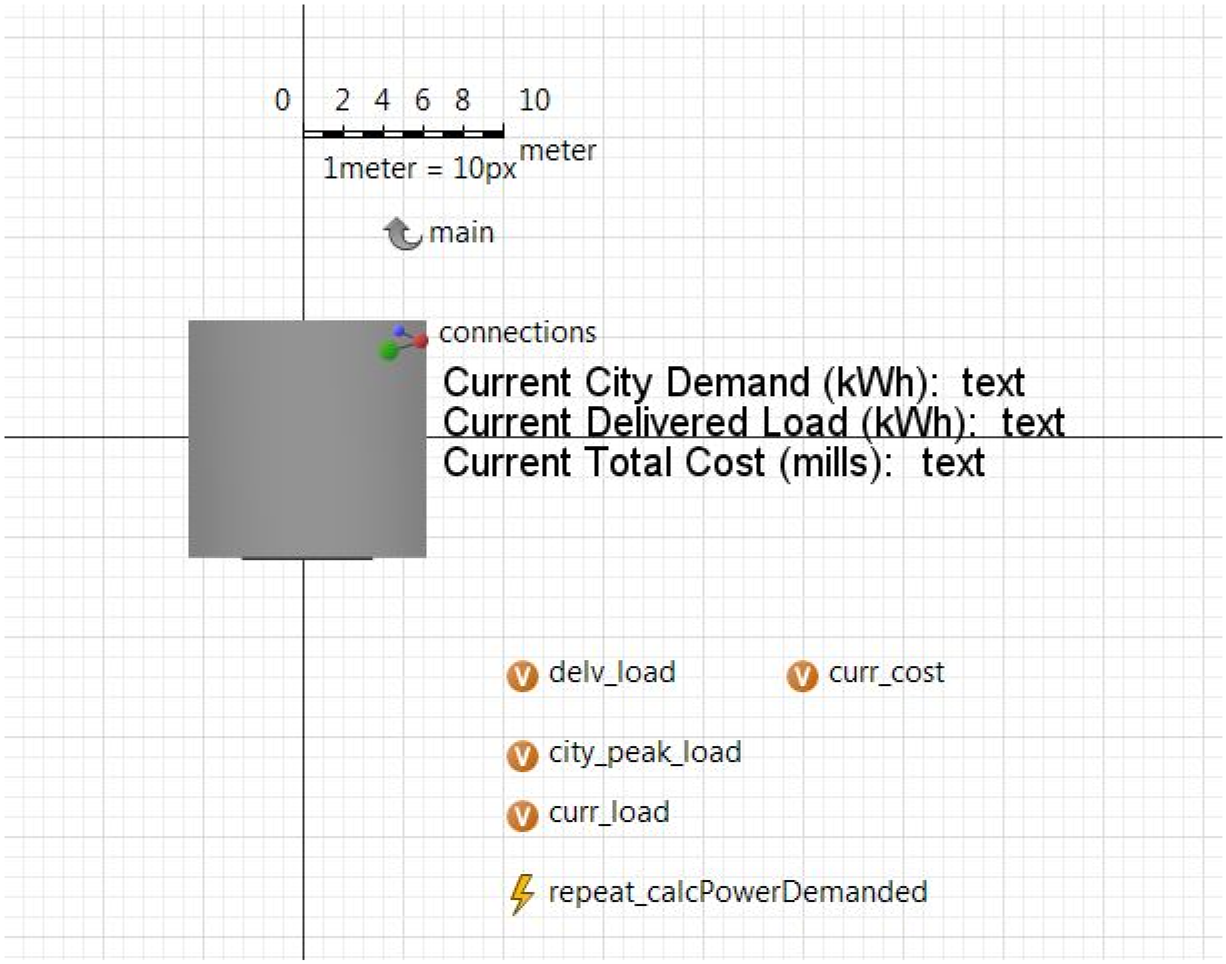

Illustration 6: Distribution Center Agents

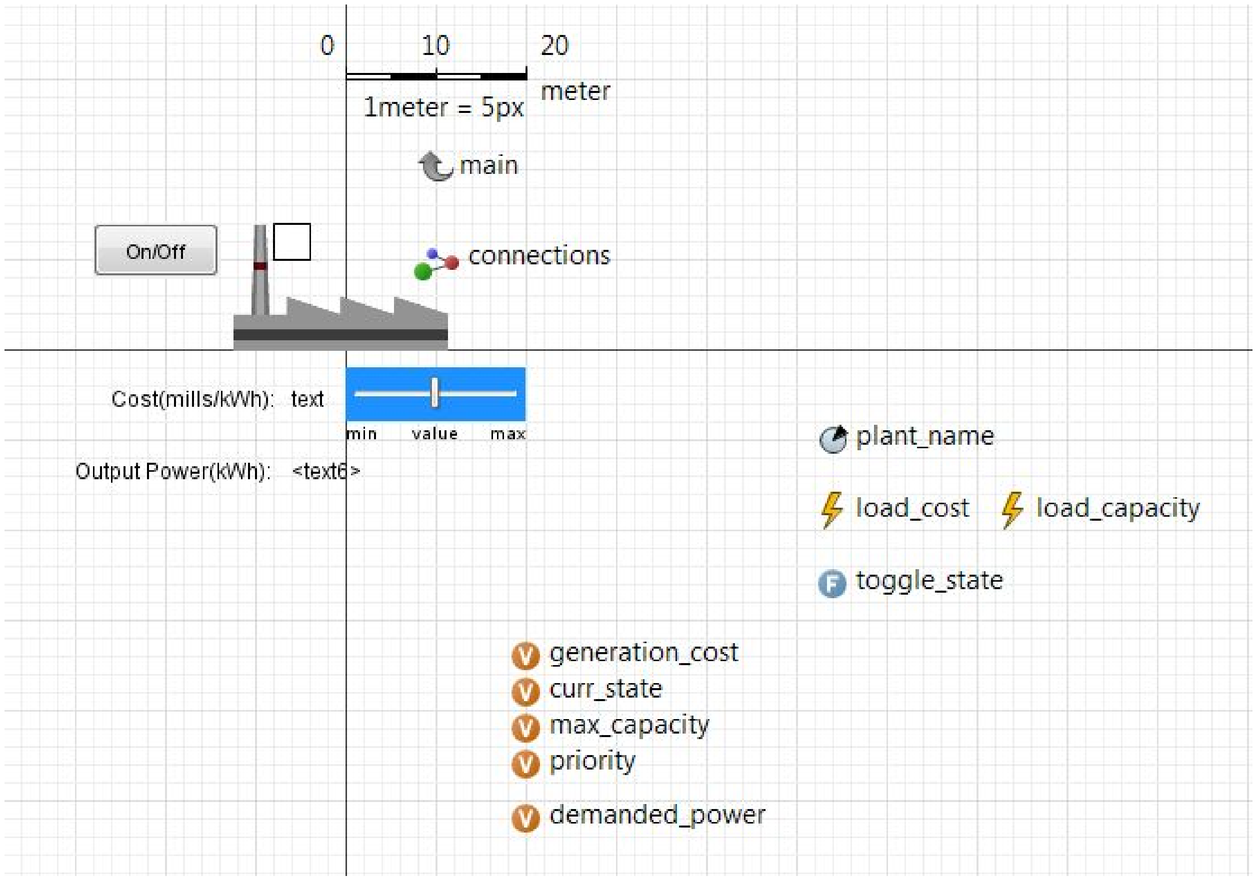

Illustration 7: Plant Agent

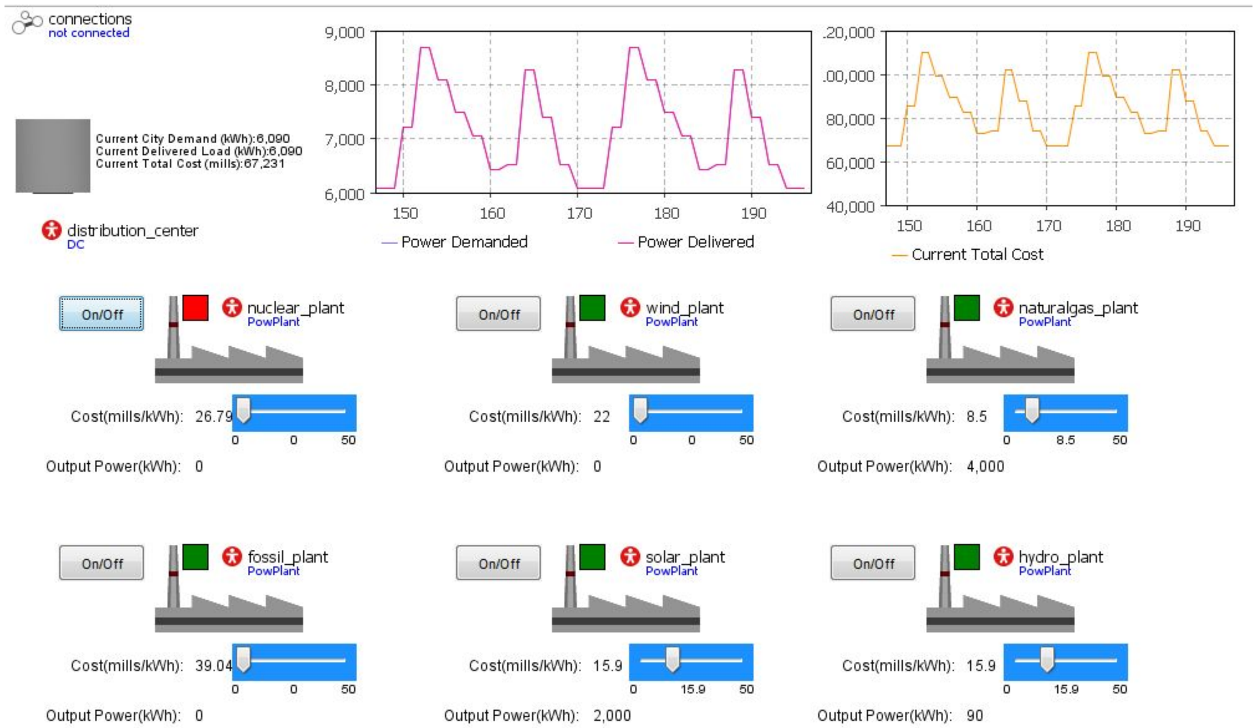

Illustration 8: Display for scenario in which the nuclear plant is offline and the cost for solar, natural gas, and hydro energy has changed.

Stakeholders & Implementation

The main clients and stakeholders for this system are electric utility companies that generate and distribute their power. Such companies will be able to track operation improvements by comparing cash flows from before and after a switch to adopting the smart generation and distribution system. This model provides electric utility companies the opportunity for increased cost savings associated with purchasing fuel and generating power. This system also ensures that the demand for power is always met as a result the electric utility will meet consumer satisfaction by providing the most reliable power distribution.

The simulation is capable of modeling various scenarios depending on the status of the power plants and the power demand of a smart city. There are six power plants modeled. The ideal equilibria is when all plants are running at 100% capacity and therefore, all the demand for power is met. Other forms of equilibria emerge when costs of resources for generating each energy source begins to vary and or when a power plant goes offline. Below are a series of screenshots displaying different scenarios and equilibria simulated to model ideal and real world situations.

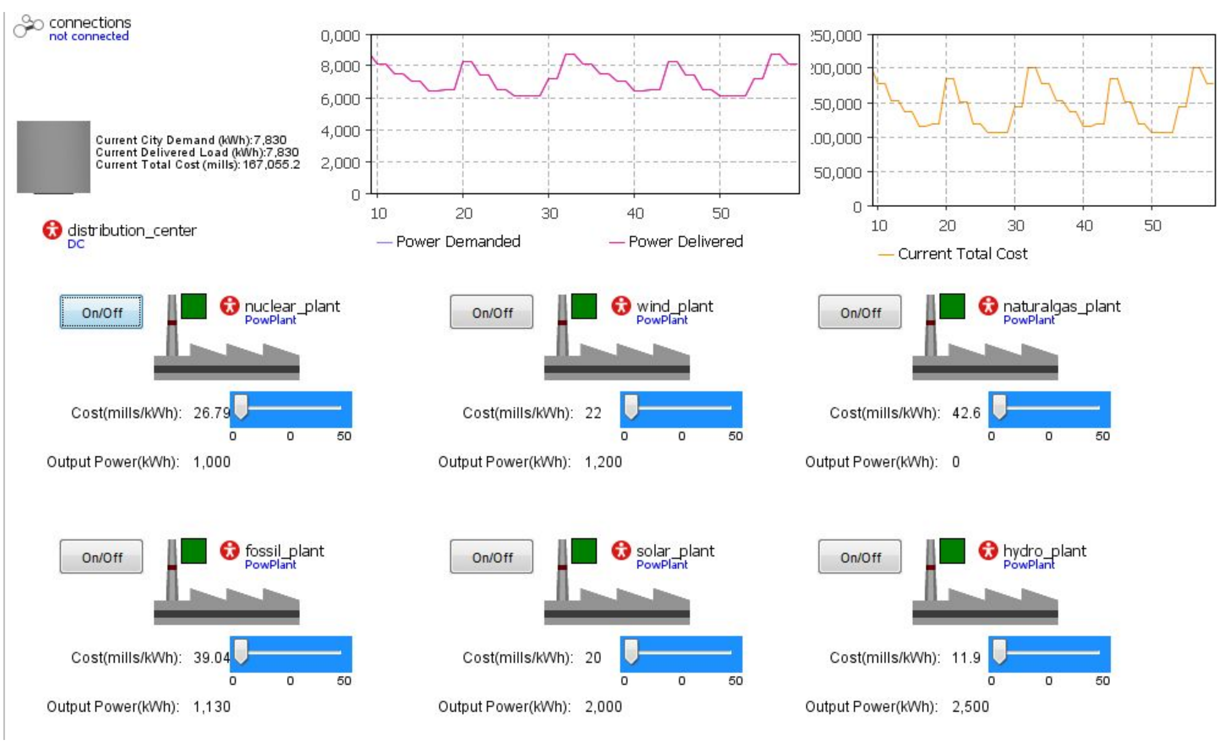

Illustration 9: All plants are functioning and generating energy at the current price rate

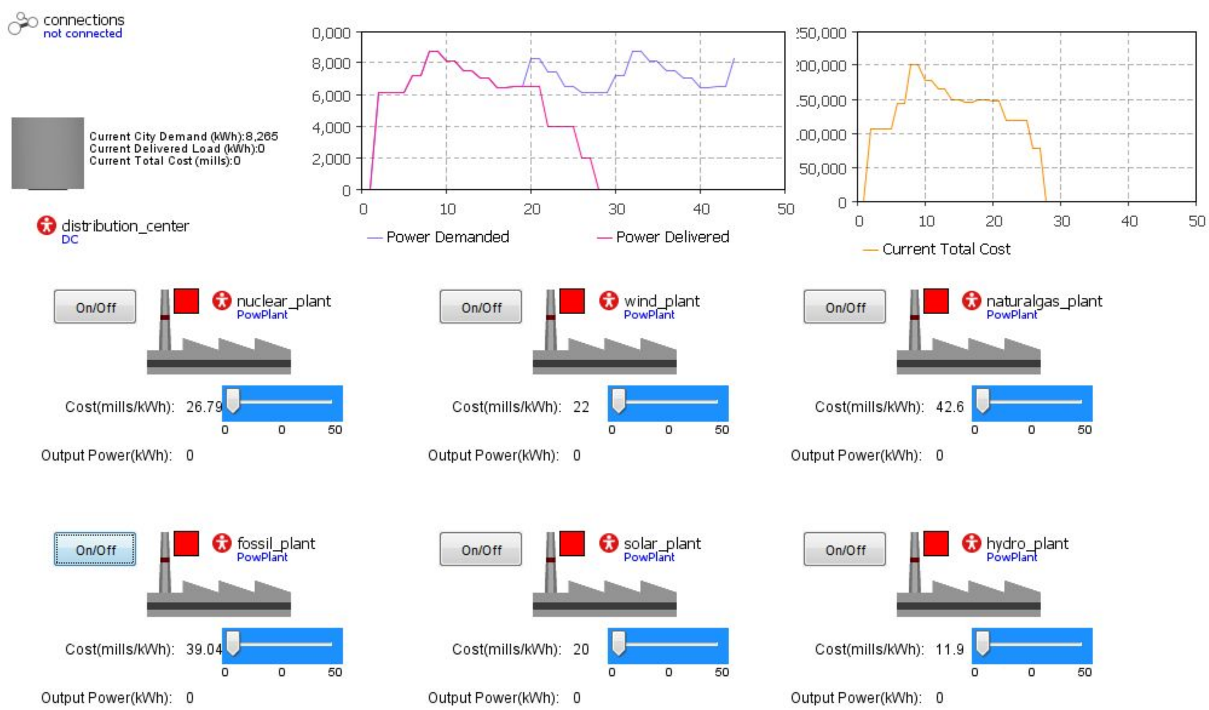

Illustration 10: All power plants are offline and the current city demand is not met

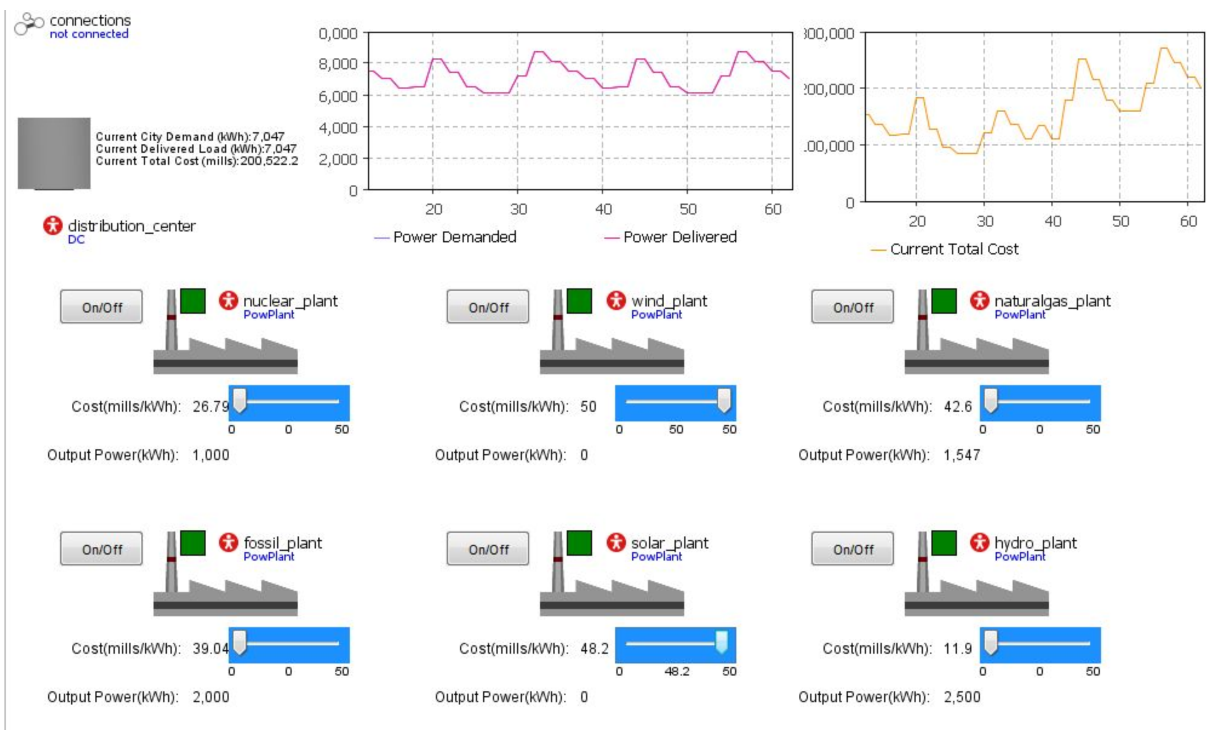

Illustration 11: Situation when total cost increases due to an increase in the price of wind and solar energy

Illustration 12: It is not uncommon for nuclear plants to go offline often because of periodic maintenance. This situation simulates a nuclear power plant shut down due to maintenance.

To summarize the layout of the simulation, the inputs are the price of each energy source and the hourly power demand of a city on daily basis. These inputs are read from a database and processed in order to calculate a minimal cost for purchasing the energy sources. The costs of each source can be varied as seen on the screen captures above. The output is the total current cost that is minimized based on the current city demand and the current available power supply. A continuous graph shows the power demand a power delivered as well as the total cost.

Future Scope

Features such as modeling a self-healing system or an intelligent system that determines how to best to respond to an outage can be added. Electric utility companies are focused on improving their response time to an outage as well as trying to prevent outages from occurring. "Most utilities count on complex power distribution schemes and manual switching to keep power flowing to most of their customers, even when power lines are damaged and destroyed." [5] However, these methods can be improved by adding sensors that can indicate when a distribution line has lost power. Simulating a system than is self-healing when the power distributed is interrupted would allow for the smart generation and distribution system to account for more dynamic occurrences within the power delivery industry and provide a useful application to all electric utility companies.

Citations

[1] R. Kempener, P. Komor and A. Hoke, *Smart Grids Renewables*, 1st ed. IRENA, 2013.
[2] *Smart Cities and Sustainability Initiative*, 1st ed. American Planning Association, 2015.
[3] Eia.gov, "SAS Output", 2016. [Online]. Available: http://www.eia.gov/electricity/annual/html/epa_08_04.html. [Accessed: 03- Mar- 2016].
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