EFFECTS OF INCORPORATING RENEWABLE ENERGY SOURCES INTO THE ELECTRICITY GRID

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By

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EFFECTS OF INCORPORATING RENEWABLE ENERGY SOURCES INTO THE ELECTRICITY GRID

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SUMMARY

With the increasing demand for energy throughout the world, the environment around us is getting severely affected. The conventional energy sources (coal, oil and gas) are unfortunately the biggest polluters of the environment. The aforementioned energy sources emit greenhouse gases like carbon dioxide and methane, which are responsible for global warming and ozone layer depletion.

The only feasible answer to this problem is to reduce the use of the conventional energy sources and focus more on other energy sources. The renewable energy sources (solar, wind and hydro) have been present in nature, but the technology to harvest these energies have always been relatively expensive until recently. The biggest advantage of using renewable energy sources is the fact that these energy sources will never run out and they also do not pollute the environment as their more conventional counterparts.

With more research being conducted into better ways of storing the power trapped from the renewable energy sources and the relative difficulty of obtaining the ever-depleting conventional energy sources, the future for renewable energy sources definitely looks better than at any time in the past

I. INTRODUCTION

1.1 Motivation for research

Global warming is a serious threat to the biodiversity of the planet and to the whole of humanity in general. On the other hand, the demand for fossil fuel is constantly increasing. As Figure 1 [1] shows, globally around 87% of the total energy used is generated by the use of fossil fuels, of which 28% comes from coal, 21% comes from natural gas and the remaining 38% comes from oil. [1]

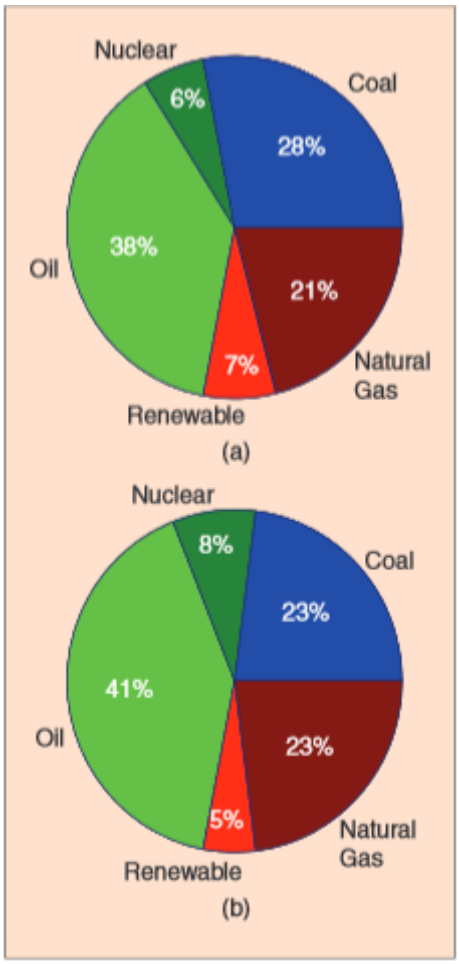

Figure 1: (a) Global and (b) U.S. energy generation scenario

On the other hand, the reserves for the conventional fuel types like coal, oil and gas are constantly being depleted as is shown in Figure 2. [1]

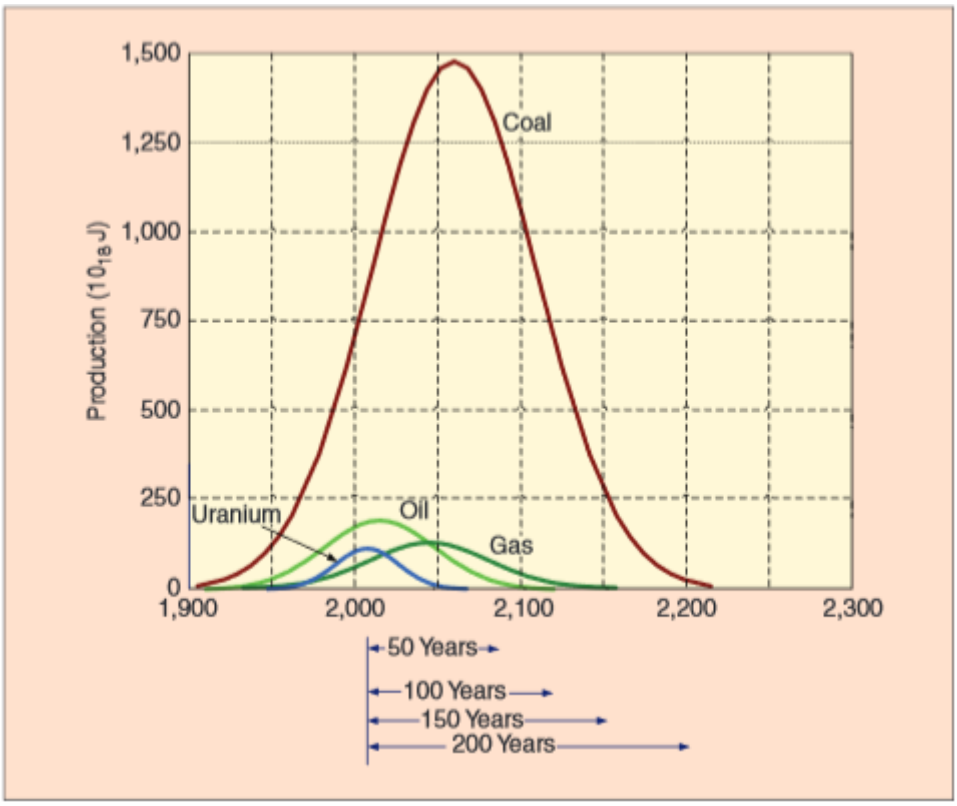

Figure 2: Idealized energy-depletion curves of the world

As Figure 2 shows, it is not a very long time before the reserves of the conventional energy sources run out, and there would be an immediate urge to look for alternative energy sources. The good news is that the alternative energy sources being discussed are surrounding us all the time, and the technology to harvest this energy is also present, though it is not as widespread as it should have been.

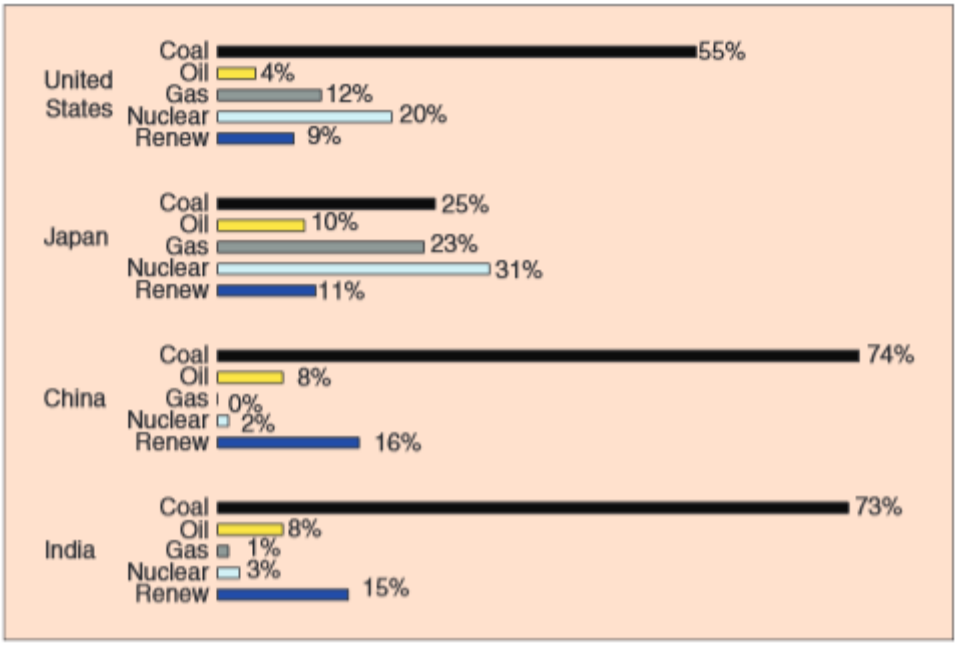

Figure 3: Electricity generation by fuel types for selected countries

Electricity has become an integral part of life for people living in various parts of the world. Hence, it is no surprise that with the explosive growth of human population worldwide, the demand for electricity has skyrocketed. The basic technology used to generated electricity is still not that different from the early days of electricity generation. Electricity generation today still relies heavily on the use of the conventional energy sources, or fossil fuels as Figure 3 [1] shows. Fossil fuels are heavy polluters of the environment and the reserves are depleting, as has been discussed before. Hence it is only natural to move away from heavy use of fossil fuels, at least to generate electricity, and think of the renewable energy sources as a viable alternative.

1.2 Generation of electricity from renewable sources

Currently the renewable energy sources that are most in use for generating electricity in the U.S. are wind, solar and biofuels as Figure 4 [2] shows.

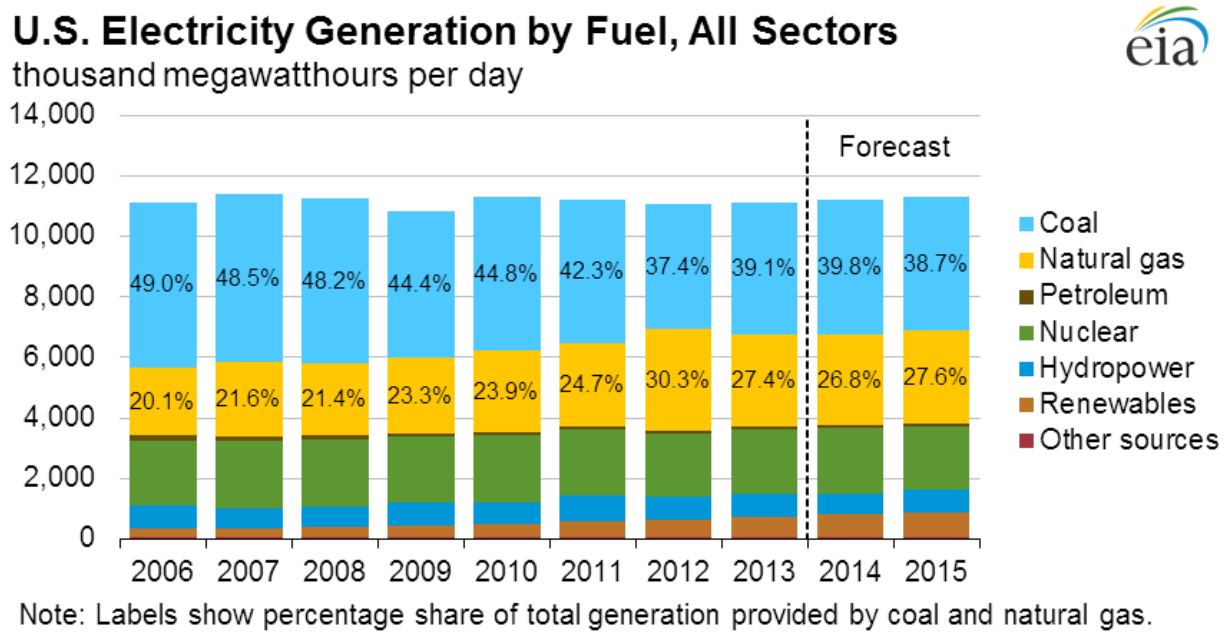

Figure 4: U.S. Electricity Generation by Fuel

Wind turbines, used to produce electricity from wind energy, are usually more efficient on a large scale like when producing power on a commercial scale to supply the national electrical grid. On a smaller scale, it is usually a good idea to pair small wind turbines with solar panels. This would ensure that power is constantly being produced- when the sun is shining, the solar panels would be producing electricity, and when the sun is not shining, wind turbines could be used to utilize the blowing wind.

Small wind turbines have their disadvantages, however. Small wind turbines are not as efficient as their larger counterparts- they need to be situated in areas with a

higher than average wind flow to generate a considerable amount of electrical power, as well as a smooth airflow. Locations near tall trees or busy roadways would not work well for situating these wind turbines as air turbulence would constantly make the wind turbine chase the wind rather than extract power from it. [3]

The problem with utilizing both these renewable energy sources is that both of these sources are highly location-specific. Not all locales have good sunshine or have a good flow of wind that can be used to generate electricity, as Figures 5 [4] and 6 [5] illustrate in the case of the U.S. Nonetheless, a clever mixture of the photovoltaic panels with the use of wind turbines can be used to offset these problems when done on a personal level. On a commercial level, as mentioned above, wind turbines are more efficient in harvesting the wind energy, and should be set up on wide open spaces like in huge prairies or on coastlines.

As Table 1 [7] depicts, the contribution of renewable energy sources to the generation of electricity in the U.S. is very small, almost negligible. As Figure 7 [6] shows, the utility companies account for a minuscule fraction of this tiny amount of power generated by renewable sources. This needs to change substantially if there is supposed to be a considerable change if global warming is to be reversed.

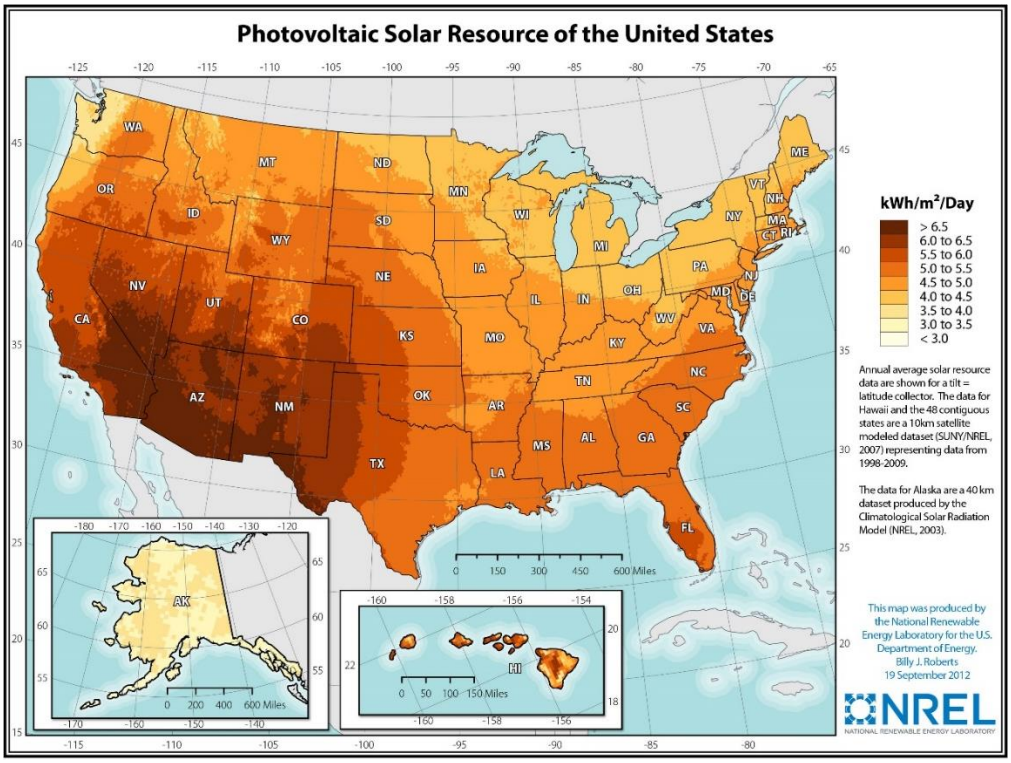

Figure 5: Solar energy map of the U.S.

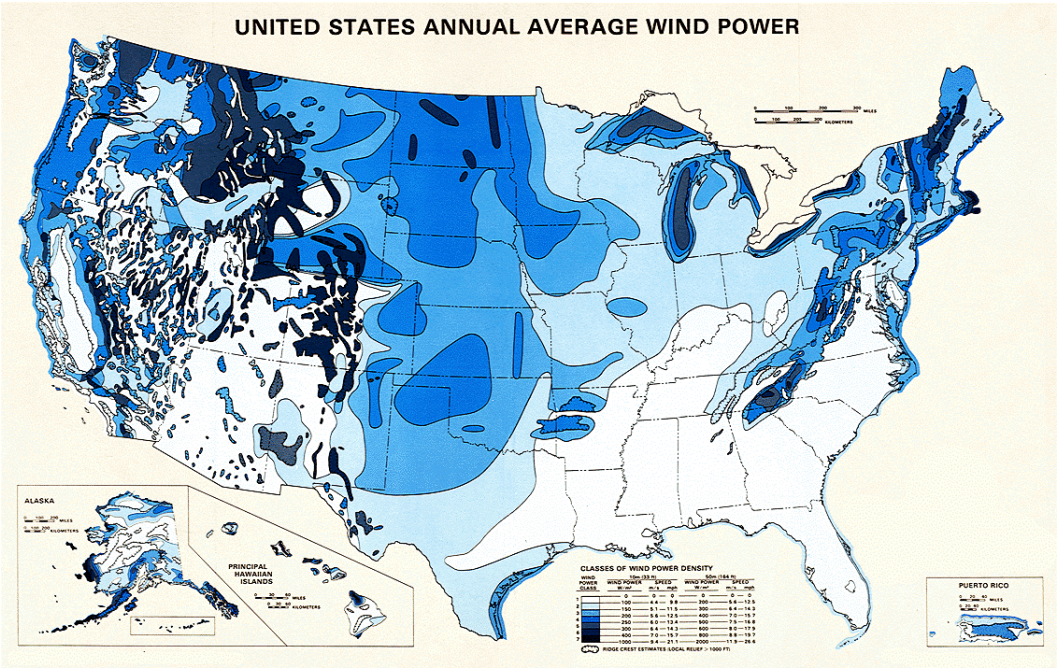

Figure 6: Wind energy map of the U.S.

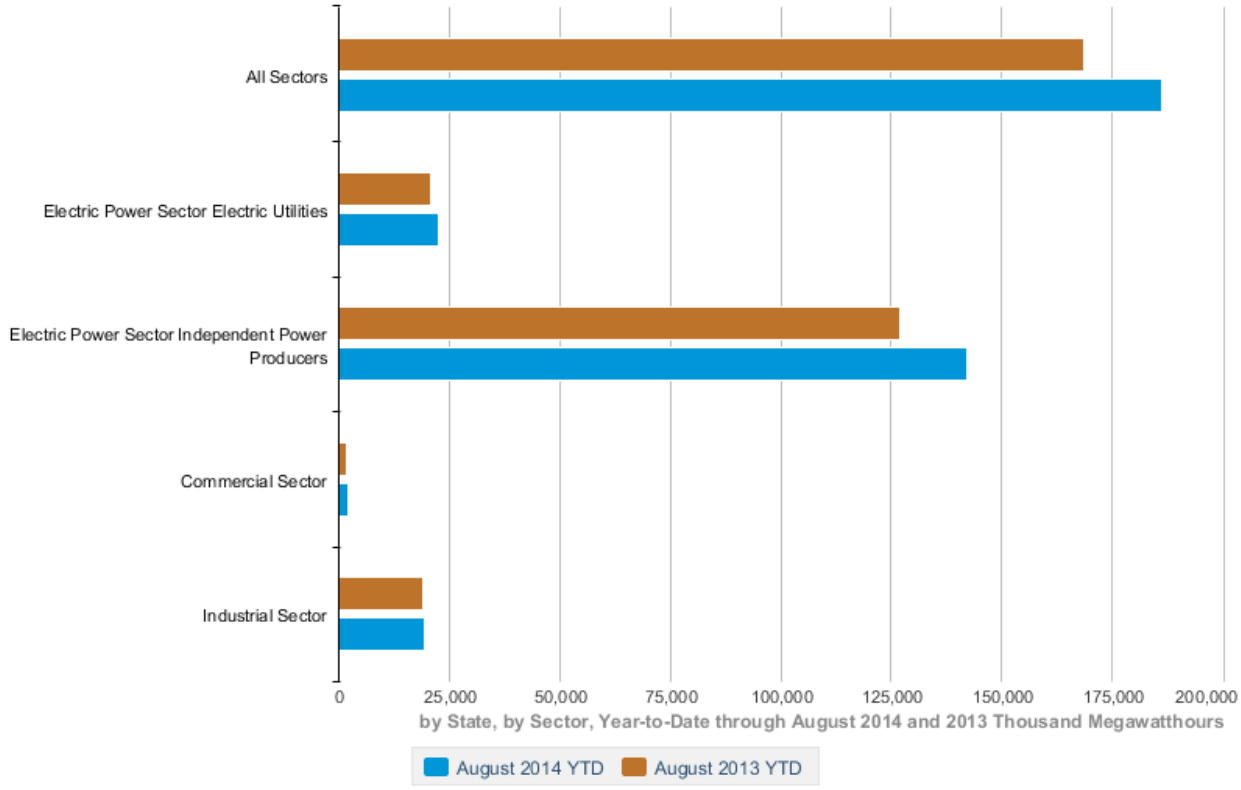

Figure 7: U.S. electricity generation from renewable energy sources

Table 1: Net generation (in thousand megawatthours) in the U.S.

Period	Renewable Sources Excluding Hydroelectric	Total
Annual Totals		
2004	83,067	3,970,555
2005	87,329	4,055,423
2006	96,525	4,064,702
2007	105,238	4,156,745
2008	126,101	4,119,388
2009	144,279	3,950,331
2010	167,173	4,125,060
2011	193,981	4,100,141
2012	218,333	4,047,765
2013	253,328	4,058,209

In this project, a model utility system was designed on which calculations could be performed, which would ultimately reveal the voltage values at all of the nodes along the transmission line. To achieve this, the various houses, offices, factories and single-phase loads connected to the transmission line were modelled as two-port circuit elements. Normally, there is a third port to the model, but in order to simplify the problem, it was assumed that in all of the loads, the third port was connected to the neutral of the transmission line and hence it did not have any effect on the calculations.

In a two-port circuit element, one of the ports is used to transmit current away from the circuit element, and the other port completes the circuit by bringing current towards the circuit element. For the project it was assumed that the voltage produced at the power generation system has already been stepped down with the use of appropriate transformers, and the stepped down voltage on the transmission line was modelled as a power generation source.

1.3 Prior and ongoing research

Wind energy has been used for centuries by human beings for various purposes. The earliest known windmills were present in Persia, present-day Iran, and looked like large paddle wheels. The largest windmills of today have blades longer than a football field [8]. The basic technology for using wind energy has remained the same however. The windmill blades utilize the kinetic energy of the wind flow and this in turn is used to serve the purpose of the windmill, for extracting water from underground for irrigation in the case of our forefathers, and generate electricity with the help of a generator in the case of the present day.

Photovoltaic cells, which are essential for harvesting energy from sunlight, is, in comparison with windmills, a more recent invention. Edmond Becquerel appears to be the first to demonstrate the photovoltaic effect while he was working in his father's laboratory as a young nineteen-year-old [9].

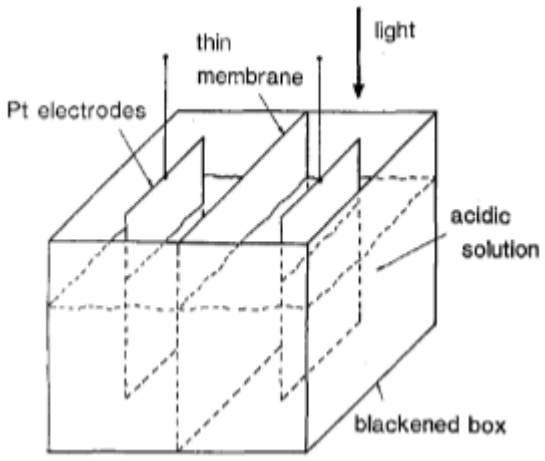

Figure 8: Diagram of apparatus described by Becquerel (1839)

Becquerel illuminated one of the electrodes in Figure 8 with lights of different colors, including sunlight. He noted that best results were obtained with blue or ultraviolet light and when the electrodes were coated with light sensitive material such as AgCl or AgBr.

The next significant development was when photoconductive effect of selenium was discovered by Adams and Day. Heated platinum contacts were pushed into vitreous selenium and then the whole setup was exposed to light to see whether it would be possible to induce current. The next step came seven years later with the work of Fritts. He managed to prepare thin selenium films by compressing molten selenium between plates made from two different metals. These selenium films would adhere to one plate but not to the other, and hence was the precursor for today's thin-film photovoltaic devices. He was also the first person to recognize the immense potential for the photovoltaic devices and could correctly predict that one day the photovoltaic devices could be manufactured at low costs. He was also the first person to note that if the current generated from these photovoltaic devices were not needed immediately, the current could be stored in batteries. It would however be fifty more years before there was another significant burst of activity in this area.

II. EXPERIMENTAL APPROACH

2.1 Experimental setup

The experiment was based on a model that consisted of seven houses, two factories, four offices and two single-phase loads. Due to the inability to gather real-life data on such models, the usage numbers for the different utility system customers were brainstormed, while trying to keep these usage numbers as close to reality as possible. The usage data for each of the customers were gathered on an hourly basis, and the calculations were performed on the software MATLAB. The following formulae were used in performing the calculations:

$I_1 = \frac{S}{(V_1-V_2)(V_1-V_2)^*}$ and $I_2 = \frac{S}{(V_2-V_1)(V_2-V_1)^*}$ where S represents the power usage of each customer per hour, and I_1, I_2, V_1 and V_2 represents the transmission line and load currents and voltages respectively. The current flowing through each terminal of each two-port circuit element were calculated using the following formulae:

$I_1 = Y_C V_1 - Y_C V_2$ and $I_2 = Y_C V_2 - Y_C V_1$ where I_1 and I_2 represent the current in each of the two terminals, Y_C represents the admittance of each customer for each hour, and V_1 and V_2 represent the voltages at the transmission line end and the load end of the circuit element respectively. For the power source, the current in each terminal I_1 and I_2 were calculated using the following formulae:

$I_1 = Y_S V_1 - Y_S V_2 + Y_S E$ and $I_2 = Y_S V_2 - Y_S V_1 + Y_S E$ where the Y_S represents the admittance matrix of the power source, V_1 and V_2 represent the voltages at each of the terminals and E represents the voltage generated at the power source.

2.2 The known numbers

The power usage of each customer per hour S is known from the utility system company data. The voltages V_1 and V_2 which represents the transmission line voltage and the load voltage respectively can also be obtained from the utility company. The value of E, the voltage generated at the power source, should be known to the utility company. The net admittance for all the customers connected to the transmission line per hour was calculated by summing up the admittance value for each customer per hour, and similarly, the net admittance of the transmission line was obtained. Then the total admittance of the whole utility network was obtained by summing these quantities, and by using the conservation of current law, a voltage expression was obtained which would give the voltage value at any point on the transmission line network.

III. RESULTS AND DISCUSSION

The results obtained from running MATLAB simulation on the utility company data for each of the customers on an hourly basis is given below:

What hour of day? Enter an integer number between 1 and 24 inclusive.

1

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	1 - j0.5	0.79 - j0.39	0.79 - j0.39	-1.6e+02 - j 85
House 2	1 - j0.8	0.77 - j0.62	0.77 - j0.62	-87 - j 59
House 3	1 - j0.4	0.28 - j0.11	0.28 - j0.11	-81 - j 59
House 4	1 - j0.8	0.55 - j0.44	0.55 - j0.44	-75 - j 56
Office 1	5 - j 3	2.2 - j1.3	2.2 - j1.3	-76 - j 56
Office 2	10 - j8.9	7.7 - j6.9	7.7 - j6.9	-92 - j 66
Office 3	10 - j9.4	5 - j4.7	5 - j4.7	-94 - j 63
Office 4	10 - j9.2	3.3 - j3.1	3.3 - j3.1	-1.1e+02 - j 77
Load 1	0.01 - j0.2	0.0057 - j0.11	0.0057 - j0.11	-1.1e+02 - j 75
Load 2	0.01 - j0.1	0.0055 - j0.055	0.0055 - j0.055	-1.1e+02 - j 71
Factory 1	5 - j0.5	2 - j0.2	2 - j0.2	-87 - j 62
Factory 2	5 - j0.5	2.2 - j0.22	2.2 - j0.22	-82 - j 59
House 5	1 - j0.2	0.77 - j0.15	0.77 - j0.15	-88 - j 63
House 6	1 - j0.3	0.28 - j0.083	0.28 - j0.083	-86 - j 59
House 7	1 - j0.2	0.75 - j0.15	0.75 - j0.15	-92 - j 66

What hour of day? Enter an integer number between 1 and 24 inclusive.

2

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	1 - j0.6	0.42 - j0.25	0.42 - j0.25	-1.5e+02 - j 78
House 2	1 - j0.7	0.5 - j0.35	0.5 - j0.35	-96 - j 60
House 3	1 - j0.4	0.29 - j0.12	0.29 - j0.12	-81 - j 56
House 4	1 - j0.7	0.41 - j0.29	0.41 - j0.29	-79 - j 55
Office 1	5 - j3.5	2.1 - j1.5	2.1 - j1.5	-80 - j 55
Office 2	10 - j 9	5 - j4.5	5 - j4.5	-80 - j 55
Office 3	15 - j 14	5.9 - j5.3	5.9 - j5.3	-1e+02 - j 63
Office 4	20 - j 15	6.2 - j4.5	6.2 - j4.5	-1.1e+02 - j 70
Load 1	0.01 - j0.3	0.0053 - j0.16	0.0053 - j0.16	-90 - j 60
Load 2	0.01 - j0.2	0.0041 - j0.083	0.0041 - j0.083	-1.2e+02 - j 69
Factory 1	5 - j0.7	1.9 - j0.26	1.9 - j0.26	-90 - j 60
Factory 2	5 - j1.7	2.1 - j0.7	2.1 - j0.7	-85 - j 58
House 5	1 - j0.3	0.5 - j0.15	0.5 - j0.15	-90 - j 60
House 6	1 - j0.4	0.29 - j0.12	0.29 - j0.12	-96 - j 60
House 7	1 - j0.3	0.38 - j0.11	0.38 - j0.11	-80 - j 55

What hour of day? Enter an integer number between 1 and 24 inclusive.

3

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.8	0.39 - j0.16	0.39 - j0.16	-1.6e+02 - j 80
House 2	3 - j 1	1.3 - j0.42	1.3 - j0.42	-93 - j 56
House 3	3 - j0.8	0.7 - j0.19	0.7 - j0.19	-83 - j 55
House 4	2 - j0.6	0.8 - j0.24	0.8 - j0.24	-79 - j 53
Office 1	5 - j3.6	2.2 - j1.6	2.2 - j1.6	-80 - j 53
Office 2	10 - j9.6	4.2 - j 4	4.2 - j 4	-81 - j 54
Office 3	15 - j 17	6.5 - j7.3	6.5 - j7.3	-96 - j 58
Office 4	20 - j 17	4.3 - j3.6	4.3 - j3.6	-1.1e+02 - j 68
Load 1	0.05 - j0.7	0.024 - j0.33	0.024 - j0.33	-92 - j 59
Load 2	0.02 - j0.2	0.008 - j0.08	0.008 - j0.08	-1.1e+02 - j 65
Factory 1	10 - j1.9	3.1 - j0.59	3.1 - j0.59	-88 - j 57
Factory 2	10 - j1.3	4.4 - j0.57	4.4 - j0.57	-83 - j 55
House 5	1 - j0.2	0.42 - j0.084	0.42 - j0.084	-92 - j 59
House 6	1 - j0.3	0.23 - j0.07	0.23 - j0.07	-89 - j 55
House 7	1 - j0.4	0.33 - j0.13	0.33 - j0.13	-81 - j 54

What hour of day? Enter an integer number between 1 and 24 inclusive.

4

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.8	0.43 - j0.17	0.43 - j0.17	-1.5e+02 - j 92
House 2	3 - j 1	1.2 - j0.42	1.2 - j0.42	-97 - j 66
House 3	3 - j0.9	0.8 - j0.24	0.8 - j0.24	-89 - j 63
House 4	2 - j1.2	0.9 - j0.54	0.9 - j0.54	-84 - j 60
Office 1	6 - j 5	2 - j1.7	2 - j1.7	-85 - j 61
Office 2	10 - j 11	4.2 - j4.4	4.2 - j4.4	-85 - j 61
Office 3	15 - j 18	7.1 - j8.4	7.1 - j8.4	-1e+02 - j 68
Office 4	20 - j 18	5.3 - j4.7	5.3 - j4.7	-1.1e+02 - j 74
Load 1	0.06 - j0.9	0.021 - j0.31	0.021 - j0.31	-95 - j 66
Load 2	0.02 - j0.3	0.009 - j0.14	0.009 - j0.14	-1.2e+02 - j 74
Factory 1	15 - j3.4	5.2 - j1.2	5.2 - j1.2	-93 - j 65
Factory 2	20 - j1.4	6.6 - j0.46	6.6 - j0.46	-88 - j 64
House 5	2 - j0.5	0.83 - j0.21	0.83 - j0.21	-95 - j 66
House 6	1 - j0.4	0.27 - j0.11	0.27 - j0.11	-95 - j 65
House 7	1 - j0.3	0.36 - j0.11	0.36 - j0.11	-85 - j 61

What hour of day? Enter an integer number between 1 and 24 inclusive.

5

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.9	0.69 - j0.31	0.69 - j0.31	-1.6e+02 - j 99
House 2	3 - j0.8	0.84 - j0.22	0.84 - j0.22	-1e+02 - j 73
House 3	3 - j1.4	0.98 - j0.46	0.98 - j0.46	-92 - j 68
House 4	4 - j1.3	1.1 - j0.37	1.1 - j0.37	-88 - j 65
Office 1	7 - j6.7	2.3 - j2.2	2.3 - j2.2	-98 - j 71
Office 2	20 - j 15	5.6 - j4.3	5.6 - j4.3	-91 - j 68
Office 3	15 - j 14	5.2 - j 5	5.2 - j 5	-1.2e+02 - j 81
Office 4	40 - j 29	13 - j9.7	13 - j9.7	-1.1e+02 - j 75
Load 1	0.06 - j 1	0.016 - j0.27	0.016 - j0.27	-99 - j 70
Load 2	0.02 - j0.6	0.0057 - j0.17	0.0057 - j0.17	-1.2e+02 - j 79
Factory 1	20 - j 6	7.7 - j2.3	7.7 - j2.3	-94 - j 67
Factory 2	20 - j2.3	6.5 - j0.75	6.5 - j0.75	-1.1e+02 - j 78
House 5	2 - j0.5	0.56 - j0.14	0.56 - j0.14	-99 - j 70
House 6	2 - j0.6	0.65 - j0.2	0.65 - j0.2	-1e+02 - j 70
House 7	1 - j0.6	0.34 - j0.21	0.34 - j0.21	-91 - j 68

What hour of day? Enter an integer number between 1 and 24 inclusive.

6

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.1	1.7 - j0.48	1.7 - j0.48	-1.5e+02 - j 92
House 2	4 - j1.6	0.091 - j0.037	0.091 - j0.037	-1e+02 - j 70
House 3	3 - j1.3	1.1 - j0.47	1.1 - j0.47	-86 - j 63
House 4	4 - j1.4	0.088 - j0.031	0.088 - j0.031	-83 - j 62
Office 1	8 - j7.5	3.1 - j 3	3.1 - j 3	-82 - j 61
Office 2	20 - j 17	0.46 - j0.38	0.46 - j0.38	-85 - j 63
Office 3	25 - j 21	8.9 - j7.3	8.9 - j7.3	-1.1e+02 - j 73
Office 4	50 - j 37	1.1 - j0.82	1.1 - j0.82	-1.1e+02 - j 70
Load 1	0.08 - j1.2	0.031 - j0.47	0.031 - j0.47	-92 - j 64
Load 2	0.03 - j0.7	0.00066 - j0.015	0.00066 - j0.015	-1.2e+02 - j 77
Factory 1	20 - j 8	10 - j4.1	10 - j4.1	-90 - j 64
Factory 2	25 - j3.4	9.8 - j1.3	9.8 - j1.3	-85 - j 63
House 5	3 - j0.8	0.069 - j0.018	0.069 - j0.018	-92 - j 64
House 6	2 - j0.8	0.72 - j0.29	0.72 - j0.29	-99 - j 69
House 7	2 - j0.8	0.71 - j0.28	0.71 - j0.28	-85 - j 63

What hour of day? Enter an integer number between 1 and 24 inclusive.

7

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.2	1.9 - j0.56	1.9 - j0.56	-1.6e+02 - j 94
House 2	4 - j1.5	1.1 - j0.43	1.1 - j0.43	-1.1e+02 - j 74
House 3	4 - j1.2	1.4 - j0.42	1.4 - j0.42	-91 - j 63
House 4	4 - j1.6	1.4 - j0.55	1.4 - j0.55	-97 - j 66
Office 1	9 - j 11	3.4 - j 4	3.4 - j 4	-1.3e+02 - j 83
Office 2	40 - j 30	11 - j8.7	11 - j8.7	-1.1e+02 - j 73
Office 3	50 - j 41	23 - j 18	23 - j 18	-1.1e+02 - j 74
Office 4	60 - j 55	24 - j 22	24 - j 22	-1.3e+02 - j 72
Load 1	0.08 - j1.3	0.029 - j0.47	0.029 - j0.47	-1.1e+02 - j 74
Load 2	0.1 - j0.6	0.035 - j0.21	0.035 - j0.21	-96 - j 66
Factory 1	40 - j 11	19 - j4.9	19 - j4.9	-1.1e+02 - j 69
Factory 2	40 - j 10	15 - j3.9	15 - j3.9	-1.3e+02 - j 83
House 5	3 - j1.3	0.86 - j0.37	0.86 - j0.37	-1.3e+02 - j 81
House 6	2 - j 1	0.7 - j0.35	0.7 - j0.35	-96 - j 66
House 7	2 - j0.9	0.79 - j0.35	0.79 - j0.35	-1.1e+02 - j 73

What hour of day? Enter an integer number between 1 and 24 inclusive.

8

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.4	1.9 - j0.66	1.9 - j0.66	-1.5e+02 - j 84
House 2	5 - j1.6	2.1 - j0.67	2.1 - j0.67	-1e+02 - j 62
House 3	5 - j1.8	2.1 - j0.75	2.1 - j0.75	-88 - j 55
House 4	5 - j 2	1.6 - j0.64	1.6 - j0.64	-92 - j 57
Office 1	15 - j 11	6.2 - j4.7	6.2 - j4.7	-1.2e+02 - j 69
Office 2	1e+02 - j 50	42 - j 21	42 - j 21	-1e+02 - j 63
Office 3	80 - j 71	27 - j 24	27 - j 24	-1e+02 - j 62
Office 4	1e+02 - j 80	40 - j 32	40 - j 32	-1.4e+02 - j 66
Load 1	0.09 - j1.6	0.035 - j0.62	0.035 - j0.62	-1e+02 - j 62
Load 2	0.1 - j0.4	0.032 - j0.13	0.032 - j0.13	-91 - j 57
Factory 1	50 - j 15	22 - j6.7	22 - j6.7	-1.1e+02 - j 62
Factory 2	60 - j 16	25 - j6.5	25 - j6.5	-1.2e+02 - j 69
House 5	3 - j1.4	1.3 - j0.59	1.3 - j0.59	-98 - j 60
House 6	2 - j1.2	0.83 - j0.5	0.83 - j0.5	-91 - j 57
House 7	2 - j1.2	0.72 - j0.43	0.72 - j0.43	-1e+02 - j 63

What hour of day? Enter an integer number between 1 and 24 inclusive.

9

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.6	2.2 - j0.87	2.2 - j0.87	-1.6e+02 - j 85
House 2	5 - j1.8	1.7 - j0.63	1.7 - j0.63	-1.1e+02 - j 62
House 3	5 - j 2	2.3 - j0.91	2.3 - j0.91	-91 - j 54
House 4	5 - j2.4	2.2 - j1.1	2.2 - j1.1	-94 - j 56
Office 1	20 - j 14	8 - j5.4	8 - j5.4	-1.2e+02 - j 68
Office 2	1e+02 - j 61	35 - j 21	35 - j 21	-1.1e+02 - j 61
Office 3	1.4e+02 - j1.1e+02	66 - j 52	66 - j 52	-1.1e+02 - j 62
Office 4	1.5e+02 - j1.2e+02	77 - j 62	77 - j 62	-1.2e+02 - j 61
Load 1	0.09 - j1.7	0.027 - j0.51	0.027 - j0.51	-1.1e+02 - j 62
Load 2	0.13 - j0.5	0.058 - j0.22	0.058 - j0.22	-95 - j 57
Factory 1	90 - j 16	49 - j8.4	49 - j8.4	-1.1e+02 - j 59
Factory 2	1.5e+02 - j 80	60 - j 32	60 - j 32	-1.2e+02 - j 68
House 5	4 - j1.5	1.4 - j0.52	1.4 - j0.52	-1e+02 - j 59
House 6	2 - j1.3	0.91 - j0.59	0.91 - j0.59	-95 - j 57
House 7	2 - j1.3	0.67 - j0.44	0.67 - j0.44	-1.1e+02 - j 61

What hour of day? Enter an integer number between 1 and 24 inclusive.

10

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	3 - j1.5	1.7 - j0.87	1.7 - j0.87	-1.7e+02 - j1.1e+02
House 2	5 - j1.9	1.5 - j0.57	1.5 - j0.57	-1e+02 - j 68
House 3	5 - j2.4	2.6 - j1.2	2.6 - j1.2	-87 - j 62
House 4	5 - j2.6	2.1 - j1.1	2.1 - j1.1	-91 - j 64
Office 1	30 - j 16	15 - j 8	15 - j 8	-1.1e+02 - j 73
Office 2	1.5e+02 - j 71	45 - j 21	45 - j 21	-1e+02 - j 68
Office 3	2e+02 - j1.5e+02	95 - j 72	95 - j 72	-1e+02 - j 68
Office 4	1.5e+02 - j1.3e+02	74 - j 64	74 - j 64	-1.2e+02 - j 73
Load 1	0.15 - j1.8	0.046 - j0.55	0.046 - j0.55	-1e+02 - j 68
Load 2	0.2 - j0.6	0.085 - j0.26	0.085 - j0.26	-91 - j 63
Factory 1	1.5e+02 - j 51	87 - j 29	87 - j 29	-1e+02 - j 68
Factory 2	2e+02 - j1.1e+02	1e+02 - j 57	1e+02 - j 57	-1.1e+02 - j 73
House 5	5 - j1.6	1.5 - j0.48	1.5 - j0.48	-97 - j 66
House 6	3 - j1.5	1.5 - j0.77	1.5 - j0.77	-91 - j 63
House 7	3 - j1.4	0.87 - j0.4	0.87 - j0.4	-1e+02 - j 68

What hour of day? Enter an integer number between 1 and 24 inclusive.

11

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	3 - j1.4	1.6 - j0.77	1.6 - j0.77	-1.7e+02 - j1.1e+02
House 2	5 - j 2	1.5 - j0.59	1.5 - j0.59	-95 - j 63
House 3	5 - j2.6	2.1 - j1.1	2.1 - j1.1	-90 - j 62
House 4	5 - j2.9	2 - j1.1	2 - j1.1	-94 - j 65
Office 1	60 - j 21	25 - j8.7	25 - j8.7	-1e+02 - j 66
Office 2	2e+02 - j 80	59 - j 24	59 - j 24	-1e+02 - j 67
Office 3	2.5e+02 - j2.2e+02	1.4e+02 - j1.2e+02	1.4e+02 - j1.2e+02	-95 - j 63
Office 4	1.5e+02 - j1.5e+02	69 - j 70	69 - j 70	-1.2e+02 - j 74
Load 1	0.2 - j 2	0.063 - j0.63	0.063 - j0.63	-95 - j 63
Load 2	0.3 - j0.6	0.12 - j0.23	0.12 - j0.23	-87 - j 61
Factory 1	2e+02 - j2e+02	1.1e+02 - j1.1e+02	1.1e+02 - j1.1e+02	-1e+02 - j 67
Factory 2	3e+02 - j1.5e+02	1.2e+02 - j 62	1.2e+02 - j 62	-1e+02 - j 66
House 5	5 - j1.8	1.5 - j0.53	1.5 - j0.53	-90 - j 61
House 6	3 - j1.6	1.3 - j0.67	1.3 - j0.67	-87 - j 61
House 7	4 - j1.5	1.6 - j0.61	1.6 - j0.61	-1e+02 - j 67

What hour of day? Enter an integer number between 1 and 24 inclusive.

12

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.9	1 - j0.46	1 - j0.46	-1.4e+02 - j1.2e+02
House 2	4 - j2.1	1.2 - j0.63	1.2 - j0.63	-87 - j 73
House 3	5 - j2.8	1.9 - j 1	1.9 - j 1	-72 - j 64
House 4	5 - j 3	1.5 - j0.91	1.5 - j0.91	-76 - j 68
Office 1	70 - j 25	25 - j 9	25 - j 9	-97 - j 76
Office 2	2.5e+02 - j1e+02	75 - j 30	75 - j 30	-84 - j 71
Office 3	3e+02 - j2.6e+02	1.2e+02 - j1e+02	1.2e+02 - j1e+02	-87 - j 73
Office 4	1.5e+02 - j1.7e+02	56 - j 63	56 - j 63	-1.3e+02 - j 96
Load 1	0.25 - j1.9	0.075 - j0.57	0.075 - j0.57	-87 - j 73
Load 2	0.5 - j0.4	0.15 - j0.12	0.15 - j0.12	-79 - j 70
Factory 1	2.5e+02 - j2.6e+02	1.3e+02 - j1.3e+02	1.3e+02 - j1.3e+02	-97 - j 81
Factory 2	4e+02 - j1.8e+02	1.4e+02 - j 65	1.4e+02 - j 65	-97 - j 76
House 5	5 - j1.9	1.5 - j0.57	1.5 - j0.57	-81 - j 69
House 6	3 - j1.7	1.1 - j0.63	1.1 - j0.63	-79 - j 70
House 7	4 - j1.6	1.7 - j0.67	1.7 - j0.67	-84 - j 71

What hour of day? Enter an integer number between 1 and 24 inclusive.

13

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.9	0.98 - j0.44	0.98 - j0.44	-82 - j 82
House 2	3 - j 2	0.96 - j0.64	0.96 - j0.64	-35 - j 49
House 3	4 - j2.7	1.2 - j0.84	1.2 - j0.84	-26 - j 40
House 4	4 - j 3	1.6 - j1.2	1.6 - j1.2	-62 - j 69
Office 1	70 - j 31	22 - j9.7	22 - j9.7	-30 - j 44
Office 2	3e+02 - j1.2e+02	96 - j 39	96 - j 39	-34 - j 45
Office 3	3e+02 - j2.8e+02	2e+02 - j1.8e+02	2e+02 - j1.8e+02	-35 - j 49
Office 4	1.4e+02 - j1.8e+02	41 - j 53	41 - j 53	-1.1e+02 - j 50
Load 1	0.3 - j1.5	0.095 - j0.48	0.095 - j0.48	-53 - j 58
Load 2	0.5 - j0.6	0.2 - j0.24	0.2 - j0.24	-46 - j 58
Factory 1	2.5e+02 - j2.8e+02	1.1e+02 - j1.2e+02	1.1e+02 - j1.2e+02	-84 - j 65
Factory 2	4e+02 - j2.1e+02	1.3e+02 - j 67	1.3e+02 - j 67	-30 - j 44
House 5	5 - j 2	1.6 - j0.64	1.6 - j0.64	-44 - j 53
House 6	3 - j1.6	0.93 - j0.5	0.93 - j0.5	-46 - j 58
House 7	4 - j1.9	1.8 - j0.84	1.8 - j0.84	-34 - j 45

What hour of day? Enter an integer number between 1 and 24 inclusive.

14

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.8	0.75 - j0.3	0.75 - j0.3	-68 - j 76
House 2	3 - j1.6	1.3 - j0.68	1.3 - j0.68	-35 - j 50
House 3	3 - j2.4	0.76 - j0.61	0.76 - j0.61	-29 - j 44
House 4	2 - j2.5	0.77 - j0.96	0.77 - j0.96	-55 - j 65
Office 1	70 - j 51	25 - j 18	25 - j 18	-31 - j 46
Office 2	3e+02 - j1.3e+02	1.3e+02 - j 56	1.3e+02 - j 56	-36 - j 48
Office 3	3e+02 - j3.2e+02	1.5e+02 - j1.6e+02	1.5e+02 - j1.6e+02	-35 - j 50
Office 4	1.4e+02 - j1.8e+02	33 - j 42	33 - j 42	-1e+02 - j 57
Load 1	0.3 - j1.2	0.13 - j0.52	0.13 - j0.52	-50 - j 57
Load 2	0.5 - j0.7	0.19 - j0.27	0.19 - j0.27	-43 - j 57
Factory 1	2.5e+02 - j2.9e+02	78 - j 91	78 - j 91	-75 - j 66
Factory 2	4e+02 - j2.8e+02	1.4e+02 - j 98	1.4e+02 - j 98	-31 - j 46
House 5	4 - j2.2	1.7 - j0.94	1.7 - j0.94	-47 - j 57
House 6	3 - j1.4	0.76 - j0.35	0.76 - j0.35	-43 - j 57
House 7	4 - j 2	2.3 - j1.1	2.3 - j1.1	-36 - j 48

What hour of day? Enter an integer number between 1 and 24 inclusive.

15

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.8	0.78 - j0.31	0.78 - j0.31	-75 - j 69
House 2	3 - j1.7	1.2 - j0.65	1.2 - j0.65	-39 - j 44
House 3	3 - j2.2	0.74 - j0.54	0.74 - j0.54	-29 - j 35
House 4	2 - j2.7	0.78 - j1.1	0.78 - j1.1	-55 - j 55
Office 1	70 - j 61	23 - j 20	23 - j 20	-31 - j 38
Office 2	2.5e+02 - j1.4e+02	96 - j 54	96 - j 54	-36 - j 39
Office 3	3e+02 - j3.4e+02	1.8e+02 - j2.1e+02	1.8e+02 - j2.1e+02	-39 - j 44
Office 4	1.3e+02 - j1.5e+02	33 - j 38	33 - j 38	-1.1e+02 - j 54
Load 1	0.3 - j1.7	0.12 - j0.71	0.12 - j0.71	-51 - j 48
Load 2	0.4 - j0.7	0.16 - j0.27	0.16 - j0.27	-48 - j 51
Factory 1	2e+02 - j3e+02	72 - j1.1e+02	72 - j1.1e+02	-75 - j 58
Factory 2	3.5e+02 - j3.1e+02	1.2e+02 - j1e+02	1.2e+02 - j1e+02	-31 - j 38
House 5	4 - j2.4	1.5 - j0.92	1.5 - j0.92	-44 - j 45
House 6	2 - j1.3	0.49 - j0.32	0.49 - j0.32	-48 - j 51
House 7	3 - j 2	1.7 - j1.1	1.7 - j1.1	-36 - j 39

What hour of day? Enter an integer number between 1 and 24 inclusive.

16

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j0.7	1.3 - j0.45	1.3 - j0.45	-84 - j 60
House 2	4 - j2.1	1.7 - j0.87	1.7 - j0.87	-41 - j 37
House 3	5 - j2.9	1.5 - j0.88	1.5 - j0.88	-35 - j 32
House 4	4 - j 3	1.7 - j1.3	1.7 - j1.3	-60 - j 46
Office 1	70 - j 71	25 - j 25	25 - j 25	-38 - j 34
Office 2	2e+02 - j1.6e+02	83 - j 66	83 - j 66	-41 - j 34
Office 3	2.5e+02 - j3e+02	1.8e+02 - j2.2e+02	1.8e+02 - j2.2e+02	-41 - j 37
Office 4	1.3e+02 - j1.4e+02	39 - j 42	39 - j 42	-1e+02 - j 53
Load 1	0.25 - j1.6	0.12 - j0.79	0.12 - j0.79	-53 - j 40
Load 2	0.3 - j0.8	0.13 - j0.34	0.13 - j0.34	-48 - j 41
Factory 1	1.5e+02 - j3.2e+02	82 - j1.8e+02	82 - j1.8e+02	-77 - j 51
Factory 2	3e+02 - j3.2e+02	1.1e+02 - j1.1e+02	1.1e+02 - j1.1e+02	-38 - j 34
House 5	3 - j2.2	1.2 - j0.91	1.2 - j0.91	-51 - j 41
House 6	2 - j1.1	0.61 - j0.33	0.61 - j0.33	-48 - j 41
House 7	3 - j1.7	1.7 - j0.95	1.7 - j0.95	-41 - j 34

What hour of day? Enter an integer number between 1 and 24 inclusive.

17

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	3 - j1.2	3 - j1.2	3 - j1.2	-72 - j 48
House 2	4 - j2.2	1.4 - j0.8	1.4 - j0.8	-34 - j 29
House 3	5 - j 3	2 - j1.2	2 - j1.2	-27 - j 24
House 4	5 - j3.4	2.4 - j1.6	2.4 - j1.6	-46 - j 34
Office 1	60 - j 76	24 - j 31	24 - j 31	-30 - j 26
Office 2	1e+02 - j1.2e+02	36 - j 44	36 - j 44	-31 - j 25
Office 3	2e+02 - j2.5e+02	1.5e+02 - j1.8e+02	1.5e+02 - j1.8e+02	-34 - j 29
Office 4	1.3e+02 - j1.4e+02	60 - j 65	60 - j 65	-1.1e+02 - j 45
Load 1	0.2 - j1.4	0.082 - j0.57	0.082 - j0.57	-40 - j 29
Load 2	0.25 - j0.6	0.12 - j0.28	0.12 - j0.28	-38 - j 31
Factory 1	1e+02 - j3.2e+02	1e+02 - j3.2e+02	1e+02 - j3.2e+02	-66 - j 40
Factory 2	3e+02 - j2.9e+02	1.2e+02 - j1.2e+02	1.2e+02 - j1.2e+02	-30 - j 26
House 5	3 - j2.1	1.1 - j0.76	1.1 - j0.76	-45 - j 35
House 6	2 - j 1	0.81 - j0.4	0.81 - j0.4	-38 - j 31
House 7	3 - j1.4	0.88 - j0.41	0.88 - j0.41	-31 - j 25

What hour of day? Enter an integer number between 1 and 24 inclusive.

18

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.7	2.7 - j1.1	2.7 - j1.1	-69 - j 58
House 2	5 - j2.4	1.9 - j0.92	1.9 - j0.92	-34 - j 36
House 3	5 - j3.4	1.6 - j1.1	1.6 - j1.1	-28 - j 31
House 4	5 - j3.3	2.5 - j1.6	2.5 - j1.6	-49 - j 42
Office 1	50 - j 70	16 - j 23	16 - j 23	-31 - j 34
Office 2	70 - j 81	27 - j 31	27 - j 31	-34 - j 33
Office 3	2e+02 - j2.3e+02	85 - j 98	85 - j 98	-34 - j 36
Office 4	1e+02 - j1.2e+02	27 - j 33	27 - j 33	-97 - j 61
Load 1	0.2 - j 1	0.08 - j0.4	0.08 - j0.4	-45 - j 38
Load 2	0.25 - j0.7	0.12 - j0.35	0.12 - j0.35	-39 - j 38
Factory 1	1e+02 - j2.8e+02	66 - j1.9e+02	66 - j1.9e+02	-66 - j 51
Factory 2	2.5e+02 - j2.8e+02	82 - j 92	82 - j 92	-31 - j 34
House 5	3 - j 2	1.1 - j0.77	1.1 - j0.77	-49 - j 46
House 6	2 - j0.9	0.66 - j0.3	0.66 - j0.3	-39 - j 38
House 7	3 - j1.3	0.9 - j0.39	0.9 - j0.39	-34 - j 33

What hour of day? Enter an integer number between 1 and 24 inclusive.

19

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.4	2.2 - j0.77	2.2 - j0.77	-1e+02 - j 89
House 2	5 - j2.5	2.3 - j1.1	2.3 - j1.1	-83 - j 72
House 3	5 - j3.3	1.4 - j0.93	1.4 - j0.93	-61 - j 65
House 4	5 - j3.3	2.7 - j1.8	2.7 - j1.8	-1.1e+02 - j 90
Office 1	20 - j 41	5.6 - j 11	5.6 - j 11	-93 - j 72
Office 2	40 - j 50	18 - j 23	18 - j 23	-72 - j 68
Office 3	1.5e+02 - j1.3e+02	58 - j 51	58 - j 51	-69 - j 67
Office 4	80 - j1.1e+02	30 - j 41	30 - j 41	-90 - j 70
Load 1	0.16 - j0.9	0.068 - j0.38	0.068 - j0.38	-59 - j 59
Load 2	0.2 - j0.4	0.11 - j0.22	0.11 - j0.22	-57 - j 62
Factory 1	60 - j1.4e+02	33 - j 77	33 - j 77	-98 - j 79
Factory 2	1e+02 - j1.9e+02	28 - j 53	28 - j 53	-77 - j 68
House 5	2 - j1.6	0.9 - j0.72	0.9 - j0.72	-85 - j 67
House 6	1 - j0.8	0.28 - j0.22	0.28 - j0.22	-75 - j 74
House 7	2 - j1.2	0.81 - j0.49	0.81 - j0.49	-65 - j 60

What hour of day? Enter an integer number between 1 and 24 inclusive.

20

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	4 - j1.3	1.7 - j0.56	1.7 - j0.56	-1.5e+02 - j 89
House 2	5 - j2.4	2.6 - j1.2	2.6 - j1.2	-1.2e+02 - j 71
House 3	5 - j3.2	1.4 - j0.9	1.4 - j0.9	-98 - j 69
House 4	5 - j3.2	4.3 - j2.7	4.3 - j2.7	-1.5e+02 - j 90
Office 1	10 - j 24	2.8 - j6.7	2.8 - j6.7	-1.3e+02 - j 69
Office 2	20 - j 31	10 - j 16	10 - j 16	-1.1e+02 - j 69
Office 3	1e+02 - j 40	73 - j 29	73 - j 29	-1.1e+02 - j 71
Office 4	50 - j 86	23 - j 40	23 - j 40	-97 - j 58
Load 1	0.1 - j0.8	0.051 - j0.4	0.051 - j0.4	-96 - j 64
Load 2	0.15 - j0.4	0.13 - j0.34	0.13 - j0.34	-91 - j 65
Factory 1	50 - j 31	21 - j 13	21 - j 13	-1.2e+02 - j 71
Factory 2	80 - j1.2e+02	23 - j 34	23 - j 34	-1.2e+02 - j 69
House 5	2 - j1.3	1 - j0.67	1 - j0.67	-1.2e+02 - j 68
House 6	1 - j0.6	0.28 - j0.17	0.28 - j0.17	-1.1e+02 - j 76
House 7	2 - j 1	0.91 - j0.45	0.91 - j0.45	-1e+02 - j 63

What hour of day? Enter an integer number between 1 and 24 inclusive.

21

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	2 - j 1	1.7 - j0.84	1.7 - j0.84	-1.4e+02 - j 86
House 2	2 - j1.5	1 - j0.77	1 - j0.77	-1.2e+02 - j 74
House 3	3 - j2.3	1.1 - j0.83	1.1 - j0.83	-1e+02 - j 71
House 4	3 - j2.4	1.5 - j1.2	1.5 - j1.2	-1.6e+02 - j 97
Office 1	5 - j 10	5.9 - j 12	5.9 - j 12	-1.3e+02 - j 73
Office 2	10 - j 20	5.1 - j 10	5.1 - j 10	-1.1e+02 - j 71
Office 3	50 - j 36	22 - j 16	22 - j 16	-1.1e+02 - j 70
Office 4	30 - j 23	15 - j 12	15 - j 12	-97 - j 58
Load 1	0.08 - j0.6	0.041 - j0.31	0.041 - j0.31	-98 - j 65
Load 2	0.1 - j0.3	0.052 - j0.15	0.052 - j0.15	-93 - j 66
Factory 1	40 - j 26	30 - j 19	30 - j 19	-1.2e+02 - j 73
Factory 2	50 - j 40	59 - j 48	59 - j 48	-1.2e+02 - j 70
House 5	2 - j 1	1 - j0.51	1 - j0.51	-1.3e+02 - j 72
House 6	2 - j0.4	0.72 - j0.14	0.72 - j0.14	-1.2e+02 - j 79
House 7	1 - j0.8	0.38 - j0.31	0.38 - j0.31	-1.1e+02 - j 65

What hour of day? Enter an integer number between 1 and 24 inclusive.

22

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	1 - j0.7	0.6 - j0.42	0.6 - j0.42	-1.4e+02 - j1e+02
House 2	2 - j 1	1.3 - j0.64	1.3 - j0.64	-1.1e+02 - j 85
House 3	3 - j 2	1.4 - j0.92	1.4 - j0.92	-96 - j 78
House 4	2 - j1.6	0.98 - j0.79	0.98 - j0.79	-1.7e+02 - j1.2e+02
Office 1	5 - j8.7	4.7 - j8.2	4.7 - j8.2	-1.2e+02 - j 83
Office 2	10 - j 15	6.4 - j9.8	6.4 - j9.8	-1.1e+02 - j 79
Office 3	30 - j 20	11 - j7.6	11 - j7.6	-1e+02 - j 81
Office 4	20 - j 20	14 - j 15	14 - j 15	-92 - j 64
Load 1	0.07 - j0.3	0.043 - j0.18	0.043 - j0.18	-95 - j 74
Load 2	0.1 - j0.4	0.049 - j0.2	0.049 - j0.2	-90 - j 76
Factory 1	30 - j 21	18 - j 13	18 - j 13	-1.2e+02 - j 83
Factory 2	30 - j 30	28 - j 28	28 - j 28	-1.1e+02 - j 79
House 5	1 - j0.9	0.64 - j0.58	0.64 - j0.58	-1.2e+02 - j 83
House 6	2 - j0.3	0.92 - j0.14	0.92 - j0.14	-1.2e+02 - j 92
House 7	1 - j0.6	0.47 - j0.28	0.47 - j0.28	-99 - j 73

What hour of day? Enter an integer number between 1 and 24 inclusive.

23

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	1 - j0.6	0.58 - j0.35	0.58 - j0.35	-1.5e+02 - j 94
House 2	1 - j0.8	0.47 - j0.38	0.47 - j0.38	-1.3e+02 - j 85
House 3	2 - j0.9	1 - j0.47	1 - j0.47	-97 - j 70
House 4	2 - j1.3	0.99 - j0.64	0.99 - j0.64	-1.7e+02 - j1.1e+02
Office 1	5 - j7.4	4.2 - j6.3	4.2 - j6.3	-1.2e+02 - j 75
Office 2	10 - j 10	4.7 - j4.9	4.7 - j4.9	-1.1e+02 - j 73
Office 3	20 - j 10	9.5 - j4.9	9.5 - j4.9	-1.2e+02 - j 80
Office 4	20 - j 15	11 - j8.2	11 - j8.2	-95 - j 59
Load 1	0.03 - j0.3	0.018 - j0.18	0.018 - j0.18	-1.1e+02 - j 75
Load 2	0.05 - j0.2	0.025 - j0.099	0.025 - j0.099	-1.1e+02 - j 78
Factory 1	20 - j 15	12 - j8.8	12 - j8.8	-1.2e+02 - j 77
Factory 2	20 - j 15	17 - j 13	17 - j 13	-1.1e+02 - j 71
House 5	1 - j0.8	0.47 - j0.38	0.47 - j0.38	-1.3e+02 - j 81
House 6	1 - j0.2	0.52 - j0.1	0.52 - j0.1	-1.3e+02 - j 91
House 7	1 - j0.5	0.46 - j0.23	0.46 - j0.23	-1e+02 - j 67

What hour of day? Enter an integer number between 1 and 24 inclusive.

24

Customer name	Power used (in kVA)	I1(in A)	I2 (in A)	Net voltage(V)
House 1	1 - j0.5	0.64 - j0.32	0.64 - j0.32	-1.5e+02 - j 93
House 2	1 - j0.6	0.56 - j0.34	0.56 - j0.34	-1.1e+02 - j 74
House 3	2 - j0.6	1.4 - j0.43	1.4 - j0.43	-92 - j 66
House 4	2 - j0.7	1.4 - j0.48	1.4 - j0.48	-1.8e+02 - j1.1e+02
Office 1	5 - j5.3	4.7 - j 5	4.7 - j 5	-1.2e+02 - j 72
Office 2	10 - j9.4	5.6 - j5.3	5.6 - j5.3	-1e+02 - j 69
Office 3	10 - j6.8	8.8 - j 6	8.8 - j 6	-1e+02 - j 73
Office 4	10 - j8.6	5.6 - j4.8	5.6 - j4.8	-96 - j 58
Load 1	0.01 - j0.2	0.0067 - j0.13	0.0067 - j0.13	-92 - j 66
Load 2	0.01 - j0.1	0.0069 - j0.069	0.0069 - j0.069	-84 - j 64
Factory 1	5 - j 10	3.8 - j7.8	3.8 - j7.8	-1.2e+02 - j 75
Factory 2	5 - j3.2	4.7 - j 3	4.7 - j 3	-1.1e+02 - j 71
House 5	1 - j0.5	0.56 - j0.28	0.56 - j0.28	-1.2e+02 - j 77
House 6	1 - j0.1	0.72 - j0.072	0.72 - j0.072	-1.1e+02 - j 81
House 7	1 - j0.4	0.71 - j0.28	0.71 - j0.28	-99 - j 65

Since the model used for the purposes of this experiment was a completely made-up one, care was taken to make sure that at least the voltage values consumed by the “customers” (the various houses, offices and factories) and the voltage values supplied by the “supplier” (the utility company providing the power to the customer and the company producing the electrical power) have some semblance of reality to them. The values for the power used matches the expected power usage from normal residential, commercial and office buildings in a normal working day. The two current

values I_1 and I_2 represent the transmission line and load currents respectively, and are equal to reflect the fact that all current flowing through the transmission line is also flowing through the load. The negative voltage values reflect the fact that voltage is being used by the houses, offices and factories that are being made part of the model. A positive voltage value would indicate that the instrument in question is producing voltage, which is not the case as far as this particular model is concerned. The consistently higher voltage values at House 4 and House 5 at all hours of the day is due to the presence of photovoltaic cells on those houses, the extra power produced being used on top of the power from the grid, resulting in a higher voltage.

The higher voltage values in House 4 and House 5 successfully depicts the fact that the installation of a photovoltaic system, or for that matter, a hybrid system consisting of both a photovoltaic cell structure and a wind turbine, if it is plausible to do so and not limited by city guidelines, would indeed result in less dependence on grid power. The less dependence on grid power translates to a win-win situation for both the consumer and the utility company. For the consumer, the absence of grid power, or less dependence on it, would be equal to lesser utility bills to pay. One might argue that there should be a big cost of installation of such a system, but this has been discussed is more detail in the Conclusion section. For the utility company, one less customer to serve translates to saved costs in installing wires to deliver power to the aforementioned customer. The company can use this money to improve their current infrastructure and for a variety of other reasons.

IV. CONCLUSION

Within the bounds of experimental uncertainty, the fact that the installation of photovoltaic cells can reduce dependency on the electricity grid is a no-brainer. Installing a photovoltaic system is not cheap, however. A 6.1-kilowatt system covering 350 square feet would cost about $28,000 for parts and installation, though tax incentives may offset the cost. [10] But, once installed, the advantages keep coming. For a five-bedroom home with multiple fridges, pool lighting, landscape lighting and HVAC zones, the electric bill can run as high as $1,000 to $2,000 a month. With a large enough kilowatt system installed, the electricity bill can be offset by half if not 75%. [10] The payback period for the photovoltaic cells are not too bad, ranging anywhere between 2 and 6 years, depending on the quality of the photovoltaic cells used, the location and the overall efficiency in the way the cells are being used to produce energy, given that the photovoltaic cells would be most efficient when sunlight is hitting the panels at a 45˚ angle.

Research is continuously being performed into inventing new and better material to construct windmills and photovoltaic cells out of. Nano Vent-Skin (NVS) is one such technology. Using nano-manufacturing with bioengineered organisms as a production method, NVS has the ability to absorb different micro-organisms from the environment. This results in a skin that can utilize both wind and solar energy. [8]

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