BENEFITS OF ELECTRIC GENERATION DISPLACEMENT USING SOLAR THERMAL WATER HEATERS

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
ELECTRIAL ENGINEERING
(Power Systems)

UNIVERSITY OF PUERTO RICO
MAYAGÜEZ CAMPUS
2005

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ABSTRACT

This work presents an estimate in increased efficiency of the power system, due to the reduction of electric losses at the transmission and distribution levels. It further explores the environmental impact due to generation displacement using solar thermal water heaters.

We performed an economic analysis of these improvements in power system operation including an estimate of the reduction in fuel and energy cost adjustment, in $/kW*h, for residential customers using SWTH.

Simulations proved that there is a considerable amount of generation displacement and power loss reduction due to SWTH. The system's reliability, reserve and spinning reserve are enhanced by means of this short term alternative to generation station construction.

Economic analysis demonstrated that there are benefits for the utility and clients. Residential customers could experience a considerable reduction in their monthly bills. Atmospheric emissions could also be reduced. This alternative should be considered for the benefits shown throughout this work.

RESUMEN

Este trabajo presenta el incremento de eficiencia en el sistema eléctrico, debido a la reducción de pérdidas a niveles de transmisión y distribución, además del impacto ambiental debido a la reducción en pérdidas por desplazamiento de generación utilizando calentadores solares termales.

Realizamos análisis económico sobre estas mejoras en la operación del sistema de potencia incluyendo un estimado del ajuste en la reducción de combustible y los costos de energía, en $/kW*h, por clientes que utiliza un calentador solar.

Las simulaciones demostraron que existe una cantidad considerable de generación desplazada y reducción de pérdidas debido a los calentadores solares. La confiabilidad del sistema, reserva y reserva rotativa, todas aumentan debido a esta alternativa de corto plazo en lugar de construcciones de estaciones de generación.

El análisis económico demostró que existen beneficios para la los clientes así como para la AEE. Clientes residenciales pueden experimentar una reducción considerable en sus facturas mensuales. Las emisiones a la atmósfera pueden ser reducidas. Esta alternativa debe ser considerada por los beneficios mencionados durante este trabajo.

To my family . . .

ACKNOWLEDGEMENTS

During the development of my graduate studies at the University of Puerto Rico several persons and institutions collaborated directly and indirectly with my research. Without their support it would have been impossible for me to finish my work. That is why I wish to dedicate this section to recognize their support.

I want to start expressing a sincere acknowledgement to my advisor, Dr. Agustín Irizarry Rivera because he gave me the opportunity to do research under his guidance and I received inspiration; encouragement and support from him during all my studies. Thanks to him I had the opportunity of writing papers for conferences and sharing my work with the public. I also want to thank the motivation, inspiration and support I received from Dr. Viviana Cesaní. At last, but the most important I would like to thank my family, for their unconditional support, inspiration and love.

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1 INTRODUCTION

A large portion of the electricity generated is wasted in the form of losses. Recent studies indicate that up to 13% of the total power generation is wasted in the form of line losses in the distribution system [1]. Losses occur at all levels of the power system-generation, transmission, and distribution. However, at least 75% of the total system losses, transmission and distribution, occur in the distribution system [2]. We present a study of real and reactive power losses reduction at the transmission and distribution level (38 kV is considered the boundary voltage between distribution and sub transmission level in Puerto Rico) due to the use of Solar Thermal Water Heaters (STWH). The developed model for this study is deterministic. It is assumed that the active power reduction in residential electric load is achieved by means of an increase in use of stand alone STWH systems. We could not find a similar study in our literature review, thus this study represents a novel variant to load side management techniques. The savings produced by STWH benefit the consumer, the power utility company, and the environment. The consumer receives a direct benefit from the reduction in kilowatt-hours. The power utility company receives savings in the form of power losses reduction and can further translate these savings to the customer by reducing energy and fuel cost adjustment portion of the customer electric bill. Environmental benefits are gained from reduced emissions due to generation displacement, which is the amount of electric energy that is not been produced to attend electric demand, in this case the electric energy is displaced by heating water using STWH instead of using electricity.

1.1 Overview of the Thesis

Chapter 1 presents the motivation to do this work and literature review. Chapter 2 presents the theoretical modeling foundation for distribution systems, data analysis related to our electric system model as well as an estimate of energy saving based on the thermodynamics of water heating. Information related to contributions of the electric energy industry to environmental damage is also included in this chapter, as well as fuel and energy cost adjustment, in dollars per kilowatt hour due to STWH. The third chapter presents simulations and analyses. Results discussion is presented in Chapter 4. Chapter 5 includes conclusions and future work.

1.2 Motivation

With the ever-increasing energy and fuel cost adjustment portion of the customer electric bill, a factor primarily based on the efficiency of the transmission and distribution grid, and the significant increase in pollution in Puerto Rico due to electricity generation from fossil fuels, the argument about using renewable energy to diminish the environmental impact is a never-ending dispute between government agencies [3]. Puerto Rico possesses two abundant renewable sources, solar energy and wind, which should be used to reduce electricity generation from oil, carbon, and gas. Since photovoltaic generation is still expensive, we may use generation displacement, in the form of water heating, as an alternative to actual generation to take advantage of this abundant solar energy. Another advantage of solar energy is that surveys have consistently shown that it is preferred as an energy supply option among consumers [4]. With the installation of Solar Thermal Water Heaters in Puerto Rico we will reduce the dependence on fossil fuels and contribute to the conservation of the environment.

The overall goal was to determine the benefits for Puerto Rico of electric generation displacement by solar thermal water heating. This type of analysis has never been done before. In our study we:

a. calculate the reduction in electric system losses at transmission (115 kV and 230 kV) and distribution (38 kV) levels and generation displacement

b. estimate the reduction in emissions released into the atmosphere

c. calculate energy savings and savings from the fuel cost adjustment portion of the customer electric bill based on increased efficiency of the transmission and distribution systems.

The major contribution of this work is the calculation of an estimate of economic and environmental benefits for Puerto Rico of using STWH. Puerto Rico's government agencies are looking for economic and environmentally positive alternatives to take care of the electricity demand. We present a realistic alternative, an electric energy saving plan that increases the efficiency of the power grid, decreases pollution, and provides economic relief to the customer.

1.3 Literature Review

An electric system's analysis of the amount of the electric generation that could be displaced using solar thermal water heaters is not reported in the literature. Generation Displacement is the amount of electric energy that is not been produced for attending an electric demand, in this case this electric energy is displaced by STWH. Other aspects such as load reduction, environmental impact, and transmission and distribution power loss minimization have been addressed previously. Studies related to these topics are presented.

I. Load Reduction

Direct Load Control on water heaters and water heating storage tanks have already been used by utilities to reduce the system peak load and improve the system reliability performance [5]. Direct load control is a form of load management in which portions of the system load is under direct operational control of the utility. Thus the load can be modified, within limits, to modify the available generating capacity thereby minimizing events of uncontrolled load loss [6]. When the power supply to water heaters is disconnected, the load drop per water heater equals its diversified demand at the time of load shed. The sum of demands imposed by a group of loads over a particular period is the diversified demand [7]. Diversified demand factors are used as an adjustment when considering the load of a particular class of customers rather than the entirety of customers of a utility [8]. The diversified demand factor would be applied as an adjustment to the contract capacity under retail standby tariffs. This adjustment would result in a reduction in their load on the system to account for the fact that there is considerable variety in their operation and that sum of their individual peak demands would exceed the actual class peak usage of the grid. When the interrupted loads are allowed to return to their normal state (turned back on), the payback demand/energy could be several times greater to the amount shed. Peak demand/energy usually occurs when high electrical usage occurs, in the summer months. A disconnected water heater load of 25MW can build up to an initial payback demand of 80-90 MW if the direct control of the water heater is not handled properly [5].

Another strategy that could be implemented for load reduction purposes is the Variable Volume Water Heater on the domestic load profile. This is a unique system that can be implemented as a residential demand-side management tool. The variable volume water heater can shift the electrical energy consumption, used to heat water, to off-peak time periods [9]. The electrical energy is shifted without influencing the hot water usage of the customer. The water level, or stored hot water volume, is controlled by two different set points. These set points determine the water level at any given instance. The two set points are: the high volume set point, and the low volume set point. The set point implies that if the volume of stored water drops below the set point value, water will be let in to recover the set point volume. If the volume of stored hot water is above the set point, no water will be let into the tank although the customer can still withdraw hot water. Variable Volume Water Heater on the domestic load profile is an option for load reduction when necessary.

II. Reduction in electric system losses at transmission and distribution levels

A large portion of the electricity generated is wasted in the form of losses. A recent study indicates that up to 13% of the total power generation is wasted in the form of line losses in the distribution system [1]. Losses occur at all levels of the power system- Generation, Transmission, and Distribution. However, at least 75% of the total system losses occur in the distribution system [2].

Methods to reduce real power losses include: Network Reconfiguration and Capacitor Installation. Network reconfiguration is based on partitioning the distribution network into groups of load buses, such that the line section losses between groups of nodes are minimized. In 1975, Merlin and Back introduced the concept of distribution system reconfiguration for system loss reduction [10]. Network Reconfiguration in Distribution Systems is realized by changing the status of sectionalizing switches, and is usually done for loss reduction or load balancing in the system. In network reconfiguration for loss reduction, the solution involves a search of possible radial configurations. In primary distribution systems, sectionalizing switches are used, for both protection, to isolate a fault, and for configuration management, for reconfiguration of the network [11]. The technique of Merlin and Back exploited the radial topology, typical of urban distribution systems. Due to the fact that the configurations of distribution networks are designed to be more efficient for a specific demand condition, the algorithm of Merlin and Back determined a new network topology that would minimize I^2R losses for the prevailing system diversity load [10]. The concept of reconfiguring the topology of the distribution network to minimize losses can immediately be recognized as being cost efficient, and consequently of interest to efficiency conscious electric utilities. In view of the increasing use of supervisory control and data acquisition systems (SCADA), and distribution automation and control (DAC), distribution system reconfiguration becomes a more viable alternative for loss reduction. Distribution systems equipped with

SCADA and DAC already possess the necessary automated switches and remote monitoring facilities [11].

Traditionally, distribution planning requires feeder reconfiguration on a seasonal or annual basis [12]. Real-time feeder reconfiguration, however, has the potential to provide substantial benefits since the magnitude of feeder load varies continuously. The problem of optimal feeder reconfiguration occurs on both urban and rural distribution systems. Initially, the reconfiguration problem concerned urban distribution systems, in the United States, whose infrastructure is mostly underground cable systems designed for closed loop networks but operated as radial feeders. In such systems each distribution transformer can be served from more than two circuits and the open/closed status of sectionalizing switches located at the transformer site determines how the transformer is served [10]. The problem of feeder reconfiguration can be regarded as that of finding branches to be opened since each branch could be opened by two switches located at both ends. The number of possible combinations of selecting open branches becomes very large.

The subject of distribution has been investigated by numerous researchers over the past years. In early studies [13, 14], involving urban distribution systems, a desirable radial distribution system solution is determined from a mesh network in which all normally open switches are simulated to be closed. Based on a power flow solution to this distribution system mesh network structure, switches to be opened are identified.

A major portion of the power losses occurs at the distribution level. Because the power loss is solved as a function of the square of the current flow, shunt capacitors have been used by utilities to provide reactive power compensation to reduce power loss as well as improve the electricity service quality effectively. Due to the high cost benefit resulted, the reactive power planning is often solved by nonlinear programming to determine the optimal locations and sizes of shunt capacitor to be installed along distribution feeders [15]. By the optimization of the objective function, the system power and energy loss reduction, voltage regulation and reserve capacity of substation can be achieved.

Placing capacitors at multiple locations on a distribution feeder could allow: 1) deeper levels of substation voltage reduction for peak load reduction; 2) power factor correction; and 3) power loss reduction. By reducing peak demand, a utility can avoid paying high prices when purchasing power or it may sell excess generation at high prices [16]. By minimizing system losses, savings are obtained through reduced demand and energy charges. Besides a positive economic response, load reduction associated with improved power factor at the substation has a beneficial effect on voltage stability by increasing the system stability limit margin.

Normally, capacitors are installed on distribution feeders for power loss reduction. However, if adequately sized and installed along the feeder, capacitors can be used to regulate the voltages on the feeder and the power factor at the substation [17]. When the voltage level is reduced at the substation during the peak times, capacitors provide acceptable voltage levels to the customers throughout the feeder. The reduction of voltage level would force all voltage dependent loads to decrease power consumption; therefore, the need for costly generation would be avoided at the peak load times. The percentage of power reduction per volt reduction, and, therefore, the benefit/cost ratio, depends on the feeder load characteristic [17]. It increases when the voltage dependence of the load changes from a constant power type to a constant impedance type. During the off-peak times, some of the installed capacitors can be controlled for power factor correction, loss reduction in both transmission and distribution systems, and load reduction when necessary [17].

III. Generation Displacement and Environmental Impact

Combined Heat and Power (CHP) systems, or cogeneration systems, generate electrical/mechanical and thermal energy simultaneously, recovering much of the energy normally lost in separate generation [18]. This recovered energy can be used for heating or cooling purposes, eliminating the need for a separate boiler. Significant reductions in energy, criteria pollutants, and carbon emissions can be achieved from the improved efficiency of fuel use. Generating electricity on or near the point of use also avoids transmission and distribution losses and defers expansion of the electricity transmission grid. Several recent developments make dramatic expansion of CHP a cost-effective possibility over the next decade [18]. First, advances in technologies such as combustion turbines, steam turbines, reciprocating engines, fuel cells, and heat-recovery equipment have decreased the cost and improved the performance of CHP systems. Second, a significant portion of the United States boiler stock will need to be replaced in the next decade, creating an opportunity to upgrade this equipment with clean and efficient CHP systems [18]. Third, environmental policies including addressing concerns about greenhouse gas emissions, have created pressures to find cleaner and more efficient means of using energy. Finally, electric power market restructuring is creating new opportunities for innovations in power generation and smaller-scale distributed systems such as CHP. An analysis from the American Council for an Energy-Efficient Economy suggests that there is enormous potential for the installation of cost-effective CHP in the industrial, district energy, and buildings sectors. The projected additional capacity by 2010 is 73 GW with corresponding energy savings of 2.6 quadrillion Btus, carbon emissions reductions of 74 million metric tons, 1.4 million tons of avoided SO_2 emissions, and 0.6 million tons of avoided NO_x emissions. They estimate that this new CHP would require cumulative capital investments of roughly $47 billion over ten years [18].

2 THEORETICAL BACKGROUND

Throughout this chapter we present the theoretical background needed of this work. The theoretical modeling foundation for distribution systems and as well as the data analysis related to our electric system model are discussed. An estimate of energy saving based on the thermodynamics of water heating is also presented. Information related to contributions of the electric energy industry to environmental damage is included, as well as fuel and energy cost adjustment, in dollars per kilowatt hour due to STWH.

2.1 Introduction to Power Systems Analysis

2.1.1 Power in balanced Three-Phase Circuits

The total power delivered by a three-phase generator or absorbed by a three-phase load is found by adding the power in each of the three phases. In a balanced circuit this is the same as multiplying the power in any one phase by three since the power is the same in all the three phases.

If the magnitude of the voltages to neutral is denoted by V_p for a Y-connected load the phase voltages are $|V_p| = |V_{an}| = |V_{bn}| = |V_{cn}|$

2.1

If the magnitude of the phase current is denoted by I_p for a Y-connected load the line, and phase, currents are

$$\left|I_p\right| = \left|I_{an}\right| = \left|I_{bn}\right| = \left|I_{cn}\right| \tag{2.2}$$

The total three-phase power is

$$P = 3\left|V_p\right|\left|I_p\right|\cos\theta_p \tag{2.3}$$

where θ_p is the angle by which the phase current I_p lags the phase voltage V_p, that is, the angle of the impedance in each phase. If $\left|V_L\right|$ and $\left|I_L\right|$ are the magnitudes of the line-to-line voltage V_L and line current I_L, respectively,

$$\left|V_p\right| = \frac{\left|V_L\right|}{\sqrt{3}} \text{ and } \left|I_p\right| = \left|I_L\right|$$

and substituting in equation 2.3 yields

$$P = \sqrt{3}\left|V_L\right|\left|I_L\right|\cos\theta_p \tag{2.4}$$

The total vars are

$$Q = 3\left|V_p\right|\left|I_p\right|\sin\theta_p \tag{2.5}$$

$$Q = \sqrt{3}\left|V_L\right|\left|I_L\right|\sin\theta_p$$

and the voltamperes of the load

$$\left|S\right| = \sqrt{P^2 + Q^2} = \sqrt{3}\left|V_L\right|\left|I_L\right| \tag{2.6}$$

2.1.2 The Transmission and Distribution Systems

Recall that the transmission line system carries bulk power at high voltages to the general areas of usage. One reason for using high transmission-line voltages is to improve energy transmission efficiency. Basically, transmission of a given amount of power requires a fixed product of voltage and line current. Thus, the higher the voltage, the lower the current can be. Lower line current is associated with lower resistive losses (I^2R) in the line. Subtransmission lines carry large amount of power from the bulk power substations to the immediate area of use at intermediate voltages. The distribution system carries electrical power from the distribution substation to the individual customer at voltages that range between 38 kV and 4.16 kV.

The distribution system typically starts with the distribution substation that is fed of more than one subtransmission lines. In some cases the distribution substation is fed directly form a high-voltage transmission line, in which case there is no subtransmission system. Each distribution substation will serve one or more primary feeders. Feeders are usually radial, which means that there is only one path for the power to flow from the distribution substation to the user.

A diagram of a very simple one-line distribution substation is shown in Figure 2.1. Although Figure 2.1 displays the simplest distribution substation, it illustrates the major components that will be found in all substations. A radial subtransmission and distribution layout is shown in Figure 2.1. The distribution lines extend from the substation to the last load with service drops to customers along the way.

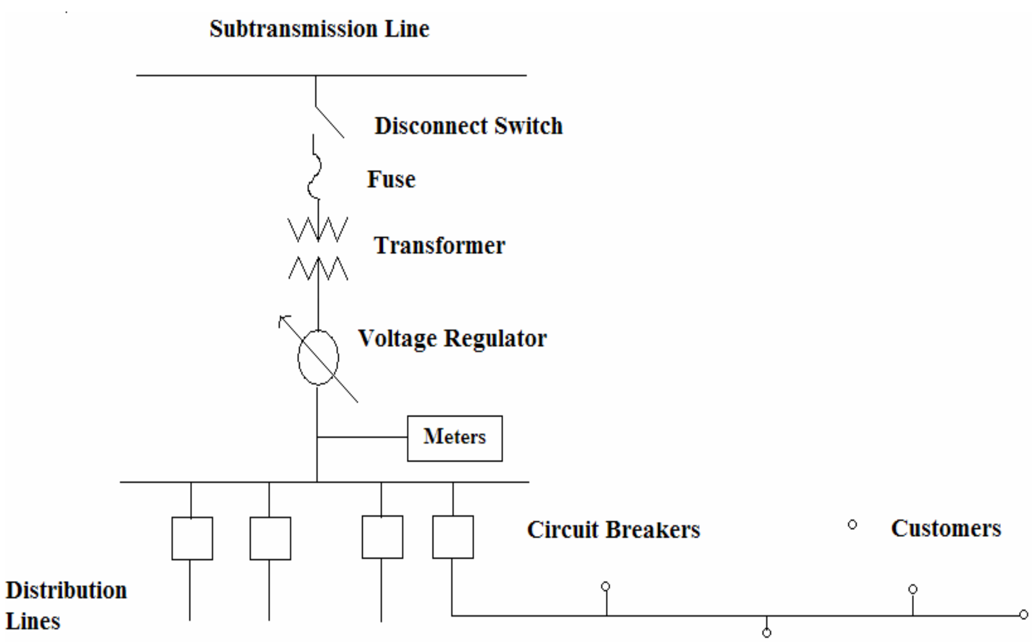


Figure 2.1 Distribution System

2.1.3 Reserve, diversity, and economic dispatch

Reserve is that portion of an electric utility's available generating capacity that is not producing electricity at a given time. Spinning reserve is the generating capacity that is being driven at the proper speed to provide proper voltage, but is not producing power. Spinning reserve can provide power to the system almost instantaneously if the system load is increased or a generator must be taken out of service.

Diversity is the term used to refer to load changes to a given period of time. Load varies during the day because people use different amounts of electricity to support their various activities.

Economic dispatch refers to serving the load at all times with as little excess capacity as possible using the most efficient generating units possible.

2.2 Approximate Modeling of the Line Segments Equations

The electric system model for the island of Puerto Rico includes the distribution voltage level at 38 kV. The equations relating distribution line segments modeling are presented in this section.

2.2.1 Approximate models of distribution line segments

Assuming that line segments are transposed only the positive sequence impedance of the line segments needed to be determined to develop our model. The equation for the positive sequence impedance ($z_{positive}$) is [19]:

$$z_{positive} = r + j0.12134[\ln(D_{eq} / GMR_i)] ohms / mile$$
$$D_{eq} = \sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}} \qquad \textbf{2.7}$$

where:

r = conductor resistance ohms/mile

GMR= conductor geometric mean radius (ft.)

Dij= spacing between conductors i and j (ft.)

In this study we assume a pole configuration as shown in Figure 2.1[20]. The assumed conductors for this study are shown in **Chapter 3, in Table 3.1**. Therefore Dab = 3.5, Dbc = 3.5 and Dca =7, Deq = 4.41, for all our conductors. The values for $z_{positive}$ are presented in Table 3.2.

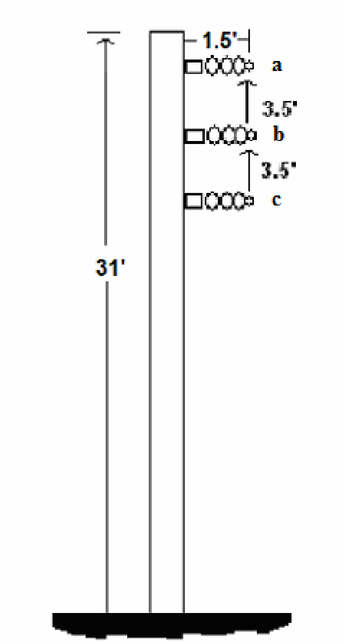


Figure 2.2 Pole Configuration at 38kV

2.3 Estimate of energy savings based on the thermodynamics of water heating

2.3.1 Thermodynamics of water heating

The electric load reduction based on the thermodynamics of water heating was estimated. A justification for the calculations is presented in this section. Thermodynamics deals with the internal energy of systems and its central concept is temperature [21].

If ΔQ is the heat energy supplied to a body and ΔT is the body's corresponding temperature rise then **heat capacity** is defined as:

C = Heat capacity = $\Delta Q / \Delta T$ [20]. **2.8**

The heat capacity per unit mass of a body is the **specific heat** that is a characteristic of the material of which the body is composed.

Specific heat = c = Heat capacity/mass = $\Delta Q / (m * \Delta T)$ **2.9**

Specific heat of water 1 cal/g °C = 1 kcal/kg °C = 1 BTU/lb °F, exactly. The specific heat of water varies less than 1% from its value of 1 cal/g °C over the temperature range from 0 to 100 °C.

Water density (@ 20 °C and 1 atm) = ρ_w = 1000 kg/m^3 = 1 g/cm^3

1 cubic meter = 1 m^3 = 1000 liters.

Assuming: The typical water heater contains 240 liters (volume) [22] of water and it increases the water temperature from 60 °F to 135 °F, i.e., $\Delta T = 135 - 60 = 75$ °F.

Recall:

$$T_F = 32 + (9/5)*T_C \qquad \textbf{2.10}$$

$$T_C = (T_F - 32)*(5/9) = (75 - 32)*(5/9) = 43*(5/9) = 23.89 \text{ °C}$$

Since ρ = mass/volume the heat energy supplied to the water is:

$$\text{water mass} = \rho_w*\text{water volume} = (1000 \text{ kg/m}^3) * 240 \text{ li} * (1 \text{ m}^3/1000 \text{ li}) = 240 \text{ kg}$$

$$c = \Delta Q/ (m*\Delta T) = 1 \text{ kcal/kg °C} \qquad \textbf{2.11}$$

$$\Delta Q = (1 \text{ kcal/kg °C})*240*23.89 = 5733.6 \text{ kcal}$$

$$\Delta Q = 5733.6 \text{ kcal} * (4187 \text{ J}/ 1 \text{ kcal}) = 2.4007 \times 10^7 \text{ J} = 0.24 \times 10^6 \text{ J} = 0.24 \text{ MJ}$$

The efficiency of water heaters is indicated by their energy factor (EF), which is based on recovery efficiency, standby losses, and cycling losses. The higher the EF, the more efficient the water heater. Electric resistance water heaters have EFs ranging from 0.7 and 0.95. [23] It is assumed that all the water heaters are old so they have low EF.

Assuming a very conservative average water heater efficiency of 70% or

$\eta_{\text{water heater}} = P_{\text{out (heat)}} / P_{\text{in (electrical)}} = 0.70$ or **2.12**

$P_{elec} = P_{heat}/0.70.$

The most efficient electric storage water heaters have energy factors ranging between 0.93 and 0.95, resulting in estimated annual energy use below 4,725 kWh/year [24].

Electric energy input = $(2.4007 \times 10^7 \text{ J})/0.7 = 3.4296 \times 10^7 \text{ J}$

Since $1 \text{ kW*h} = 1000 \text{ W} * 3600 \text{ s} = 3.6 \times 10^6 \text{ J}$

Electric energy input = $3.4296 \times 10^7 \text{ J} * (1 \text{ kW*h} / 3.6 \times 10^6 \text{ J}) = 9.5266 \text{ kW*h}$

Currently the domestic electric energy cost in Puerto Rico is between $ 0.16 per kW*h and 0.17 $ per kW*h. Let us assume a 0.16 $/kW*h for electric energy cost, then the annual cost of heating 240 liters (63.41gallons) of water daily from 60 °F to135 °F is:

(9.5266 kW*h/day)*(0.16 $/kW*h)*365 days = $556.35

2.4 Contributions of the Electric Energy Industry to Environmental Damage

There is interdependence between economic activity and natural resources. Raw materials due to production and consumption are released back to nature as by-products or residuals, causing pollution [25]. Human induced residuals associated with production and consumption affects society, but also other life-forms such as animals and plants. These pollutants also cause damage to materials, contaminating soil, as well as causing global warming. These effects may be interpreted as costs because they damage our life in one way or another. The contributions of the electric energy industry to environmental damage raise questions concerning environmental protection and methods of reducing pollution from power generation plants either by operating strategies or by introducing renewable power energy technology.

2.4.1 Polluting effects due to electricity production from fossil fuels:

Now we present some of the contributions of the electricity generation to environmental damage. In Chapter three we present an analysis of the emissions reduction into the atmosphere due to the installation of STWH. The emissions reduction include: SO_2, CO_2, NO_x and PM10 pollutants.

• In the case of oil and coal-fired plants, a significant public health risk results from exposure to large amounts of gaseous and solid wastes in the combustion process. Coal fired stations also discharge fly ash, trace metals and radionuclides. The presence of these pollutants leads to increased incidence of respiratory disease, toxicity and cancer. Disposal of resulting solid waste leads to health risks associated with leachate and groundwater contamination. [26]

• The existence of potential carcinogens and mutagens in the waste can have negative impacts on health and agricultural productivity.

• Local impacts are mainly in the form of heavy hydrocarbons and particulate matter (including sulphur flakes) which are deposited within hours and can travel up to 100km from the source. [26]

• Regional impacts involve emissions and effluents, the most important of which are SO_2 acid depositions which have a residence time in the atmosphere of a few days and may travel to a few thousand kilometers thus causing cross boundary effects.

• Acid deposition caused by sulphur and nitrogen oxides results in damage to trees and crops, and sometimes extends to acidification of stream and lakes, resulting in destruction of aquatic ecosystems. It also leads to the corrosion, erosion and discoloration of buildings, monuments and bridges.

• Global pollution is exemplified by CO_2 emissions and other gases (mainly methane) which have long residence times in the atmosphere.

• The relative contribution of electricity generation to the prospect of overall global warming (mainly in the form of CO_2 emissions) has been estimated at about 20% until now, but rapidly increasing. [26]

2.5 Energy and fuel cost adjustment portion of the customer electric bill equations

Once the total generation displacement per year was calculated we performed an economic analysis of the fuel cost adjustment of the customer bill. Before discussing the equations related to these calculations, we present a brief explanation of the Fuel Adjustment Clause, which states the adjustment factors of the customer's bill portion related to the energy and fuel purchase.

Throughout the first years of the petroleum supremacy the prices were low, so clients did not worried about the Fuel Adjustment Clause since back then it would represent a credit for the clients of PREPA (Puerto Rico Power Authority) [27].

The legislation for the approval of this clause was imposed by the first executive director of PREPA, Engineer Don Antonio Lucchetti. The Fuel Adjustment Clause follows the same principles as that of the electric industry of the United States.

The electric services tariffs have to components: (1) charges for the electric service except for the fuels, known as basic tariff, and (2) charges for the used fuel plus the energy purchased, which is calculated through factors. [27]

The fuel and/or petroleum market is experiencing a substantial augmentation in the price of these products [27]. This has caused an increase in the electric bill by concept of the PREPA Fuel Adjustment Clause. The forecasting process for the adjustment factors is random, sometimes resulting in underestimations and overestimations, which will result in positive and negative corrections. The positive ones indicate recoveries, and the negative ones indicate devolutions to the customer as shown in Figure 2.2.

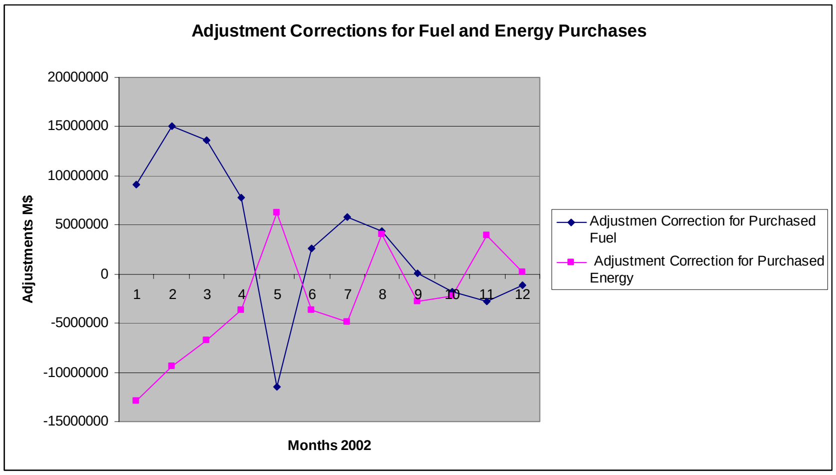


Figure 2.3 Adjustment Corrections for Fuel and Energy Purchases

The following factors are important in the calculation of the fuel adjustment:

Fuel Purchase Factor= FCC_i (\$/kWh) = $\frac{\$/BBLS \times BBL\ Estimated \pm Adjustment_C}{0.89 \times Total\ Estimated\ Generation \times E_i}$ **2.13**

Energy Purchase Factor:

=FCE_i(\$/kWh)= $\frac{Energy\ Purchase\ Estimated\ Cost \pm Adjustment_e}{0.89 \times Total\ Estimated\ Generation \times E_i}$ **2.14**

Factor 0.89 is used to include the effect of contributions instead of government taxes and the municipalities, according to PREPA's Organic Law [27].

Adjustment Factor= FA_i= FCC_i+FCE_i **2.15** where i= generation bus, transmission, primary and secondary distribution

Total of adjustment for billing of fuel and energy purchases:

$$=((FA_i)/E_i)\times kWh\ consumed \qquad \textbf{2.16}$$

In Table 2.1 a description of the factor's formulas is presented. This table includes the values of the efficiencies, estimated generation, estimated barrels, and the adjustment factors for energy and fuel purchases. The values are given in ranges from minimum values to maximum.

Table 2.1 Important factors included in the adjustment formulas

Assigned #	Factor	Name	Value (ranges)
1	E_{bg}	Generation Bus Efficiency	1.0000
2	E_t	Transmission Voltage Efficiency	0.95-0.97
3	E_{dp}	Primary Distribution Voltage Efficiency	0.88-0.89
4	E_{ds}	Secondary Distribution Voltage Efficiency	0.85-0.86
5	$/BBL	Price per fuel barrel	19-57 $/BBL
6	$BBLS_{Est}$	Estimated Barrels	2.26M-2.804M BBL
7	$T\ Gen_{Est}$	Total Estimated Generation	1535579000-2026209000 kWh
8	$E\ Purchase_{Est}$	Estimated Cost of Purchased Energy	$ 18866392.4- $ 37176903.24
9	$Adjustment_c$	Adjustment Correction for Purchased Fuel	$ -1156990- $ 15040660
10	$Adjustment_e$	Adjustment Correction for Purchased Energy	$ -12947653- $ 6198704
11	FCC_i	Fuel Purchase Factor	-0.006335736-0.002616159
12	FCE_i	Energy Purchase Factor	0.010552034-0.017286598
13	FA_i	Adjustment Factor= FCC_i+FCE_i	0.009483198 -0.026481409

3 SIMULATIONS AND ANALYSES

Previously we presented the theoretical foundations for following the analysis successfully. Theoretical information associated with distribution modeling, energy saving based on the thermodynamics of water heating and information related to the contributions of the electric energy industry to environmental damage, in terms of emissions released into the atmosphere. Aspects of fuel and energy cost adjustment were also shown.

A study of real power losses reduction at the transmission and distribution level (38 kV is considered the boundary voltage between distribution and sub transmission level in Puerto Rico) due to the use of Solar Thermal Water Heaters (STWH) for Puerto Rico is presented. It is assumed that the reduction in residential electric load is achieved by means of an increase in use of stand alone STWH systems. The residential electric load of water heaters is calculated in *section 3.3.4.* The power loss reduction at the transmission level is also estimated. Possible sources of error for the model and analysis is presented.

3.1 Transmission and Distribution Systems Analyses

The base case for our study is defined from the load and power flow conditions described in [28]. The system and load conditions are presented in Appendix A for convenience. A one line equivalent of Puerto Rico’s existing electric power system is shown in Figure 3.1. This model represents the transmission system, 230 kV (orange lines and buses) and 115 kV (yellow lines and buses), and generators. Loads are represented at the 115 kV voltage level. This is a deterministic model.

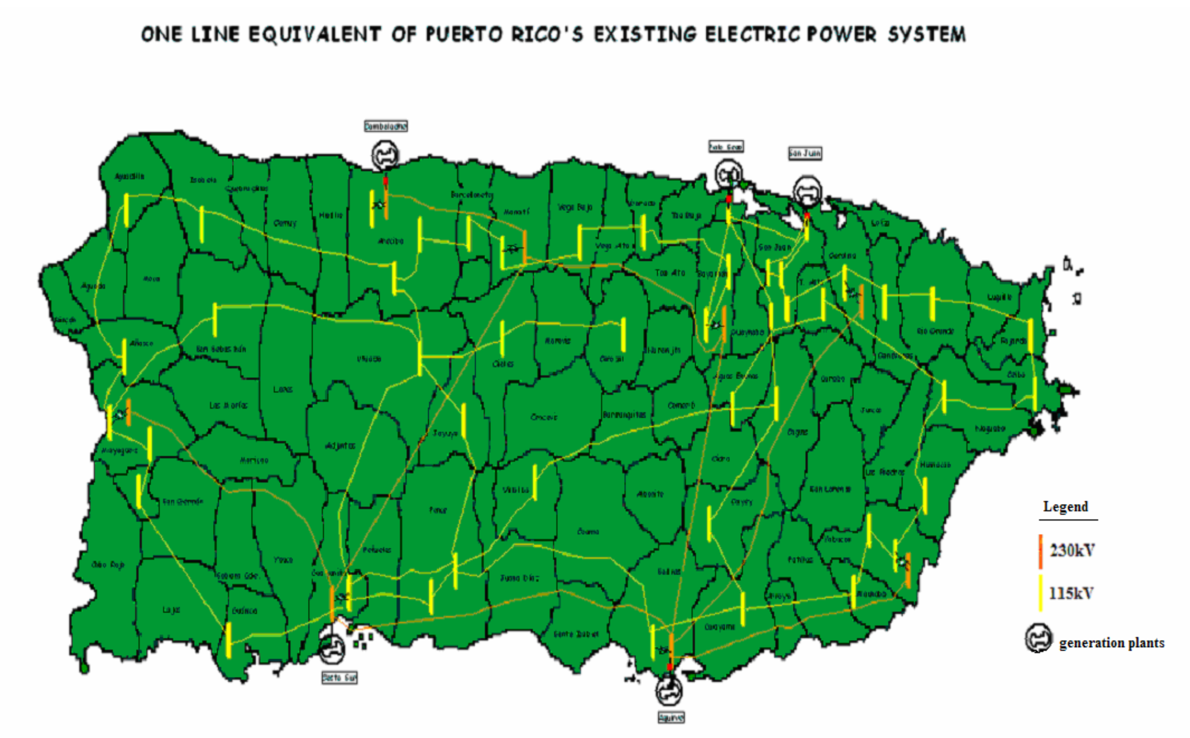


Figure 3.1 One Line Equivalent of Puerto Rico’s Existing Electric Power System

3.1.1 Sources of Error in Our the Model

There are sources of errors in the model we used. Line segments were modeled using an approximate model where it was assumed that the line segments are transposed. Therefore only the positive sequence impedance was determined. The system was considered to be perfectly balanced. In a more exact model it is necessary to retain the identity of the self and mutual impedances of the conductors and take into account the ground return path for unbalanced currents. This is because distribution systems consist of single-phase, two-phase, and untransposed three-phase lines serving unbalanced loads.

Another source of error could be the assumed line lengths. We considered lengths of 5 mi, 10 mi and 15 mi lengths to be representative of short, medium and long distribution lines. To be exact each distribution line length must have been used.

To calculate power loss reduction a load forecasting was done using the total load demand curve. Use of the residential load demand curve would be more accurate but we could not obtain this data from the local utility.

Finally, our analysis assumes that 80 % to 60 % of the residences in Puerto Rico could use STWH to replace the electric energy actually use to heat water. A better estimate of the number of residences in Puerto Rico capable of installing a solar water heater will improve our analysis.

3.1.2 Modeling of distribution line segments

With the equations described in section 2.1 we developed the line segments at 38 kV level. For the approximate modeling of the line segments, it was assumed that the line segments were transposed. With this assumption, only the positive sequence impedance of the line segments needed to be determined. This is a deterministic model. Table 3.1 summarizes the values of parameters for these line segments. Different conductor types are presented, all of them representative of the Puerto Rico's sub-transmission line segments.

The equation for the positive sequence impedance is:

$$z_{positive} = r + j0.12134[\ln(D_{eq} / GMR_i)] ohms / mile$$
$$D_{eq} = \sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}} \qquad \textbf{3.1}$$

r = conductor resistance ohms/mile

GMR= conductor geometric mean radius (ft.)

Dij= spacing between conductors i and j (ft.)

The spacing between conductors Dab, Dbc, Dca is: 3.5 ft., 3.5 ft., and 7ft., respectively. Then the Deq is 4.4097 ft.

TABLE 3.1 Line Impedances at 38kV Sub-transmission Level

Conductor Type	r(ohm/mi)	GMR(ft)	LN(Deq/GMR)	z=r+(j0.12134*LN(Deq/GMR) (ohm/mi)
556.5 ACSR	0.1859	0.0313	4.94795	0.1859+0.60038
3/0 ACSR	0.7230	0.0060	6.59981	0.7230+0.8008
266.8 ACSR	0.3850	0.0217	5.31425	0.3850+0.64483
1/0 C/U	0.6070	0.01113	5.98192	0.6070+0.72585
300 CU	0.2150	0.01987	5.40236	0.2150+0.65552
1192.5 ACSR	0.0133	0.0460	4.56293	0.01326+0.55366
795 ACSR	0.1288	0.0375	4.76723	0.1288+0.57846

Table 3.2 shows the per unit values for the line segments. The per unit values for these line impedances where calculated with the following assumptions:

V_{base}=38 kV

S_{base}=100 MVA

$Z_{p.u.}=Z_{real}/Z_{base}$

$Z_{base}=V_{base}^2/S_{base}$ and

Z_{base}=14.44Ω.

Where: $Z_{Real} = z_{positive}$.

TABLE 3.2 Line Impedances in per unit values at 38kV Sub-transmission Level

Conductor Type	**$Z_{p.u.}$**
556.5 ACSR	0.012874+0.04158
3/0 ACSR	0.05007+0.05546
266.8 ACSR	0.02666+0.04466
1/0 C/U	0.04204+0.05027
300 CU	0.01489+0.04540
1192.5 ACSR	0.00092+0.03834
795 ACSR	0.00892+0.04006

For the case in [28] the power loss that occur at 38 kV lines was estimated, and the load conditions were adjusted. The calculated power loss at 38 kV is shown in Table 3.3. The analysis and results for these numbers are discussed in the next section.

Table 3.3 Total Power Losses at 38 kV Lines

119.06 MW	264.19 MVR

The base case for all trials is presented in Table 3.4. This is the load and power flow conditions described in [28], scaled for the new load conditions. This case will be used to calculate the power losses at 230 and 115kV transmission level.

Table 3.4 Transmission System Base Case

Base Case	MW	MVR
Load	2405.17	1180.49
Generation	2448.1	1284.7
Losses	42.96	416.06

3.1.3 System Parameters for the Distribution Level Analysis

For the purpose of this study the distribution system voltage for the residential loads was 4.16 kV. The 115/38 kV transformers per unit impedance used was 0.0007 + j0.03480. The 38/4.16 kV transformers per unit impedance used was 0.00769 + j0.076903 or z=7.7%.

We divided Puerto Rico's system load buses (PQ buses) into ten different categories in terms of its complex power (in MVA) at 115 kV transmission voltage. For this analysis we considered average values of the base case load conditions in [28].

Table 3.5 shows the different categories and scenarios. Each load category was chosen according to the apparent power bus load at the 115 kV buses of our base case, at a given time *t*. The MVA's ranged in ten different categories, in intervals of twenty MVA, from 0 MVA to 220 MVA. We considered load percentages from 20% to 50%, this represents the residential sector for the electric system total load as in [29], and they are show in Table 3.5. All load values are at 0.90 lagging power factor. The conductor types were chosen according to their current carrying capacity and power capacity for each type of load. The last column of Table 3.5 represents the residential load used for our analysis of distribution power loss calculations. This amount of load was distributed uniformly among the number of loads (3 to 4 loads) depending on the case scenario. Note that the cases are grouped by color representing the type of conductors used according to their current carrying capacity and power capacity for each type of load.

Table 3.5 Residential Load Scenarios and Conductor Types

Case Identification	**Conductor Type**	**S average 115kV(MVA)**	**P+jQ (MVA)**	**Residential Load %**	**P+jQ(MVA) Residential**
C0	556.5ASCR, 3/0ACSR,1/0CU	10	9+4.36i	45.8	4.122+1.997i
C1	556.5ASCR, 3/0ACSR,1/0CU	15.25	13.73+6.65i	45.8	6.288+3.0457i
C2	556.5ASCR, 3/0ACSR,1/0CU	50.5	45.45+22i	45.8	20.8161+10.076i
C3	795 ACSR , 556.5 ACSR, 1/0 CU	70.5	63.45+30.73i	20	12.69+6.146i
C4	556.5 ASCR, 3/0 ACSR, 1/0 CU	90.5	81.45+39.44i	45.8	37.3041+18.06352i
C5	556.5ACSR, 1/0CU (2),1192.5ACSR	110.5	99.45+48.16i	45.8	45.5481+22.05728i
C6	556.5 ASCR, 795 ACSR,1/0 CU(2)	130.5	117.45+56.88i	45.8	53.7921+26.05104i
C7	556.5ACSR,300CU,1/0CU(2)	150.5	135.45+65.59i	45.8	62.0361+30.04022i
C8	556.5ACSR, 1/0CU (2),1192.5ACSR	170.5	153.45+74.31i	50	76.725+37.15i
C9	556.5ACSR, 1/0CU (2),1192.5ACSR	210.5	189.45+91.75i	20	37.89+18.35i

The per unit values of the impedances of the conductors and their lengths are shown in Table 3.6. In Puerto Rico a typical 38 kV substation has 3 to four distribution feeders emanating from it. Short feeders are 4 to 5 mi long, while the longest feeders are 15 mi long. For this study we assumed lengths of 5, 10 and 15 miles for short, medium and long feeders, respectively. We assumed that 3 to 4 lines emanate from a 115 kV bus. Note that the cases are grouped by color representing the type of conductors used according to their current carrying capacity and power capacity for each type of load.

Table 3.6 Conductor Types and Their Per Unit Impedances Values

Conductor Types	**Zp.u.**
795 ACSR , 556.5 ACSR, 1/0 CU	
5 miles- 795 ACSR	0.04459+0.20030
10 miles-556.5 ACSR	0.12874+0.41578
15 miles-1/0 CU	0.63054+0.75400
556.5 ASCR, 3/0 ACSR, 1/0 CU	
5 miles- 1/0 CU	0.21018+0.25133
10 miles- 556.5 ACSR	0.12874+0.41578
15 miles- 3/0 ACSR	0.75104+0.83188
556.5ACSR, 1/0CU (2 conductors),1192.5ACSR	
5 miles-1192.5	0.00459+0.19171
10 miles- 556.5 ACSR	0.12874+0.41578
10miles-1/0 CU (2 conductors)	0.42036+0.5026667i
795 ACSR, 556.5 ASCR, 1/0 CU(2 conductors)	
5 miles- 795 ACSR	0.04459+0.20030
10 miles-556.5 ACSR	0.12874+0.41578
10miles-1/0 CU(2 conductors)	0.42036+0.5026667i
300 CU, 556.5 ACSR, 1/0 CU(2 conductors)	
5 miles- 300 CU	0.07444+0.22698
10 miles- 556.5 ACSR	0.12874+0.41578
10miles- 1/0 CU(2 conductors)	0.42036+0.5026667i

3.1.4 Simulations of the Ten Different Categories at the Distribution Level-38 kV

Now we present the different simulations for the scenarios discussed in the previous section. These simulations do not include the reduction due to STWH so far. The tables from 3.7 to 3.15 show the losses in the transformers and lines, the ampere rating, and the taps of the transformers as well. For the purpose of this study the distribution system voltage for the residential load of all cases 4.16 kV. The 115/38 kV transformers per unit impedance used was 0.0007 + j0.03480. The 38/4.16 kV transformers per unit impedance used was 0.00769 + j0.076903 or z=7.7%.

Each table is accompanied by a simulation diagram which shows the lines, transformers (at 115/38 kV and 38/4.16 kV), loads, and the bus voltages. The diagrams also include the injected generation into the area. The diagrams are below each table. Note that all per unit voltages are under acceptable values as well as the loading on the lines. The taps changes of the transformers are under acceptable values, this is ±16 steps according to [30].

After the last case (C9) a summary of all the simulations results is shown in Table 3.17. This table also includes the number of buses per load category.

Table 3.7 C0-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	4.6	1.5	0.00	0.01	23.2	1.00000
2	3	1	1.5	3.8	0.00	0.01	23.4	
2	4	1	1.5	3.2	0.00	0.01	23.4	
2	5	1	1.5	7.8	0.02	0.02	23.4	
3	6	1	1.5	1.5	0.00	0.00	23.4	1.00000
4	7	1	1.5	1.5	0.00	0.00	23.4	1.00000
5	8	1	1.5	1.5	0.00	0.00	23.4	1.00000

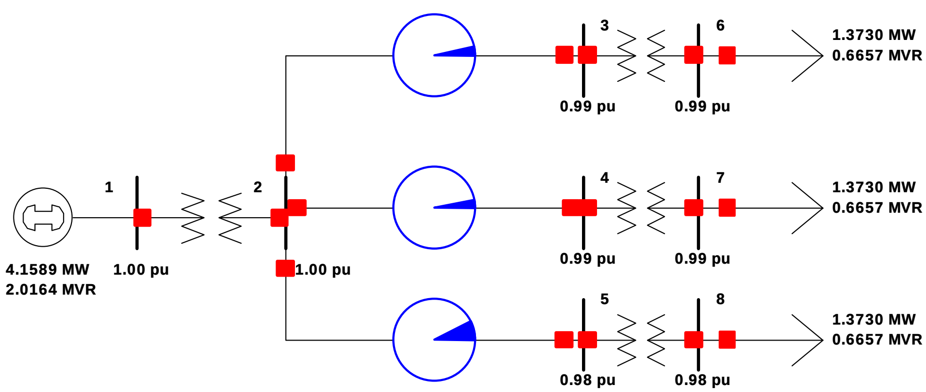


Figure 3.2 C0-Case without reduction of residential load

Table 3.8 C1-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	7.1	2.4	0.00	0.02	35.6	1.00000
2	3	1	2.4	5.8	0.01	0.01	35.9	
2	4	1	2.4	4.9	0.01	0.02	35.9	
2	5	1	2.4	12.0	0.04	0.05	35.9	
3	6	1	2.3	2.3	0.00	0.00	35.9	1.00000
4	7	1	2.3	2.3	0.00	0.00	35.9	1.00000
5	8	1	2.3	2.3	0.00	0.00	35.9	1.00000

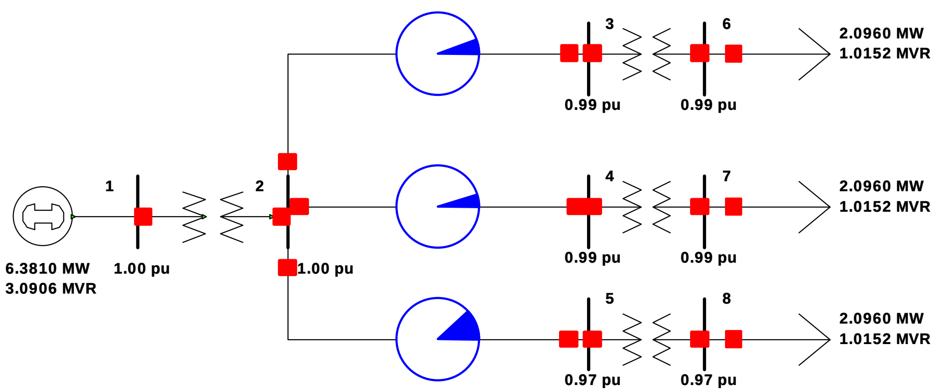


Figure 3.3 C1-Case without reduction of residential load

Table 3.9 C2-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	24.3	8.1	0.00	0.19	122.0	0.95000
2	3	1	7.9	19.4	0.12	0.14	114.4	
2	4	1	7.9	16.5	0.07	0.24	114.4	
2	5	1	8.4	42.6	0.48	0.53	121.6	
3	6	1	7.7	7.7	0.00	0.05	114.4	1.00000
4	7	1	7.7	7.7	0.00	0.04	114.4	1.00000
5	8	1	7.7	7.7	0.00	0.04	121.6	0.91250

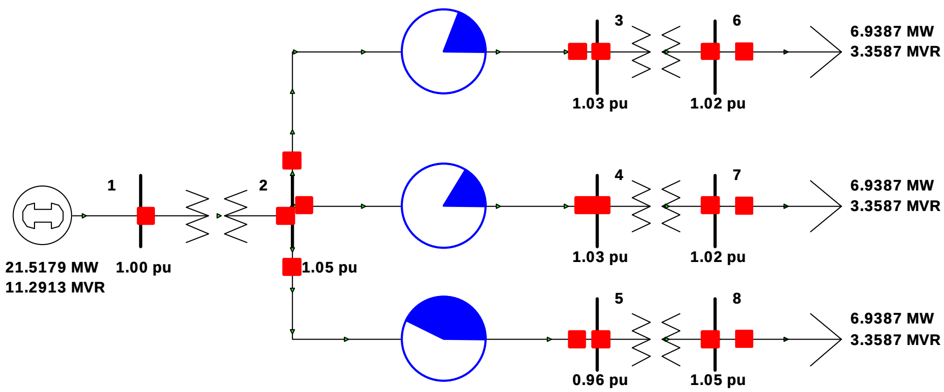


Figure 3.4 C2-Case without reduction of residential load

Table 3.10 C3-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	14.4	4.8	0.00	0.07	72.5	1.00000
2	3	1	4.7	8.0	0.01	0.05	72.2	
2	4	1	4.8	10.0	0.03	0.10	72.8	
2	5	1	4.9	23.9	0.10	0.18	74.3	
3	6	1	4.7	4.7	0.00	0.02	72.2	1.00000
4	7	1	4.7	4.7	0.00	0.02	72.8	1.00000
5	8	1	4.7	4.7	0.00	0.02	74.3	1.00000

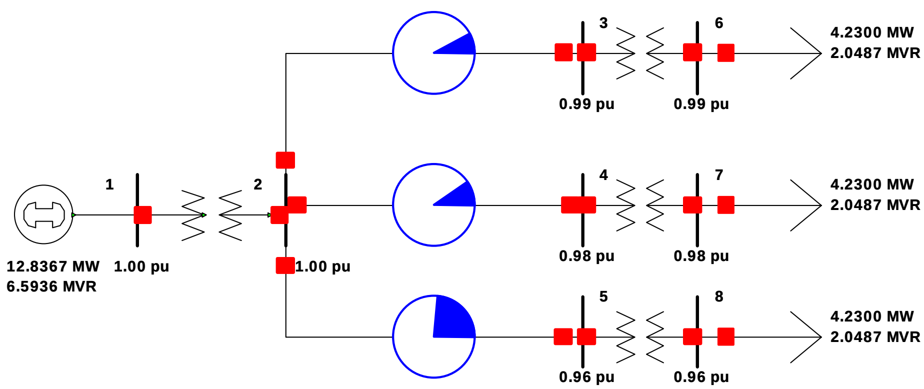


Figure 3.5 C3-Case without reduction of residential load

Table 3.11 C4-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	44.6	14.9	0.01	0.62	224.0	0.94375
2	3	1	14.5	35.4	0.40	0.47	208.8	
2	4	1	14.5	30.1	0.24	0.79	208.9	
2	5	1	15.4	78.1	1.07	1.19	222.1	
3	6	1	13.9	13.9	0.01	0.15	208.8	1.00000
4	7	1	13.9	13.9	0.01	0.15	208.9	1.00000
5	8	1	13.9	13.9	0.01	0.14	222.1	0.91250

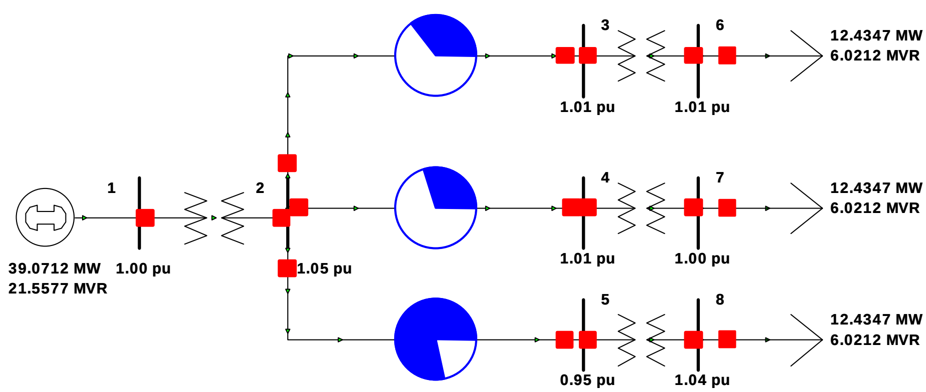


Figure 3.6 C4-Case without reduction of residential load

Table 3.12 C5-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	54.1	18.0	0.02	0.93	271.6	0.95625
2	3	1	12.9	16.8	0.01	0.29	188.4	
2	4	1	13.2	27.5	0.21	0.67	193.6	
2	5	1	13.8	33.8	0.74	0.89	201.9	
2	9	1	13.8	33.8	0.74	0.89	201.9	
3	6	1	12.7	12.7	0.01	0.12	188.4	1.00000
4	7	1	12.7	12.7	0.01	0.12	193.6	0.98750
5	8	1	12.7	12.7	0.01	0.12	201.9	0.92500
9	10	1	12.7	12.7	0.01	0.12	201.9	0.92500

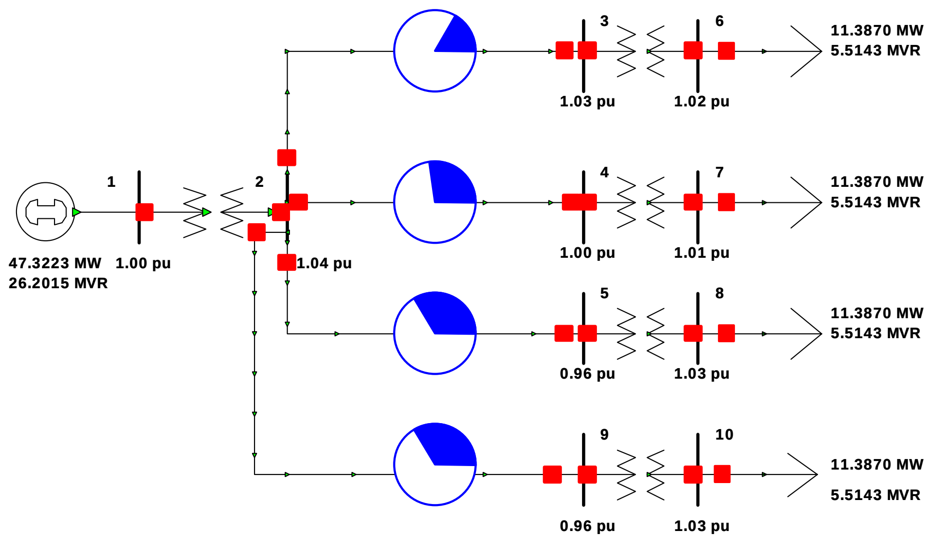


Figure 3.7 C5-Case without reduction of residential load

Table 3.13 C6- Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	64.7	21.6	0.03	1.30	325.0	0.94375
2	3	1	15.3	25.8	0.09	0.43	221.7	
2	4	1	15.7	32.7	0.29	0.93	227.6	
2	5	1	16.5	40.5	1.04	1.25	239.3	
2	9	1	16.5	40.5	1.04	1.25	239.3	
3	6	1	15.0	15.0	0.02	0.17	221.7	1.00000
4	7	1	15.0	15.0	0.02	0.16	227.6	0.97500
5	8	1	15.0	15.0	0.02	0.16	239.3	0.92500
9	10	1	15.0	15.0	0.02	0.16	239.3	0.92500

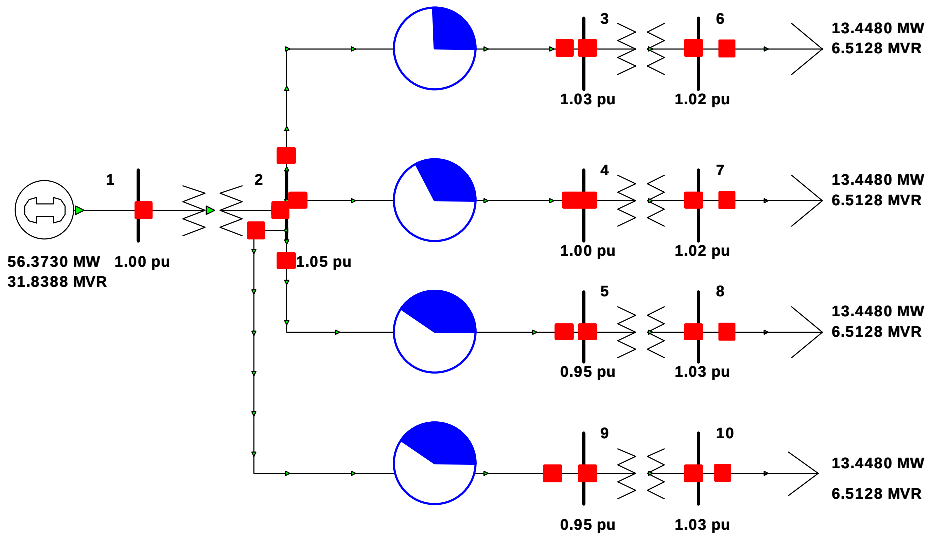


Figure 3.8 C6-Case without reduction of residential load

Table 3.14 C7- Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	75.7	25.2	0.03	1.73	380.0	0.93125
2	3	1	17.8	44.5	0.21	0.64	255.2	
2	4	1	18.3	38.0	0.38	1.23	261.4	
2	5	1	19.4	47.5	1.40	1.67	277.1	
2	9	1	19.4	47.5	1.40	1.67	277.2	
3	6	1	17.3	17.3	0.02	0.22	255.2	1.00000
4	7	1	17.3	17.3	0.02	0.22	261.4	0.97500
5	8	1	17.3	17.3	0.02	0.21	277.1	0.91250
9	10	1	17.3	17.3	0.02	0.21	277.2	0.91250

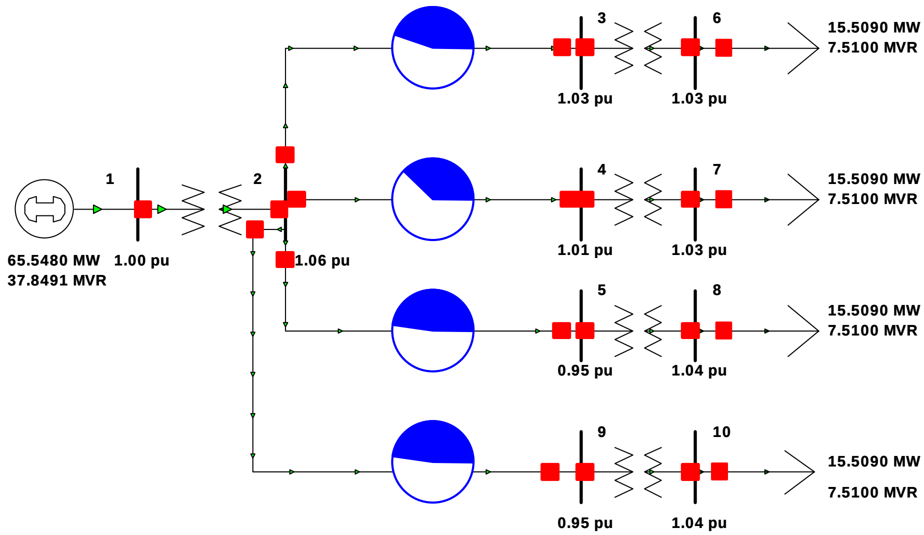


Figure 3.9 C7-Case without reduction of residential load

Table 3.15 C8 Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	95.9	32.0	0.06	2.74	481.5	0.92500
2	3	1	21.9	28.7	0.02	0.81	312.1	
2	4	1	22.9	47.8	0.60	1.93	327.3	
2	5	1	24.8	60.9	2.29	2.73	354.3	
2	9	1	24.8	60.8	2.28	2.73	354.2	
3	6	1	21.5	21.5	0.03	0.33	312.1	0.99375
4	7	1	21.5	21.5	0.03	0.32	327.3	0.94375
5	8	1	21.5	21.5	0.04	0.39	354.3	0.96250
9	10	1	21.5	21.5	0.04	0.39	354.2	0.96250

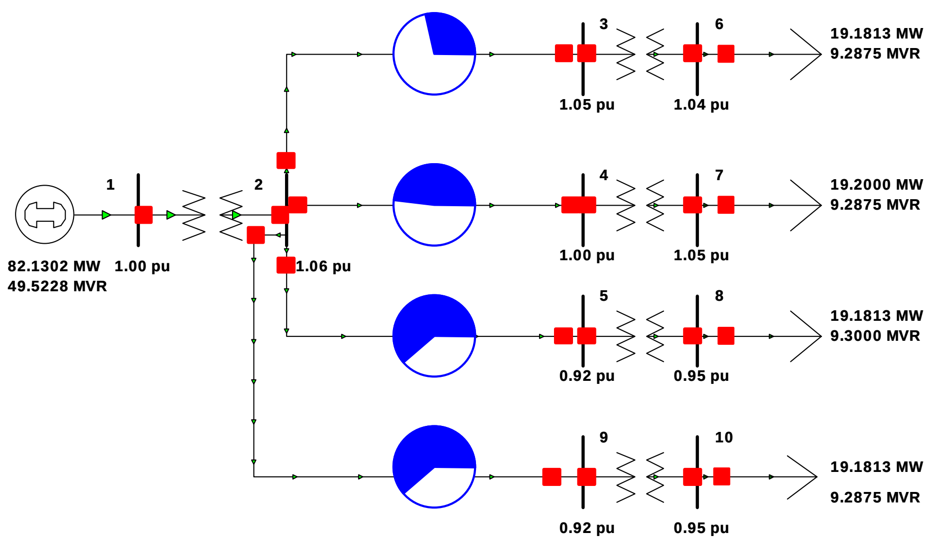


Figure 3.10 C8-Case without reduction of residential load

Table 3.16 C9-Line Information-no load reduction due to STWH

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	44.5	14.8	0.01	0.64	223.3	0.96250
2	3	1	10.7	14.0	0.00	0.20	157.1	
2	4	1	10.9	22.7	0.14	0.47	160.7	
2	5	1	11.3	27.7	0.50	0.60	166.3	
2	9	1	11.3	27.7	0.50	0.60	166.3	
3	6	1	10.6	10.6	0.01	0.09	157.1	1.00000
4	7	1	10.6	10.6	0.01	0.09	160.7	1.00000
5	8	1	10.6	10.6	0.01	0.09	166.3	0.96250
9	10	1	10.6	10.6	0.01	0.09	166.3	0.96250

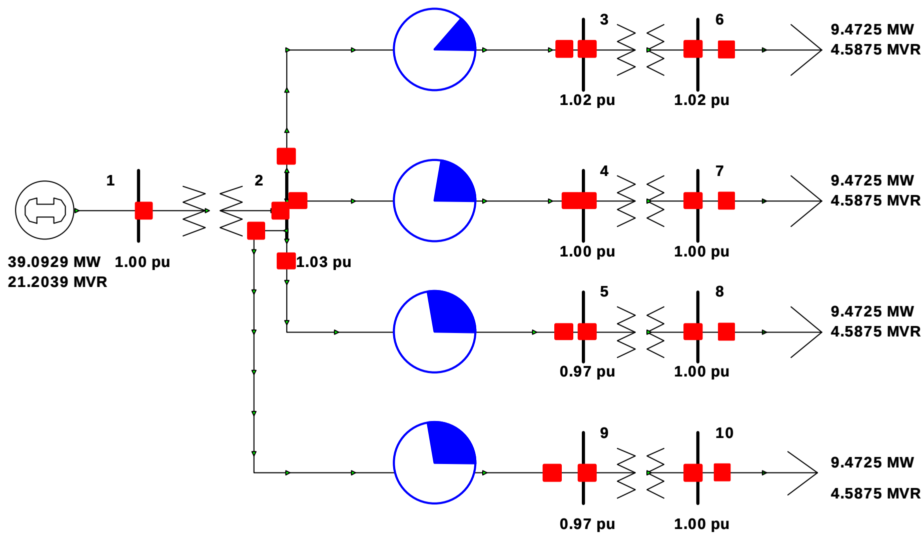


Figure 3.11 C9-Case without reduction of residential load

Now we present the summary of the simulations. In Table 3.17 the number of buses per load category multiplies the total losses in each case. Then we finally get to the total distribution (38 kV) power loss mentioned in *section 3.1.2*. The total power loss and the power flow conditions for the base case is shown in Table 3.16.

Table 3.17 Power Loss and Load Conditions at Distribution Level-Cases with no load reduction by STWH

C0 9 buses	MW	MVR	MW*#buses	MVR*#buses
Load	4.1	2	36.9	18
Generation	4.2	2	37.8	18
Losses	0.02	0.05	0.18	0.45
C1 15 buses	MW	MVR		
Load	6.3	3	94.5	45
Generation	6.4	3.1	96	46.5
Losses	0.06	0.1	0.9	1.5
C2 15 buses	MW	MVR		
Load	20.8	10.1	312	151.5
Generation	21.5	11.3	322.5	169.5
Losses	0.67	1.23	10.05	18.45
C3 6 buses	MW	MVR		
Load	12.7	6.1	76.2	36.6
Generation	12.8	6.6	76.8	39.6
Losses	0.14	0.46	0.84	2.76
C4 7 buses	MW	MVR		
Load	37.3	18.1	261.1	126.7
Generation	39.1	21.6	273.7	151.2
Losses	1.75	3.51	12.25	24.57
C5 2 buses	MW	MVR		
Load	45.5	22.1	91	44.2
Generation	47.3	26.2	94.6	52.4
Losses	1.76	4.15	3.52	8.3

Table 3.17 Cont. Power Loss and Load Conditions at Distribution Level-Cases with no load reduction by STWH

C6 5 buses	MW	MVR		
Load	53.8	26.1	269	130.5
Generation	56.4	31.8	282	159
Losses	2.57	5.81	12.85	29.05
C7 6 buses	MW	MVR		
Load	62	30	372	180
Generation	65.5	37.8	393	226.8
Losses	3.5	7.8	21	46.8
C8 10 buses	MW	MVR		
Load	76.7	37.2	767	372
Generation	82.1	49.5	821	495
Losses	5.39	12.37	53.9	123.7
C9 3 buses	MW	MVR		
Load	37.9	18.4	113.7	55.2
Generation	39.1	21.2	117.3	63.6
Losses	1.19	2.87	3.57	8.61

The total power loss and the power flow conditions for the base case is shown in Table 3.18. Note this is the case with no load reduction. The residential electric load of water heaters is calculated in the next section, *section 3.3.4.*

Table 3.18 Distribution Level Case 38kV-no load reduction by STWH

Total Losses	Total Losses
119.06 MW	264.19 MVR
Total Generation	Total Generation
2514.7 MW	1421.6 MVR
Total Load	Total Load
2393.4 MW	1159.7 MVR

3.1.5 Load Reduction Due to Solar Thermal Water Heaters

Domestic hot water is the second-highest energy cost in the typical household. In fact, for some homes it can be the highest energy expenditure [31]. Estimating the energy needed for domestic water heating using electric water heaters will provide us with a residential load reduction due to STWH assuming that water heating is done using STWH.

The General Demographic Characteristic in 2000 [32] for Puerto Rico is:

- Total occupied housing units………………................... 1,157,353
- Average family size . . . . ………………..… 3.41

The typical U.S. household hot water consumption for 4 persons is 240 liters/day (63.41 US gallons/day) [21]. Let us assume a water temperature rise of 75 °F (23.89

°C), corresponding to an inlet water temperature of 60 °F and water heater set point temperature of 135 °F. Since water density equals 1000 kg/m3 and 1 m3 = 1000 liters then 240 liters of water equal 240 kg. Recall that the specific heat of water, c, is 1 kcal/kg °C, then the heat energy, ΔQ, supplied to the 240 kg of water for a temperature rise of 23.89 °C is [19]:

$$\Delta Q = c * m * \Delta T = (1 \text{ kcal/kg °C})*240*23.89 = 5733.6 \text{ kcal}$$

$$\Delta Q = 5733.6 \text{ kcal} * (4187 \text{ J}/ 1 \text{ kcal}) = 2.4007 \text{ x } 107 \text{ J.}$$

Assuming an average water heater efficiency of 70% the electric energy input to the electric water heater is (2.4007 x 107 J)/0.7 = 3.4296 x 107 J = 9.5266 kW*h.

Currently the domestic electric energy cost in Puerto Rico is 0.16 $ per kW*h. Let us assume a 0.16 $/kW*h for electric energy cost, then the annual cost of heating 240 liters of water daily from 60 °F to 135 °F is (9.5266 kW*h/day)*(0.16 $/kW*h)*365 days = $556.35

We further assume that 80 % and 60 % of occupied housing units can use STWH to replace its electric water heater. The electric power consumption that may be replaced in Puerto Rico, adjusting for an average family size of 3.41 persons, using STWH is:

$$1,157,353 *0.80*(3.4296 \text{ x } 10^7 \text{ J}/ (24*60*60))*(3.41/4) = 313.31 \text{ MW}$$

$$1,157,353 *0.60*(3.4296 \text{ x } 10^7 \text{ J}/ (24*60*60))*(3.41/4) = 234.99 \text{ MW}$$

For 80% or 60% of the total residences in Puerto Rico using STWH (925,882.4 STWH- 694,411.8), assuming an average family of 3.41 people, and electric energy input to a electric water heater been 3.4296 x 10^7 J, the electric load reduction is 313.31 MW a day. This means that the families in Puerto Rico require 313.31 0r 234.99 MW of the total generation of the electric system a day for water heating purposes.

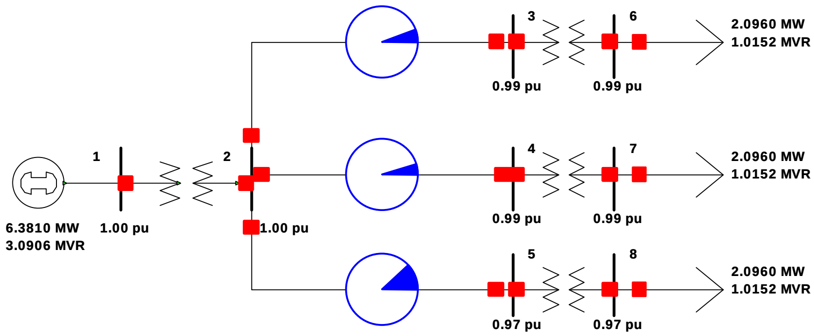
Since we will further calculate the power loss reduction (at 230 kV and 115 kV levels) at different load conditions of minimum, peak, and average load of a typical week of January and August, we need to calculate the electric load per hour. This is:

313.31MW/24 hours a day=13.0548 MW per hour

234.99 MW/24 hours a day=9.7911 MW per hour

The different load scenarios for the power loss calculation at the distribution level will be explained in detail in the later section.

Table 3.19 shows the new load conditions at 38 kV level due to the reduction of load by STWH. The ten cases now are simulated with this reduction in load of 13.0548 MW per hour. About 3.6% of the total load is reduced by 80 % of STWH and 2.74% for 60 % of STWH. A summary of the results for the new load conditions is listed in Tables 3.20-3.21 for convenience, since the cases with and without reduction differ slightly. The Figure 12 shows an example of the cases with the load reduction, specifically the case (C1) with the load reduction due to STWH. Compare the cases below with and without the reduction, respectively, there is a slight difference between them. The load, voltages and line loading vary slightly.



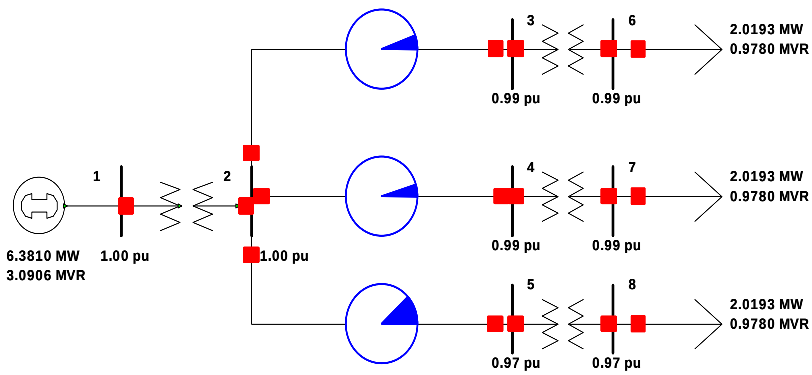


Figure 3.12 –Cases with and without reduction of residential load for C1

Table 3.19 Load Reduction by STWH at 38kV for 80% and 60%

Load Reduction by STWH's-80%	Total load MW
13.0548MW/hr	357.1 MW
P_{new} Load MW	% of Load Reduction
344.04 MW	3.6%
Load Reduction by STWH's-60%	Total load MW
9.7911MW/hr	357.1 MW
P_{new} Load MW	% of Load Reduction
347.31 MW	2.74%

Table 3.20 Power Loss and Load Conditions at Distribution Level-Cases with load reduction by STWH- 80 %

C02 9 buses	MW	MVR	MW*#buses	MVR*#buses
Load	4	1.9	36	17.1
Generation	4.2	2		
Losses	0.02	0.05	0.18	0.45
C12 15 buses	MW	MVR		
Load	6.1	2.9	91.5	43.5
Generation	6.4	3.1		
Losses	0.07	0.1	1.05	1.5
C22 15 buses	MW	MVR		
Load	20.1	9.7	301.5	145.5
Generation	20.7	10.8		
Losses	0.62	1.13	9.3	16.95
C32 6 buses	MW	MVR		
Load	12.2	5.9	73.2	35.4
Generation	12.4	6.3		
Losses	0.13	0.43	0.78	2.58
C42 7 buses	MW	MVR		
Load	35.9	17.4	251.3	121.8
Generation	37.6	20.6		
Losses	1.62	3.23	11.34	22.61
C52 2 buses	MW	MVR		
Load	43.9	21.3	87.8	42.6
Generation	45.5	25.1		
Losses	1.61	3.83	3.22	7.66

Table 3.20 Cont. Power Loss and Load Conditions at Distribution Level-Cases with load reduction by STWH-80%

C62 5 buses	MW	MVR		
Load	51.8	25.1	259	125.5
Generation	54.2	30.5		
Losses	2.38	5.37	11.9	26.85
C72 6 buses	MW	MVR		
Load	59.8	28.9	358.8	173.4
Generation	63	36.1		
Losses	3.21	7.19	19.26	43.14
C82 10 buses	MW	MVR		
Load	73.9	35.8	739	358
Generation	78.8	47.1		
Losses	4.92	11.31	49.2	113.1
C92 3 buses	MW	MVR		
Load	36.5	17.7	109.5	53.1
Generation	37.6	20.3		
Losses	1.1	2.09	3.3	6.27

Table 3.21 Power Loss and Load Conditions at Distribution Level-Cases with load reduction by STWH- 60 %

C02 9 buses	MW	MVR	MW*#buses	MVR*#buses
Load	4.0	2.0	36.1	17.9
Generation	4.2	2.0	37.4	18.1
Losses	0.2	0.0	1.4	0.2
C12 15 buses	MW	MVR		
Load	6.0	3.0	90.6	45.7
Generation	6.1	3.2	91.4	47.3
Losses	0.1	0.1	0.9	1.6
C22 15 buses	MW	MVR		
Load	20.2	10.1	303.7	151.1
Generation	20.9	11.2	313.6	168.7
Losses	0.7	1.2	9.9	17.6
C32 6 buses	MW	MVR		
Load	12.3	6.1	74.1	36.9
Generation	12.5	6.6	74.9	39.4
Losses	0.1	0.4	0.8	2.6
C42 7 buses	MW	MVR		
Load	36.3	18.1	254.0	126.4
Generation	38.0	21.4	265.8	149.8
Losses	1.7	3.3	11.8	23.3
C52 2 buses	MW	MVR		
Load	44.3	22.1	88.6	44.1
Generation	46.0	26.0	92.0	52.0
Losses	1.7	4.0	3.4	7.9

Table 3.21 Cont. Power Loss and Load Conditions at Distribution Level-Cases with load reduction by STWH-60%

C62 5 buses	MW	MVR		
Load	52.3	26.1	261.6	130.3
Generation	54.8	31.6	273.8	158.0
Losses	2.4	5.5	12.2	27.7
C72 6 buses	MW	MVR		
Load	60.3	30.0	362.0	180.2
Generation	63.7	37.5	382.1	224.9
Losses	3.3	7.4	20.0	44.6
C82 10 buses	MW	MVR		
Load	74.6	37.2	746.2	371.5
Generation	79.7	48.9	797.3	489.0
Losses	5.1	11.7	51.1	117.5
C92 3 buses	MW	MVR		
Load	36.9	18.4	110.6	55.1
Generation	38.0	21.1	114.0	63.2
Losses	1.1	2.7	3.4	8.2

The power loss reduction at the distribution level (38 kV) is presented in Table 3.22. This reduction was calculated to be 8% and 8.74% for 80 % of STWH and 3.45 % and 4.93 % (for 60 % STWH) of the total losses per hour, in terms of real and reactive power, respectively.

Table 3.22 Power Loss Reduction at 38kV Level with load reduction by STWH-80 % and 60 %

Total losses MW- **80 %**	Total losses MVR- **80 %**
109.53	241.11
Power Loss Reduction MW	Power Loss Reduction MVR
9.53	23.08
8 % of total losses	**8.74** % of total losses
Total losses MW- **60 %**	Total losses MVR- **60 %**
114.95	251.18
Power Loss Reduction MW	Power Loss Reduction MVR
4.11	13.02
3.45 % of total losses	**4.93 %** of total losses

3.1.6 Simulations of the Transmission Level Cases- 230 & 115 kV

Once the distribution power loss reduction at 38 kV is calculated, we proceed to estimate the transmission level (at 230 kV and 115 kV) power loss reduction as well as the generation displacement due to STWH. The base case for all the different load scenarios is presented in Table 3.23. The power flow results are also shown, before and after the load reduction. The same 13.0548 MW load reduction per hour is considered throughout all the simulations of [28].

Table 3.23 Transmission System Base Case

Base Case	**MW**	**MVR**
Load	2405.17	1180.49
Generation	2448.1	1284.7
Losses	42.96	416.06
With Load Reduction by STWH	**MW**	**MVR**
Load	2392.12	1180.49
Generation	2434.8	1281.9
Losses	42.74	413.45
Generation Displaced	13.3 MW	2.8 MVR
% of the total generation	0.543 %	0.218 %
Power Loss Reduction	0.22 MW	2.61 MVR
% of the total system losses	0.512 %	0.627 %

The base case was scaled for different load conditions shown in Table 3.24. For our study we developed 30 different cases representing typical week load curves for the months of January and August. These months will further characterize the remaining months of the year based on the load size which happens to have a direct relation with the intensity of solar radiation. Simulations included these load values with a reduction in demand due to STWH.

We performed sixty simulations, thirty with no reduction in residential load and thirty considering the reduction. The load curves shown in Figures 3.13 and 3.14 are a load forecast for the Puerto Rico electric system on a 24 hour basis [33].

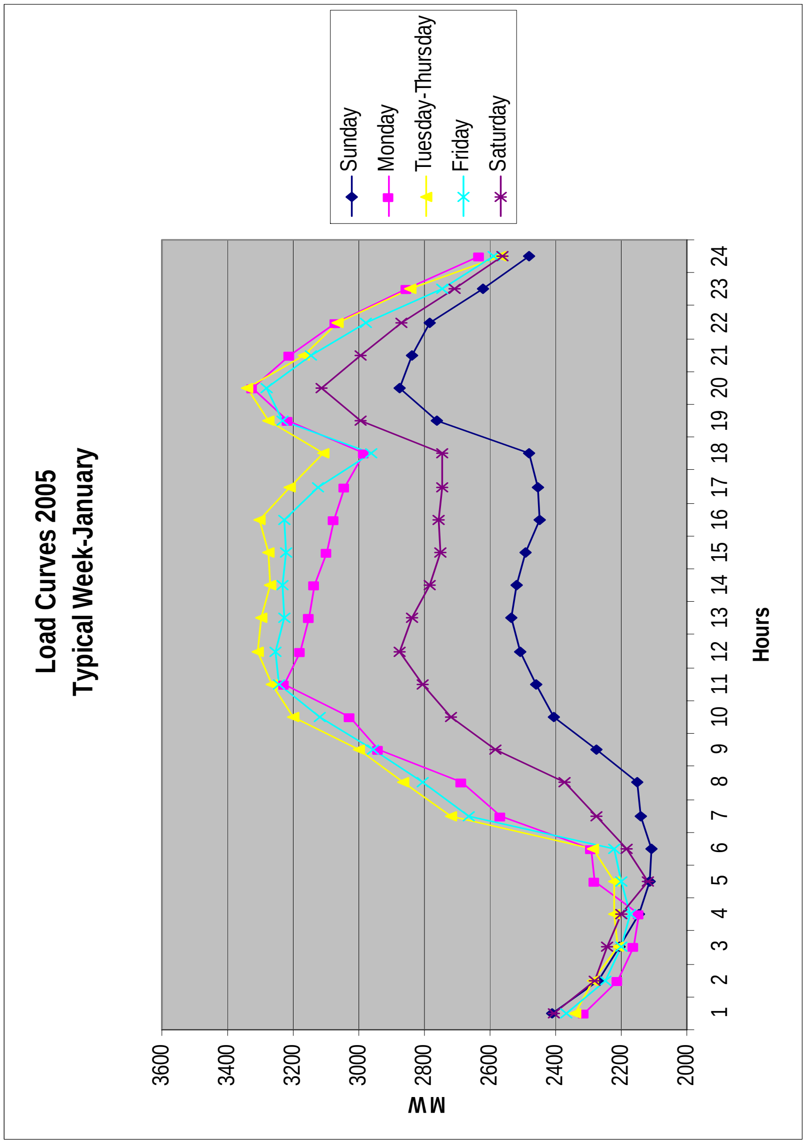


Figure 3.13 Typical Week Load Curve-January

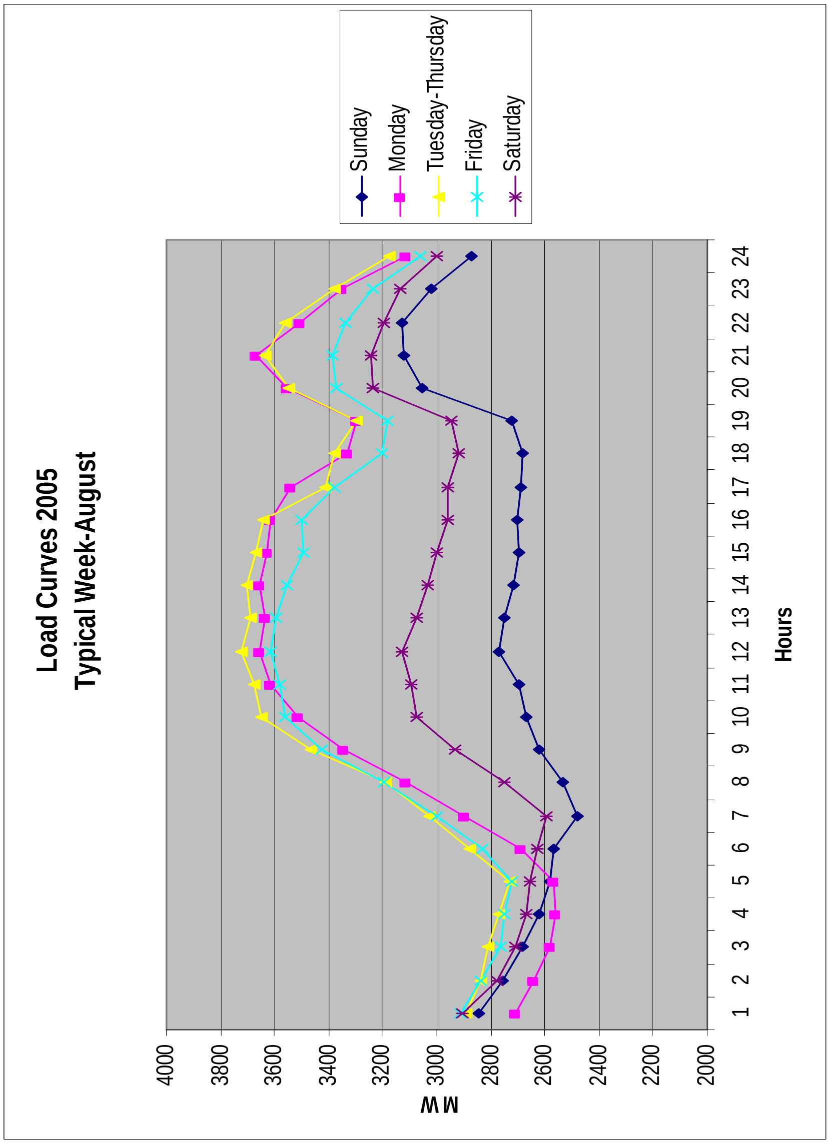


Figure 3.14 Typical Week Load Curve-August

We considered a period of time between 9:00a.m.and 4:00p.m., which is a period with sufficient solar radiation for the STWH to work. The values of solar radiation intensity vary from 171.0 W/m^2 in the cloudiest months of the year, to 254.1 W/m^2 in August. We did not consider aspects such as cloud coverage, stochastic behavior of solar radiation and rain effects. We developed our load forecast from the typical week load curves for January and August, for the year 1998, because the data available was from that year [33]. Our estimate includes the increase in electric load of 3% per year according to [27].

For each day of the week we performed a simulation at the minimum load, at the peak load, and the average load between 9:00 a.m. and 4:00 p.m. Note that the peak load hour is usually at 12:00 p.m.

The simulations were done for the cases with no load reduction and with load reduction due to STWH. We calculated the power loss reduction (at 230 kV and 115 kV levels) at different load conditions of minimum, peak, and average load of a typical week of January and August. The electric power consumption that may be replaced in Puerto Rico, adjusting for an average family size of 3.41 persons, using STWH is 313.31 MW (80 %) and 234.99 (60 %). The electric load reduction per hour, assuming 9.5266 kW*h is the energy input to a 240 liters electric water heater with efficiency of 70%, is:

313.31 MW/24 hours a day=13.0548 MW per hour

234.99 MW/24 hours a day=9.7911 MW per hour

This means that the families in Puerto Rico require 13.0548 MW or 9.7911 of the total generation of the electric system per hour.

Table 3.24 Different load levels for typical January an August weeks

Typical Week Load(MW) Year 2005	January								
	9:00a.m.	10:00a.m.	11:00a.m.	12:00p.m.	1:00p.m.	2:00p.m.	3:00p.m.	4:00p.m.	Average
Sunday	2276.497	2408.093	2458.518	2508.943	2536.0	2517.552	2490.495	2448.679	2455.597
Monday	2940.628	3027.949	3227.189	3176.764	3149.707	3137.408	3098.052	3075.915	3104.202
Tuesday-Thursday	2999.662	3201.362	3262.855	3305.901	3297.292	3271.464	3277.614	3300.981	3239.641
Friday	2955.387	3121.42	3244.407	3251.787	3224.729	3233.338	3223.499	3227.189	3185.22
Saturday	2585.195	2719.251	2805.342	2876.675	2838.549	2784.434	2751.228	2756.147	2764.603
	August								
Sunday	2618.401	2671.286	2698.343	2768.446	2749.998	2713.102	2698.343	2700.803	2702.34
Monday	3345.257	3511.29	3615.829	3656.415	3637.967	3652.725	3625.668	3613.369	3582.315
Tuesday-Thursday	3468.244	3650.266	3673.633	3724.058	3692.081	3701.92	3666.254	3644.116	3652.572
Friday	3422.739	3562.945	3582.623	3613.369	3591.232	3551.876	3494.072	3501.451	3540.038
Saturday	2929.56	3070.995	3095.593	3126.339	3072.225	3034.099	2999.662	2960.306	3036.097

All the selected cases were simulated adjusting the base case by scaling the load in terms of real power in MW. For example: Sunday-January (min. load) 2776.5 MW, the base case was 2405.17 MW, this is 5.35% of the real power was scaled up from the base case load. The same was done for the cases of maximum and average loads with and without load reduction due to STWH. They are divided in tables for each day for the weeks of January and August. The tables include the cases with no load reduction and the cases with the reduction in load due to STWH. They also include the power loss reduction and the generation displacement in terms of real and reactive power, MW and MVR, respectively. We presented the power loss reduction and generation displacement in percentages for a better appreciation of the improvements at each period.

The sixty simulations were tabulated (Tables 3.25- 3.44) putting together the minimum and maximum results and the average case separately, for convenience. This was done for the case of 80 % of STWH. The average scenarios for 80 % and 60 % of STWH are used in *section 3.1.6* to calculate the average annual power loss reduction and generation displacement. This will be discussed in more detail in the following chapter.

Table 3.25 Minimum and Maximum Load Scenarios- Sunday, January

Sunday, January, 9:00a.m., min. load	MW	MVR	**Sunday, January, 1:00 p.m., max. load**	MW	MVR
Load	2276.5	1180.5	**Load**	2536.0	1180.5
Generation	2317.6	1261.2	**Generation**	2581.0	1310.1
Losses	41.02	393.9	**Losses**	45.03	440.2
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	2263.4	1180.5	**Load**	2523.0	1180.5
Generation	2304.3	1259.3	**Generation**	2567.7	1307.4
Losses	40.9	392.1	**Losses**	44.81	437.6
Generation Displaced	13.3 MW	1.9 MVR	**Generation Displaced**	13.3 MW	2.7 MVR
% of the total generation	0.574 %	0.15 %	**% of the total generation**	0.524 %	0.229 %
Power Loss Reduction	0.17 MW	1.8 MVR	**Power Loss Reduction**	0.22 MW	2.6MVR
% of the total system losses	0.414 %	0.457 %	**% of the total system losses**	0.488 %	0.588 %

Table 3.26 Average Load Scenario- Sunday, January

Sunday, January, avg. load	MW	MVR
Load	2455.6	1180.5
Generation	2499.3	1294.0
Losses	43.73	428.9
With load reduction by STWH	MW	MVR
Load	2442.5	1180.5
Generation	2486.0	1291.5
Losses	43.5	422.5
Generation Displaced	13.3 MW	2.5 MVR
% of the total generation	0.532 %	0.212 %
Power Loss Reduction	0.2 MW	6.3 MVR
% of the total system losses	0.457 %	1.48 %

Table 3.27 Minimum and Maximum Load Scenarios- Monday, January

Monday, January, 9:00a.m., min. load	MW	MVR	**Monday, January, 11:00 p.m., max. load**	MW	MVR
Load	2940.6	1180.5	**Load**	3227.19	1180.5
Generation	2993.3	1395.0	**Generation**	3287.4	1490.0
Losses	52.7	525.1	**Losses**	60.21	617.3
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	2927.6	1180.5	**Load**	3214.1	1180.5
Generation	2979.9	1391.3	**Generation**	3273.9	1482.9
Losses	52.4	521.9	**Losses**	59.8	610.3
Generation Displaced	13.4 MW	3.7 MVR	**Generation Displaced**	13.5 MW	7.1 MVR
% of the total generation	0.456 %	0.265 %	**% of the total generation**	0.411 %	0.476 %
Power Loss Reduction	0.3 MW	3.2 MVR	**Power Loss Reduction**	0.42 MW	7.05 MVR
% of the total system losses	0.569 %	0.601 %	**% of the total system losses**	0.698 %	1.14 %

Table 3.28 Average Load Scenario- Monday, January

Monday, January, avg. load	MW	MVR
Load	3104.2	1180.5
Generation	3160.8	1444.6
Losses	56.7	573.32
With load reduction by STWH	MW	MVR
Load	3091.2	1180.5
Generation	3147.4	1440
Losses	56.3	568.9
Generation Displaced	13.4 MW	4.6 MVR
% of the total generation	0.424 %	0.318 %
Power Loss Reduction	0.34 MW	4.4 MVR
% of the total system losses	0.600 %	0.772 %

Table 3.29 Minimum and Maximum Load Scenarios- Tuesday- Thursday, January

Tuesday-Thursday, January, 9:00a.m., min. load	MW	MVR	**Tuesday-Thursday, January, 12:00 p.m., max. load**	MW	MVR
Load	2999.7	1180.5	**Load**	3305.9	1180.5
Generation	3053.7	1411.9	**Generation**	3368.9	1530.9
Losses	54.1	541.0	**Losses**	63.0	656.7
With load reduction by STWH	MW	MVR	**With load reduction by STWH's**	MW	MVR
Load	2986.6	1180.5	**Load**	3292.8	1180.5
Generation	3040.3	1407.6	**Generation**	3355.2	1512.8
Losses	53.78	537.0	**Losses**	62.4	638.9
Generation Displaced	13.4 MW	4.3 MVR	**Generation Displaced**	13.7 MW	18.1 MVR
% of the total generation	0.439 %	0.795 %	**% of the total generation**	0.406 %	1.18 %
Power Loss Reduction	0.31 MW	4.1 MVR	**Power Loss Reduction**	0.66 MW	17.8 MVR
% of the total system losses	0.573 %	0.752 %	**% of the total system losses**	1.046 %	2.710 %

Table 3.30 Average Load Scenario Tuesday- Thursday, January

Tuesday-Thursday, January, avg. load	MW	MVR
Load	3239.6	1180.5
Generation	3300.3	1496.4
Losses	60.6	623.4
With load reduction by STWH	MW	MVR
Load	3226.6	1180.5
Generation	3286.8	1487.5
Losses	60.19	614.7
Generation Displaced	13.5 MW	8.9 MVR
% of the total generation	0.409 %	0.595 %
Power Loss Reduction	0.45 MW	8.7 MVR
% of the total system losses	0.742 %	1.390%

Table 3.31 Minimum and Maximum Load Scenarios- Friday, January

Friday, January, 9:00a.m., min. load	MW	MVR	Friday, January, 12:00 p.m., max. load	MW	MVR
Load	2955.4	1180.5	Load	3251.8	1180.5
Generation	3008.4	1397.5	Generation	3312.8	1501.0
Losses	53.0	527.4	Losses	61.01	629.0
With load reduction by STWH	MW	MVR	With load reduction by STWH	MW	MVR
Load	2942.3	1180.5	Load	3238.7	1180.5
Generation	2995.1	1393.6	Generation	3299.2	1490.4
Losses	52.7	523.5	Losses	60.5	618.8
Generation Displaced	13.3 MW	3.9 MVR	Generation Displaced	13.6 MW	10.6 MVR
% of the total generation	0.442 %	0.279 %	% of the total generation	0.411 %	0.706 %
Power Loss Reduction	0.30 MW	3.9 MVR	**Power Loss Reduction**	0.48 MW	10.3 MVR
% of the total system losses	0.566 %	0.739 %	% of the total system losses	0.787 %	1.630 %

Table 3.32 Average Load Scenario- Friday, January

Friday, January, avg. load	MW	MVR
Load	3185.2	1180.5
Generation	3244.0	1472.3
Losses	58.8	600.2
With load reduction by STWH	MW	MVR
Load	3172.2	1180.5
Generation	3230.6	1467.4
Losses	58.5	595.5
Generation Displaced	13.4 MW	4.9 MVR
% of the total generation	0.413 %	0.333 %
Power Loss Reduction	0.36 MW	4.71 MVR
% of the total system losses	0.611 %	0.785 %

Table 3.33 Minimum and Maximum Load Scenarios- Saturday, January

Saturday, January, 9:00a.m., min load	MW	MVR	Saturday, January, 12:00 p.m., max. load	MW	MVR
Load	2585.2	1180.5	**Load**	2876.7	1180.5
Generation	2637.0	1320.7	**Generation**	2928.1	1378.0
Losses	45.9	450.3	**Losses**	51.4	507.3
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	2572.1	1180.5	**Load**	2863.6202	1180.49
Generation	2617.7	1317.8	**Generation**	2914.7	1374.4
Losses	45.6	447.5	**Losses**	51.2	503.6
Generation Displaced	19.3 MW	2.9 MVR	**Generation Displaced**	13.4 MW	3.6 MVR
% of the total generation	0.731 %	0.220 %	**% of the total generation**	0.458 %	0.262 %
Power Loss Reduction	0.23 MW	2.7 MVR	**Power Loss Reduction**	0.29 MW	3.7 MVR
% of the total system losses	0.501 %	0.608 %	**% of the total system losses**	0.564 %	0.723 %

Table 3.34 Average Load Scenario- Saturday, January

Saturday, January, avg. load	MW	MVR
Load	2764.6	1180.5
Generation	2813.8	1362.1
Losses	49.21	490.96
With load reduction by STWH	MW	MVR
Load	2751.6	1180.5
Generation	2800.5	1358.6
Losses	49.0	487.7
Generation Displaced	13.3 MW	3.5 MVR
% of the total generation	0.473 %	0.257 %
Power Loss Reduction	0.26 MW	3.3 MVR
% of the total system losses	0.528 %	0.672 %

Table 3.35 Minimum and Maximum Load Scenarios- Sunday, August

Sunday, August, 9:00a.m., min load	MW	MVR	**Sunday, August, 12:00 p.m., max. load**	MW	MVR
Load	2618.4	1180.5	**Load**	2768.5	1180.5
Generation	2664.8	1328.2	**Generation**	2817.7	1363.1
Losses	46.48	457.4	**Losses**	49.29	492.0
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	2605.2	1180.5	**Load**	2755.4	1180.5
Generation	2651.6	1325.2	**Generation**	2804.4	1359.6
Losses	46.2	454.6	**Losses**	49.02	488.6
Generation Displaced	13.2 MW	3.0 MVR	**Generation Displaced**	13.3 MW	2.7 MVR
% of the total generation	0.495 %	0.226 %	**% of the total generation**	0.472 %	0.198 %
Power Loss Reduction	0.24 MW	2.84MVR	**Power Loss Reduction**	0.27 MW	3.5 MVR
% of the total system losses	0.516 %	6.14 %	**% of the total system losses**	0.548 %	0.711 %

Table 3.36 Average Load Scenario- Sunday, August

Sunday, August, avg. load	MW	MVR
Load	2702.3	1180.5
Generation	2750.3	1346.0
Losses	47.97	475.59
With load reduction by STWH	MW	MVR
Load	2689.3	1180.5
Generation	2737.0	1342.8
Losses	47.7	472.5
Generation Displaced	13.3 MW	3.2 MVR
% of the total generation	0.484 %	0.238 %
Power Loss Reduction	0.250 MW	3.1 MVR
% of the total system losses	0.521 %	0.652 %

Table 3.37 Minimum and Maximum Load Scenarios- Monday, August

Monday, August, 9:00a.m., min. load	MW	MVR	**Monday, August, 12:00 p.m., max. load**	MW	MVR
Load	3345.3	1180.5	**Load**	3656.4	1180.5
Generation	3409.8	1551.4	**Generation**	3735.3	1760.2
Losses	64.55	676.67	**Losses**	78.96	884.4
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	3332.2	1180.5	**Load**	3643.36	1180.5
Generation	3395.9	1527.4	**Generation**	3720.2	1674.9
Losses	63.8	653.06	**Losses**	76.9	800.2
Generation Displaced	13.9 MW	24 MVR	**Generation Displaced**	15.1 MW	85.3 MVR
% of the total generation	0.407 %	3.55 %	**% of the total generation**	0.404 %	4.85 %
Power Loss Reduction	0.780 MW	23.6 MVR	**Power Loss Reduction**	2.1 MW	84.2 MVR
% of the total system losses	1.210 %	3.490 %	**% of the total system losses**	2.610 %	9.519 %

Table 3.38 Average Load Scenario- Monday, August

Monday, August, avg. load	MW	MVR
Load	3582.3	1180.5
Generation	3656.6	1694.4
Losses	74.4	821.05
With load reduction by STWH	MW	MVR
Load	3569.3	1180.5
Generation	3641.9	1625.8
Losses	72.71	753.5
Generation Displaced	14.7 MW	68.6 MVR
% of the total generation	0.402 %	4.05 %
Power Loss Reduction	1.72 MW	67.6 MVR
% of the total system losses	2.310 %	8.230 %

Table 3.39 Minimum and Maximum Load Scenarios- Tuesday-Thursday, August

Tuesday-Thursday, August, 9:00a.m., min. load	MW	MVR	**Tuesday-Thursday, January, 12:00 p.m., max. load**	MW	MVR
Load	3468.2	1180.5	**Load**	3724.1	1180.5
Generation	3538.1	1625.0	**Generation**	3807.3	1823.0
Losses	69.9	748.4	**Losses**	83.3	948.0
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	3455.2	1180.5	**Load**	3711.0	1180.5
Generation	3523.8	1579.6	**Generation**	3791.7	1717.0
Losses	68.7	703.7	**Losses**	80.8	843.4
Generation Displaced	14.3 MW	45.4 MVR	**Generation Displaced**	15.6 MW	106.0 MVR
% of the total generation	0.404 %	2.79 %	**% of the total generation**	0.410 %	5.81 %
Power Loss Reduction	1.24 MW	44.6 MVR	**Power Loss Reduction**	2.5 MW	104.6 MVR
% of the total system losses	1.770 %	5.960 %	**% of the total system losses**	2.970%	11.020 %

Table 3.40 Average Load Scenario- Tuesday-Thursday, August

Tuesday-Thursday, August, avg. load	MW	MVR
Load	3652.6	1180.5
Generation	3731.2	1756.7
Losses	78.72	881.0
With load reduction by STWH	MW	MVR
Load	3639.5	1180.5
Generation	3716.2	1672.3
Losses	76.7	797.8
Generation Displaced	15 MW	84.4 MVR
% of the total generation	0.402 %	4.800 %
Power Loss Reduction	2.0 MW	83.3 MVR
% of the total system losses	2.590 %	9.450 %

Table 3.41 Minimum and Maximum Load Scenarios- Friday, August,

Friday, August, 9:00a.m., min. load	MW	MVR	**Friday, August, 12:00 p.m., max. load**	MW	MVR
Load	3422.7	1180.5	**Load**	3613.4	1180.5
Generation	3490.4	1593.8	**Generation**	3689.5	1720.7
Losses	67.76	718.14	**Losses**	76.23	846.6
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	3409.7	1180.5	**Load**	3600.3	1180.5
Generation	3476.3	1557.5	**Generation**	3674.6	1645.3
Losses	66.7	682.3	**Losses**	74.37	772.2
Generation Displaced	14.1 MW	36.3 MVR	**Generation Displaced**	14.9 MW	75.4 MVR
% of the total generation	0.403 %	2.27 %	**% of the total generation**	0.404 %	4.38 %
Power Loss Reduction	1.1 MW	35.8 MVR	**Power Loss Reduction**	1.9 MW	74.4 MVR
% of the total system losses	1.560%	4.990 %	**% of the total system losses**	2.440 %	8.780 %

Table 3.42 Average Load Scenario- Friday, August,

Friday, August, avg. load	MW	MVR
Load	3540.0	1180.5
Generation	3613.7	1678.4
Losses	73.72	801.9
With load reduction by STWH	MW	MVR
Load	3527.0	1180.5
Generation	3599.1	1618.7
Losses	72.2	743.1
Generation Displaced	14.6 MW	59.7 MVR
% of the total generation	0.404 %	3.560 %
Power Loss Reduction	1.54 MW	58.8 MVR
% of the total system losses	2.090 %	7.330 %

Table 3.43 Minimum and Maximum Load Scenarios- Saturday, August

Saturday, August, 9:00a.m., min. load	MW	MVR	**Saturday, August, 12:00 p.m., max. load**	MW	MVR
Load	2929.6	2916.5	**Load**	3126.3	1180.5
Generation	2981.9	1391.7	**Generation**	3183.4	1452.4
Losses	52.4	521.7	**Losses**	57.2	580.8
With load reduction by STWH	MW	MVR	**With load reduction by STWH**	MW	MVR
Load	2572.1	1180.5	**Load**	3113.3	1180.5
Generation	2968.6	1387.8	**Generation**	3170.0	1447.7
Losses	52.1	517.8	**Losses**	56.9	576.3
Generation Displaced	13.3 MW	3.9 MVR	**Generation Displaced**	13.4 MW	4.7 MVR
% of the total generation	0.446 %	0.28 %	**% of the total generation**	0.420 %	0.323 %
Power Loss Reduction	0.3 MW	3.83 MVR	**Power Loss Reduction**	0.34 MW	4.5 MVR
% of the total system losses	0.572 %	0.734 %	**% of the total system losses**	0.594 %	0.775 %

Table 3.44 Average Load Scenario- Saturday, August

Saturday, August, avg. load	MW	MVR
Load	3036.1	1180.5
Generation	3091.0	1423.9
Losses	54.99	552.6
With load reduction by STWH	MW	MVR
Load	3023.042	1180.49
Generation	3077.7	1419.5
Losses	54.7	548.4
Generation Displaced	13.3 MW	4.4 MVR
% of the total generation	0.403 %	0.309 %
Power Loss Reduction	0.32 MW	4.2MVR
% of the total system losses	0.582 %	0.758 %

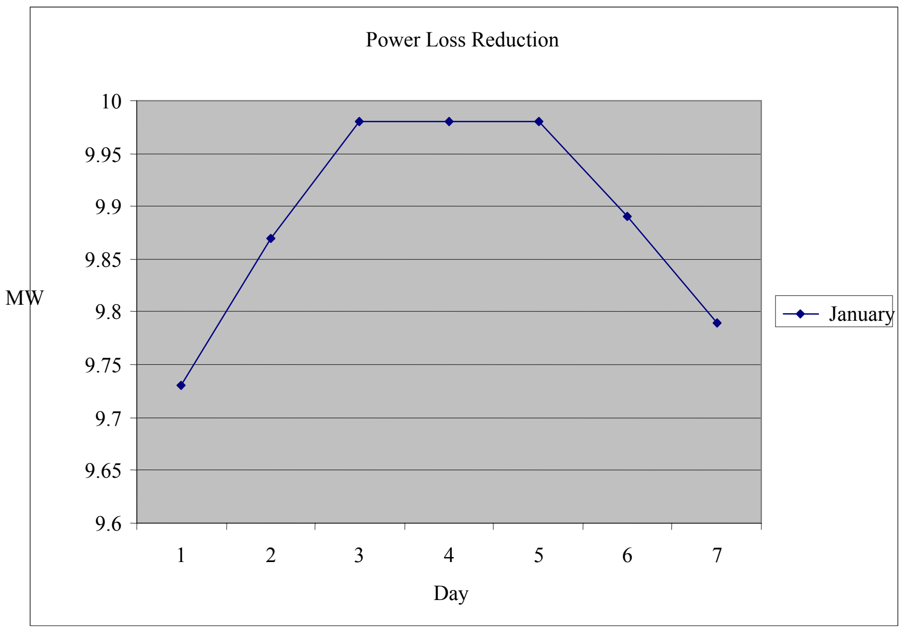
3.1.6 Annual Average Power Loss and Generation Displacement Calculation

The average values for each day of the week in the time period from 9:00 p.m. to 4:00 p.m. are presented in the Table 3.44. From these average week values we finally get to the average annual power loss reduction and generation displacement.

Table 3.44 Average Weekly Power Loss Reduction and Generation Displacement

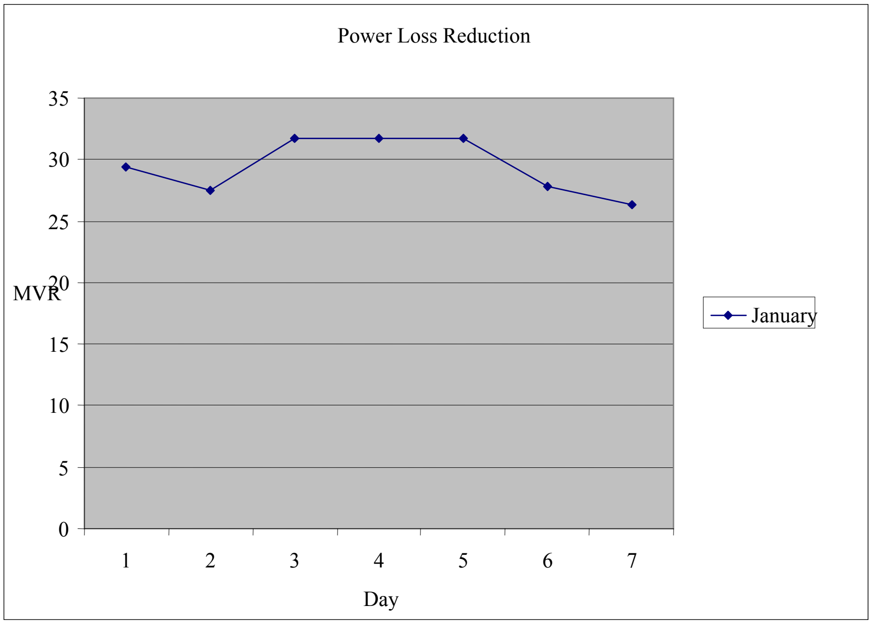
	January	Power Loss Reduction MW	Power Loss Reduction MVR	Generation Displaced MW	Generation Displaced MVR
1	Sunday	9.73	29.42	13.30	2.50
2	Monday	9.87	27.51	13.40	4.60
3	Tuesday-Thursday	9.98	31.77	13.50	8.90
4	Tuesday-Thursday	9.98	31.77	13.50	8.90
5	Tuesday-Thursday	9.98	31.77	13.50	8.90
6	Friday	9.89	27.79	13.40	4.90
7	Saturday	9.79	26.38	13.30	3.50
		9.89	29.48	13.41	6.03
	August	**Power Loss Reduction MW**	**Power Loss Reduction MVR**	**Generation Displaced MW**	**Generation Displaced MW**
1	Sunday	9.78	26.18	13.30	3.20
2	Monday	11.25	90.64	14.70	68.60
3	Tuesday-Thursday	11.57	106.37	15.00	84.40
4	Tuesday-Thursday	11.57	106.37	15.00	84.40
5	Tuesday-Thursday	11.57	106.37	15.00	84.40
6	Friday	11.07	81.89	14.60	59.70
7	Saturday	9.85	27.27	13.30	4.40
		10.95	77.87	14.41	55.59

Figures 3.15 through 3.22 represent the average week values for power loss reduction and generation displacement. The same characteristics repeated for the results of power loss minimization and generation displacement, in terms of the real and reactive power. This is due to the load behavior during the selected period of time from 9:00 a. m. to 4:00 p.m. and that the load reduction due to STWH was constant for our study. The peak of the curve is evidently different for these two months of the year. For the study, August characterizes the largest demand month of the year while January represent the smallest demand of the year, for the Puerto Rico's electric total demand.



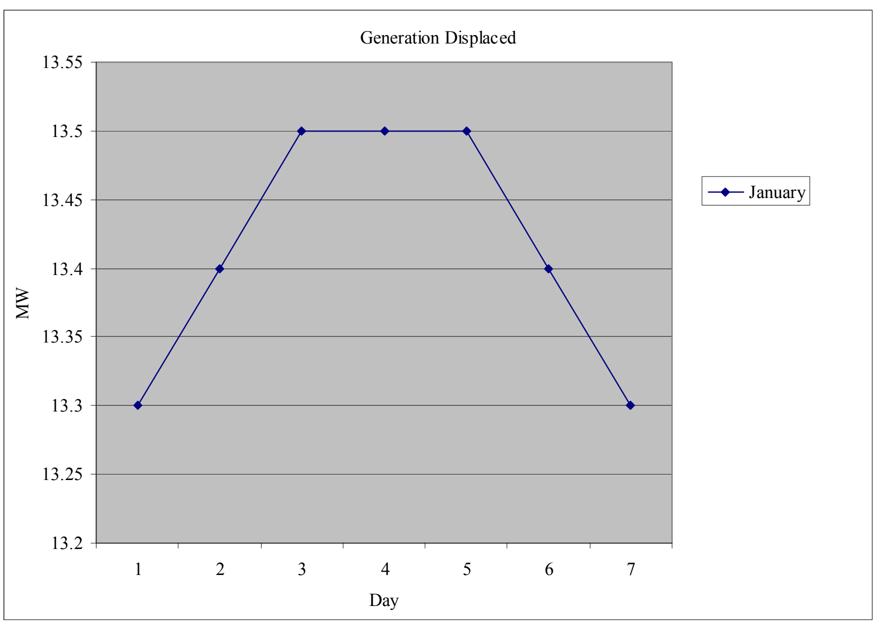
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.15 January Power Loss Reduction Curve- MW



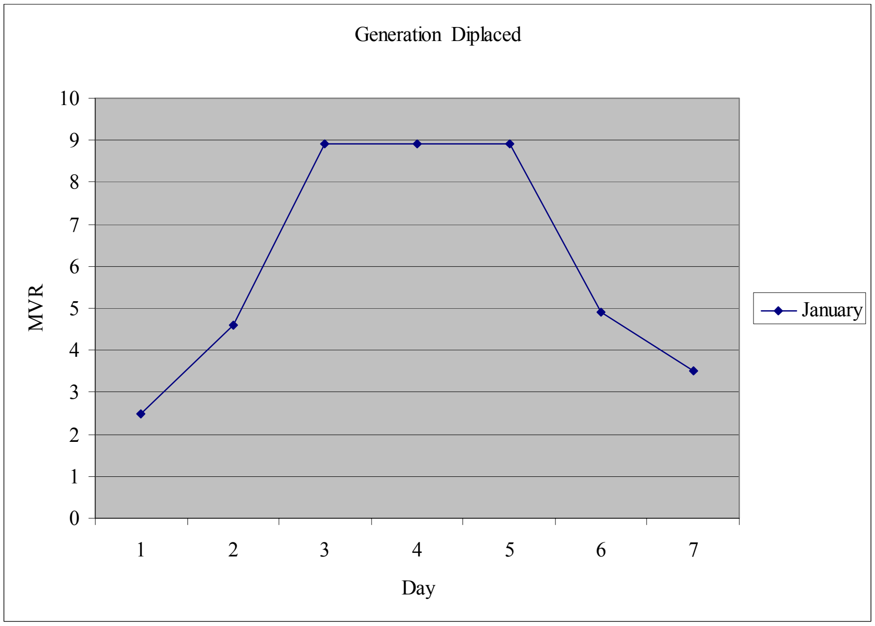
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.16 January Power Loss Reduction Curve- MVR



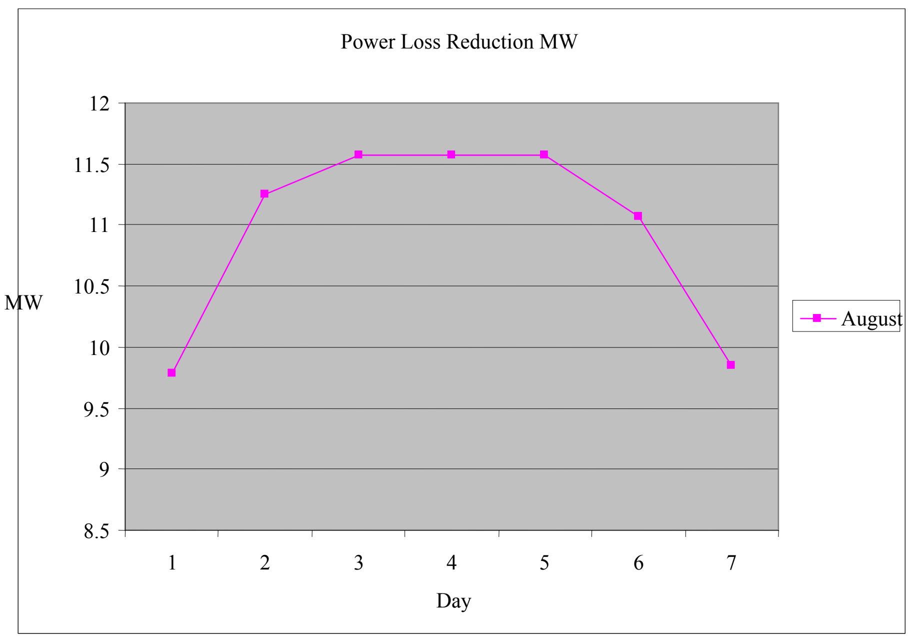
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.17 January Generation Displacement Curve- MW



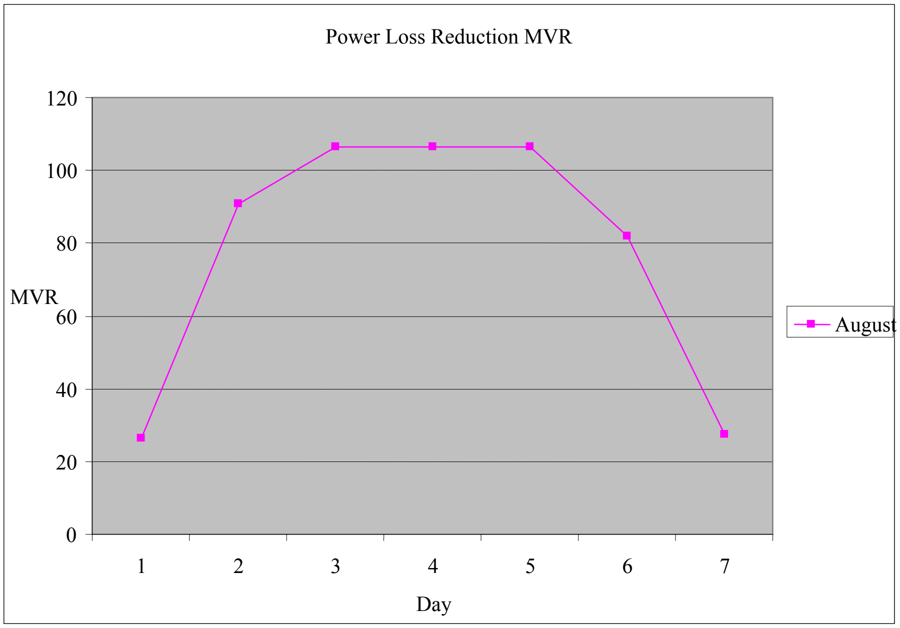
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.18 January Generation Displacement Curve- MVR



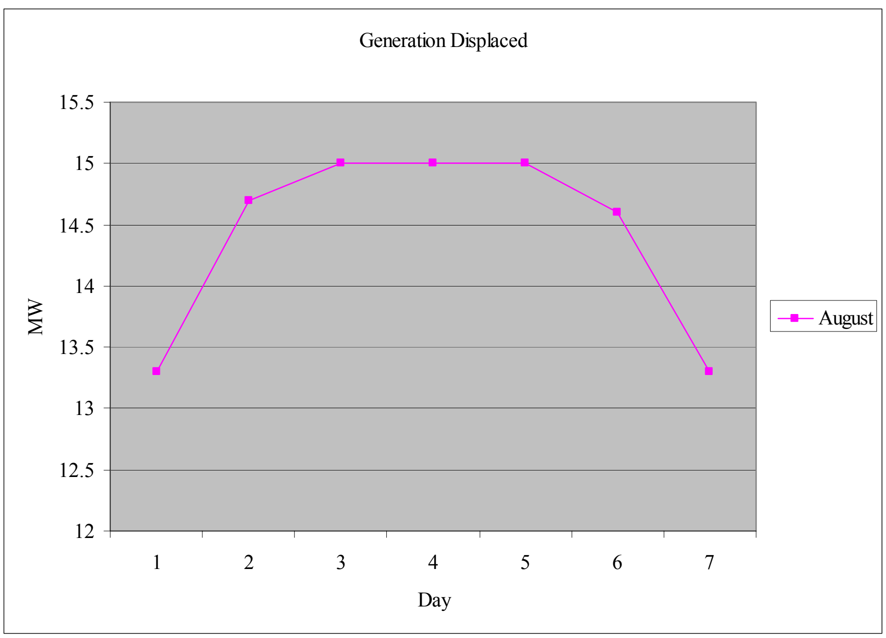
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.19 August Power Loss Reduction Curve- MW



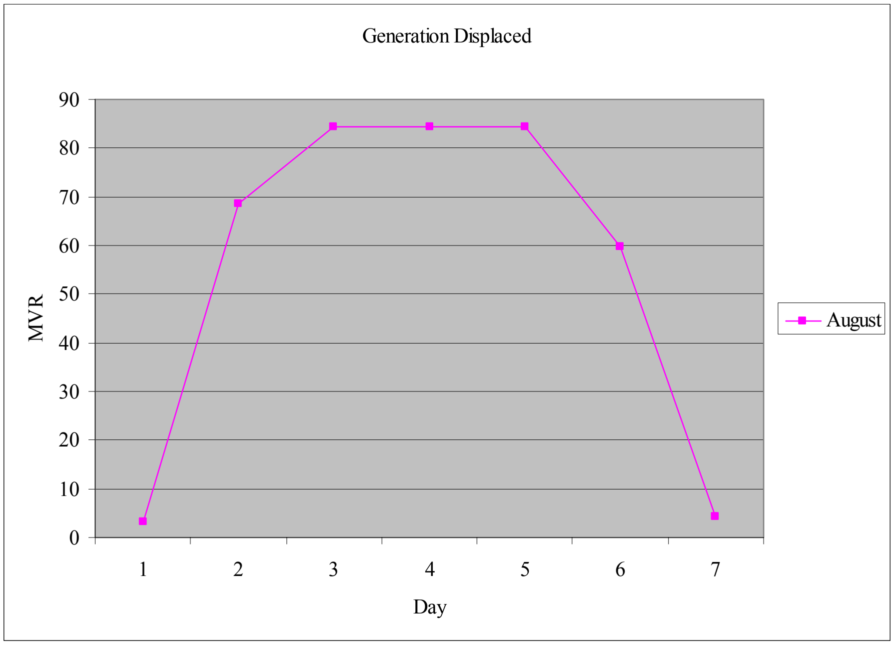
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.20 August Power Loss Reduction Curve- MVR



1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

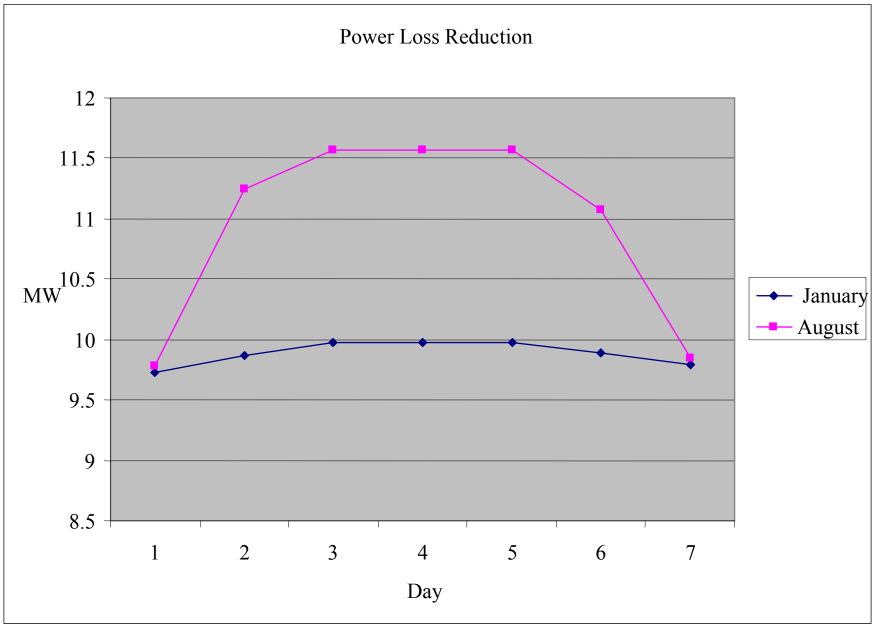
Figure 3.21 August Generation Displacement Curve- MW



1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

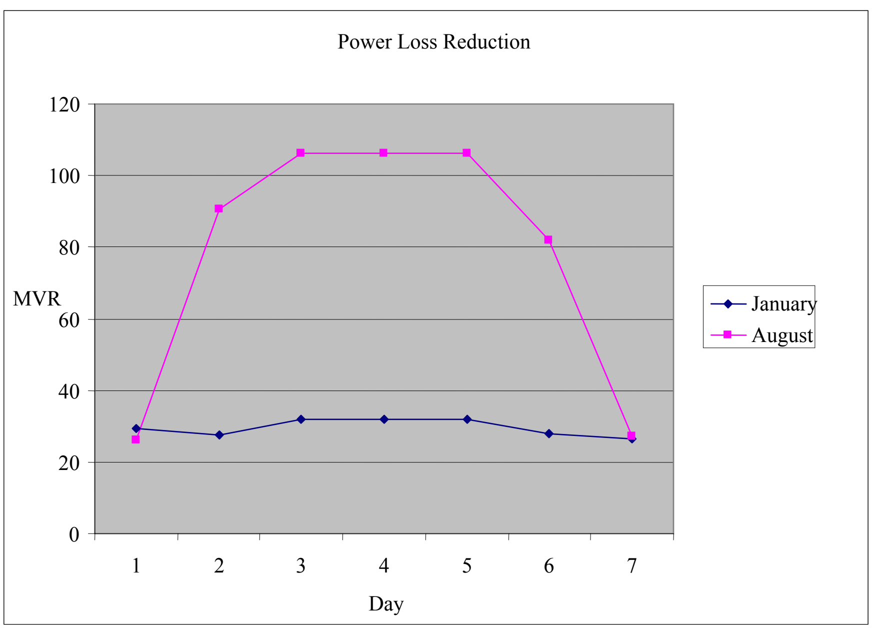
Figure 3.22 August Generation Displacement Curve- MVR

In Figures 3.23 through 3.26 it can be noticed the difference between the months with larger demand (August-pink curve) and the months with less demand (January-blue curve). For the months with larger demand the power loss reduction and generation displacement is larger. The same characteristics were found in the results of power loss reduction and generation displacement, in terms of the real and reactive power. This is due to the load behavior during the selected period of time from 9:00 a. m. to 4:00 p.m. and that the load reduction due to STWH was constant. In a typical week curve of the load behavior in Puerto Rico it can be seen that from 9:00 a.m. till 11:00 a.m. the load increases, between 11:00 a.m. to 1:00 p.m. it remains almost constant, and after that time the load behavior starts to decrease. (See Figures 3.13-3.14.)



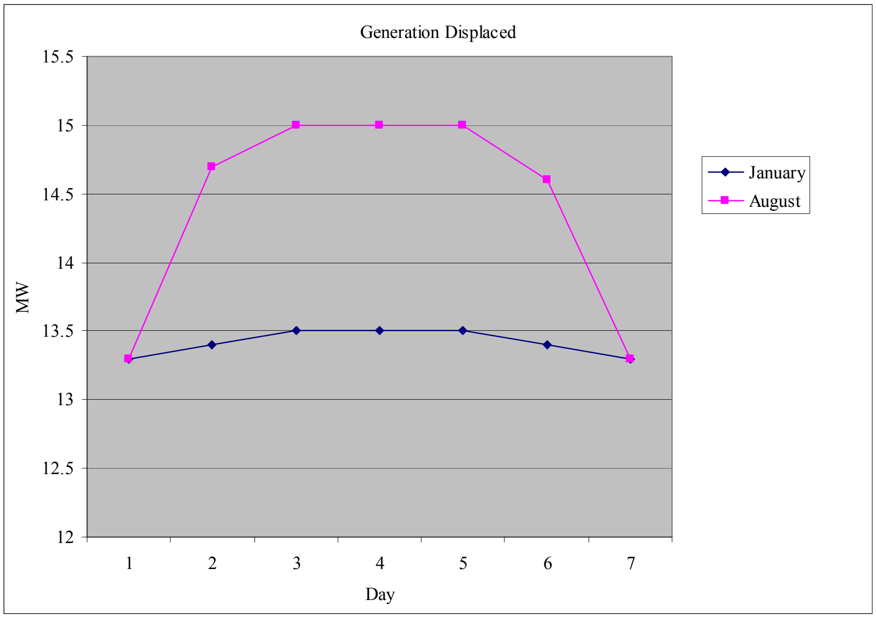
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.23 January vs. August Power Loss Reduction Curves- MW



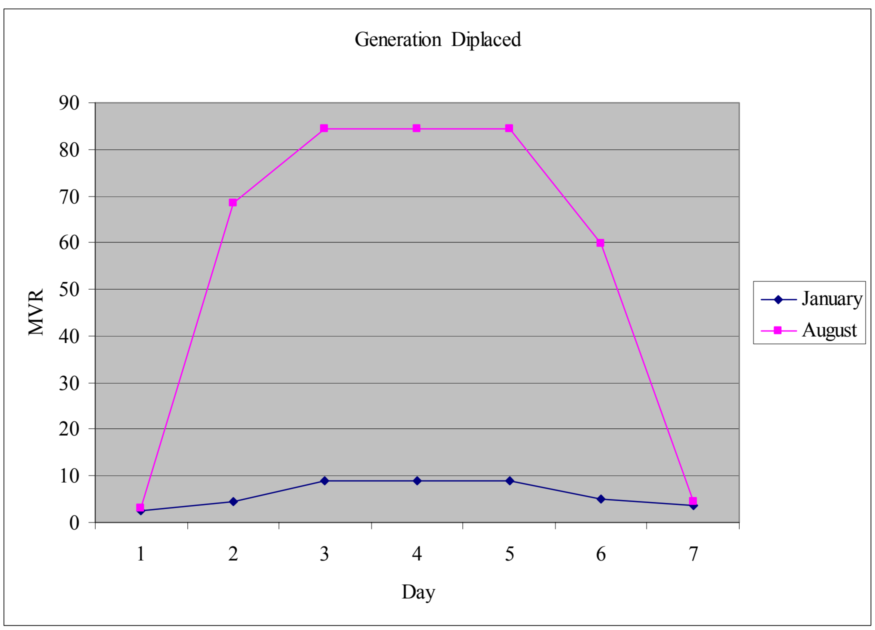
1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.24 January vs. August Power Loss Reduction Curves- MVR



1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.25 January vs. August Generation Displacement Curves- MW



1= Sunday 2=Monday 3= Tuesday 4=Wednesday 5=Thursday 6=Friday 7= Saturday

Figure 3.26 January vs. August Generation Displacement Curves- MVR

In our analysis, August characterizes the month with the largest electricity demand of the year while January represent the month with the smallest electricity demand of the year, for the Puerto Rico electric system. We divided the year in three different categories according to their solar radiation intensity. The months from March through May were represented as intermediate (I); this is an average value between that of January (J) and August (A). Table 3.45 shows these values for average monthly power loss reduction and generation displacement. Figures 3.27 and 3.28 show the mean solar radiations in W/m^2 for the municipalities of San Juan and Lajas, this was the date available.

Table 3.45 Average Monthly Power Loss Reduction and Generation Displacement-

80 % STWH

		Type	**Power Loss Reduction** MW	**Power Loss Reduction** MVR	Generation Displaced MW	Generation Displaced MVR
1	January	J	276.88	825.64	375.6	168.8
2	February	J	276.88	825.64	389.6	862.6
3	March	I	291.76	1503	389.6	862.6
4	April	I	291.76	1503	389.6	862.6
5	May	I	291.76	1503	389.6	862.6
6	June	A	306.64	2180.36	403.6	1556.4
7	July	A	306.64	2180.36	403.6	1556.4
8	August	A	306.64	2180.36	403.6	1556.4
9	September	A	306.64	2180.36	403.6	1556.4
10	October	A	306.64	2180.36	403.6	1556.4
11	November	J	276.88	825.64	375.6	168.8
12	December	J	276.88	825.64	375.6	168.8
	Average		293	1559.447	391.9333	978.2333

J=January, A=August, I= Intermediate (between January and August)

Table 3.46 Average Monthly Power Loss Reduction and Generation Displacement-

60 % STWH

		Type	**Power Loss Reduction** MW	**Power Loss Reduction** MVR	Generation Displaced MW	Generation Displaced MVR
1	January	J	122.9228	497.456	280.8	136.4
2	February	J	122.9228	497.456	280.8	136.4
3	March	I	137.3428	586.296	295.8	823.6
4	April	I	144.5528	630.716	303.3	1167.2
5	May	I	148.1578	652.926	307.05	1339
6	June	A	151.7628	675.136	310.8	1510.8
7	July	A	151.7628	675.136	310.8	1510.8
8	August	A	151.7628	675.136	310.8	1510.8
9	September	A	151.7628	675.136	310.8	1510.8
10	October	A	151.7628	675.136	310.8	1510.8
11	November	J	122.9228	497.456	280.8	136.4
12	December	J	122.9228	497.456	280.8	136.4
	Average		122.9228	497.456	280.8	136.4

J=January, A=August, I= Intermediate (between January and August)

From the results presented above we finally get to the average annual total power loss reduction and generation displacement for the cases of 80 % and 60 % of STWH. These results will be further discussed and used for the emissions and economic analyses.

Table 3.47 Average Annual Total Power Loss Reduction and Generation Displacement- 80 % and 60 % of STWH

Power Loss Reduction MW-**80 %**	**Power Loss Reduction** MVR-**80 %**	**Generation Displaced** MW-**80 %**	**Generation Displaced** MVR-**80 %**
3516	18713.4	4703.2	11738.8
Power Loss Reduction MW-**60 %**	**Power Loss Reduction** MVR-**60 %**	**Generation Displaced** MW-6**0 %**	**Generation Displaced** MVR-**60 %**
1680.6	7235.4	3583.4	11429.4

Since we do not have solar radiation data for every Municipality in Puerto Rico, we chose San Juan to represent the eastern and northern municipalities of the Island, while Lajas represents the western and southern municipalities of Puerto Rico in terms of solar radiation intensity in W/m^2. The data is for the year 2001 [*] .

Solar radiation data provide information on how much of the sun's energy strikes a surface at a location on earth during a particular time period. The data give values of energy per unit of area [34]. The values of solar radiation intensity vary from 171.0 W/m^2 in the cloudiest months of the year, to 254.1 W/m^2 in August. This is equivalent to 4.0 and 6.1 kWh/m^2/day. The island average daily solar radiation is approximately 5.52 kWh/m^2 per day [35]. This value is among the highest in the world and very favorable for

[*] Information provided by Raúl Zapata, PhD University of Puerto Rico – Mayagüez.

solar energy applications [36]. Since photovoltaic generation is still expensive we may use generation displacement, in the form of water heating, as an alternative to actual generation to take advantage of this abundant solar energy.

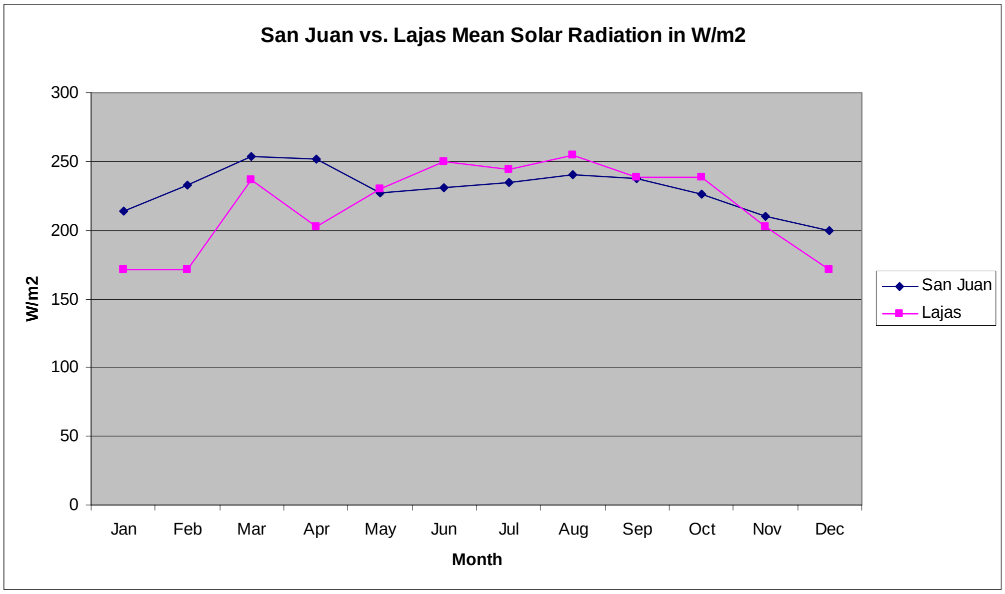


Figure 3.27 San Juan vs. Lajas Mean Solar Radiation in W/m^2

The data used for the previous graphs is presented in Tables 3.48 and 3.49. Note that they behave quite different during the months of January, February and April. The solar radiation data shown in the graph provides a foundation to our assumptions. It is a reasonable model to divide the year in three different categories according to their solar radiation intensity. The months from March through May were represented as intermediate (I); this is an average value between that of January (J) and August (A).

Table 3.48 San Juan Mean Solar Radiation in W/m^2

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
214.2	232.9	253.3	252.1	226.7	230.8	235.0	240.4	237.1	225.8	210.4	199.6

Table 3.49 Lajas Mean Solar Radiation in W/m^2

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
171.0	171.0	236.2	202.8	229.7	250.0	244.0	254.1	238.5	238.4	202.7	171.0

Figures 3.27 through 3.30 show the Average Annual Power Loss Minimization and Generation Displacement, in terms of real and reactive power for 80 % of STWH.

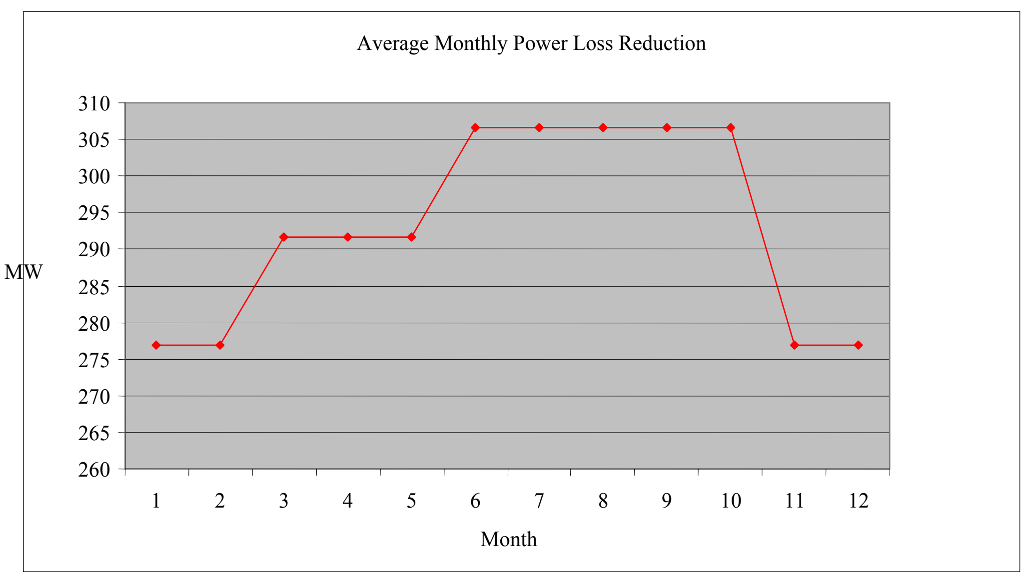


Figure 3.28 Average Monthly Power Loss Reduction- MW

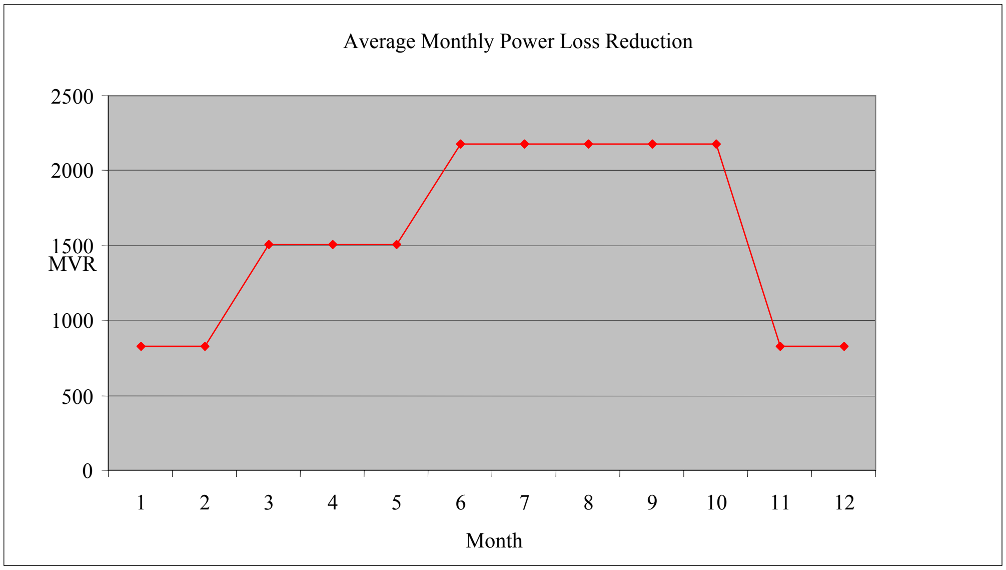


Figure 3.29 Average Monthly Power Loss Reduction- MVR

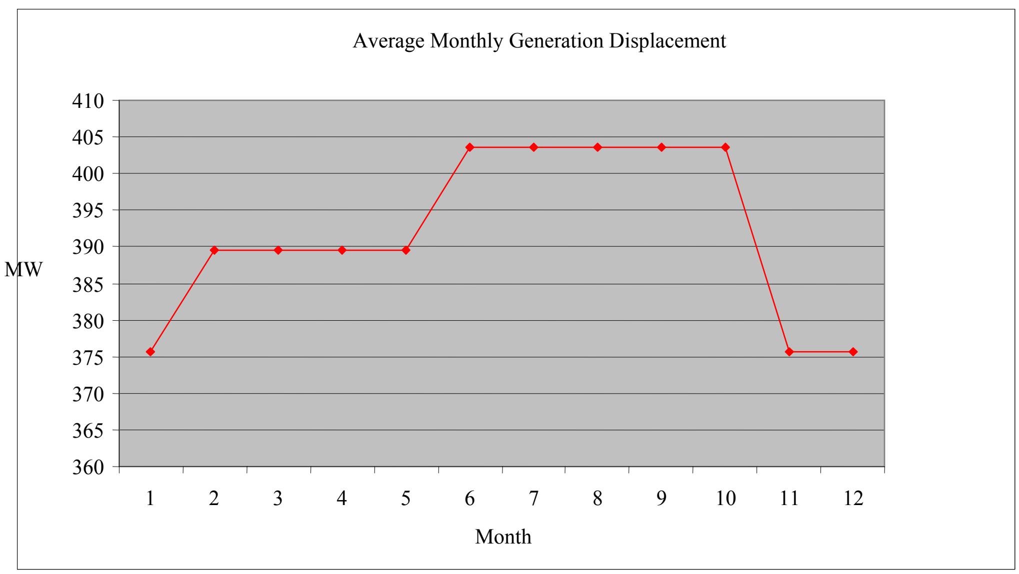


Figure 3.30 Average Monthly Generation Displacement- MW

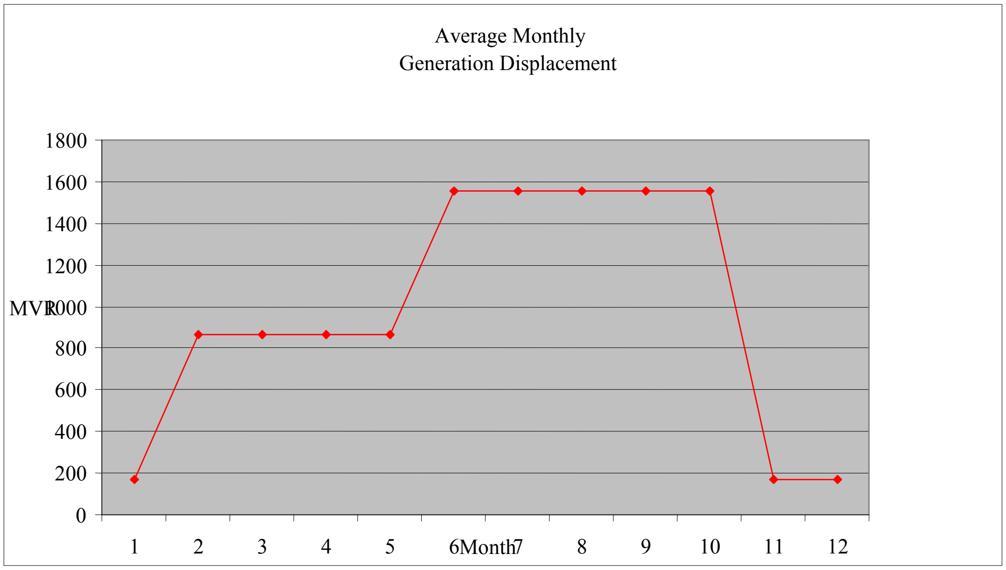


Figure 3.31 Average Monthly Generation Displacement- MVR

3.2 Emissions Analysis

The contributions of the electric energy industry to environmental damage raise questions concerning environmental protection. We should search for methods of reducing pollution from power generation plants either by operating strategies or by introducing renewable power energy technology such as STWH.

In an effort to reduce emissions into the atmosphere STWH may be an environmental alternative. In our study, the total average generation displaced in terms of real power was 4703.2 MW a year. This could be the generation displaced if 80% of Puerto Rico residences have a STWH. For 60 % of STWH the generation displaced was 3583.4 MW. We calculated the emissions reduction for these amounts of generation displacement.

Table 3.50 presents the emissions related to 1kWh of burning oil for four different types of pollutants, Carbon Dioxide, Nitrogen Dioxide, Sulfur Dioxide and Particulate Matter (PM10). It also includes a brief description of some of the damage these pollutants can cause.

Table 3.50 Emissions per 1kWh of fired oil [37]

Pollutant	Emission 1kWh per year
Carbon Dioxide (CO_2) *"probably the most important climate forcing agent"*	1.68 lbs
Nitrogen Oxide (NO_x) *"smog-forming chemical... an ingredient of acid rain"*	0.00126 lbs
Sulfur Dioxide (SO_2) *"may cause permanent damage to lungs"*	0.00102 lbs
10 micron Particulate Matter (PM10) - *"nose and throat irritation, lung damage, bronchitis, early death"*	0.00004 oz

Table 3.51 presents the emissions reduction analysis for four different types of pollutants, Carbon Dioxide, Nitrogen Dioxide, Sulfur Dioxide, and Particulate Matter (PM10). The analysis was done for oil as fuel. The fuel used in the generation plants (Palo Seco, Costa Sur, Central Aguirre, and Central San Juan) according to PREPA [38] is No.6 oil (Bunker C). This fuel is a dense, viscous oil produced by blending heavy residual oils with a lighter oil (often No. 2 fuel oil) to meet specifications for viscosity

and pour point [39]. The Central Plant Cambalache (Arecibo Plant) fires No. 2 fuel oil (Bunker #2).

Table 3.51 Emissions Reduction by 80 % and 60 % of STWH

Pollutant	Emission Reduction of 59.9 GW*h per year- 80 % of STWH	Emission Reduction of 28.2 GW*h per year- 60 % of STWH
Carbon Dioxide (CO_2) *"probably the most important climate forcing agent"*	1.44 G lbs.	0.568 G lbs.
Nitrogen Oxide (NO_x) *"smog-forming chemical... an ingredient of acid rain"*	4.17 M lbs.	0.426 M lbs.
Sulfur Dioxide (SO_2) *"may cause permanent damage to lungs"*	2.5 M lbs.	0.345 M lbs.
10 micron Particulate Matter (PM10) - *"nose and throat irritation, lung damage, bronchitis, early death"*	0.114 M oz.	0.014 M oz.

3.3 Economic Analysis

In the previous chapter we presented an estimate in power system increased efficiency, due to electric losses reduction at the transmission (230 and 115kV) and distribution level (38kV), as well as the emissions reduction due to generation displacement using solar thermal water heaters (**section 3.2**).

Now we produce an economic analysis of these improvements in the power system operation including an estimate of the reduction in fuel and energy cost adjustment, in dollars per kilowatt hour, for each residential customer using solar thermal water heaters.

3.3.1 Base Case for the Economic Analysis

We perform an economic analysis for the power loss reduction and its effect on the transmission system efficiency. This increase in E_t efficiency will produce a reduction in the fuel adjustment factor (FA_i). We developed our analysis from the information provided by PREPA in "Clarifications on the Fuel Adjustment Clause and Energy Purchase" [27].

The base case for our study is presented in Table 3.52. (refer to Table 2.1) This table summarizes the important factors included in the adjustment formulas. Further, we will be changing some of the parameters in Table 3.52, to represent our study.

Unfortunately, the data is from year 2002. It would be more accurate to have data from the present year, but it is not possible at the moment since of this data is not published. The case will be refer to the available case of year 2002 [27], in terms of the adjustment factors in the formulas. We will use the same values of this document for E_{dp}, E_{ds}, estimated energy purchase, estimated generation, and estimated BBLS.

The parameters that we changed for our study case are: the transmission bus efficiency, the $/BBL, and since FCC_i, FCE_i and FA_i depend on these values they will be changing as well.

Table 3.52 Fuel Clause Parameters (year 2002) – generation base case [27]

		Fuel Clause Parameters- year 2002											
			#'s and/or columns										
			Factors										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
		Ei											
Month	Ebg	Et	Edp	Eds	$/BBL (MBBL)	BBLS Est (MBBL)	T Gen Est (kWh)	E Purchase Est ($)	Adjsutment c ($)	Adjustment e ($)	FCC g ($/kWh)	FCE g ($/kWh)	FA g ($/kWh)
Dec	1	0.9594	0.8851	0.8528	27.959	2.19	1813779000	37176903.24	9087790	-12947653	0.00562972	0.015009478	0.020639199
Nov	1	0.9597	0.8861	0.8542	28.663	2.16	1801604000	36858564.2	15040660	-9438327	0.009380356	0.017101014	0.02648137
Oct	1	0.9602	0.8875	0.8562	29.026	2.346	1962943000	33229155.69	13645549	-6777154	0.007810799	0.015141219	0.022952019
Sept	1	0.96	0.887	0.8554	26.89	2.328	1919332000	27144760.69	7817419	-3659349	0.004576429	0.013748587	0.018325016
Aug	1	0.9604	0.8882	0.8571	25.996	2.722	2026209000	24974667.68	-11425553	6198704	-0.006335783	0.017286598	0.010950815
Jul	1	0.9603	0.8879	0.8568	24.588	2.661	1876082000	22809879.7	2662325	-3634366	0.00159452	0.011484317	0.013078837
Jun	1	0.9605	0.8883	0.8573	24.539	2.615	1827737000	22081418.57	5768633	-4916574	0.003546288	0.010552034	0.014098322
May	1	0.961	0.8898	0.8595	23.751	2.804	1885564000	21393802.25	4390153	4067816	0.002616104	0.015172415	0.017788519
Abr	1	0.9606	0.8886	0.8577	21.734	2.501	1703420000	20165395.94	109649	-2831055	7.23616E-05	0.011433931	0.011506293
Mar	1	0.9612	0.8903	0.8601	19.411	2.705	1762316000	18866392.4	-1751710	-2240808	-0.0011168	0.010599933	0.009483133
Feb	1	0.9612	0.8903	0.8601	19.758	2.289	1535579000	18482539.17	-2825696	3961750	-0.002067551	0.016422667	0.014355116
Jan	1	0.9613	0.8905	0.8605	20.66	2.538	1713946000	19683018.63	-1156990	147024	-0.000758443	0.012999795	0.012241352

(-) indicates a credit for the client

Form Table 2.1 we present some of the adjustment factors just to let their significance clear.

1. $Adjustment_c$= (real cost of consumed fuel two months ahead of billing/ 0.89) – amount charged based on fuel purchase in the same period

2. $Adjustment_e$= (real cost of purchased energy two months ahead of billing/ 0.89) - amount charged based on energy purchase in the same period

3. Factor 0.89 is used to include the effect of contributions instead of government taxes and the municipalities, according to PREPA's Organic Law [27].

The following factor is very important since at the end this will help to obtain the real customer savings. This factor is the total of adjustment for billing of fuel and energy purchases in a typical residential customer bill.

4. Total of adjustment for billing of fuel and energy purchases:

$$= ((FA_i)/E_i) \times kWh\ consumed$$

3.3.2 Analysis for losses reduction due to STWH

Now the analysis starting from the base case in [27]. Table 3.53 presents the Fuel Clause Parameters with a modification of column #5 ($/BBL), which is the price in dollars per barrel for the beginnings of year 2005 [40]. This is the generation base case with the calculations of the energy and fuel purchase factors with the generation bus efficiency (E_{bg}) that happens to be 1.0 for all the months. Compare the changes in columns #11 through #13 with those in the previous table.

Table 3.53 Fuel Clause Parameters (year 2002) – generation base case [27] with fuel adjustment in ($/BBL)

		Fuel Clause Parameters- year 2002											
			#'s and/or columns										
			Factors										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
		Ei											
Month	Ebg	Et	Edp	Eds	$/BBL (MBBL)	BBLS Est (MBBL)	T Gen Est (kWh)	E Purchase Est ($)	Adjsutment c ($)	Adjustment e ($)	FCC g ($/kWh)	FCE g ($/kWh)	FA g ($/kWh)
Dec	1	0.9594	0.8851	0.8528	57	2.19	1813779000	37176903.24	9087790	-12947653	0.00562976	0.015009478	0.020639238
Nov	1	0.9597	0.8861	0.8542	57	2.16	1801604000	36858564.2	15040660	-9438327	0.009380395	0.017101014	0.026481409
Oct	1	0.9602	0.8875	0.8562	57	2.346	1962943000	33229155.69	13645549	-6777154	0.007810837	0.015141219	0.022952056
Sept	1	0.96	0.887	0.8554	57	2.328	1919332000	27144760.69	7817419	-3659349	0.00457647	0.013748587	0.018325057
Aug	1	0.9604	0.8882	0.8571	57	2.722	2026209000	24974667.68	-11425553	6198704	-0.006335736	0.017286598	0.010950862
Jul	1	0.9603	0.8879	0.8568	57	2.661	1876082000	22809879.7	2662325	-3634366	0.001594571	0.011484317	0.013078889
Jun	1	0.9605	0.8883	0.8573	57	2.615	1827737000	22081418.57	5768633	-4916574	0.00354634	0.010552034	0.014098374
May	1	0.961	0.8898	0.8595	57	2.804	1885564000	21393802.25	4390153	4067816	0.002616159	0.015172415	0.017788574
Abr	1	0.9606	0.8886	0.8577	57	2.501	1703420000	20165395.94	109649	-2831055	7.24198E-05	0.011433931	0.011506351
Mar	1	0.9612	0.8903	0.8601	57	2.705	1762316000	18866392.4	-1751710	-2240808	-0.001116735	0.010599933	0.009483198
Feb	1	0.9612	0.8903	0.8601	57	2.289	1535579000	18482539.17	-2825696	3961750	-0.002067489	0.016422667	0.014355178
Jan	1	0.9613	0.8905	0.8605	57	2.538	1713946000	19683018.63	-1156990	147024	-0.000758382	0.012999795	0.012241413

(-) indicates a credit for the client

Table 3.54 presents the Fuel Clause Parameters with a modification of column #5 ($/BBL), which is the price in dollars per barrel for the beginnings of year 2005 [40]. This is the transmission base case. The calculations of the energy and fuel purchase factors (FCC, FCE and FA) were done with the transmission bus efficiency that happens to change depending on the electric system losses per month. Comparison of the changes in columns #11 through #13 with those in the previous table, these values indicate that increased slightly.

Table 3.54 Fuel Clause Parameters (year 2002) – transmission base case with fuel adjustment in ($/BBL)

		Fuel Clause Parameters- year 2002											
			#'s and/or columns										
			Factors										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
		Ei											
Month	Ebg	Et	Edp	Eds	$/BBL (MBBL)	BBLS Est (MBBL)	T Gen Est (kWh)	E Purchase Est ($)	Adjsutment c ($)	Adjustment e ($)	FCC t ($/kWh)	FCE t ($/kWh)	FA t ($/kWh)
Dec	1	0.9594	0.8851	0.8528	57	2.19	1813779000	37176903.24	9087790	-12947653	0.005868001	0.015644651	0.021512652
Nov	1	0.9597	0.8861	0.8542	57	2.16	1801604000	36858564.2	15040660	-9438327	0.009774299	0.017819125	0.027593424
Oct	1	0.9602	0.8875	0.8562	57	2.346	1962943000	33229155.69	13645549	-6777154	0.008134594	0.015768818	0.023903412
Sept	1	0.96	0.887	0.8554	57	2.328	1919332000	27144760.69	7817419	-3659349	0.004767157	0.014321445	0.019088601
Aug	1	0.9604	0.8882	0.8571	57	2.722	2026209000	24974667.68	-11425553	6198704	-0.006596976	0.017999373	0.011402397
Jul	1	0.9603	0.8879	0.8568	57	2.661	1876082000	22809879.7	2662325	-3634366	0.001660493	0.011959093	0.013619586
Jun	1	0.9605	0.8883	0.8573	57	2.615	1827737000	22081418.57	5768633	-4916574	0.003692182	0.01098598	0.014678161
May	1	0.961	0.8898	0.8595	57	2.804	1885564000	21393802.25	4390153	4067816	0.00272233	0.015788153	0.018510483
Abr	1	0.9606	0.8886	0.8577	57	2.501	1703420000	20165395.94	109649	-2831055	7.53902E-05	0.011902906	0.011978296
Mar	1	0.9612	0.8903	0.8601	57	2.705	1762316000	18866392.4	-1751710	-2240808	-0.001161814	0.011027812	0.009865999
Feb	1	0.9612	0.8903	0.8601	57	2.289	1535579000	18482539.17	-2825696	3961750	-0.002150946	0.017085588	0.014934642
Jan	1	0.9613	0.8905	0.8605	57	2.538	1713946000	19683018.63	-1156990	147024	-0.000788913	0.013523141	0.012734227

(-) indicates a credit for the client

Table 3.55 also includes the modification of column #5 ($/BBL). This is the primary distribution base case. The calculations of the energy and fuel purchase factors (FCC, FCE and FA) were done with the primary distribution (E_{dp}) efficiency which changes depending on the electric system losses per month. Compare the changes in columns #11 through #13 with those in the previous table. These values also increased slightly.

Table 3.55 Fuel Clause Parameters (year 2002) – Primary distribution base case with fuel adjustment

		Fuel Clause Parameters- year 2002											
			#'s and/or columns										
			Factors										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
		Ei											
Month	Ebg	Et	Edp	Eds	$/BBL (MBBL)	BBLS Est (MBBL)	T Gen Est (kWh)	E Purchase Est ($)	Adjsutment c ($)	Adjustment e ($)	FCC g ($/kWh)	FCE g ($/kWh)	FA g ($/kWh)
Dec	1	0.9594	0.8851	0.8528	57	2.19	1813779000	37176903.24	9087790	-12947653	0.006360592	0.016957946	0.023318538
Nov	1	0.9597	0.8861	0.8542	57	2.16	1801604000	36858564.2	15040660	-9438327	0.010586158	0.019299192	0.02988535
Oct	1	0.9602	0.8875	0.8562	57	2.346	1962943000	33229155.69	13645549	-6777154	0.008800943	0.017060529	0.025861472
Sept	1	0.96	0.887	0.8554	57	2.328	1919332000	27144760.69	7817419	-3659349	0.005159493	0.015500098	0.020659591
Aug	1	0.9604	0.8882	0.8571	57	2.722	2026209000	24974667.68	-11425553	6198704	-0.007133231	0.019462506	0.012329275
Jul	1	0.9603	0.8879	0.8568	57	2.661	1876082000	22809879.7	2662325	-3634366	0.001795891	0.012934246	0.014730137
Jun	1	0.9605	0.8883	0.8573	57	2.615	1827737000	22081418.57	5768633	-4916574	0.003992278	0.011878908	0.015871185
May	1	0.961	0.8898	0.8595	57	2.804	1885564000	21393802.25	4390153	4067816	0.002940166	0.017051489	0.019991655
Abr	1	0.9606	0.8886	0.8577	57	2.501	1703420000	20165395.94	109649	-2831055	8.14987E-05	0.012867355	0.012948854
Mar	1	0.9612	0.8903	0.8601	57	2.705	1762316000	18866392.4	-1751710	-2240808	-0.001254336	0.011906024	0.010651688
Feb	1	0.9612	0.8903	0.8601	57	2.289	1535579000	18482539.17	-2825696	3961750	-0.002322239	0.018446217	0.016123978
Jan	1	0.9613	0.8905	0.8605	57	2.538	1713946000	19683018.63	-1156990	147024	-0.000851636	0.01459831	0.013746674

(-) indicates a credit for the client

Table 3.56 also includes the modification of column #5 ($/BBL). This is the primary distribution base case. The calculations of the energy and fuel purchase factors (FCC, FCE and FA) were done with the secondary distribution (E_{ds}) efficiency which changes depending on the electric system losses per month. Compare the changes in columns #11 through #13 with those in the previous table. These values also increased.

Table 3.56 Fuel Clause Parameters (year 2002) – Secondary distribution base case with fuel adjustment

		Fuel Clause Parameters- year 2002											
			#'s and/or columns										
			Factors										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
		Ei											
Month	Ebg	Et	Edp	Eds	$/BBL (MBBL)	BBLS Est (MBBL)	T Gen Est (kWh)	E Purchase Est ($)	Adjsutment c ($)	Adjustment e ($)	FCC g ($/kWh)	FCE g ($/kWh)	FA g ($/kWh)
Dec	1	0.9594	0.8851	0.8528	57	2.19	1813779000	37176903.24	9087790	-12947653	0.006601501	0.017600233	0.024201733
Nov	1	0.9597	0.8861	0.8542	57	2.16	1801604000	36858564.2	15040660	-9438327	0.010981497	0.020019918	0.031001415
Oct	1	0.9602	0.8875	0.8562	57	2.346	1962943000	33229155.69	13645549	-6777154	0.009122678	0.017684208	0.026806886
Sept	1	0.96	0.887	0.8554	57	2.328	1919332000	27144760.69	7817419	-3659349	0.005350094	0.016072699	0.021422793
Aug	1	0.9604	0.8882	0.8571	57	2.722	2026209000	24974667.68	-11425553	6198704	-0.007392062	0.020168706	0.012776644
Jul	1	0.9603	0.8879	0.8568	57	2.661	1876082000	22809879.7	2662325	-3634366	0.001861078	0.013403732	0.01526481
Jun	1	0.9605	0.8883	0.8573	57	2.615	1827737000	22081418.57	5768633	-4916574	0.004136639	0.012308449	0.016445088
May	1	0.961	0.8898	0.8595	57	2.804	1885564000	21393802.25	4390153	4067816	0.003043815	0.017652606	0.020696422
Abr	1	0.9606	0.8886	0.8577	57	2.501	1703420000	20165395.94	109649	-2831055	8.44349E-05	0.013330922	0.013415356
Mar	1	0.9612	0.8903	0.8601	57	2.705	1762316000	18866392.4	-1751710	-2240808	-0.001298378	0.012324071	0.011025692
Feb	1	0.9612	0.8903	0.8601	57	2.289	1535579000	18482539.17	-2825696	3961750	-0.002403777	0.019093904	0.016690127
Jan	1	0.9613	0.8905	0.8605	57	2.538	1713946000	19683018.63	-1156990	147024	-0.000881327	0.015107257	0.01422593

(-) indicates a credit for the client

Now we proceed to perform our analysis starting from our findings. Table 3.57 presents the Fuel Clause Parameters with a modification of column #5 ($/BBL). This is the transmission base case with the calculations of the energy and fuel purchase factors with the transmission bus efficiency (E_t). The new transmission efficiency was calculated with the values obtained in our study results (see **section 3.1**). This is the annual average power loss reduction in terms of real power in MW. This progress can be seen in Table 3.58 for the cases with 80 % and 60 % of STWH.

Table 3.57 Fuel Clause Parameters (year 2002) – transmission case 1 with fuel adjustment in ($/BBL)

Transmission		Fuel Clause Parameters- year 2002											
			#'s and/or columns										
			Factors										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
		Ei											
Month	Ebg	Et	Edp	Eds	$/BBL (MBBL)	BBLS Est (MBBL)	T Gen Est (kWh)	E Purchase Est ($)	Adjsutment c ($)	Adjustment e ($)	FCC t ($/kWh)	FCE t ($/kWh)	FA t ($/kWh)
Dec	1	0.97355	0.8851	0.8528	57	2.19	1813779000	37176903.24	9087790	-12947653	0.005782707	0.015417249	0.021199956
Nov	1	0.97395	0.8861	0.8542	57	2.16	1801604000	36858564.2	15040660	-9438327	0.009631323	0.017558471	0.027189794
Oct	1	0.97328	0.8875	0.8562	57	2.346	1962943000	33229155.69	13645549	-6777154	0.008025308	0.015556969	0.023582277
Sept	1	0.97337	0.887	0.8554	57	2.328	1919332000	27144760.69	7817419	-3659349	0.004701663	0.014124688	0.018826351
Aug	1	0.97307	0.8882	0.8571	57	2.722	2026209000	24974667.68	-11425553	6198704	-0.006511097	0.017765057	0.01125396
Jul	1	0.97398	0.8879	0.8568	57	2.661	1876082000	22809879.7	2662325	-3634366	0.001637169	0.011791109	0.013428278
Jun	1	0.97454	0.8883	0.8573	57	2.615	1827737000	22081418.57	5768633	-4916574	0.003638978	0.010827674	0.014466652
May	1	0.97461	0.8898	0.8595	57	2.804	1885564000	21393802.25	4390153	4067816	0.002684308	0.015567642	0.01825195
Abr	1	0.97567	0.8886	0.8577	57	2.501	1703420000	20165395.94	109649	-2831055	7.42259E-05	0.011719082	0.011793308
Mar	1	0.97576	0.8903	0.8601	57	2.705	1762316000	18866392.4	-1751710	-2240808	-0.001144472	0.010863211	0.009718739
Feb	1	0.97791	0.8903	0.8601	57	2.289	1535579000	18482539.17	-2825696	3961750	-0.002114181	0.016793557	0.014679376
Jan	1	0.97628	0.8905	0.8605	57	2.538	1713946000	19683018.63	-1156990	147024	-0.000776812	0.013315707	0.012538895

(-) indicates a credit for the client

The new E_t was calculated from the base case [27] system losses. Column represents the total losses percent at the transmission level. The third column presents these losses in kW*h. The total annual average power loss reduction was 3,516 MW per year which is equivalent to 2.57 E+9 kW*h per month. The fourth column represents this power loss reduction percent. Finally, the new transmission efficiency is shown in the last column.

Table 3.58 Transmission Efficiency (E_t) Improvement

Et	**Total losses (%)**	**Total losses kW*h[27]**	**New E_t- 80 %**	**New E_t- 60 %**
0.9594	0.0406	73639427.4	**0.9735**	**0.9653**
0.9597	0.0403	72604641.2	**0.9739**	**0.9657**
0.9602	0.0398	78125131.4	**0.9732**	**0.9657**
0.96	0.0400	76773280	**0.9733**	**0.9656**
0.9604	0.0396	80237876.4	**0.9730**	**0.9657**
0.9603	0.0397	74480455.4	**0.9740**	**0.9660**
0.9605	0.0395	72195611.5	**0.9745**	**0.9664**
0.961	0.0390	73536996	**0.9746**	**0.9667**
0.9606	0.0394	67114748	**0.9757**	**0.9669**
0.9612	0.0388	68377860.8	**0.9758**	**0.9673**
0.9612	0.0388	59580465.2	**0.9779**	**0.9682**
0.9613	0.0387	66329710.2	**0.9763**	**0.9676**

With the transmission efficiency improvement and a change in the $/BBL to $ 57 we calculated the total Factor of Adjustments for the case without power loss reduction and the case with the power loss reduction due to 80 % and 60 % of STWH. This is shown in Table 3.59. The fourth and fifth columns (A-B) represents the reduction in the Factor of Adjustment FA_i in $/kWh. These monthly values are total; they include all the different levels such as: generation, transmission, primary distribution and secondary distribution.

Table 3.59 Total Factor of Adjustment for the case without power loss reduction and the case with power loss reduction due to 80 % and 60 % of STWH

Month	A. Total FA_i- no reduction by STWH($/kWh)	B. Total FA_i- with reduction by STWH ($/kWh)	A-B($/kWh) 80 % of STWH	A-B($/kWh) 60% of STWH
Dec	0.089672162	0.089359466	0.000312696	0.000132277
Nov	0.114961597	0.114557967	0.000403629	0.000170753
Oct	0.099523826	0.099202691	0.000321135	0.00013576
Sept	0.079496043	0.079233793	0.000262251	0.000110886
Aug	0.047459177	0.047310741	0.000148437	6.27362E-05
Jul	0.056693422	0.056502114	0.000191308	8.09044E-05
Jun	0.061092809	0.0608813	0.000211509	8.94664E-05
May	0.076987134	0.076728601	0.000258533	0.000109329
Abr	0.049848857	0.04966387	0.000184988	7.82955E-05
Mar	0.041026578	0.040879318	0.00014726	6.23084E-05
Feb	0.062103925	0.061848659	0.000255266	0.000108145
Jan	0.052948244	0.052752911	0.000195333	8.26689E-05

3.3.3 Analysis for the different types of residential customers

Once the Total Fuel Adjustment Factor (FA_i) was calculated, we proceeded to calculate of the customer savings. We divided the analysis in two parts. We first calculate the savings in terms of the power loss reduction by STWH and the Fuel Adjustment Clause.

There are three different types of residential customers. (See Table 3.60) PREPA divided them into these categories: Standard Residential Service, Special Residential Service, and Public Projects Service. All of them with alternating current, at 60 Hertz, 2 or 3 wires, single-phase or three-phase; 120, 208 or 240 volts.

Tables 3.60-3.61 show the specifications for each type of service in terms of fixed monthly charges, monthly charges per kW*h, and Fuel Adjustment Clause related monthly charges. This table also shows the analysis for the cases with and without power loss reduction if 80% of the residences use a STWH. It does not include the customer savings for owning a STWH yet. This particular analysis is shown in Tables 3.62-3.63, and it includes the calculations of the customer savings due to owning a STWH and the Fuel Adjustment factor reduction.

From our study: assuming an average water heater efficiency of 70% the electric energy input to the electric water heater is (2.4007 x 107 J)/0.7 = 3.4296 x 107 J = 9.5266 kW*h, this is 285.798 kW*h per month (see *section 3.1.3* for details). If you own a STWH this would be the amount of electric energy that can be saved monthly.

For convenience, we assumed all residential customers monthly kW*h consumption to be 425 kW*h and 1400 kW*h. For example for the case where the residential customer owns a STWH the monthly consumption is (425 kW*h – 285.798 kW*h), this represents 139.202 kW*h per month. The savings related to this electric energy reduction are listed in Tables 3.62 and 3.63 for 425 kW*h and 1400 kW*h, for 80 % of STWH, and Tables 3.66- 3.67 for 60 % of STWH. Scenario A represents the case without power loss reduction and B represents the case with the power loss reduction due to STWH.

Table 3.60 Types of Residential Customers

Type of Service			
	Monthly Energy Charge (¢)	**Fixed Charge($)**	**Fuel Adjustment Clause Charge %**
Standard			
first 425 kWh	4.35	3	1
over 425kWh	4.97		
Special			
first 425 kWh	1.46		
over 425kWh	4.97	3	
0 - 100 kWh			0.1
101 - 200 kWh			0.25
201 - 300 kWh			0.35
301 - 400 kWh			0.45
401 - 425 kWh			*
400 kWh			0.45
over 400 kWh			1
over 425 kWh			1
Public Proyects			
0-425 kWh	0.1	2	
0 - 100 kWh			0.1
101 - 200 kWh			0.25
201 - 300 kWh			0.35
301 - 400 kWh			0.45
401 - 425 kWh			*
400 kWh			0.45
over 400 kWh			1

Table 3.61 Calculation of the customer savings based on the Fuel Adjustment Clause and to power loss reduction due to STWH-425 kWh (80 % of STWH)

Type of Scenario	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	**Customers Savings ($)**
A- Standard	59.6	70.3	63.79	55.3	41.7	45.6	47.5	54.2	42.67	38.9	47.9	43.99	
B	59.47	70.2	63.65	55.2	41.6	45.5	47.4	54.1	42.59	38.9	47.8	43.91	
A-B	0.133	0.17	0.136	0.11	0.06	0.08	0.09	0.11	0.079	0.06	0.11	0.083	1.229246517
A- Special	47.32	58.1	51.5	43	29.4	33.3	35.2	41.9	30.39	26.6	35.6	31.71	
B	47.18	57.9	51.37	42.9	29.3	33.2	35.1	41.8	30.31	26.6	35.5	31.62	
A-B	0.133	0.17	0.136	0.11	0.06	0.08	0.09	0.11	0.079	0.06	0.11	0.083	1.229246517
A- Public Projects	40.54	51.3	44.72	36.2	22.6	26.5	28.4	35.1	23.61	19.9	28.8	24.93	
B	40.4	51.1	44.59	36.1	22.5	26.4	28.3	35	23.53	19.8	28.7	24.84	
A-B	0.133	0.17	0.136	0.11	0.06	0.08	0.09	0.11	0.079	0.06	0.11	0.083	1.229246517

Table 3.62 Calculation of the customer savings based on the Fuel Adjustment Clause and to power loss reduction due to STWH- 1400kWh (80 % of STWH)

Type of Scenario	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Customers Savings ($)
A	195.5	230.9	209.3	181.2	136.4	149.3	155.5	177.7	139.7	127.4	156.9	144.1	
B	195	230.3	208.8	180.9	136.2	149	155.2	177.4	139.5	127.2	156.5	143.8	
A-B	0.438	0.565	0.45	0.367	0.208	0.268	0.296	0.362	0.259	0.206	0.357	0.273	4.049282644
A	183.2	218.6	197	169	124.1	137	143.2	165.4	127.5	115.1	144.6	131.8	
B	182.8	218	196.5	168.6	123.9	136.8	142.9	165.1	127.2	114.9	144.3	131.5	
A-B	0.438	0.565	0.45	0.367	0.208	0.268	0.296	0.362	0.259	0.206	0.357	0.273	4.049282644
A	128	163.4	141.8	113.7	68.87	81.8	87.95	110.2	72.21	59.86	89.37	76.55	
B	127.5	162.8	141.3	113.4	68.66	81.53	87.66	109.8	71.95	59.66	89.01	76.28	
A-B	0.438	0.565	0.45	0.367	0.208	0.268	0.296	0.362	0.259	0.206	0.357	0.273	4.049282644

Table 3.63 Total Calculation of the customer savings due to owning a STWH and the Fuel Adjustment Clause Reduction- 425 kWh (80 % of STWH)

Type of Scenar	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	**Customers Savings**	%
A	59.5982	70.3462	63.7851	55.2733	41.6577	45.5822	47.4519	54.207	42.6733	38.9238	47.8817	43.9905	611.3708541	
B	21.4943	25.002	22.8645	20.0848	15.641	16.9205	17.5301	19.7361	15.9686	14.7458	17.6647	16.3986	224.0509648	
A-B	38.1039	45.3442	40.9206	35.1885	26.0166	28.6617	29.9219	34.471	26.7047	24.178	30.2169	27.5919	**387.3198892**	63.3527
A	47.3157	58.0637	51.5026	42.9908	29.3752	33.2997	35.1694	41.9245	30.3908	26.6413	35.5992	31.708	463.9808541	
B	17.4714	20.979	18.8416	16.0619	11.6181	12.8976	13.5071	15.7131	11.9457	10.7228	13.6418	12.3757	175.7757112	
A-B	29.8443	37.0846	32.6611	26.929	17.7571	20.4021	21.6623	26.2114	18.4451	15.9185	21.9574	19.3323	**288.2051428**	62.1157
A	40.5357	51.2837	44.7226	36.2108	22.5952	26.5197	28.3894	35.1445	23.6108	19.8613	28.8192	24.928	382.6208541	
B	14.5782	18.0859	15.9484	13.1687	8.72495	10.0044	10.614	12.82	9.05251	7.82968	10.7487	9.48251	141.0579448	
A-B	25.9575	33.1978	28.7742	23.0421	13.8702	16.5153	17.7754	22.3246	14.5583	12.0316	18.0705	15.4455	**241.5629092**	63.1338

Table 3.64 Total Calculation of the customer savings due to owning a STWH and the Fuel Adjustment Clause Reduction-1400 kWh (80 % of STWH)

Type of Scena	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Customers Savings	%
A	195.5	230.9	209	181.2	136.4	149	155	177.7	139.7	127.4	157	144	2003.879284	
B	155.3	183.4	166	144	108.5	119	124	141.2	111.1	101.3	125	115	1592.475987	
A-B	40.18	47.51	43	37.22	27.93	30.6	31.9	36.49	28.66	26.09	32.2	29.6	**411.4032966**	20.53
A	183.2	218.6	197	169	124.1	137	143	165.4	127.5	115.1	145	132	1856.489284	
B	143	171.1	154	131.7	96.17	106	111	128.9	98.79	89.01	112	102	1445.085987	
A-B	40.18	47.51	43	37.22	27.93	30.6	31.9	36.49	28.66	26.09	32.2	29.6	**411.4032966**	22.16
A	128	163.4	142	113.7	68.87	81.8	88	110.2	72.21	59.86	89.4	76.6	1193.639284	
B	102	130.1	113	90.71	55.14	65.4	70.3	87.92	57.76	47.97	71.3	61.2	952.6859146	
A-B	25.98	33.31	28.8	23.01	13.73	16.4	17.7	22.29	14.45	11.89	18	15.4	**240.9533694**	20.186

Table 3.65 Calculation of the customer savings based on the Fuel Adjustment Clause and to power loss reduction due to STWH-425 kWh (60 % of STWH)

Type of Scenario	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Customers Savings ($)
A	59.6	70.35	63.8	55.27	41.7	45.6	47.45	54.2	42.7	38.9	47.9	43.991	
B	59.5	70.27	63.7	55.23	41.6	45.5	47.41	54.2	42.6	38.9	47.8	43.955	
A-B	0.06	0.073	0.06	0.047	0.03	0.03	0.038	0.05	0.03	0.03	0.05	0.0351	0.520000414
A	47.3	58.06	51.5	42.99	29.4	33.3	35.17	41.9	30.4	26.6	35.6	31.708	
B	47.3	57.99	51.4	42.94	29.3	33.3	35.13	41.9	30.4	26.6	35.6	31.673	
A-B	0.06	0.073	0.06	0.047	0.03	0.03	0.038	0.05	0.03	0.03	0.05	0.0351	0.520000414
A	40.5	51.28	44.7	36.21	22.6	26.5	28.39	35.1	23.6	19.9	28.8	24.928	
B	40.5	51.21	44.7	36.16	22.6	26.5	28.35	35.1	23.6	19.8	28.8	24.893	
A-B	0.06	0.073	0.06	0.047	0.03	0.03	0.038	0.05	0.03	0.03	0.05	0.0351	0.520000414

Table 3.66 Calculation of the customer savings based on the Fuel Adjustment Clause and to power loss reduction due to STWH- 1400kWh (60 % of STWH)

Type of Scenario	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Customers Savings ($)
A	195.5	230.9	209.3	181.2	136.4	149.3	155.5	177.7	140	127.4	156.9	144.1	
B	195.3	230.7	209.1	181.1	136.3	149.2	155.3	177.6	140	127.3	156.7	144	
A-B	0.185	0.239	0.19	0.155	0.088	0.113	0.125	0.153	0.11	0.087	0.151	0.116	1.712942541
A	183.2	218.6	197	169	124.1	137	143.2	165.4	127	115.1	144.6	131.8	
B	183	218.4	196.8	168.8	124	136.9	143.1	165.3	127	115	144.5	131.7	
A-B	0.185	0.239	0.19	0.155	0.088	0.113	0.125	0.153	0.11	0.087	0.151	0.116	1.712942541
A	128	163.4	141.8	113.7	68.87	81.8	87.95	110.2	72.2	59.86	89.37	76.55	
B	127.8	163.1	141.6	113.6	68.78	81.68	87.83	110.1	72.1	59.77	89.22	76.44	
A-B	0.185	0.239	0.19	0.155	0.088	0.113	0.125	0.153	0.11	0.087	0.151	0.116	1.712942541

Table 3.67 Total Calculation of the customer savings due to owning a STWH and the Fuel Adjustment Clause Reduction- 425 kWh (60 % of STWH)

Type of Scenar	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	**Customers Savings**	%
A	59.5982	70.3462	63.7851	55.2733	41.6577	45.5822	47.4519	54.207	42.6733	38.9238	47.8817	43.9905	611.3708541	
B	21.5194	25.0344	22.8903	20.1059	15.653	16.9359	17.5471	19.7568	15.9834	14.7576	17.6852	16.4143	224.2832671	
A-B	38.0788	45.3118	40.8948	35.1675	26.0047	28.6463	29.9049	34.4502	26.6898	24.1662	30.1964	27.5762	**387.0875869**	63.3147
A	47.3157	58.0637	51.5026	42.9908	29.3752	33.2997	35.1694	41.9245	30.3908	26.6413	35.5992	31.708	463.9808541	
B	17.4965	21.0115	18.8674	16.0829	11.63	12.9129	13.5241	15.7339	11.9605	10.7347	13.6623	12.3913	176.0080135	
A-B	29.8192	37.0522	32.6353	26.9079	17.7451	20.3868	21.6453	26.1906	18.4303	15.9066	21.9369	19.3167	**287.9728405**	62.0657
A	40.5357	51.2837	44.7226	36.2108	22.5952	26.5197	28.3894	35.1445	23.6108	19.8613	28.8192	24.928	382.6208541	
B	14.6033	18.1183	15.9742	13.1898	8.73688	10.0198	10.631	12.8407	9.06736	7.84151	10.7691	9.4982	141.2902471	
A-B	25.9323	33.1654	28.7484	23.021	13.8583	16.4999	17.7585	22.3038	14.5434	12.0198	18.05	15.4298	**241.3306069**	63.073

Table 3.68 Total Calculation of the customer savings due to owning a STWH and the Fuel Adjustment Clause Reduction-1400 kWh (60 % of STWH)

Type of Scena	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Customers Savings	%
A	195.5	230.9	209	181.2	136.4	149	155	177.7	139.7	127.4	157	144	2003.879284	
B	155.5	183.6	166	144.2	108.6	119	124	141.4	111.2	101.4	125	115	1594.335384	
A-B	39.98	47.25	42.8	37.05	27.84	30.5	31.8	36.33	28.54	26	32.1	29.4	**409.5439003**	20.438
A	183.2	218.6	197	169	124.1	137	143	165.4	127.5	115.1	145	132	1856.489284	
B	143.2	171.4	154	131.9	96.27	107	111	129.1	98.91	89.1	113	102	1446.945384	
A-B	39.98	47.25	42.8	37.05	27.84	30.5	31.8	36.33	28.54	26	32.1	29.4	**409.5439003**	22.06
A	128	163.4	142	113.7	68.87	81.8	88	110.2	72.21	59.86	89.4	76.6	1193.639284	
B	102.2	130.3	113	90.88	55.23	65.5	70.4	88.08	57.88	48.07	71.5	61.3	954.5453109	
A-B	25.78	33.05	28.6	22.84	13.63	16.3	17.6	22.12	14.33	11.79	17.9	15.2	**239.0939731**	20.031

The total annual average power loss reduction was 3,516 MW per year which is equivalent to 2.57 E+9 kW*h per month. This amount of kW*h was reduced from the base case total losses to finally get to the new transmission efficiency (E_t). The efficiency is definitely improved by the power loss reduction due to STWH. With the transmission efficiency improvement and a change in the $/BBL to $ 57 we calculated the total Factor of Adjustments for the case without power loss reduction and the case with the power loss reduction due to STWH. Once the Total Fuel Adjustment Factor (FA_i) was calculated, we proceeded to calculate the customer savings. We divided the analysis in two parts. We first calculate the savings in terms of the power loss reduction by STWH and the Fuel Adjustment Clause for the three types of residential customers. Tables 3.68 and 3.69 present the utility economic losses due to the installation of STWH. This is the amount of money the local utility losses by a reduction in the customer bill portion related to the Fuel Clause and reduced kilowatts- hour consumption.

Table 3.69 Utility Annual Economic losses- 80 % of STWH

Type of Residential Customer	**425 kW*h consumed**	**1400 kW*h consumed**
Standard	$ 358,612,669	$ 380,911,072
Special	$ 266,440,069	$ 380,911,072
Public Projects	$ 223,658, 846	$ 223,094,484
Fuel Adjustment Clause		
Standard	0.32 %	0.98 %
Special	0.43 %	0.98%
Public Projects	0.51 %	1.68 %

Table 3.70 Utility Annual Economic losses- 60 % of STWH

Type of Residential Customer	425 kW*h consumed	1400 kW*h consumed
Standard	$ 268,798,188	$ 284,392,117
Special	$ 199,971,739	$ 284,392,117
Public Projects	$ 167,582,821	$ 166,029,676.2
Fuel Adjustment Clause		
Standard	0.13 %	0.56 %
Special	0.18 %	0.56 %
Public Projects	0.22 %	0.96 %

3.3.4 Payback Period Analysis

A simple analysis of Payback Period is been done for the residential customers to notice the time they will recover the inversion on a STWH. The analysis was done for a $ 1695 STWH with a life expectancy of 15 to 30 years. The specifications for this STWH are shown below. The size of this water heater is 80 gallons.

Payback (Payout) Period:

$$\frac{Investment}{Net\,cash\;flow/yr}$$

For a $1695 STWH (15-30 years of life expectancy): Porcelain coated inside to prevent the interior corrosion, aluminum cover, 1 ½ of foam as insulator. It is designed to store heat from 2 to three days, with an electric water heater for backup in case of emergency. The collectors are impact resistant. The STWH is hurricane resistant. [9]

Table 3.71 Payback Period Analysis

Type of Residential Customer- 80 % of STWH	**425 kWh** consumed	**1400 kWh** consumed
Standard	4.37 years	4.12years
Special	5.88 years	4.12years
Public Projects	7.02 years	7.03 years
Type of Residential Customer- 60 % of STWH	**425 kWh** consumed	**1400 kWh** consumed
Standard	4.38 years	4.14 years
Special	5.88 years	4.14 years
Public Projects	7.02 years	7.09 years

4 RESULTS DISCUSSION

Once the analysis relating demand reduction power loss reduction, generation displacement, emissions reduction and economic benefits were done, we now proceed to discuss the results and potential benefits of this environmental alternative of Solar Thermal Water Heating.

4.1 Electric System Analysis Results Discussion

Our study shows that with the installation of STWH we can achieve demand reduction, generation displacement, power loss reduction, as well as reduction of emissions and customer saving both from demand reduction and reduction of the fuel adjustment clause thanks to increased system efficiency. We estimated a 313.31 MW reduction in residential demand for Puerto Rico for the case of 80 % of STWH, assuming STWH can heat the desired amount of water throughout the year. With this reduction the Arecibo Plant (248 MW) could be shut down.

The total annual average power loss was reduction was 3516.0 MW and 18713.36 MVR (230 kV, 115 kV and 38 kV). The power loss reduction at the distribution level (38 kV) was calculated to be 8% and 8.74% of the total losses per hour, in terms of real and reactive power, respectively, for 80 % of STWH. Both real and reactive power represents an economic saving, since they cost money in any electric system. The generation displaced was 4703.2 MW (equivalent to 25.8 hours) and 11738.8 MVR for 80 % of STWH.

It is very interesting to observe that with the real power (MW) reduction due to the installation of STWH a considerable reduction in reactive power (MVR) occurred. This event can be corroborated throughout all the tables of the analysis for power loss reduction and generation displacement. The amount of reduced reactive power kept augmenting due to the base case fixed MVR. Through all the simulations the only varying factor was the real power. The reduction in electric load was purely real, since water heaters will only replace electric real power in MW.

The potential benefits mentioned earlier definitely support the environmental alternative of STWH, besides that Puerto Rico's abundant solar resource could be exploited via STWH to achieve generation displacement. Furthermore, the constant fluctuating fuel prices certainly contribute to the efforts for searching new alternatives supplementary to the PREPA's interests on fuel diversification.

The power loss reduction could also benefit the generation plants in terms of the penalty factor and the systems efficiencies (E_i). Moreover, since the penalty factor considers the fact that the generation may have losses before getting to the load center; this improvement in the system efficiency could contribute to this penalty to be lessen.

By means of installing STWH the reserve and spinning reserve could be enhanced helping to achieve the PREPA's security criteria. Spinning reserve is the total amount of generation available from all units synchronized on the system, minus the present load and losses supplied [41]. This alternative would also help the PREPA's dynamic maintenance plan of ensuring the Puerto Rico electric system's reliability.

Solar Thermal Water Heaters are stand alone systems and they cause no impact on the grid, aspect that is of major concern these days. By means of installing STWH the flows on the electric system are reduced. By reducing the flows on the system the risk of thermal overheating is also lessen, thus causing an overall improvement on the system's reliability. Load creates resistive heating as well. As the load on an electrical component rises, so does the temperature. Thermal overheating could cause the components of the electric system to deteriorate; the temperature will continue to increase until the melting points of the materials are reached and complete failure could occurs.

4.2 Emission Analysis Results Discussion

The effects of pollution by electricity generation may be interpreted as a cost because they damage our life in one way or another. The electric energy industry contributions to environmental damage are among the highest these days. The energy sector is one of the major concerns nowadays since the generation of electricity from fossil fuel causes the deterioration of the environment. Damaging such as greenhouse gases, acid rain, irreparable damage to ecosystems, health hazards; which definitely contribute to social problems. There are local and regional impacts and each have its own negative consequences, but what we also dread is the global damage.

The Puerto Rico's 1999 energy related carbon dioxide emissions totaled 6.01 millions metric tons. For example: for fixing this amount of emissions in one year, a sub-tropical forest 0f 40,000 hectares (four times bigger than el Yunque) needs about 30 years [42]. A way to reduce this environmental damage is by reducing gases emissions into the atmosphere and preserving the generated electricity.

There has been a significant increase in carbon dioxide energy related emissions since year 1999. Puerto Rico's 2002 energy related carbon dioxide emissions totaled 16.82 millions metric tons [43]. Our study shows that the reduced carbon dioxide emissions per year were 59.9 G lbs, which is equivalent to 0.61 millions metric tons. This is a contribution to the cause.

4.3 Economic Analysis Results Discussion

Our study shows the potential benefits of installing STWH, benefits such as demand reduction, reduced power losses, resulting in reduced costs for both the utility and its residential customers.

The benefits of using STWH will result in reduced costs for the utility in terms of the generation displaced and power loss reduction. This is, penalty factors could be diminished as well as the barrels of oil consumed per day (BBL/day). This could help against the today's rising crude oil prices and Puerto Rico's economy.

There is an evident benefit for the customer since their annual payments could be reduced by approximately 20 % to 63.3 % (see Tables 3.61 and 3.62) if they own a STWH, and by the reduction in the fuel and energy purchase factors.

The residential load reduction implies a benefit for customers, the environment and PREPA. The generation displacement could be seen as a gain but also as a loss since customers will reduce considerably the payments for domestic water heating purposes. In addition, the real and reactive power displacement could represent an economic saving, since they cost money in any electric system.

5 CONCLUSIONS AND FUTURE WORK

Our study shows that installing STWH has the potential benefits of demand reduction and reduced power losses resulting in reduced costs for both utility and residential customers. From the increased system's efficiency there will be a reduction in fuel and energy cost adjustment, in dollars per kilowatt hour, per residential customer monthly bills.

The residential load reduction implies a benefit for customers, the environment and PREPA. Using STWH will result in reduced costs for the utility in terms of the generation displaced and power loss reduction. Penalty factors could be diminished as well as the barrels of oil consumed per day (BBL/day). This could certainly help against the today's rising crude oil prices and benefit Puerto Rico's economy. By means of installing STWH the reserve and spinning reserve could be enhanced helping to achieve PREPA's security criteria. Solar Thermal Water Heaters are stand alone systems and they cause no impact on the grid, aspect that is of major concern these days.

Solar Thermal Water Heating is definitely a supplementary alternative to fuel diversification given constant fluctuating fuel prices. Puerto Rico's abundant solar resource could be exploited via Solar Thermal Water Heating to achieve all of these potential benefits.

By reducing the flows on the system the risk of thermal overheating is reduced, thus causing an overall improvement in the system's reliability. The improvement on the system's reliability could be included in future studies. Aspects related to daily sunshine duration, cloud coverage, stochastic behavior of solar radiation and rain effects should be included in a more exact model. Future studies could also include the industrial and commercial sectors, as well as social aspects or even public perception to renewable alternatives. Upcoming studies could also calculate the power loss reduction and generation displacement including distribution voltages as 13.2kV, 4.16kV and so on.

Optimization of the model could be done by placing the STWH in strategic sectors of the island, for example, the metropolitan area. Economic analysis including the value of money throughout time could be done.

The results were as expected, so this alternative should be considered for all the benefits mentioned throughout this work.

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APPENDIX A

REPORT OF BASE CASE [I]

Area 1 - S.JUAN

Number of Buses	13		
Total Load	664.4 MW	343.0 MVAR	
Total Generation	232.0 MW	245.0 MVAR	
Losses	3.4 MW	22.1 MVAR	
Actual Tie Line Flow	-333.6 MW	To Area 2	
	-143.2 MW	To Area 3	
	41.2 MW	To Area 4	
	17.9 MW	To Area 7	
	-18.2 MW	To Area 8	
Unserved Load	0.0 MW		
Interchange Error	-4.36		

Tie Lines for Area 1 - S.JUAN

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
280	4	16	1	-10.0	0.2	0.1	-1.4	280
50	4	21	1	36.6	37.5	0.4	0.8	50
88	2	45	1	-43.6	22.9	0.1	0.2	88
50	2	45	1	-64.4	-11.9	0.4	0.8	50
50	2	271	1	-49.1	-8.4	0.1	0.2	271
50	4	149	1	14.7	31.3	0.1	0.0	149
50	2	127	1	-33.3	-63.3	0.1	0.3	127
50	2	63	1	-104.2	-47.4	0.6	3.4	63
88	2	63	1	-93.4	-7.2	0.4	2.2	88
84	3	85	1	-109.8	-68.4	0.2	1.5	85
175	3	85	1	-33.4	-35.9	0.2	0.3	175
88	2	127	1	54.4	73.5	0.2	0.4	127
884	7	100	1	60.3	-13.6	0.0	4.0	100
884	8	232	1	-18.2	63.2	0.3	-6.8	232
884	7	440	1	-42.3	-46.9	0.2	-7.7	884

Bus Information for Area 1 - S.JUAN

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle	
50	MONAC115	1	115	192	70	0	0	1.02	-1.7	0
84	BERWD115	1	115	82	62	0	0	1.03	-2.0	0
86	VIADT115	1	115	134	87	0	0	1.03	-2.1	0
87	H.REY115	1	115	141	46	0	0	1.03	-2.3	0
88	SJSP.115	1	115	52	46	77	87	1.04	-1.3	0
175	CONQUIST	1	115	33	16	0	0	1.03	-1.7	0
280	V.BETINA	1	115	17	8	0	0	1.02	-1.7	0
813	SANJUAN7	1	14	4	2	0	0	1.02	-1.5	0

814	SANJUAN8	1	14	4	2	77	80	1.05	1.8	0
815	SANJUAN9	1	14	4	2	77	78	1.05	1.8	0
816	S.JUAN10	1	14	0	0	0	0	0.99	-1.3	0
883	883	1	138	0	0	0	0	0.00	90.0	0
884		1	230	0	0	0	0	0.97	1.3	0

Load Information for Area 1 - S.JUAN

Bus	ID	Area	Zone	MW	MVR
50	1	1	1	192	70
84	1	1	1	82	62
86	1	1	1	134	87
87	1	1	1	141	46
88	1	1	1	52	46
175	1	1	1	33	16
280	1	1	1	17	8
813	1	1	1	4	2
814	1	1	1	4	2
815	1	1	1	4	2

Generator Information for Area 1 - S.JUAN

Bus	ID	Area	Zone	MW	MVR
88	1	1	1	77	87
814	1	1	1	77	80
815	1	1	1	77	78
816	1	1	1	0	0

Transmission Line Information for Area 1 - S.JUAN

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
16	280	1	10.2	11.2	0.06	-1.38	50.1	
21	50	1	51.6	35.6	0.39	0.76	260.5	
45	50	1	66.0	45.5	0.39	0.79	321.6	
45	88	1	49.2	21.3	0.09	0.20	239.6	
50	63	1	112.5	31.4	0.61	3.40	553.7	
50	127	1	71.2	29.3	0.10	0.30	350.2	
50	149	1	34.6	23.8	0.14	-0.01	170.1	
50	175	1	20.1	13.8	0.03	-0.31	98.7	
50	271	1	49.7	34.2	0.14	0.25	244.3	
50	280	1	10.7	11.7	0.00	-0.02	52.6	
63	88	1	94.2	40.8	0.35	2.17	453.6	
84	85	1	128.4	55.6	0.25	1.52	625.5	
84	87	1	28.1	12.2	0.03	-0.44	137.1	
85	175	1	49.4	34.0	0.16	0.25	238.5	
86	87	1	42.6	18.4	0.03	-0.03	208.3	

86	88	1	87.9	36.6	0.40	1.13	430.3	
86	88	2	89.5	37.3	0.40	1.15	437.9	
87	88	1	83.9	36.3	0.21	1.23	409.6	
88	127	1	91.8	37.8	0.16	0.38	445.0	
88	813	1	5.0	3.5	0.00	0.02	24.0	
88	814	1	100.4	71.7	0.29	8.16	486.5	
88	815	1	99.4	71.0	0.31	8.13	481.7	
88	816	1	0.0	0.0	0.00	0.00	0.00	
100	884	1	61.8	6.2	0.00	3.99	317.1	1.00000
232	884	1	65.8	14.2	0.26	-6.78	177.3	
884	440	1	63.1	13.7	0.23	-7.70	164.1	

Area 2 - BAYAMON

Number of Buses	22	
Total Load	555.3 MW	197.9 MVAR
Total Generation	528.5 MW	190.5 MVAR
Losses	6.8 MW	71.4 MVAR
Actual Tie Line Flow	333.6 MW	To Area 1
	-302.3 MW	To Area 5
	-64.9 MW	To Area 7
Unserved Load	0.0 MW	
Interchange Error	-0.34	

Tie Lines for Area 2 - BAYAMON

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
41	7	153	1	-72.0	-37.9	0.4	1.2	153
45	1	88	1	43.6	-22.9	0.1	0.2	88
45	1	50	1	64.4	11.9	0.4	0.8	50
271	1	50	1	49.1	8.4	0.1	0.2	271
127	1	50	1	33.3	63.3	0.1	0.3	127
63	1	50	1	104.2	47.4	0.6	3.4	63
63	1	88	1	93.4	7.2	0.4	2.2	88
83	7	177	1	-14.2	-6.5	0.1	-0.4	177
127	1	88	1	-54.4	-73.5	0.2	0.4	127
99	7	196	1	21.3	14.0	0.0	-9.5	196
99	5	106	1	-302.3	-75.3	2.9	26.8	106

Bus Information for Area 2 - BAYAMON

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
41	VBAJA115	2	115	55	17	0	0	1.02	-1.3
45	BAY.115	2	115	132	50	0	0	1.03	-0.5
63	P.S.115	2	115	34	-17	0	0	1.04	0.4
83	CORZL115	2	115	14	7	0	0	0.96	-3.2
93	DORAD115	2	115	56	55	0	0	1.01	-1.6
99	BAY.230	2	230	0	0	0	0	0.98	2.4
111	R.PLA115	2	115	35	17	0	0	1.02	-1.1
127	CACHE.13	2	115	21	10	0	0	1.03	-1.5
190	CANA 115	2	115	34	17	0	0	1.02	-1.4
192	LEVITTOW	2	115	25	12	0	0	1.02	-3.2
262	1-P.S.3W	2	0	31	-5	0	0	1.05	-1.0
271	R.BAY115	2	115	32	15	0	0	1.03	-1.0
310	BO-PINAS	2	115	7	3	0	0	1.02	-1.5
362	2-P.S.3W	2	0	57	5	0	0	1.05	0.2
400	MONTERRE	2	115	0	0	0	0	1.02	-1.5
817	P.SECO1	2	14	0	0	0	0	1.05	-1.0
818	P.SECO2	2	14	3	2	56	16	1.05	0.2
819	P.SECO3	2	19	9	173	87	0	1.05	3.4
820	P.SECO4	2	19	9	173	87	0	1.05	3.5
829	P.S.GAS1	2	13	0	42	0	0	1.04	3.5
830	P.S.GAS2	2	13	0	42	0	0	1.04	3.5
831	P.S.GAS3	2	13	0	42	0	0	1.04	3.5

Load Information for Area 2 - BAYAMON

Bus	ID	Area	Zone	MW	MVR
41	1	2	1	55	17
45	1	2	1	132	50
63	1	2	1	34	-17
83	1	2	11	14	7
93	1	2	1	56	55
111	1	2	10	35	17
127	1	2	2	21	10
190	1	2	10	34	17
192	1	2	10	25	12
262	1	2	1	31	-5
271	1	2	1	32	15
310	1	2	11	7	3
362	1	4	1	57	5
818	1	2	1	3	2
819	1	2	1	9	5
820	1	2	1	9	5

Generator Information for Area 2 - BAYAMON

Bus	ID	Area	Zone	MW	MVR
817	1	2	1	0	0
818	1	2	1	56	16
819	1	2	1	173	87
820	1	2	1	173	87
829	1	2	1	21	0
829	2	2	1	21	0
830	1	2	1	21	0
830	2	2	1	21	0
831	1	2	1	21	0
831	2	2	1	21	0

Transmission Line Information for Area 2 - BAYAMON

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
41	93	1	26.4	11.0	0.10	-0.44	129.4	
41	153	1	80.5	33.5	0.39	1.16	394.5	
45	50	1	66.0	45.5	0.39	0.79	321.6	
45	63	1	92.7	51.8	0.20	1.36	451.4	
45	63	2	92.7	51.8	0.20	1.36	451.4	
45	88	1	49.2	21.3	0.09	0.20	239.6	
45	99	1	279.2	51.3	0.32	14.57	1360.3	1.06084
45	111	1	91.6	39.7	0.16	1.02	446.3	
45	190	1	42.2	46.4	0.33	0.43	205.5	
45	271	1	84.6	58.4	0.20	0.70	412.2	
50	63	1	112.5	31.4	0.61	3.40	553.7	
50	127	1	71.2	29.3	0.10	0.30	350.2	
50	271	1	49.7	34.2	0.14	0.25	244.3	
63	88	1	94.2	40.8	0.35	2.17	453.6	
63	192	1	28.8	65.4	0.00	2.00	138.5	
63	262	1	30.8	25.7	0.02	0.72	148.4	
63	362	1	10.2	8.5	0.00	0.08	49.2	
819	63	1	183.0	68.0	0.35	10.86	5296.8	
820	63	1	183.1	68.1	0.35	10.86	5297.6	
829	63	1	42.0	76.4	0.07	2.27	1761.7	
830	63	1	42.0	76.4	0.07	2.27	1761.7	
831	63	1	42.0	76.4	0.07	2.27	1761.7	
83	177	1	15.7	17.3	0.08	-0.38	82.2	
83	400	1	0.0	0.00	0.00	0.00	0.0	
88	127	1	91.8	37.8	0.16	0.38	445.0	
93	111	1	52.1	22.5	0.09	0.31	258.9	
99	106	1	303.3	32.8	2.92	26.81	777.5	
99	196	1	21.9	4.7	0.03	-9.46	56.0	

190	310	1	7.7	8.5	0.01	-0.18	38.0
817	262	1	0.0	0.0	0 .00	0.00	0.0
310	400	1	0.3	0.3	0.00	-0.29	1.4
818	362	1	55.1	45.9	0.00	-0.02	2196.7

Area 3 - CAROLINA

Number of Buses	7	
Total Load	249.0 MW	140.8 MVAR
Total Generation	0.0 MW	0.0 MVAR
Losses	1.4 MW	18.2 MVAR
Actual Tie Line Flow	143.2 MW	To Area 1
	-59.6 MW	To Area 4
	-334.0 MW	To Area 5
Unserved Load	0.0 MW	
Interchange Error	-2.50	

Tie Lines for Area 3 - CAROLINA

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
101	4	16	1	-59.6	-11.7	0.6	1.5	101
85	1	84	1	109.8	68.4	0.2	1.5	85
85	1	175	1	33.4	35.9	0.2	0.3	175
120	5	106	1	-334.0	-193.9	5.9	66.4	120

Bus Information for Area 3 - CAROLINA

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
18	FAJ.115	3	115	33	22	0	0	1.01	-3.7
82	CANOV115	3	115	60	42	0	0	1.02	-2.9
85	S.LL.115	3	115	98	43	0	0	1.04	-1.4
101	DAGU.115	3	115	31	21	0	0	1.01	-2.8
120	S.LL.230	3	230	0	0	0	0	0.90	0.8
211	PALM.115	3	115	28	14	0	0	1.01	-3.6
278	T.PALMER	3	115	0	0	0	0	1.01	-3.6

Load Information for Area 3 - CAROLINA

Bus	ID	Area	Zone	MW	MVR
18	1	3	1	33	22
82	1	3	1	60	42
85	1	3	1	98	43
101	1	3	1	31	21
211	1	4	1	28	14

Transmission Line Information for Area 3 - CAROLINA

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
16	101	1	61.7	45.0	0.60	1.53	302.4	
18	101	1	30.3	22.1	0.12	-0.16	150.9	
18	278	1	6.5	4.5	0.00	-0.79	32.4	
82	85	1	95.9	66.2	0.70	2.21	470.8	
82	278	1	36.4	25.1	0.16	-0.19	178.7	
84	85	1	128.4	55.6	0.25	1.52	625.5	
85	120	1	232.7	42.8	0.21	10.92	1124.3	1.18902
85	120	2	148.4	27.3	0.08	5.95	716.9	1.17300
85	175	1	49.4	34.0	0.16	0.25	238.5	
106	120	1	428.1	46.3	5.86	66.39	1058.9	
211	278	1	30.9	21.3	0.01	0.01	153.6	

Area 4 - CAGUAS

Number of Buses	10	
Total Load	366.4 MW	180.8 MVAR
Total Generation	0.0 MW	0.0 MVAR
Losses	4.1 MW	24.4 MVAR
Actual Tie Line Flow	-41.2 MW	To Area 1
	59.6 MW	To Area 3
	-359.4 MW	To Area 5
	-29.5 MW	To Area 6
Unserved Load	0.0 MW	
Interchange Error	-3.71	

Tie Lines for Area 4 - CAGUAS

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
10	5	8	1	-136.5	-1.8	3.5	16.1	10
16	1	280	1	10.0	-0.2	0.1	-1.4	280
16	3	101	1	59.6	11.7	0.6	1.5	101
21	1	50	1	-36.6	-37.5	0.4	0.8	50
149	1	50	1	-14.7	-31.3	0.1	0.0	149
233	5	106	1	-201.3	-102.9	1.4	7.2	233
149	6	213	1	-29.5	11.6	0.4	-0.3	213
185	5	334	1	-21.6	20.0	0.0	-0.2	185

Bus Information for Area 4 - CAGUAS

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
5	YAB. 115	4	115	-42	11	0	0	1.05	2.6
10	CAYEY115	4	115	88	38	0	0	1.00	-0.8
14	HUM. 115	4	115	96	27	0	0	1.04	1.8
16	R.BLA115	4	115	17	-2	0	0	1.02	-0.9
21	CAG.115	4	115	128	94	0	0	0.99	-2.6

149	A.BNAS T	4	115	0	0	0	0	1.00	-1.9
185	S.OIL-U.	4	115	21	7	0	0	1.04	2.7
233	YABUC230	4	230	0	0	0	0	0.97	5.8
234	JUNCO115	4	115	57	7	0	0	1.03	0.0
294	HUM.TAP	4	115	0	0	0	0	1.04	1.8

Load Information for Area 4 - CAGUAS

Bus	ID	Area	Zone	MW	MVR
5	1	4	1	-42	11
10	1	4	1	88	38
14	1	4	1	96	27
16	1	4	1	17	-2
21	1	4	1	128	94
185	1	4	2	21	7
234	1	2	1	57	7

Transmission Line Information for Area 4 - CAGUAS

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
5	14	1	124.1	53.7	0.23	1.62	595.4	
5	185	1	26.9	11.7	0.03	-0.13	129.1	
5	233	1	219.9	43.6	0.22	13.98	1054.8	1.10672
5	294	1	124.6	53.9	0.22	1.83	597.7	
8	10	1	141.2	61.1	3.49	16.06	686.3	
10	21	1	48.8	35.6	0.40	1.47	245.1	
14	234	1	58.4	40.3	0.46	1.05	281.7	
14	294	1	34.9	0.0	0.00	0.01	168.0	
16	101	1	61.7	45.0	0.60	1.53	302.4	
16	280	1	10.2	11.2	0.06	-1.38	50.1	
16	294	1	88.1	36.7	1.00	3.56	432.1	
21	50	1	51.6	35.6	0.39	0.76	260.5	
21	149	1	47.9	33.0	0.16	0.36	242.0	
50	149	1	34.6	23.8	0.14	-0.01	170.1	
106	233	1	230.7	25.0	1.38	7.23	570.5	
149	213	1	31.3	21.6	0.37	-0.31	156.5	
185	334	1	29.5	12.8	0.03	-0.21	142.3	

Area 5 - PONCE ES

Number of Buses	18	
Total Load	124.9 MW	70.4 MVAR
Total Generation	1304.0 MW	716.2 MVAR
Losses	17.7 MW	263.2 MVAR
Actual Tie Line Flow	302.3 MW	To Area 2
	334.0 MW	To Area 3
	359.4 MW	To Area 4
	165.6 MW	To Area 6
Unserved Load	0.0 MW	
Interchange Error	11.61	

Tie Lines for Area 5 - PONCE ES

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
107	6	3	1	57.8	5.9	1.2	3.4	3
8	4	10	1	136.5	1.8	3.5	16.1	10
106	6	96	1	107.8	22.8	0.6	-3.0	106
106	2	99	1	302.3	75.3	2.9	26.8	106
106	4	233	1	201.3	102.9	1.4	7.2	233
106	3	120	1	334.0	193.9	5.9	66.4	120
334	4	185	1	21.6	-20.0	0.0	-0.2	185

Bus Information for Area 5 - PONCE ES

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
8	JOBOS115	5	115	49	27	0	0	1.03	5.7
106	AGUI.230	5	230	0	0	0	0	1.01	9.7
107	AGUI.115	5	115	0	0	0	0	1.05	8.6
184	MAUNA115	5	115	20	14	0	0	1.03	3.1
334	T.MAUNAB	5	115	0	0	0	0	1.03	3.1
807	AGCCST1	5	13	5	2	84	59	1.05	14.5
808	AGCCST2	5	13	3	2	63	59	1.05	13.3
809	AG.1	5	24	22	12	400	234	1.05	15.7
810	AG.2	5	23	22	12	400	236	1.05	15.7
821	CCGAS11	5	13	0	0	45	18	1.05	14.9
822	CCGAS12	5	13	0	0	45	18	1.05	14.9
823	CCGAS13	5	13	0	0	45	18	1.05	14.9
824	CCGAS21	5	13	0	0	45	18	1.05	14.9
825	CCGAS22	5	13	0	0	45	18	1.05	14.9
826	CCGAS23	5	13	0	0	45	18	1.05	14.9
832	CCGAS14	5	13	0	0	45	18	1.05	14.9
833	CCGAS24	5	13	0	0	0	0	1.01	9.7
862	AGUIRRGT	5	14	0	0	42	0	1.02	13.9

Load Information for Area 5 - PONCE ES

Bus	ID	Area	Zone	MW	MVR
8	1	5	2	49	27
184	1	4	1	20	14
807	1	5	1	5	2
808	1	5	1	3	2
809	1	5	1	22	12
810	1	5	1	22	12
821	1	5	1	0	0
822	1	5	1	0	0
823	1	5	1	0	0
824	1	5	1	0	0
825	1	5	1	0	0
826	1	5	1	0	0
832	1	5	1	0	0

Generator Information for Area 5 - PONCE ES

Bus	ID	Area	Zone	MW	MVR
807	1	5	1	84	59
808	1	5	1	63	59
809	1	5	1	400	234
810	1	5	1	400	236
821	1	5	1	45	18
822	1	5	1	45	18
823	1	5	1	45	18
824	1	5	1	45	18
825	1	5	1	45	18
826	1	5	1	45	18
832	1	5	1	45	18
833	1	5	1	0	0
862	1	5	1	21	0
862	2	5	1	21	0

Transmission Line Information for Area 5 - PONCE ES

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
3	107	1	58.1	40.0	1.20	3.39	287.5	
8	10	1	141.2	61.1	3.49	16.06	686.3	
8	107	1	116.1	25.1	0.48	5.06	564.3	
8	107	2	118.8	25.7	0.48	5.21	577.5	
8	334	1	42.7	18.5	0.24	0.64	207.8	
96	106	1	110.3	23.9	0.62	-3.01	277.4	
99	106	1	303.3	32.8	2.92	26.81	777.5	
107	106	1	127.5	23.4	0.05	2.46	611.6	1.03708
107	106	2	129.8	23.9	0.05	2.50	622.5	1.03708

106	120	1	428.1	46.3	5.86	66.39	1058.9
106	233	1	230.7	25.0	1.38	7.23	570.5
106	807	1	92.0	69.2	0.32	9.68	227.6
106	808	1	77.8	58.5	0.11	6.91	192.3
106	809	1	413.6	72.6	1.74	50.77	1022.9
106	810	1	414.2	72.7	1.58	50.93	1024.6
821	106	1	48.1	70.7	0.08	4.61	2002.4
822	106	1	48.1	70.7	0.08	4.61	2002.4
823	106	1	48.1	70.7	0.08	4.61	2002.4
824	106	1	48.1	70.7	0.08	4.61	2002.4
106	825	1	46.5	68.3	0.08	4.61	114.9
826	106	1	48.1	70.7	0.08	4.61	2002.4
106	832	1	46.5	68.3	0.08	4.61	114.9
106	833	1	0.0	0.0	0.00	0.00	0.0
107	862	1	42.0	84.0	0.17	3.87	201.5
184	334	1	24.9	10.8	0.00	0.00	120.9
185	334	1	29.5	12.8	0.03	-0.21	142.3

Area 6 - PONCE OE

Number of Buses	14	
Total Load	323.4 MW	147.9 MVAR
Total Generation	695.9 MW	342.1 MVAR
Losses	15.6 MW	124.3 MVAR
Actual Tie Line Flow	29.5 MW	To Area 4
	-165.6 MW	To Area 5
	274.6 MW	To Area 7
	218.4 MW	To Area 8
Unserved Load	0.0 MW	
Interchange Error	3.57	

Tie Lines for Area 6 - PONCE OE

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
2	7	38	1	86.7	1.0	3.1	9.3	38
3	7	266	1	22.2	-7.7	0.7	1.1	266
3	5	107	1	-57.8	-5.9	1.2	3.4	3
23	8	116	1	61.6	4.4	1.3	3.3	116
96	8	232	1	156.7	99.0	2.3	10.7	232
96	7	196	1	165.7	25.7	1.7	7.2	196
96	5	106	1	-107.8	-22.8	0.6	-3.0	106
213	4	149	1	29.5	-11.6	0.4	-0.3	213

Bus Information for Area 6 - PONCE OE

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
1	COSTASUR	6	38	82	0	0	0	1.05	6.1
3	PONCE115	6	115	106	68	0	0	1.01	3.5
23	GUANI115	6	115	18	6	0	0	1.02	3.3
96	S.C. 230	6	230	0	0	0	0	1.00	6.9
103	CANAS115	6	115	62	33	0	0	1.02	3.7
213	TO.NG115	6	115	24	24	0	0	0.99	1.2
801	C.S.1	6	14	2	1	30	1	1.05	7.3
802	C.S.2	6	14	2	1	30	1	1.05	7.3
803	C.S.3	6	14	4	2	75	68	1.04	8.4
804	C.S.4	6	14	4	2	75	68	1.03	8.6
805	C.S.5	6	23	21	11	444	205	1.05	13.9
806	C.S.6	6	23	0	0	0	0	1.00	6.9
850	C.S. GAS	6	14	0	0	42	0	1.04	12.5

Load Information for Area 6 - PONCE OE

Bus	ID	Area	Zone	MW	MVR
1	1	6	2	82	0
2	1	6	2	0	0
3	1	6	1	106	68
23	1	6	1	18	6
103	1	6	11	62	33
213	1	6	1	24	24
801	1	6	1	2	1
802	1	6	1	2	1
803	1	6	1	4	2
804	1	6	1	4	2
805	1	6	1	21	11

Generator Information for Area 6 - PONCE OE

Bus	ID	Area	Zone	MW	MVR
801	1	6	1	30	1
802	1	6	1	30	1
803	1	6	1	75	68
804	1	6	1	75	68
805	1	6	1	444	205
806	1	6	1	0	0
850	1	6	1	21	0
850	2	6	1	21	0

Transmission Line Information for Area 6 - PONCE OE

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	12.6	11.3	0.01	0.21	182.5	1.00622
1	2	2	12.6	11.3	0.01	0.21	182.5	1.00622
1	801	1	28.3	42.9	0.04	1.09	410.2	
1	802	1	28.3	42.9	0.04	1.08	410.2	
2	3	1	114.2	49.5	0.84	5.25	548.8	
2	23	1	83.6	61.0	1.15	3.29	401.7	
2	38	1	90.4	66.0	3.13	9.30	434.5	
2	96	1	101.5	18.7	0.03	1.59	487.4	1.04876
2	96	2	101.5	18.7	0.03	1.59	487.4	1.04876
2	103	1	98.2	42.5	0.58	3.95	471.6	
803	2	1	96.7	87.9	0.57	5.74	3871.1	
804	2	1	96.7	87.9	0.23	5.77	3926.4	
2	850	1	42.1	84.2	0.16	4.76	202.3	
3	103	1	25.7	11.1	0.01	-0.18	127.1	
3	107	1	58.1	40.0	1.20	3.39	287.5	
3	213	1	55.5	38.3	0.55	1.54	274.7	
3	266	1	23.9	40.4	0.74	1.05	118.1	
23	116	1	63.4	43.7	1.34	3.30	311.8	
96	106	1	110.3	23.9	0.62	-3.01	277.4	
96	196	1	170.5	36.9	1.65	7.21	428.9	
96	232	1	193.2	41.8	2.28	10.67	485.9	
96	805	1	442.3	81.3	1.57	59.91	1112.5	
806	96	1	0.0	0.0	0.00	0.00	0.0	
149	213	1	31.3	21.6	0.37	-0.31	156.5	

Area 7 - ARECIBO

Number of Buses	16	
Total Load	291.0 MW	91.4 MVAR
Total Generation	98.0 MW	108.7 MVAR
Losses	3.5 MW	12.9 MVAR
Actual Tie Line Flow	-17.9 MW	To Area 1
	64.9 MW	To Area 2
	-274.6 MW	To Area 6
	31.1 MW	To Area 8
Unserved Load	0.0 MW	
Interchange Error	-1.96	

Tie Lines for Area 7 - ARECIBO

Area Bus Other Area Bus ID MWLeave MVR Leave MWLoss MVRLoss Meter

38	6	2	1	-86.7	-1.0	3.1	9.3	38
266	6	3	1	-22.2	7.7	0.7	1.1	266
100	8	32	1	20.2	-24.8	0.0	-0.5	100
38	8	35	1	10.9	-9.7	0.1	-1.3	38
153	2	41	1	72.0	37.9	0.4	1.2	153
177	2	83	1	14.2	-6.5	0.1	-0.4	177
196	6	96	1	-165.7	-25.7	1.7	7.2	196
196	2	99	1	-21.3	-14.0	0.0	-9.5	196
100	1	884	1	-60.3	13.6	0.0	4.0	100
440	1	884	1	42.3	46.9	0.2	-7.7	884

Bus Information for Area 7 - ARECIBO

Number	Name	Area	kVLevel	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
38	DBOCA115	7	115	26	-9	0	0	1.00	-1.2
40	CAMBA115	7	115	50	23	0	0	0.99	-2.6
100	MORA 115	7	115	37	23	0	0	0.98	-2.3
102	BARCL115	7	115	76	38	0	0	1.01	-2.8
153	MANAT115	7	115	74	13	0	0	1.04	-0.5
167	UPJHN115	7	115	13	4	0	0	1.01	-2.8
177	CIALE115	7	115	14	7	0	0	0.97	-2.7
196	MANAT230	7	230	0	0	0	0	0.97	1.7
266	JAYUYA	7	115	5	3	0	0	1.00	0.5
290	CAONILL1	7	115	-10	-12	0	0	1.00	-1.1
343	ABBOT115	7	115	4	1	0	0	1.01	-2.8
440	CAMB230	7	230	0	0	0	0	0.99	2.6
441	CAMB115	7	115	0	0	0	0	1.04	2.6
880	CAMBGT1	7	14	0	0	49	54	1.05	5.4
881	CAMBGT2	7	14	0	0	50	55	1.05	5.4
882	CAMBGT3	7	14	0	0	0	0	0.99	2.6

Load Information for Area 7 - ARECIBO

Bus	ID	Area	Zone	MW	MVR
38	1	7	1	26	-9
40	1	7	1	50	23
100	1	7	1	37	23
102	1	7	2	76	38
153	1	7	10	74	13
167	1	7	2	13	4
177	1	7	11	14	7
266	1	7	11	5	3
290	98	7	1	-10	-12
290	98	7	1	-10	-12
343	1	7	1	4	1

880	1	7	1	0	0
881	1	7	1	0	0
882	1	7	1	0	0

Generator Information for Area 7 - ARECIBO

Bus	ID	Area	Zone	MW	MVR
290	1	7	1	0	0
880	1	7	1	49	54
881	1	7	1	50	55
882	1	7	1	0	0

Transmission Line Information for Area 7 - ARECIBO

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
2	38	1	90.4	66.0	3.13	9.30	434.5	
3	266	1	23.9	40.4	0.74	1.05	118.1	
32	100	1	31.6	6.8	0.04	-0.45	160.5	
35	38	1	13.6	15.0	0.14	-1.32	68.0	
38	40	1	48.2	40.2	0.33	0.64	241.8	
38	177	1	32.0	35.1	0.58	-0.04	160.5	
38	266	1	19.9	33.7	0.25	0.53	99.6	
38	290	1	15.8	17.3	0.02	-0.19	79.0	
40	100	1	10.4	4.5	0.01	-1.96	52.6	
40	167	1	25.8	10.7	0.10	-0.40	130.8	
40	441	1	0.0	0.0	0.00	0.00	0.0	
41	153	1	80.5	33.5	0.39	1.16	394.5	
83	177	1	15.7	17.3	0.08	-0.38	82.2	
96	196	1	170.5	36.9	1.65	7.21	428.9	
99	196	1	21.9	4.7	0.03	-9.46	56.0	
100	884	1	61.8	6.2	0.00	3.99	317.1	1.0000
102	153	1	99.6	41.5	1.18	4.13	496.3	
102	167	1	32.3	13.5	0.02	-0.02	161.0	
102	343	1	3.9	2.7	0.00	-0.04	19.5	
153	196	1	256.7	47.2	0.22	11.10	1243.5	1.0838
196	440	1	81.8	17.7	0.24	-3.51	211.2	
440	441	1	0.0	0.0	0.00	0.00	0.0	0.9563
440	880	1	68.3	68.3	0.17	5.15	172.6	
440	881	1	69.2	69.2	0.17	5.25	174.9	
440	882	1	0.5	0.5	0.00	0.00	1.3	
884	440	1	63.1	13.7	0.23	-7.70	164.1	

Area 8 - MAYAGUEZ

Number of Buses	7	
Total Load	228.9 MW	174.5 MVAR
Total Generation	0.0 MW	0.0 MVAR
Losses	2.4 MW	22.1 MVAR
Actual Tie Line Flow	18.2 MW	To Area 1
	-218.4 MW	To Area 6
	-31.1 MW	To Area 7
Unserved Load	0.0 MW	
Interchange Error	-2.31	

Tie Lines for Area 8 - MAYAGUEZ

Area Bus	Other Area	Bus	ID	MW Leave	MVR Leave	MWLoss	MVRLoss	Meter
116	6	23	1	-61.6	-4.4	1.3	3.3	116
32	7	100	1	-20.2	24.8	0.0	-0.5	100
35	7	38	1	-10.9	9.7	0.1	-1.3	38
232	6	96	1	-156.7	-99.0	2.3	10.7	232
232	1	884	1	18.2	-63.2	0.3	-6.8	232

Bus Information for Area 8 - MAYAGUEZ

Number	Name	Area	kV Level	LoadMW	LoadMVR	GenMW	GenMVR	Volt	Angle
29	MAYA.115	8	115	27	39	0	0	1.03	-1.6
32	AGUAD115	8	115	61	44	0	0	0.99	-3.0
35	S.SEB115	8	115	40	21	0	0	1.01	-2.4
116	ACAC.115	8	115	73	52	0	0	0.99	-1.6
231	A&ASC115	8	115	28	18	0	0	1.01	-2.3
232	MAYTC230	8	230	0	0	0	0	0.93	2.2
277	MAYTC115	8	115	0	0	0	0	1.03	-1.5

Load Information for Area 8 - MAYAGUEZ

Bus	ID	Area	Zone	MW	MVR
29	1	8	11	27	39
32	1	8	1	61	44
35	1	8	11	40	21
116	1	8	1	73	52
231	1	8	1	28	18

Transmission Line Information for Area 8 - MAYAGUEZ

From	To	ID	MVA	% Loaded	Loss-MW	Loss-MVR	Amps	Tap
23	116	1	63.4	43.7	1.34	3.30	311.8	
29	116	1	49.9	36.4	0.46	0.76	243.3	
29	277	1	25.3	11.0	0.03	-0.13	123.5	
29	277	2	37.5	27.4	0.04	0.04	182.8	
32	100	1	31.6	6.8	0.04	-0.45	160.5	

32	231	1	58.0	42.3	0.40	0.83	294.2	
35	38	1	13.6	15.0	0.14	-1.32	68.0	
35	277	1	42.1	29.0	0.32	0.26	210.1	
96	232	1	193.2	41.8	2.28	10.67	485.9	
231	277	1	91.6	66.9	0.60	1.93	454.1	
277	232	1	198.2	66.1	0.37	20.16	962.5	1.19500
232	884	1	65.8	14.2	0.26	-6.78	177.3	