Abstract— With the growing concerns of carbon emissions and the Green House Effect, renewable energy is key to the survival of the world. Renewable energy takes many different forms. Nuclear energy has been a good gateway to limit carbon emissions, but with the nuclear waste that is produced by the reactor nuclear energy is not the answer to the world's energy problems. Renewable energy includes solar energy, tidal power, and wind power just to name a few. This document will provide insight on Solar Energy.


I. INTRODUCTION

Renewable energy must continue to be researched in order for the world’s population to continue to thrive. Solar energy has been around for a very long time. Steps and bounds must still be taken in order to produce equipment capable of capturing and storing enough energy that come from a solar source. Many techniques have been used and are still used such as photovoltaic cells, solar tower, and the solar trough. These different types of solar devices utilize different ways of converting the solar energy into electric energy. These will be discussed in the subsequent sections. It is important to note that although this paper refers to solar power, solar power can not accomplish the world’s energy crisis on it’s own. Help will be needed from other renewable sources such as wind and hydroelectric power. It is also worth stating that in the years to come coal, natural gas, and oil along with nuclear plants must still be used until the technology of the storage devices have drastically improved.

II. HISTORY

A. 1950 and earlier

Throughout life many people think that solar power has been a recent discovery. This couldn’t be further from the truth. [1] The first solar device called the Solar Collector was designed and created in 1767 by a Swiss scientist named Horace-Benedict de Saussure. In 1939, French scientist named Edmond Becquerel defined the photovoltaic effect. 2In 1876, William Adams and Richard day discovered that when selenium cells were exposed to sunlight electricity was produced. [2] These selenium cells were far from efficient but proved that electricity could be produced with out having the need for moving parts. At this point, it had been proved that electricity could be produced from the absorption of sunlight, but this did very little for the public or mainstream companies. Two of the biggest reason for this was the inefficiency of the selenium cells and the shear cost of this material. Also, at this point in time few people thought about carbon emissions or the Green House Effect.

B. 1950 to present

It wasn’t until the 1950s that solar energy took another big step. [2] In 1953, three gentlemen named Fuller, Pearson, and Chapin discovered the silicon solar cell. This solar cell was actually capable of producing enough electricity to run small electronic devices. The key downfall of their discovery was the cost of the new silicon cell. It was some three hundred dollars for a one-watt cell. [2] The United States and Soviet space programs began experimenting and using solar panels to power their satellites. By the end of the 1960s this was the standard practice. In the 1970s, the price of the silicon solar cell dropped to around twenty dollars for a one-watt cell. Exxon took advantage of this opportunity to begin to implement some auxiliary power on board of oilrigs with solar energy. [3] In 1980, a company named ARCO became the first company to produce more than one megawatt of photovoltaic modules in a single year. In 1982, the U.S. Department of Energy began operating Solar One. [3] This was an experiment that implemented system of Solar-Power Towers, which use solar concentration rather than the photovoltaic effect. In 1996, Solar Two was began by DOE, which was an upgraded version of the older Solar One. Today we see solar energy used in a multitude of areas from traffic lights to the more traditional ways of satellites. It is obvious of the growth in the solar energy industry just by noticing the photovoltaic panels are being used on residential homes. Some twenty years ago this was thought to be impossible. We must continue to grow and research in this are in order for solar power to become a viable alternative to the more harmful types of generation used today.
III. ADVANTAGES AND DISADVANTAGES

A. Advantages

There are many advantages to solar power. The environment sees some of the biggest advantages. As stated previously, with the growing pressure from environmental activists and organizations such as the EPA, it is imperative that a way to reduce carbon emissions while maintaining the integrity of the infrastructure. The reduction on carbon emissions is one of the greatest advantages of solar energy. Solar energy relies on the Sun, which is a renewable source, thus relying on this type of energy drastically decreases the unknowns. The use of solar power is very advantageous for the residential user as well. The residential user will see a monetary savings over time. This will not be immediate as the cost of the equipment will be large, but over time the user will see a reduction in his or her utilities. The utilities may also pay the user for its contribution to the grid.

B. Disadvantages

There are also a number of disadvantages associated with solar energy. One big concern is the peak load times of the grid. Presently the technology of solar power, whether it be solar tower, solar trough, or photovoltaic panels, is no adequate enough to provide enough power to the grid to supply the demand during peak load times. Much of the power that is used during these peak times still comes from carbon-emission type sources. Many different storage devices are being researched, but the technology isn’t where it needs to be in order for the sustainability of electricity via solar energy during peak load times. Geographic location is another concern when discussing solar energy. There are many areas around the country and world that solar energy isn’t a viable option due to the insufficient levels of radiation from the sun.

IV. PHOTOVOLTAIC PANELS

Photovoltaic panels can be also called solar panels. Photovoltaic, abbreviated to PV, is a method of generating electrical power by converting sunlight into direct current electricity using semiconducting materials that exhibit the photovoltaic effect [4].

A. Overview

The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. PV panels generate direct current (DC) power that can be used for charging batteries, running loads directly or generating mains quality Alternated Current (AC) power via an inverter. PV panels generally consist of 36 cells and provide a nominal Voltage of 12 Volts [5]. The material used for making a solar panel is silicon, one of the most abundant elements on Earth.

B. The way it work

As mentioned before, the photovoltaic effect is the creation of voltage or electric current in a material upon exposure to light [6]. That means, when sunlight hits the surface of a PV panel, part of the light passes through the panel, starting a flow of electricity. As shown in the Figure 1 below, there is a p-n junction inside the panel. Carries will be excited by energy from sunlight. The collection of light-generated carriers by the p-n junction causes a movement of electrons to the n-type side and holes to the p-type side of the junction. Thus, a flow of electricity occurs.

C. Categories

1) Polycrystalline: Polycrystalline cells are effectively a slice cut from a block of silicon, consisting of a large number of crystals.

2) Monocrystalline: Monocrystalline cells are cut from a single crystal of silicon- they are effectively a slice from a crystal. These cells are slightly more efficient and expensive than polycrystalline cells.

3) Hybrid: Hybrid panels are a cut above crystalline ones in terms of efficiency, which means that they generate a larger power from a smaller area. However, they are much too expensive compared to crystalline panels and are really not worthwhile, unless having very limited roof space.

4) All Black: All black panels with black frames and black backing have a better appearance than standard aluminum framed panel. However, black backed panels, in particular, will get a lot hotter, which will cause the solar cells to work less efficiently and will generate less electricity.

D. Advantages and disadvantages

1) Advantages

a) Pollution-free during use: When using PV panels to receiving and transferring solar power, no pollution will be produced, since they are operated without any moving parts or environmental emissions.
b) **Long-term lifespan**: PV installations can operate for 100 years or even more with little maintenance or intervention after their initial set-up [8].

c) **Low operating costs**: Compared to other existing power technologies, PV panels require much lower costs after initial set-up, for sunlight is free and available for everyone equally. It is also because of their long operating time. Production end-wastes and emissions are manageable using existing pollution controls.

2) **Disadvantages**

a) **Limited working hours**: Solar power is not available at night, so it needs some other kinds of generators or batteries to maintain night power supply.

b) **Pollution during manufacture**: Although solar power is always considered as clean energy, pollution still exists during manufacture of PV panels. The following table evaluates the environmental impact of major solar PV manufacturing phases.

<table>
<thead>
<tr>
<th>Phases of Production</th>
<th>Three Wastes</th>
<th>Energy Consumption</th>
<th>Evaluation</th>
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<td>Polysilicon</td>
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### V. CHALLENGE OF PV SYSTEM

These three distinct challenges for generation owners and grid operators in PV system

A. **Non-controllable variability**

Solar output varies in a way that generation operators cannot control, because sunlight may vary from moment to moment, affecting moment-to-moment power output. This fluctuation in power output results in the need for additional energy to balance supply and demand on the grid on an instantaneous basis, as well as ancillary services such as frequency regulation and voltage support [10].

B. **Partial unpredictability**

The PV systems require the presence of sunlight in order to operate. Unpredictability can be managed through improved weather and generation forecasting technologies.

### C. Location Dependence

The solar resources are based in specific locations and, unlike coal, gas, oil, or uranium cannot be transported to a generation site [11]. Generation must be collocated with the resource itself, and often these locations are far from the places where the power will ultimately be used.

### VI. DATA ANALYSIS AND PREDICTION METHOD

The total harmonic distortion of current has a strong relationship with solar irradiance. Harmonics can cause of premature aging of equipment by generating additional heat and damaging electrical insulation. The development of methods to predict power quality values from environmental variables will lead to power quality forecasts. This, in turn, would allow better mitigation of the effects solar energy have on electricity grids. This may eventually lead to the ability to have higher and higher amounts of solar energy penetration without undesirable power quality issues.

A. **Data**

The data for this work was collected from a PV power plant located near Starojicka Lhota in the Czech Republic. The data was collected using an electric network analyzer BK-ELCOM. The time spanned by the available data was from 2010-July-1 to 2011-March-31. The following power quality values were recorded:

- Voltage $U$ (V), Current $I$ (A), power $P$ (W)
- Frequency $f$ (Hz)
- Harmonic distortion of voltage $THD_{iMax}$ (%)
- Harmonic distortion of voltage $THD_{aMax}$ (%)
- Voltage and current unbalance (%);

These values were recorded as ten minute averages. Also recorded were the values of solar irradiance.

B. **Data Analysis**

A histogram of the THDiMax values is shown in Fig. 3. The first of the two peaks corresponds to the states when inverters are loaded (i.e. the sun is shining and the plant produces electricity), while the second, higher peak corresponds to the night periods when the inverters are idle.
C. Prediction Method

The extreme learning machine (ELM) method of feed forward neural networks and random forests (RF) have been utilized to predict values. These two methods were selected for an initial look into the prediction of a power quality variable using this grid connected PV power plant data because of their speed in training and the relatively low number of parameters that must be tuned, compared with some other machine learning methods.

1) Extreme learning machine (ELM)

A single hidden layer feed-forward neural network does not rely on iterative training and instead randomly assigns the input weights and biases, and performs matrix pseudo inverses in order to calculate the output weights [12]-[13]. The ELM method of training a neural network is capable of providing good generalization performance while completing learning extremely quickly.

2) Random forest

This method involves the creation of a number of decision trees, which can then be averaged in order to predict continuous values. While building each of the trees, splits are performed based on a randomly selected variable, introducing some additional randomness to the process. The addition of randomness and the averaging performed to arrive at the result improves the generalization and accuracy when compared to single trees.

VII. RESULTS AND DISCUSSION

In Fig. 5 we see both methods have linear patterns to their error, however the random forest prediction errors had a larger variability, likely owing to the better tracking it demonstrates (Fig. 6).

Time series comparisons of the different predictions methods are shown in Fig. 6. As suggested by the MAE values, this figure shows the RF predictions outperforming those made using the ELM neural network. These results also show that higher values of THD_{max} occur during instances of low solar irradiance, owing to problems with the inverters producing non-sinusoidal currents during these times.

As seen in Fig. 7, during periods of zero solar irradiance, values of THD_{max} are uniformly higher. As these low values are not due to variation in solar radiation, night periods may be discarded, further lowering the prediction errors. Cross correlation values between G and THD_{max} for different lags are shown in Fig. 4. This figure demonstrates the strong relationship between solar irradiance and values of harmonic distortion of current.

VIII. DATA ANALYSIS AND PREDICTION METHOD

Total harmonic distortion of current was selected because of its strong relationship with solar irradiance. Two machine learning techniques were applied in order to perform predictions. Neither method was able to successfully predict values above 12%, likely a result of poor data quality at these THD levels. This work could potentially be combined with short term weather forecasts in order to predict the values of
irradiance-dependent \( THD_{\text{Max}} \). By developing models that relate environmental variables to the power quality produced from highly variable renewable energy sources, the approaches to mitigation of power quality issues can be improved. This will allow for increased penetration of energy from these sources.

IX. SOLAR POWER TOWER

The Solar Power Tower is another concept for generating electricity by using the solar energy in the form of heat. This technology has seen and presently going through developments. Tower Power technology is less mature as compared to the technology of electricity generation using parabolic trough collector or stirling dish collectors. They are even known by the name Solar Updraft Tower [16]. However, the Solar Power Tower is well known for being a renewable energy source. Basically it consists of mirrors reflecting sunlight onto a surface, in order to heat a medium. The thermal energy of the medium gets converted to electricity in the end.

The different components of the Solar Power Tower are illustrated in figure 8. A receiver is surrounded by an array of moveable, flat mirrors called “heliostats”. They track the sun and reflect the sunlight onto the receiver. In the receiver a working fluid is circulating, which is heated by the focused sunlight. The heated working fluid, which is molten salt in nowadays designs, is transported to the Hot Salt Storage Tank. The next station is the steam generator. This is basically a heat exchanger that transfers the thermal energy of the working fluid from the primary cycle to the secondary cycle in order to generate steam for the turbine. The steam turbine drives a generator to produce electric energy. The cold molten salt comes to the Cold Salt Storage Tank and afterwards back to the receiver, while the low-pressure steam, exiting the turbine flows to a condenser and the resulting water back to the Steam Generator. As can be seen, both cycles are closed.

![Figure 8. Illustration of the basic principle [15].](image)

A. Working Fluid, Heat Storage and Transfere

Early designs used these focused rays to heat water, and used the resulting steam to power a turbine. Newer designs using liquid sodium have been demonstrated, and systems using molten salts (40% potassium nitrate, 60% sodium nitrate) as the working fluids are now in operation. These working fluids have high heat capacity, which can be used to store the energy before using it to boil water to drive turbines.

These designs also allow power to be generated, when the sun is not shining [14]. The salt melts at about 700°C and is liquid at approx. 1000°C, it will be kept in an insulated storage tank until the time, when it will be needed for heating up the water in the steam generator. This way of energy storage has an efficiency of approx. 99%, i.e. due to the imperfect insulation 1% of the stored energy gets lost [15].

B. List of Plants

- Ivanpah Solar Power Facility – 600MW – US
- PS20 solar power tower – 20MW – Spain
- Gemasolar – 17MW – Spain
- PS10 solar power tower – 11MW – Spain
- Sierra SunTower – 20MW – US

C. Pros and Cons

The three major advantages are: There are no fuel costs, since sunlight is basically available everywhere on earth for free, the maintenance costs are low and the heat capacity of the molten salt is used to store energy. If necessary the hot salt can be stored in well-isolated tanks. This way electricity can be produced even in times of reduced or no sunshine (cloudy or night). If a leak should develop, the salt would “freeze” (return to solid form) almost instantly so there is essentially no chance of significant contamination [17]. The major drawbacks are the sole dependence on the sun and a lot of water and land is required.

D. Discussion

The solar power tower is a fairly new technology, which implies that there is still a lot of potential. The drawback that can be attributed to this fact is, that although costs have been decreasing over time it is still quite expensive. Most of the plants are located in deserts, where the radiation intensity is highest. On the other hand the plants require a lot of space and water; especially the latter one is in fact a huge problem in these regions. Another problem is the fact that since the desserts are not populated the gained energy needs to be transmitted into areas where it is needed, which also involves additional costs to a high extend. Furthermore, it can be stated that heat energy storage is much more efficient than electrical energy storage. That makes the Solar Power Tower very efficient. [18]

X. SOLAR TROUGHS

The first use of solar trough technology was by Frank Shuman, an American engineer and inventor. Shuman used solar trough technology to power a motor and developed his technology even further. In 1912 Shuman was able to patent his entire design. Once Shuman had developed solar trough technology to a certain level, he build the first solar trough power station in Maadi, Egypt in 1913. This solar power station was used power a pump 22,000 liters of water from the Nile river to nearby cotton fields.

When solar trough technology was first developed solar energy was reflected onto black boxes filled with ether. The
ether then boiled from the heat transferred and the result was steam energy that could be used by a steam turbine to convert the steam energy into power. The technology for solar troughs has slightly changed since then. Now solar troughs are usually long rows of parabolic mirrors that concentrate solar energy into a pipe that is filled with a synthetic oil that is located at the focal point of the parabolic mirrors. The synthetic oil in the pipe is constantly pumped along the row of mirrors and retains the heat received from the mirrors. At times the temperature of the oil reached about 400 degrees Celsius. The oil is then pumped into a standard steam turbine generator and used to heat the steam for energy generation. The overall efficiency of this method is around 42.8 percent in the right conditions.

There are possible downsides to the use of solar troughs. One of these downsides can come from the possibility of the sun not being available due to the weather. Without the availability of direct sunlight the efficiency of a solar trough will decrease substantially. When a solar trough farm is not able to use sunlight to generate energy the farm is forced to use another method of generating electricity such as natural gas. Since only about 27 percent of the energy produced comes from natural gas the solar trough plant is still considered a clean energy production plant. Another downfall that can come from the use of solar troughs is the incredible amount of space that a solar trough power plant requires. For the most part all solar trough plants are located in the desert or in other sunlight intense areas. Many solar farms utilize many miles of reflective panels that allow for greater energy production due to the area of reflective panels used.

There are currently multiple solar trough plants in use today. Of these solar trough farms the largest one is the Solar Energy Generating Systems plant, or SEGS. The Solar Energy Generating Systems consists of nine solar power plants in California’s Mojave Desert, where solar power is among the best available in the United States. The plants have a 354 MW installed capacity. The average gross solar output for all nine plants at SEGS is around 75 MWe. SEGS claims that the solar plants power 232,500 homes at peak power and displace 3,800 tons of pollution per year that would have been produced if the electricity had been provided by fossil fuels, such as oil or coal. The facilities have a total of 936,384 mirrors and cover more than 1,600 acres. Lined up, the parabolic mirrors would extend over 229 miles.

XI. THE WORLD’S LARGEST CONCENTRATED SOLAR POWER PLANT

Thanks to the perfect geographic location of the United Arab Emirates (UAE) where there is high percentage of shiny days, UAE has made worldwide headlines with inaugurating the world’s largest operating concentrated solar power (CSP) [19]. To meet the huge rapidly growing in power demand, UAE started to think about utilizing sustainable energy sources rather than depending only on hydrocarbons, mainly oil and natural gas. The Shams 1 power plant – shames means the sun in Arabic language – which generates solar thermal electricity is the first step in the way to power the entire country with renewable energy.

A. Project Details

Shams 1 concentrating solar power plant as shown in Fig. 9 located at Madinat Zayed in the Western region of Abu Dhabi extends over an area of 2.5 km2 which equals an area of 285 football fields. The installed capacity of this plant is 100 megawatt and it can produce clean energy that is enough to power around 20,000 homes in UAE. The work on this plant started on 2010 and took three years to complete the construction and the total cost of this project is $600 million [20].

Shams 1 was designed and built by Shams Power Company and the major equipment for the plant were built by more than 70 local and foreign companies. It is a joint project between Masdar, an Abu Dhabi renewable energy company, Abengoa Solar, Spain’s energy infrastructure company, and Total, French energy company that is the world leader in solar industry. Masdar owns the 60 percent of Shams 1 while Total and Abengoa each own a 20 percent share of the plant. The power production is sold to Abu Dhabi Water and Electricity Company (ADWEC) [20].

B. How the Shams 1 CSP station works

The solar field in Shams 1 power plant utilizes the latest in parabolic trough technology to generate solar thermal electricity. It consists of 258,000 mirrors mounted on 768 parabolic trough collectors as shown in Fig. 10. These collectors track the sun from sunrise to sunset and use the mirrors to concentrate the heat from the sunlight onto oil-filled pipes. Then, the concentrated heat boils the water and produces high-pressure steam to drive a steam turbine and generate the electricity. Shams 1 has 130 km closed loop pipes that contain oil while water and steam circulate in 15 km long pipes. It has a dry-cooling system that significantly keeps the water consumption down. It is used to condense the steam existing from the steam turbine. The plant has booster heaters, which are used to further superheat the steam before entering the turbine to improve the efficiency of the system [20].

C. Advantages of the Shams 1 CSP

Shams 1 is a significant milestone on the pathway of Abu Dhabi’s goal to have seven percent of its generation capacity comes from renewable energy power source by the year 2020. The UAE can reduce its need for “peak shaving” generators when using solar power during peak demand.

There are environmental benefits associated with Shams 1 power plant that it helps to reduce the UAE’s carbon footprint by roughly 175,000 tons of carbon dioxide per year which equates to planting 1.5 million of tree or taking 15,000 cars from Abu Dhabi’s roads.

Although Shams 1 represents about 68 percent of the Gulf renewable energy capacity and nearly 12% percent of the world’s installed concentrated solar power capacity, it does not seem that Shams 1 is likely to hold the title as the largest
CSP because there are higher capacity CSP plants already under construction in the U.S., India and Morocco, and many more planned around the world [19].

Figure 9. Shams 1 is the largest concentrated solar power plant in the world [19].

Figure 10. The mirrors used in Shams 1 power plant [20].

REFERENCES


