Journal of Asian Scientific Research, 2013, 3(4):373-380

Journal of Asian Scientific Research

journal homepage: http://aessweb.com/journal-detail.php?id=5003

GRAVITATIONAL SOLAR ENERGY STORAGE CASE STUDY: MOSUL DAM

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ABSTRACT

Scientific, technical and economical feasibility of using water as an effective storage medium of solar energy generated by photovoltaic (PV) method is presented. The idea is based on using PV modules to generate electricity, and using this electricity to re-pump water from the outlet of an already existing hydroelectric power station back to the water reservoir. This technique may provide one way of storing and reuse of solar energy.

Keywords: PV, Gravitational energy storage, Solar energy

INTRODUCTION

Solar energy can be considered as the ultimate clean future type of world energy. This consideration is dictated by the social, economic, and environmental facts related to the absolute necessity for finding clean energy alternatives to replace the current types of energy.

One of the most important issues which dictate this necessity is the global warming or climate change which is now being generally accepted to be a result of burning fossil fuels such as coal, gas, and oil. This can result in increased atmospheric carbon dioxide concentrations which will result in increasing the globe temperature and cause many climate changes in many parts of the world (Moller, 1963), (Lorenz, 1970), (Bryson and Wayne, 1970), (Broecker, 1971), (Sawyer, 1972), (Budyko, 1972), (Lee, 1973), and (Kukla and Kukla, 1974).

The intergovernmental panel for climate change IPCC suggests that the world temperature will increase by as much as five degrees by the end of this century if the current trends of the use of fossil fuels continue unchecked (Hansen, 1988), (IPCC., 2007).

In spite of the fact that abundant amounts of solar energy is available in many parts of the world, its use has been very limited so far compared with other types of energy. This may be due to technical, economical and political reasons. Photovoltaic solar energy contributed only 0.07% to the world energy budget in 2007 (IEA, 2012). During the past five years, some developed countries started some relatively large solar electricity power generation projects and by the end of 2011 PV electricity started to contribute few percent to the total world generated electricity (IEA, 2012). By the end of 2010, some of the largest twenty PV power projects in about ten developed countries were producing about 1300 MW of PV electricity (Lenardic, 2011).Excluding transportation, most of the world energy is consumed as electricity. The transportation sector is following suit and most car manufacturers started building new generations of electric cars. Consequently, energy in its electricity form will continue to dominate in the foreseen future. The arguments for further development of PV electricity are thus becoming more pressing.

The basic building block of any PV system is the PV cell which converts sunlight to DC electricity. As a result of intensive research worldwide, the conversion efficiency of these cells has drastically increased over the past four or five decades. This is summarized in figure (1) which shows compilation of efficiencies over the past few decades. It indicates that while this efficiency did not exceed 15% in 1970, it is now at about 47% using quantum PV cells. Prices have dropped over this period from about 25 US$ per watt in 1990 to about 2 US$ in 2011 as seen in figure (2) (Naam, 2011). It is anticipated that the price may drop to below 1 US$/watt in 2012 (REN, 2012).

Figure-1. Development of Photovoltaic cells efficiencies

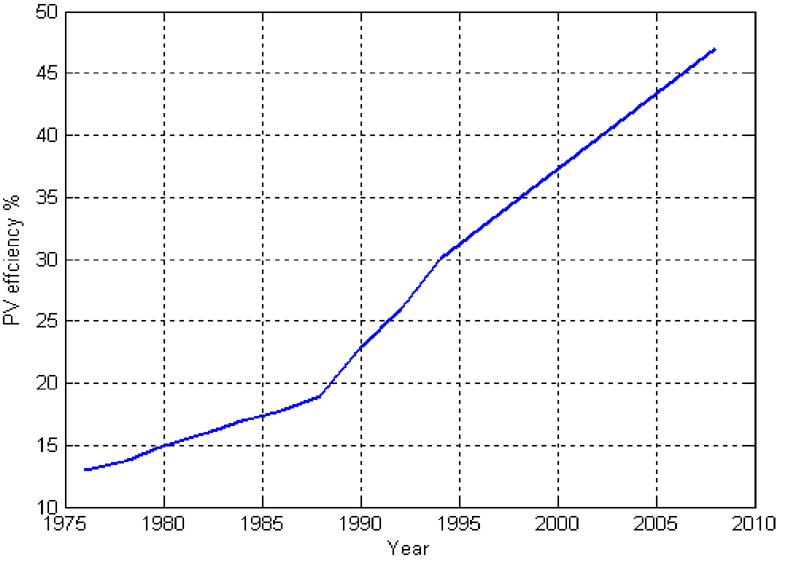
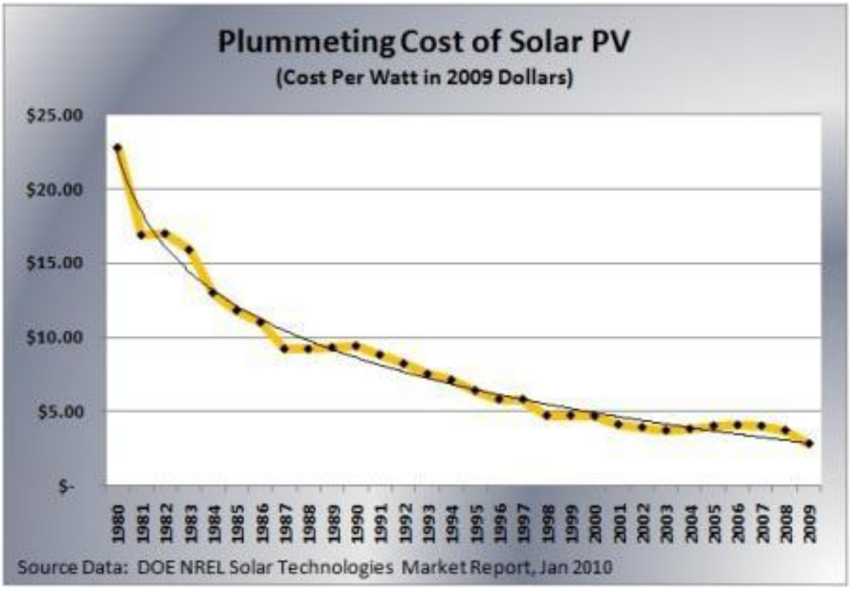


Figure-2. PV price trends (From reference 14)

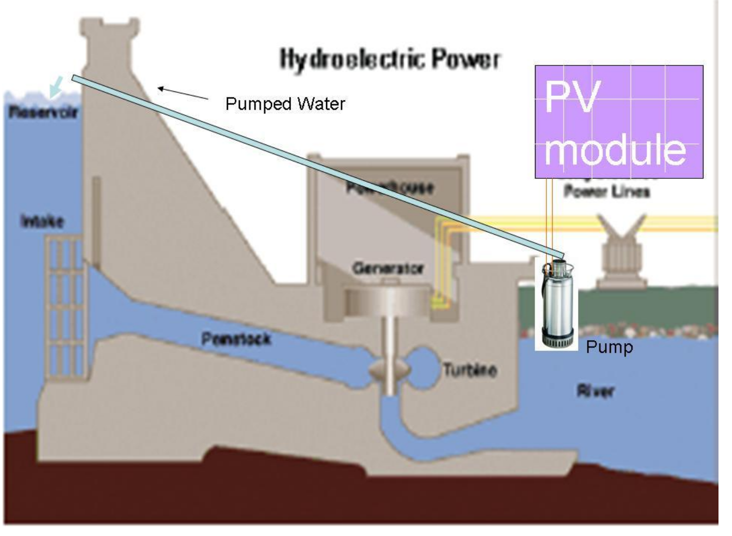


Even with this progress as far as higher PV efficiencies and lower prices are concerned, the contribution of PV energy to the overall world energy generation has remained remarkably small and not exceeding the 0.05% level in 2008. This is due to several reasons. Among many reasons, electrical energy storage remains as one of the most importance. To be able to use solar electric power in effective ways, sufficient energy storage facilities that can ensure continuous electricity production day and night are needed. Thermal solar electricity generations are testing pilot plants which use heat storage in molten salt reservoirs (Fairley, 2008). But, and as far as PV electric power is concerned, it can be reasonably stated that and after one hundred years of electrical storage batteries research, we do not seem to have anything significantly better than the good old lead-acid storage battery. Under such circumstances, it may be all that necessary to start considering new and even unconventional ideas related to energy storage. It is our purpose here to present one such idea that depends on gravitational storage method using water elevated and stored at higher heights. We shall demonstrate that such idea is not only feasible, but it may be also practical within the capabilities of present day available technologies.

Gravitational Energy Storage

Once PV power in the form of DC electricity is generated, it has to be used directly, stored if possible, or otherwise lost altogether. The idea here is to go to the second alternative. This involves the storage of this generated power by uplifting water from the bottom of hydroelectric power plant back to the dam. The uplifted water here plays the role of the storage medium which will store the generated electricity for later use. The purpose here is two fold. The first is related to increasing the production of hydropower plants that are operating at reduced capacity due to water shortages. The second is to increase the production capacity of hydropower plant operating at full capacity through the installation of additional generating units but using the same water resources. The idea is demonstrated in figure (3)

Figure-3. Sketch of the suggested method



Solar PV modules are to be installed near any hydroelectric power station. The electricity generated by these modules is used to drive high lift pumps to pump the water disposed from the outlet of the hydroelectric power station back to the top of the water reservoir. The re-circulated water can be used at any later time to generate electricity by passing it back through the generators. This will ensure that the power generated by the PV modules is stored for any required length of time. This idea is not entirely new. Many hydroelectric power stations do indeed have high lift pumps which are usually used for the process of load leveling. Hydroelectric power stations are usually designed to conform to maximum peak loads demands. During low load periods, these stations continue to produce the same peak load levels of electricity and use the excess power generated to drive the lift pumps to pump the water back to the reservoir. Simple as it seem, the use of such method for solar energy storage was confronted with important technical difficulties until two or three years ago. These difficulties are associated with the following technological facts:

1. Electricity generated by PV modules is of DC type
2. Technology has so far not reached the state to produce DC operated pumps in the MW range to be able to utilize the power generated by PV modules directly. The maximum rated power of a DC pump cited on the web is about 900 HP which is about 0.7 MW. The bulky and expensive nature of these pumps hinders their use in any electromechanical DC to AC conversion which has efficiency of about 80%
3. DC to AC inverters technology was able to reach the MW scale only recently with several producers offering inverters with rating between 1-2.4 MW

The third point above may play a key role in making the above idea technically feasible as far as present and near future technology is concerned. Several major industrial companies are now offering turnkey inverter units with power rating above one MW with DC to AC conversion with efficiencies of about 98%. Further increases in these powers rating within the next few years are to be expected. Such units are now being installed in several PV experimental solar power stations in different parts of the world for the purpose of converting the solar power to three-phase AC and supplying the national grids (Shahan, 2012).

The idea here is to install PV modules and inverters near to hydroelectric dams and instead of connecting directly to the grid, the generated power is to be used in operating load leveling pumps and/or additional high lift pumps to pump water from the outlet of the hydroelectric power station back to the top of the water reservoir to act as energy storage medium. The quantities of water involved will not have any significant effect on the water levels in the reservoirs or on the flow of outlet water which is supposed to be used for other purposes such as irrigation. This is because the amount of water being re-circulated is approximately equal to about 120% of the amount of water needed by the generators to produce wattage equal to that of the feed pump over a one to two days period. This is only a small percentage of the storage capacity of most hydroelectric reservoirs which are usually designed to store quantities of water sufficient for one year of operation at least.

The land area needed for such installation will certainly depend upon several factors, these include the following:

1. The average daily sunlight intensity at the particular location. Most middle east countries get more than 1000 Watt/M^2 on average
2. The conversion efficiency of the photovoltaic modules. This is price related. However, efficiency value of about 20% can be considered reasonable
3. High lift pumps efficiency which is about 80%
4. Hydroelectric generators efficiency which is about 80%

This will bring the efficiency of the overall conversion process of direct sunlight to an uninterrupted electricity supply to about 13%. This dictates the need for the installation of PV modules over land area of about 8000 square meters to generate one MW of electricity.

Cost Estimations

Assuming the presence of electric load leveling pumps at a particular hydropower station, the additional cost of such system will be limited to the prices of the PV modules, the inverters and installation costs. Large scale PV modules are now being offered at about 1.5 US$ per watt. Thus a one MW installation will cost about 1,500,000 US$. The authors have contacted several manufactures of MW inverters to obtain an idea about the general price range of such inverters. Unfortunately, no response was received. However, one manufactures has put a price tag on their product on their website (POSHARP, 2012). It is about 250,000 US$ for a one MW unit. This will bring the total cost of a one MW pilot installation between 1,750,000- 2,000,000 US$ depending on local installation costs and manufactures.

Case Study: Mosul Dam

Irrespective of the controversies surrounding the soundness of its basic structure (U.S.ARMY CORPS OF ENGINEERS CENWD, 2003), Mosul Dam and its associated hydroelectric power station can be considered as a typical example for a location where such an idea can be implemented. This Dam is located on the Tigris River 50 km north of the city of Mosul in Iraq. This location is characterized by abundant sunshine in excess of 3000 watts/m^2 for most parts of the year (Alaa and Alasady, 2011). The working water storage capacity of the reservoir is 8,000,000,000 m^3. The dam's main 750 MW power generation house contains four 187.5 MW Frances turbines. Furthermore, and the most important point related to our purpose here is that the project has a pumped-storage hydroelectricity power plant with a capacity of 240 MW which was supposed to be used for load leveling. The method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation during Low-cost off-peak hours when electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. With the current chronic electricity shortage in Iraq, It is thought that this particular system has been idle for the last twenty years at least. The maintenance work required to put this unit into operation is not known to the authors, but it is known that Mosul Dam authorities have the reputation of keeping adequate maintenance. Even so, and if this pumped storage facility can be operated at some acceptable maintenance cost, it can provide one of the basic requirements for what may be one the world largest solar energy farms with excess of 120 MW of power production (assuming a yearly average of 12 hours of sunshine per day) at a cost of about 480,000,000 US$ based on our above calculations. Although this number may sound high enough, it can be said that it is considered reasonable compared with the original cost of the whole project which was 1,500,000,000 US$ in 1980 prices needed to produce 750 MW of electricity which puts the cost at about 2 US$ per Watt. As far as the suggested project is concerned, the cost for the additional power added is about 4 US$ per Watt in today prices. If one takes inflation into consideration, the suggested solar harvesting method may even look more economical. Implementing this method will help solve another chronic problem with Mosul Dam hydroelectric power generation. This is related to the fact that the plant has been running at reduced production capacity for several years due to water shortages. At least, one of the four 187.5 turbines has been continuously idle for such reason. Using solar energy harvesting will help to put the power production closer to full capacity.

CONCLUSIONS AND SUGGESTIONS

It is demonstrated that recent scientific, technological, and economical developments related to PV electricity generation and MW DC to AC inverters rating have made the amalgamation of these technologies with existing hydroelectric power stations a feasible and cost effective way of electricity-load leveling of solar electric power at industrial level. This technique is by no means restricted to the case study presented. This type of solar energy storage using water storage capabilities of hydroelectric dams and associated electric power load leveling utilities can be applied in any hydroelectric power plant. It may be slightly surprising that we were unable to cite any project using such method in spite of our extensive search. Even so, and in order to asses any unexpected shortcomings of using such method, it may be useful to perform some pilot plants experimentations. These can be small pilot experimental units in the one MW range using such system. Such projects can form pioneering joint research projects between universities and electric power industry.

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