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CASE STUDIES OF PHOTOVOLTAIC CELL APPLIANCES AND ALTERNATIVE ENERGY PRODUCTION METHODS

Ivo Zatti Lima Meyer
Glycon Pena de Souza Barros
Hélio Augusto Goulart Diniz
Tomás Pessoa Londe Camargos
Federal University of Minas Gerais (UFMG), Postgraduate Program in Mechanical Engineering, Av. Antônio Carlos 6627, 31270-901 Belo Horizonte, MG, Brazil
ivozatti@hotmail.com; glyconb@gmail.com; helioufmg@gmail.com; tomascamargos@yahoo.com.br;

Willian Moreira Duarte
Federal University of Minas Gerais (UFMG), Postgraduate Program in Mechanical Engineering, Belo Horizonte, MG, Brazil
University Center of Belo Horizonte (UniBH), Department of Mechanical Engineering, Av. Prof. Mário Werneck, 1685, Estoril, 30575-180, Belo Horizonte (MG), Brazil
willianmoreiraduarte@gmail.com

Abstract. *With the increasing demand and cost of Brazilian electric energy, alternatives for the production of energy from renewable sources, among them solar, have been investigated. This work presents a literature review on this topic, focusing on photovoltaic energy and the use of reversible hydroelectric plants. It includes a case study of OPV photovoltaic panels and the proposal of the use of a reversible power plant at the open pit mine Águas Claras, which is located in the metropolitan area of Belo Horizonte and has a great potential for hydraulic energy storage.*

Keywords: *Renewable energies, photovoltaic panel, reversible plant*.

1. INTRODUCTION

With the recent increase in awareness of the problems of global warming and the exhaustion of natural resources, alternatives have been sought to obtain energy.

Solar cells have received worldwide attention, and in the future, solar energy is expected to be a major market worldwide. However, it requires a scenario for its propagation, where the costs of generating energy using solar cells are lower than the costs of commercial energy. Nevertheless, the cost of generating energy using current solar cells is higher than commercial power generation, and the current situation is one in which the spread is happening mainly because of government subsidies.

One of the main ways of capturing and converting solar energy to electric energy applicable in the life of society is through photovoltaic cells. At present, there is constant research and development in a type of photovoltaic cell, known by the acronym OPV, it is the organic photovoltaic cell. It is a rapidly evolving technology that has the potential for extremely low cost manufacturing. OPV provides a revolutionary form factor, which can combine flexibility and robustness with transparency (unique technology with this capability). This not only allows OPV to enter into existing markets, but also to create entirely new markets. Additionally, OPV has the lower module cost potential ($/W) than any other photovoltaic technology. This is due to the low cost of material, in addition to the simple installation and logistics, inherent to the OPV. It is also the ideal technology for remote locations and still without access to energy, being robust, light and easy to transport.

One of the difficulties in generating alternative energies, such as wind and photovoltaic, is the intermittent characteristic in the generation of energy throughout the day. This fact could be mitigated by the storage of energy and its efficient use (Notton *et. al.*, 2011). There are a few technologies to do this, such as Battery Energy Storage Systems (BESS), Compressed Air Energy Storage (CAES) systems and reversible hydroelectric plants, for instance the Pumped Hydroelectric Energy Storage (PHES). The latter two are currently the most used commercially, and the PHES are the most present in the world scale.

This work presents a review of the literature on photovoltaic energy and the use of reversible hydroelectric plants. It includes a case study of OVP photovoltaic panels and the proposal of the use of a reversible plant in the open pit mine Águas Claras. Also present are several researches conducted with the focus on new forms of energy production.

2. PHOTOVOLTAIC PANELS APPLICATIONS

Several are the means of application for photovoltaic systems. In Brazil and in the world, the management of solar energy by photovoltaic systems can be observed in the most distinct activities, some of them being exemplified below.

2.1.1 Water Pumping

The solar pumping system consists of the transformation, by photovoltaic modules, of the solar energy in electrical for the water pumping, being considered quite advantageous. The pumping of water promoted by the use of solar energy can be applied in irrigation, residential supply and livestock. (Sá and Augusto, 2010).

2.1.2 Urban and Rural Electrification

In several European countries there are several incentive policies for the implementation of small domestic photovoltaic energy generation systems and their sale of electricity to the grid. However, in Brazil, where there is a great potential for expansion of this energy source, regulation for this is still lacking (Serrao, 2010).

Electricity systems with photovoltaic power can be divided as autonomous systems and grid connected systems. In systems connected to the grid, the photovoltaic panel generates electricity in direct current, and the frequency inverter converts to alternating current and inserts it into the power grid. So when the electric appliances are consuming more than the photovoltaic system is generating at the moment, the missing part is withdrawn from the power grid. In contrast, when the photovoltaic system is generating more power than it is being consumed, surplus energy is directed to the grid and the energy meter "turns upside down" generating energy credits for the home.

2.1.3 Satellites

The first solar-powered satellite was the North American Vanguard I, launched in 1958 with a system that produced 0.1 watt and worked for 8 years. Telstar launched in 1962 generated 14 watts, being powered by solar cells, it was the first commercial telecommunications satellite, thus establishing reliability of the use of photovoltaic cells in orbit. Currently, most satellites in orbit around the Earth have solar panels generating several thousand watts of power (Veissid and Baruel, 2012).

2.1.4 Monitoring Stations

Remote data measurement equipment such as weather monitoring, road traffic radars, seismic records, and more require a reliable power source to avoid interruption or loss of data. Photovoltaic systems are suitable, since the required energy is low and certain monitoring sites are away from conventional power grids (Braga, 2008).

2.1.5 Solar Vehicles

A more in-depth approach to solar vehicles came only after 1990 because of the growing restrictions on the emission of gaseous pollutants. This vehicle uses the diffuse radiation as fuel, which is transformed into electric energy by the photovoltaic cells. The excess solar energy collected during the day is stored in the batteries, which are rechargeable (Castro *et. al.*, 2009).

2.1.6 Hybrid Systems

They consist of the combination of other photovoltaic systems with other sources of energy that assure the charge of the batteries in the absence of sun. Auxiliary power sources can be wind generators, diesel, gas, gasoline and other fuels. In general, they are applied in medium to large systems that aim to serve a larger number of users (Braga, 2008).

3. ORGANIC PHOTOVOLTAIC CELLS (OPV)

Organic Photovoltaic Cells (OPV) have attracted a lot of attention being considered as solar cells of last generation. In recent years, the performance of OPV device technology has accelerated considerably, with efficiency of 10.6% in those processed with solution and 10.7% in those with vacuum deposition demonstrated in the laboratory (Hoppe and Sariciftci, 2004). This cell efficiency is enough to establish a multibillion-dollar market. However, to make this possible, a coordinated effort and investments are required to transfer the technology from the laboratory scale to the low cost manufacturing.

The main attributes of the OPV technology are summarized below with regard to their eminent commercial products, technical characteristics, worldwide development trends and the current status of the OPV.

3.1 Characteristics of the OPV

Fine film OPV devices are a new generation of solar cells to overcome the disadvantages of inorganic solar cells. The main materials for these devices are conjugated polymers. Since high temperature manufacturing processes are not used, plastic substrates can be used, and a common feature is the ease of making them flexible. In addition, if the manufacturing characteristics by printing are used, a continuous process (roll-to-roll) can be used as a production method. In this way large cost reductions are possible through continuous production. In addition, since OPVs are quite light and flexible, they can be easily installed in homes and are expected to be provided at a low cost (Krebs and Mikkel, 2010).

The main advantages and disadvantages of organic OPV cells are presented in the following sections.

Advantages

- Potential for module efficiency of approximately 10%;
- Materials and processes are compatible with low-cost R2R (roll-to-roll) production;
- The devices are lightweight, flexible, resistant and, above all, can be transparent;
- The fact that it is transparent is essential because it creates the market associated with solar generation from windows integrated to smart facades, as well as in greenhouses for agriculture, which represent billionaire markets. Smart facades (which need to be transparent) correspond to the highest market promise for solar panels.

Disadvantages

- Module efficiency may not reach the levels of crystalline / polycrystalline devices Si, CdTe or CIGS;
- Research efforts and substantial and coordinated development are necessary to optimize the useful life, efficiency and cost.

3.2 Other technologies for the production of solar panels

Other existing technologies for producing solar panels will be discussed below.

3.2.1 Silicon Amorphous (a-Si)

The a-Si technology is mature and well-established, well suited for low-power applications where space is not a limitation. However, it has shown almost no improvement in the performance of its technology over the past 20 years, and little progress is expected. Efficiency of the module is modest, and can be overcome by emerging technologies.

Advantages

- Relatively low cost (a-Si uses 1% of Si in crystalline / polycrystalline cells).

Disadvantages

- Significant improvement in device performance is not expected;
- Flexible module efficiency less than 5%.

3.2.2 Copper Indium Gallium (Di) Selinide (CIGS)

CIGS technology has been around for 40 years. Records of cellular efficiencies of 20.3% were reached. Also, flexible devices on metal substrates with efficiency of approximately 10% were demonstrated. However, market adoption to date has been minimal due to major difficulties in scaling up to larger areas.

Advantages

- Module efficiency is relatively high.

Disadvantages

- Production processes are relatively expensive;
- Raw materials are very expensive and supply chains can be volatile;
- Major difficulties in scaling up to larger areas have prevented market adoption so far.

3.2.3 Cadmium telluride (CdTe)

Due to relatively high efficiency and low production costs, CdTe thin-film photovoltaic cells have a large world market share, approaching 8% in 2011. However, there are major concerns about the safety of CdTe devices due to high toxicity of cadmium. The very limited supply of tellurium is also a problem that will eventually limit the market's achievement.

Advantages

- Module efficiency is relatively high;
- Production costs are relatively low.

Disadvantages

- Cadmium is one of the most toxic and dangerous materials known. Long-term stability and disposal are a major concern;
- The tellurium is an extremely rare material, which implies limitations in its offer.

3.2.4 Quantum Dot Solar Cells (QDSC)

QDSC is an early stage technology that has some potential, but progress is still needed at a stage where it becomes of commercial interest.

Advantages

- Potential for high efficiency;
- Potential for continuous processing (R2R).

Disadvantages

- Efficiencies in the state of the art are very low;
- P & D (research and development) is currently held at the academic level and substantial improvements are required for business processes.

3.2.5 Dye-sensitized solar cells (DSSC)

DSSC is an emerging technology that has reasonable potential for module efficiency and is compatible with R2R processing. In recent years the first commercial devices have been available for powering portable electronic devices with DSSC panels. The main barrier currently preventing DSSC from expanding beyond indoor niche applications is the low prospect of increasing its efficiency beyond what has already been achieved and the need for liquid electrolyte. This is necessary for optimum efficiency, but can not operate at temperatures below 10 ° C.

Advantages

- Low cost R2R production processes can be used;
- Thin, lightweight and conforming shape makes it ideal for indoor applications.

Disadvantages

- To achieve maximum efficiency and service life a liquid electrolyte is required;
- Current commercial DSSC samples with liquid electrolytes can not operate at temperatures below 10 ° C;
- Devices using a solid electrolyte are substantially less efficient;
- Efficiency limit achieved unchanged for several years, indicating possible limit of the technology already close to being achieved.

3.3 The potential market for OPV

According to consulting firm Ernest & Young, Brazil is expected to consume 1,000 TW/h of electricity per year by 2030. Current consumption is approximately half that, approximately 500 TW/h per year.

Considering the increasing need and motivation for clean and renewable energies and assuming that 3% of Brazil's energy demands can be met by solar energy, 5% of which are supplied by organic solar cells (poor and remote populations), we have in the short term a potential energy demand of 750 GWh of energy per year to be generated by the organic cells of low cost and easy transport (off-grid generation).

Assuming an average sunshine for Brazil and a capacity factor of 20% (less than 8h of sun per day), there is already demand for more than double the production capacity of a pilot line, capable of a generation of 350 GWh per year.

With regard to price evolution, there are already well-established estimates that it will be possible to achieve a cost 50% lower than the cost of silicon panels in the short term, with potential for much greater reduction in the medium and long term. In 10 years, studies indicate that the technology with organic photovoltaic will have a market of 1.5 times the market of the technologies of the previous generation (based on silicon) according to the graph of Fig. 1.

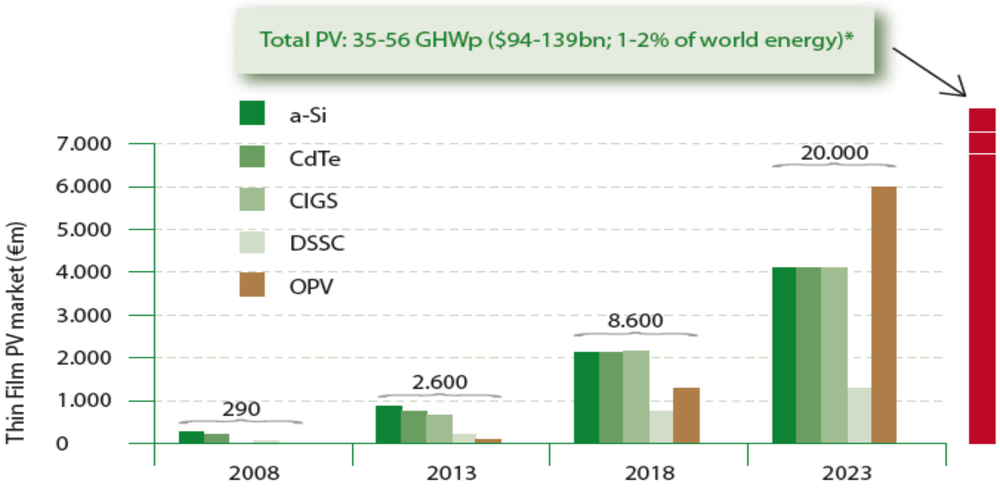

Figure 1. Evolution of the thin-film photovoltaic market (Towards green electronics in Europe, 2011).

According to the 2011 European Union report (Towards green electronics in Europe, 2011), the world market for solar energy will reach EUR 20 billion by 2023, with only OPV technology representing an opportunity of EUR 6 billion.

4. CASE STUDY - HYDROELECTRIC OPV

Any solar generation system requires large areas for the installation of panels and transmission lines to transport the energy produced.

Hydroelectric plants offer a great opportunity to transform the surface of water reservoirs into an asset capable of generating additional energy, reusing space, personnel and existing networks for energy transmission.

The OPV solar panel being of low weight, allows a simple floating structure and low cost, ensuring easy maintenance, anchorage and high resilience. The structural concept should focus on modularity so that the hydroelectric power plant can benefit from scalability and the possibility of applying the solution in different size Hydroelectric Power Plants (HPPs).

Considering the capacity factor of the HPPs, that is, the idle capacity of the plants throughout the year in order to maximize the use of the transmission assets already installed, the following sizes of solar plants linked to the HPPs can be calculated, according to spreadsheet of Fig. 2 (EPE, 2015).

CALCULATIONS FOR GENERATING 1 MW.AVERAGE		Active Area	517 Wp/module
		Power	396 Wp/module
		CAPEX	1187 R$/module
		Estimated CAPEX	136 R$/module
ELECTRICITY GENERATION			
SOLAR PANELS		**COMMENTS**	
Panel Efficiency	6.0%	Estimated OPV.	
Capacity Factor	25.0%	Estimated OPV.	
Incident Energy	5746 Wh/m^2/year	Varies by location. This data comes from the Brazilian solar map.	
	2.097 MWh/m^2/year		
Energy Generated	0.126 MWh/m^2/year		
Special Capacity	57.5 Wp/m^2	Active area.	
Effective Capacity	25.9 Wp/m^2	Occupied area.	
PLANT			
Active Area	73607 m^2		
	7.4 hectares		
Sales	1.0 MW.average		
Occupancy Factor	45.0%	Consider panels with 3x3m with arrangement to be defined.	
Parasitic Loads	2.5%	Loss of active area to the plant substation.	
Losses to the GC	6.0%	Systemic losses in the dam of the plant to the gravity center (GC) of the submarket.	
Total Generation	9262 MWh/year		
Net Generation	9031MWh/year		
GC Generation	8760 MWh/year		
CAPACITY	4,2 MWp	To generate 1 MW.average = 8760 MWh/year.	
Occupied Area			
Plant	16.4 hectares	Area occupied by the OPV plant to generate 1 MW.average in the GC.	
Active Area	7.4 hectares	Area of organic polymer only.	
Specific Power			
Energy	16.4 hectares/MW.average		
Power	3.9 hectares/MWp		

Figure 2. Estimated calculations for integration of solar power plant with hydroelectric power plant.

Table 1 presents examples of estimates for the integration of Brazilian hydroelectric plants to solar plants (EPE, 2015).

Table 1. Examples of estimates for the integration of a hydroelectric power plant into solar power in Brazil.

		BAESA	**CHESF**	**ITAIPU**	**FURNAS**	
Plant		**Barra Grande**	**Sobradinho**	**Itaipu**	**Serra da Mesa**	**Total**
HYDROELECTRIC POWER PLANT						
Reservoir Area	[hectares]	5.000	421.400	135.000	178.400	836.650
Nominal Power	[MW]	708	1.050	14.000	1.275	17.969
Avg. Generated Energy	[MW.avg.]	595	683	8.792	719	11.289
Capacity Factor	[%]	84,0%	65,0%	62,8%	56,4%	62,8%
SOLAR POWER PLANT						
Occupied Area	[% reservoir]	35,0%	1,0%	40,1%	2,8%	8,2%
	[hectares]	1.752	4.053	54.144	4.919	68.489
Nominal Power	[MW]	453	1.048	14.000	1.272	17.709
Avg. Generated Energy	[MW.avg.]	113,3	262,0	3.500,0	318,0	4.427
	[of hydraulic energy]	19,0%	38,4%	39,8%	44,2%	39,2%
Capacity Factor	[%]	25,0%	25,0%	25,0%	25,0%	25,0%

5. CASE STUDY – ÁGUAS CLARAS MINE

Pumped Hydroelectric Energy Storage (PHES) systems, which can be considered as reversible hydroelectric plants, are used to supply demand peaks by pumping water from a lower reservoir to a higher reservoir (Anagnostopoulos and Papantonis, 2008). At a time when there is high demand and high cost of electricity, the water in the upper reservoir is directed to the bottom by a forced conduit and passes through a turbine (usually of Francis type), thus providing the energy needed to meet peak times. In periods of low energy consumption or low energy costs, the water can be pumped back to the upper reservoir by means of pumps or the turbine pump mode, which can be driven with energy from photovoltaic or wind energy sources, thus storing hydraulic potential energy (Andritz, 2012).

Figure 3 illustrates the operation scheme of the reversible hydroelectric plant using the open pit mine Águas Claras in Minas Gerais, with an upper reservoir as a way to store hydraulic potential energy and using photovoltaic solar energy to supply the pumping system (Palomino *et. al.*, 2015). This proposal is similar, structurally, to the size and gap between the lakes of the Olivenhain-Hodges plant (Kaneshiro *et. al.*, 2016).

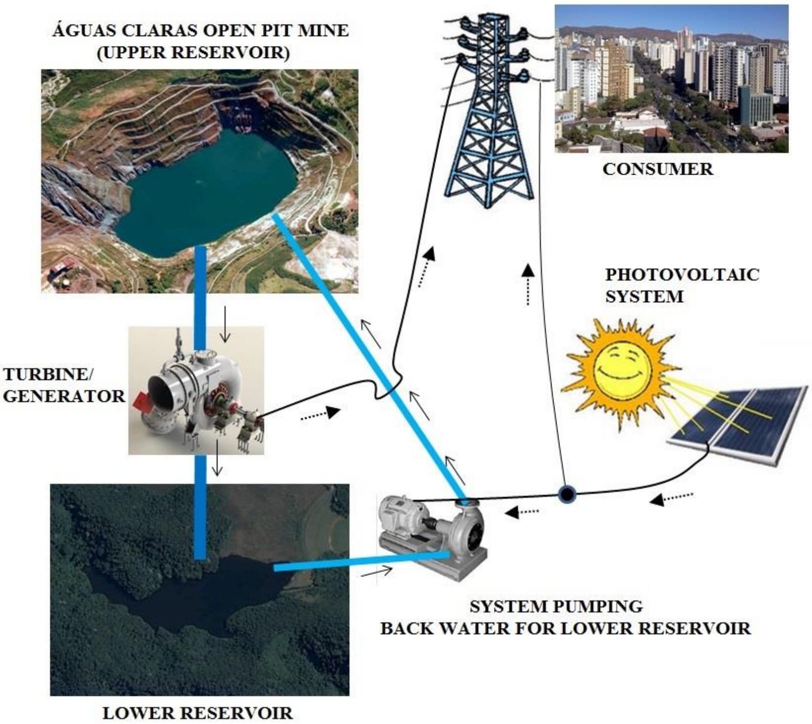

Figure 3. Operation scheme of the reversible hydroelectric plant of the open pit mine Águas Claras. (Palomino *et. al.*, 2015).

The basic idea is to generate electricity for two to three hours in peak demand hours. This generation period can be used to reinforce the needs of the system. During the day, there is water stored in the main reservoir, this reserve can be turbinated at any time of the day. The generated energy can also be used as an emergency (no-break), this service will be partial considering that the turbine has limited capacity.

The energy generated by the solar power plant should be able to power a pumping system for the reversible hydroelectric power plant, whose estimated power is 1.06 MW.

The theoretical period of exposure of the sun, considered for the generation of electric energy through the solar plant, will be from 9 to 15 hours, totaling 6 hours of daily generation during all days of the year. Throughout the year, this time is variable due to climatic conditions, such as cloudy weather, rainy periods and seasons, in which there is a decrease in the generation of electric energy.

For this project, the period of generation between 10 and 15 hours is conservatively considered. Any longer generation time will be posted on the grid as "savings" to be used when needed.

The operation of the reversible hydroelectric plant is limited to the storage capacity of the lower reservoir. The maximum continuous generation period of the plant will be 16 hours, at which time the lower reservoir would be completely full. The planning is to operate and meet demand during peak hours from 7:00 p.m. to 10:00 p.m., totaling 3 hours per day. If it is necessary to operate the plant outside these hours, it will be subject to the verification of the available capacity of the lower reservoir and the criteria of the National System Operator (ONS).

Once the water volume is available in the lower reservoir, it must be pumped into the upper reservoir. For the 3 hour plant generation, it will take 6 hours to pump. If the plant generation is greater than 3 hours, it will be necessary to evaluate the new pumping time.

In the Manual of Engineering for Photovoltaic Systems (CEPEL-CRESESB, 2014) the two possible systems of the isolated or connected installation in the distribution grid are clarified. Due to the pumping capacity of 1.06 MW, the plant will be considered within the electric energy compensation system.

In this work the option of the interconnected system in the distribution grid is considered, with the availability of electric energy for the pumping, if necessary.

For the sizing of the energy generated by the photovoltaic panels, the criterion of "Solar Peak Hour" was used, which corresponds to the number of hours per day for 1000 W/m². For example, 5 hours of sun peaks + 5 kWh/m² is the energy received for a total number of hours a day equivalent to the energy received by insolation 1,000.00 W / m² during 5 hours (Lopez, 2012).

The solar panels were chosen in the market, and the most appropriate model found was the model YGE 60 cells of 40 mm - Series YL24P-29b (Yingli Solar, 2012). This model was selected for the dimensions that will provide ease of handling and transportation to the installation site.

The installation of the solar plants requires the installation of the modules over a significant area, taking into account the correct distance between the rows of panels, one behind the other, to prevent the panels from shading one over the other, since this condition is not desirable to the performance of photovoltaic systems, that is, to maximize the area utilization factor (Villalva and Gazoli, 2012). Due to the irregular area of open pit mine Águas Claras, in the project was considered that the area required for installation of the solar plant will be 4 times the total area of the panels.

Table 2 gives the summary of the necessary calculations of the photovoltaic system in this project.

Table 2. Scaling with commercial photovoltaic.

IMPUT DATA		
Description	Value	Unit
Daily average of solar irradiation	4.33	kWh/m² day
Exposure Day	1	Day
Irradiation hours	6	Hours
Irradiation received	722	W/m²
DATASHEET PANEL: YGE 60 CELULAS DE 40mm - SERIE YL245P-29b - Yingle Solar		
Description	Value	Unit
Efficiency	15	%
Energy produced by the module	245	W
Area	1.63	m²
RESULTS		
Description	Value	Unit
Number of panels needed (added in 3%)	4456	Parts
Wp installed	1.06	MWp
Total area occupied by modules	7279	m²
Service area (hallways, room to maneuver, etc.)	21838	-
Office areas and panels room	100	m²
Total area required	29218	m²

6. OTHER CASE STUDIES

Alternative methods of energy production are being widely researched around the world. Table 2 presents works that were developed with this theme. Among the topics covered are: reversible hydroelectric plants, photovoltaic panels, wind energy, optimization in the construction of plants for energy production, different solutions to obtain energy using existing concepts, and analysis and simulations of power plants.

Table 3. Case studies.

Autor	**Work summary**
(Pasquali, 2006)	The objective of this work was to study the influence of the various variables present in a hydraulic energy reservation system, aiming at exploring the use of wind energy, and ensuring attendance to the growing energy demand. Through numerical simulations, using the Visual Basic software, variables such as quotas between reservoirs, proportion between demand and installed powers, and different reservoir capacities were explored.
(Kušnír *et. al.*, 2010)	This work deals with pumped storage hydro power plants in the Slovak Republic. The objective of this work is to describe pumped storage hydro power plants, which play an important role in the operation of the energy system. They are a way of storing energy so that it can be released quickly when needed. If the power stations did not generate more energy immediately in that country, there would be power cuts across the country and the traffic lights would go out, causing accidents and problems in general.

(Abelho, 2011)	Given the global and European context, a very significant increase of the renewable component in the electricity generation sector seems inevitable. Some studies point to a scenario of electricity production without any emissions of greenhouse gases, which implies a very important percentage (80% or more) of the renewable component. In this dissertation two contexts of energy storage are studied, one of which considers a ceiling of 50% of emissions of greenhouse gases in 2050 compared to the level of emissions registered in 1990, and another that considers an important component of decentralized production power. These approaches were characterized and worked up to 2050 using an optimization model.
(Shabrina *et. al.*, 2014)	This article presents the best operational condition of a storage system pumped in a residential area with mass introduction of PV (photovoltaic panel). The optimization is applied to examine the effectiveness of the proposed operation from the point of view of the cost of electricity and the emergency supply capacity. The seasonal adjustment of the storage system operation during the pumping and generation process is examined to evaluate its effect on system performance. In addition, three types of pumped storage systems with different characteristics of the operating range and conversion time, i.e., conventional adjustable speed, double fed and adjustable speed of the complete converter, are analyzed as a comparative study. Some optimization results obtained by simulation of one-year system operation are presented. Also, to extract more design information for the pumped storage operation, the results of the improvements are analyzed using the dispersion matrix.
(Notton *et. al.*, 2011)	This article deals with the analysis of the pumping storage system, giving an idea of some procedures to be done before its integration into the system of electric energy with sources of renewable energies. The water reservoir serves for the daily and seasonal storage of energy, basically resolving the problem of energy storage, which is the biggest problem of the wider use of renewable sources. The excess electricity produced by the renewable energy system is converted into potential energy by pumping the water to a higher elevation where it can be stored indefinitely and then released to pass through hydraulic turbines and generate electricity. The estimate of the stored energy, the nominal electric power of the hydroelectric plant and the rate of evaporation of the water reservoir are presented along the same.
(Madlener and Specht, 2013)	In Germany, the mitigation of CO2 emissions as well as the elimination of nuclear energy are important policy objectives in the process of sustainable energy transformation. Conventional technologies for this purpose are reversible hydropower (Pumped Storage Hydropower Plant, PSHP) installations. In Germany, unfortunately, suitable sites are rather rare and construction measures often have a negative impact on the landscape and ecosphere, which often induces public resistance. A possible future solution may be the use of underground PSHP (UPSHP) plants, for example in closed mines. This study is an initial attempt to model these plants in order to better evaluate and understand the economic viability of such UPSHP underground hydroelectric plants in closed coal mines. Based on the technical-economic evaluation, it was concluded that, under favorable conditions, the realization of UPSHP plants seems technically feasible and economically reasonable.
(Koury *et. al.*, 2014)	This work presents a simulation model of a hybrid CSP (Concentrated Solar Power) with TES (Thermal Energy Storage) designed for the city of Pirapora, Brazil. The objective of this model is to evaluate the Brazilian potential, specifically in the northern region of Minas Gerais, for the generation of solar thermal energy. With the results of the simulation it was possible to obtain the annual profile of power generation, storage levels and consumption of natural gas of the plant. An analysis of the influence of climatic instability during the summer months on plant production is also presented. For a power of 30 MW, the simulation model of the CSP plant proved that it is possible to generate energy throughout the year in a stable way. On days of high solar radiation, which prevail for most of the year, the solar resource is sufficient for the power plant to provide electricity during the sun period, and some of the energy absorbed by the solar collectors is stored to supply the demand for several hours at night. On winter days and rainy summer days, with low and unstable solar radiation, or when the storage system is insufficient, the use of natural gas as reserve fuel was the solution found to maintain the power output of the plant.

(Abdo *et. al.*, 2014)	Energy and exergetic analysis of a hybrid generation and energy storage plant using photovoltaic panels and liquid air were carried out. The system operates according to the Linde cycle and consists of a compressor / turbine, heat exchangers, expansion valves, a pump and a cryogenic tank. Attached to the compressor, there are photovoltaic panels to supply all or part of the energy that will later be used to liquefy the air. The focus of this study was to analyze the temporal variation of the solar incidence in the region of Belo Horizonte/MG, simultaneously with the process of storage and generation of energy. The realization of this study also aimed at providing relevant information on the feasibility of implementing a hybrid generation plant, since solar irradiation is the component responsible, simultaneously, for the generation and destruction of exergy. The results are discussed and presented in the form of tables and tables, so as to make it possible to perceive, through performance coefficients, the climatic interference in the process of generation and storage of the system and the quantity and need of aggregate technology directly or indirectly in the process . According to the results, the application of this type of system, in principle, may be more useful in the small residential and commercial sectors, with long term returns. It is necessary that further investigation into the improvement of the internal components of the generation cycle be carried out, in order to reduce and potentiate the losses, and more importantly, it is important to check other cycles, such as Collins and Claude, for the same use.
(Denholm *et. al.*, 2010)	This report explored the role of energy storage in the grid, focusing on the effects of large-scale deployment of variable (mainly wind and solar) renewable sources. It began by discussing the existing grid and the current role that energy storage has in meeting the constantly changing demand for electricity, as well as the need for operational reservations to obtain a reliable service. The impact of variable renewable energies on the grid is then discussed, including how these energy sources will require a variety of enabling techniques and technologies to reach their full potential. Finally, the potential role of various forms of enabling technologies, including energy storage, is assessed. With the conclusion that VG (variable generation) increases the need for flexible reserves of generation and operation, which can be met by energy storage. However, the value of energy storage is best captured when selling across the grid, rather than a single source. Evaluating the role of storage with VG sources requires continuous analysis, improved data, and new techniques to evaluate the operation of a more dynamic and intelligent grid of the future.

With the works presented above, it is possible to note the need to diversify the electric energy production methods, both to supply increased production and to reduce environmental impacts. One way to do this is by combining technologies, such as reversible plants, where turbines and photovoltaic panels can be used to recover some of the energy.

7. CONCLUSIONS

The constant research and development in the field of alternative sources of energy, in particular solar photovoltaic energy is justified, as this type of energy generation contributes to the preservation of the environmental balance and stimulates social inclusion by providing the participation of small private initiative to electric energy.

The main types of applications presented were in water pumping and electrification system. The analysis of applications shows that the photovoltaic solar energy generation sector is highly strategic for developing countries.

The analysis of a particular type of photovoltaic technology, the organic cell OPV, has evidenced the numerous advantages, such as: the devices are low weight, flexible, resistant and can be transparent. However, continuous research and development efforts are required to optimize the technology's useful life, efficiency and costs. The energy study of solar plants, composed of panels with organic photovoltaic cells, integrated to the national hydroelectric plants proved attractive and is currently the target of constant research and development.

The open pit mine Águas Claras project has an available lower reservoir and water in the mine pit, closing the hydraulic system and reusing the available water. Under ideal conditions for a reversible plant the generation efficiency is 64% and the real efficiency in the mine generation was very close, with value of 62.4%. To facilitate their interconnection and to avoid large transmission losses, it is recommended that the plant be located near the main transmission grid.

Future prospects are that reversible plants will be increasingly present, as well as hybrid generation, where the same plant has more than one type of technology to obtain energy (*e.g.* solar and thermal).

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