XXVI engema

ISSN: 2359-1048
Dezembro 2024

APPLICATION OF SYSTEMS DYNAMICS TO OBTAIN THE FLOW OF PHOTOVOLTAIC MODULES IN HALF-CYCLE.

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Resumo
Photovoltaic systems are used all over the world, providing a sustainable supply of electrical energy to industries, businesses and homes. The average lifespan of a photovoltaic module is around 25 years. There is concern about waste disposal from photovoltaic systems after the end of their life cycle due to the constant increase in the production of PV modules. The crystalline silicon (c-Si) modules are made up of the following elements, aluminum frames, glass, thin layer of EVA, photovoltaic cells, protective polymer (TEDLAR) and junction box. Recycling or reusing damaged, mid-cycle or end-of-life photovoltaic modules can lead to economic and environmental benefits. Therefore, this study's main objective is to evaluate an electromeasurement process at the module terminals to identify the conversion efficiency, with the aim of applying the principle of reuse without the need to apply complex recycling processes. The electromeasurement tests will be applied with the aid of system dynamics software, whose function is to determine the number of modules in half cycle, end of cycle and subsequently quantify the equivalent number of modules suitable for reuse. The results were satisfactory, where the amount of waste from photovoltaic modules increases until 2050. Thus, the application of recycling or reuse becomes mandatory, whose function is to improve the conversion efficiency and lifetime of the module. Providing sustainable development for future generations.

Palavras Chave
Photovoltaic module, Sustainable development, systems dynamics

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1 INTRODUCTION

Photovoltaic systems are used all over the world, using solar radiation as a primary source, the resource of which is converted into electrical energy by the photovoltaic effect. Therefore, this energy source is considered environmentally sustainable, clean and its prices have become increasingly lower and more accessible. These sources generate a direct current connected to the module's output terminals, which has the effect of making this energy supply variable over time.

In Brazil we have the availability of using the sun as an energy process, so solar energy is not only another advantage in installed power but also in the number of jobs that are generated through flexible use, and can be used in both industries and homes.

According to IRENA (International Renewable Energy Agency), it is predicted that by 2050, solar heating will be responsible for 15% of all renewable energy in the world.

There is a loss of conversion efficiency through oxidation of the electrical terminals. These terminals connect each cell forming an arrangement, giving rise to the photovoltaic module. Oxidation occurs depending on the type of chemical elements with which the electrode is manufactured, normally silver (Ag) is used, but to reduce costs, a mixture is generally made with other types of metals, such as copper, aluminum and iron.

Therefore, based on these anomalies, the photovoltaic cells degrade and thus cease to be efficient and must be replaced. Using the aforementioned premises, it is proposed to develop a project aimed at recovering the photovoltaic module without going through the complex recycling process, with the aim of reusing this module in a new photovoltaic solar generation system, adding positive aspects to sustainable development and the environment.

Considering the recovery of pure silicon from the recycling process, it is possible to reduce the high cost and energy demand when producing solar-grade silicon, essential in the production of photovoltaic cells, and thus limit unfavorable impacts on the environment.

Thus, the project has a general objective. Evaluate a process for reusing the crystalline silicon photovoltaic module, in half a cycle.

Photovoltaic (PV) technology is considered an energy source responsible for relatively small amounts of waste, since none is generated during the useful life of the photovoltaic modules, the average estimate of which is around 25 years based on the manufacturers' datasheet. photovoltaic modules. However, as mentioned previously, we should not ignore the waste stream generated at the end of the use phase of photovoltaic installations. A small waste stream is also created in the module production stages that are rejected by quality control, as well as during operation in the case of damaged modules, which have reduced efficiency.

2 DEVELOPMENT

In accordance with what was reported above, this project proposes to analyze a system dynamics model, considering several variables (production, use, waste, disposal and time), with emphasis on the possible condition of reusing photovoltaic modules in half a cycle.

2.1 RECYCLING PROCESSES FOR PHOTOVOLTAIC MODULES

According to Jing and Suiran, (2015), the recycling process follows:

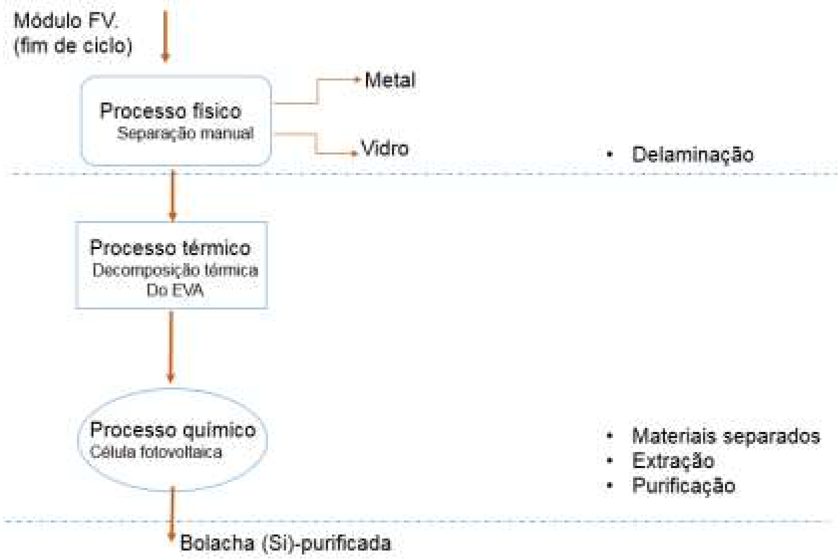
end-of-life modules are incinerated and plastic components are burned in a complex semiconductor protection process at 600 °C. The remaining materials, such as solar cells, glass and metals, are separated manually. Glass and metal are sent for recycling.

Figure 1 presents a flowchart of the PV module recycling process, based on the steps proposed by Solar World. Solar World is a research group related to renewable energy with an emphasis on solar photovoltaics, and is a manufacturer of photovoltaic modules based in Germany.

Figures, tables, and frames should be aligned with the lateral margins of the page. Position the caption above the figures, tables, and frames, in Times New Roman font, size 12, left-aligned, text spacing 1.0 (single), with a space between the caption and the figure, table or frame. In case of a font, it should be in Times New Roman font, size 10, left-aligned, text spacing 1.0 (single), with a space between the figure, table or frame and the font. Below you can find examples for formatting figures, tables and frames.

2.1.1 Figures

Figure 1 - Solar World photovoltaic module recycling processes



Source: Jing e Suiran, (2015).

Figure 1 presents the three main processes used, highlighting the results from each stage of PV module recovery. At the end of the recycling process, the solar cells are purified and re-etched into wafers, better known as (Si) wafers.

According to Pagnanelli et al. (2019), recycled pellets after being subjected to recycling processing, have the same performance as new cells and can be reused again in a standard solar cell production line and integrated in the manufacture of new PV modules.

Jing and Suiran, (2015), showed that the process can recover more than 84% of the module weight. Furthermore, it has the possibility of extracting more than 90% of the glass, which can be recovered and used in new products, and 95% of the semiconductor materials for use in new solar modules. The energy from polymer incineration can be used in other processes or to preheat new loads in future production.

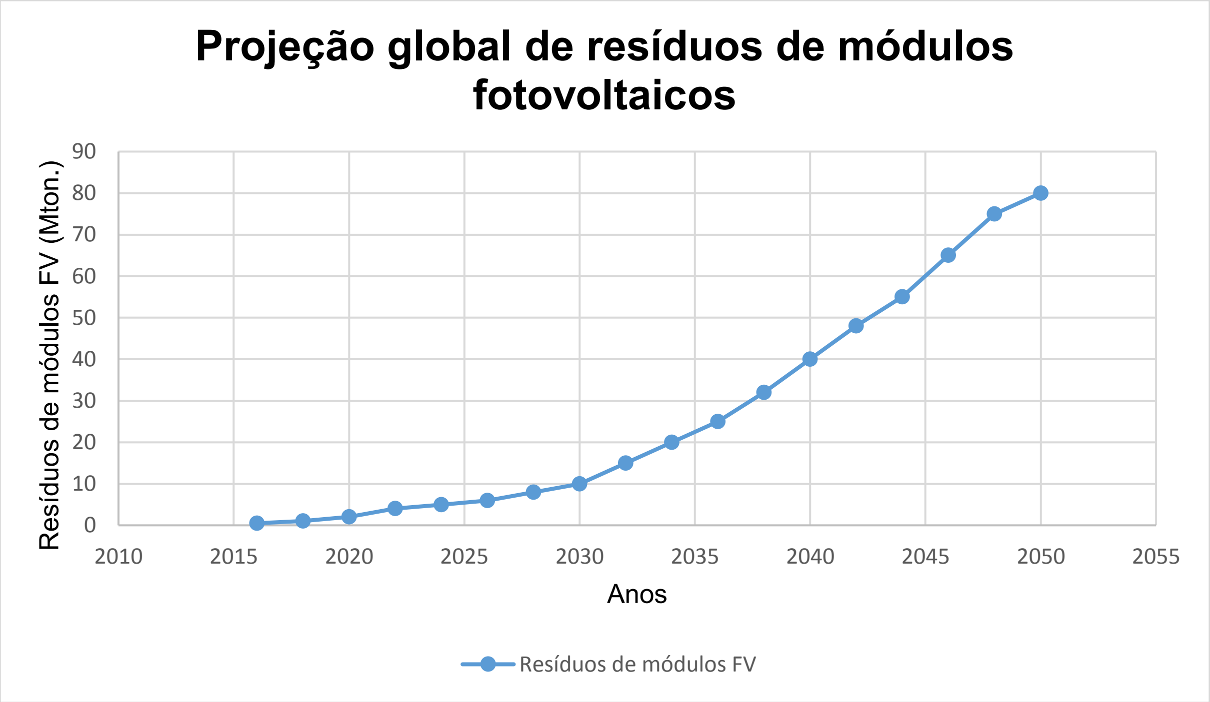
3 METHODOLOGY

This project will be developed in three phases: (1) Theoretical, (2) Descriptive research, (3) Quantitative research. The theoretical phase (1) will serve as a theoretical basis supported by the literature review. Descriptive research (2) will focus on gathering information regarding practical data for sizing the system for reusing half-cycle photovoltaic modules, with the purpose of developing the project and indicating its sustainability. Quantitative research (3) will assess the number of end-of-cycle photovoltaic modules to be explored and used in the development of the project.

The study proposal will be developed to meet the growing demand for the use of photovoltaic technology, referring to the mono and polycrystalline silicon photovoltaic module, highlighting a study that makes it possible to recover the photovoltaic module without the need to go through the recycling systems presented in course of the research

Figure 2 presents a sketch characterizing the projection of photovoltaic module waste until the year 2050.

Figure 2 - Photovoltaic module waste



Source: IRENA, (2020)

In this scenario, the constant increase in photovoltaic solar panels is considered to be reaching the end of their useful life and, if not treated properly and efficiently within this period, a surprising increase in waste will occur over the next three decades, considering the nominal useful life. of photovoltaic modules from 25 to 30 years.

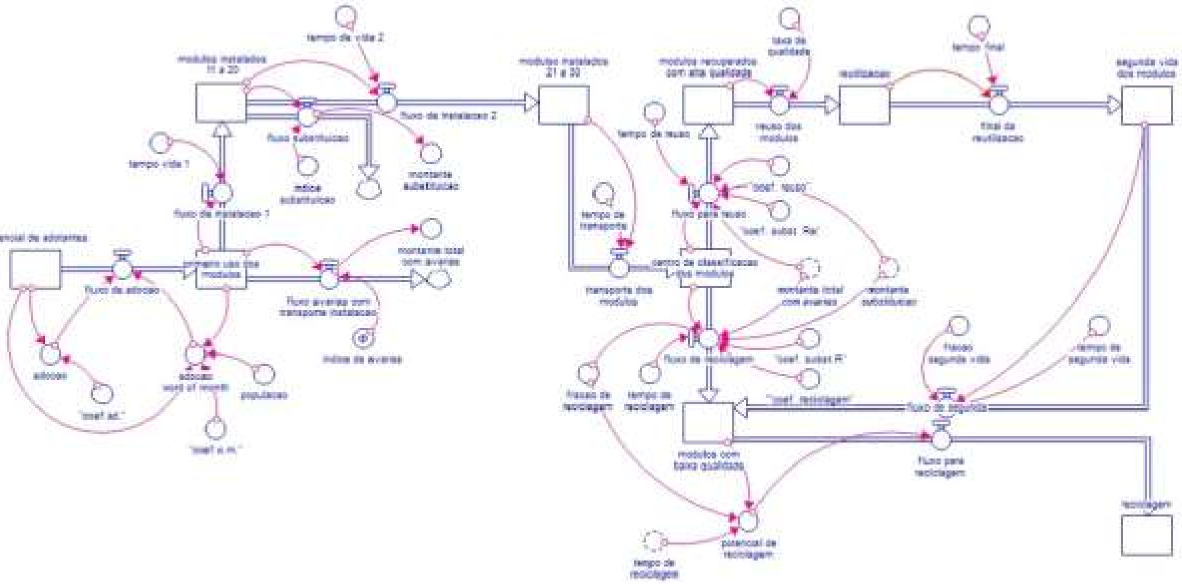
According to figure 2, it is expected that, by the end of 2050, 60 million tons of end-of-cycle (EoL) photovoltaic modules will be accumulated, the amount of which is approximately equivalent to 4500GW of installed power.

Based on the information above and, knowing the variable of interest represented by the exponential growth of photovoltaic module waste, a system dynamics model is applied with the aim of determining the quantity and quality of half-cycle photovoltaic modules, which can be reused. without going through the complex recycling process.

3.1 STOCK AND FLOW

Figure 3 highlights a stock and flow model based on the data presented previously.

Figure 3 - Stock and flow model of the photovoltaic module recycling system



Source: Author, (2024)

In this model, a module supply circuit managed by Bass' proposal stands out. In the sequence there are three delays corresponding to installation flows 1, 2 and 3. Each flow was given an installation time of 10 years. At the end of the order 3 delay cycle, a stock is connected to the module classification center. This center is responsible for determining the physical operational state of the photovoltaic modules. In this case, if the module is in good operating condition, it is directed to the reuse flow. Instead, the damaged module is sent to the recycling stream.

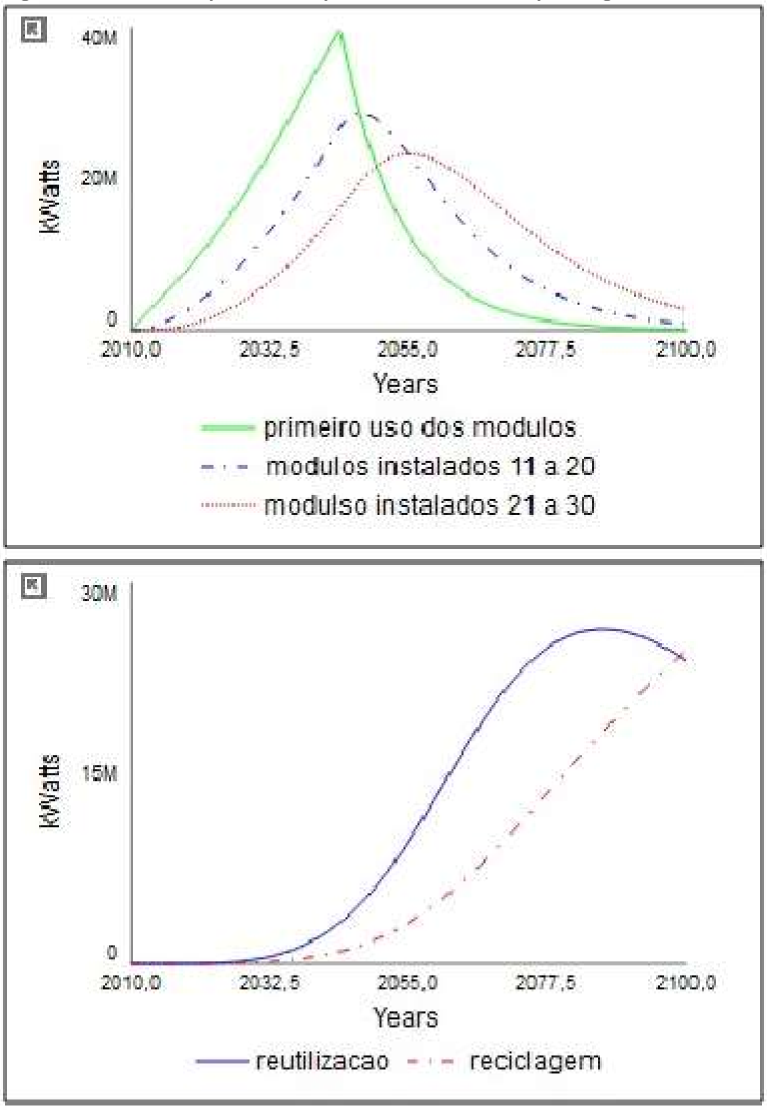
It can be seen that there is a flow leaving the stock corresponding to the first use of the modules. This flow represents the number of modules that are damaged before or during installation for the end customer, so this amount of photovoltaic modules with faults (damaged) will be chosen in the classification center and directed to the stock of modules with high or low quality depending on the good operational condition of the module. The same procedure is applied to the replacement flow.

Finally, the reused modules go through a quality control procedure, if approved, they will be installed in a new photovoltaic system to meet a demand approved by an electrical project and after a period of time these reused modules go through the second life flow as low quality modules and will later be recycled. And, modules that are already of low quality will automatically go to the recycling stream.

4. RESULTS

This section presents the preliminary results of the model under study. Firstly, the data generated by the order 3 delay cycle will be addressed, as well as reuse and recycling. All results are measured in Mwatts shown by Figure. 4.

Figure 4 - Data cycle delays, reuse and recycling



Source: Author, (2024)

Figure 4 shows the configuration of the growth curves. It identifies an exponential growth in the first uses and, after an average time of 30 years, the values of use and installation of photovoltaic systems begin to decline. This effect occurs due to the fact that the model does not consider the manufacturing of new photovoltaic modules after each simulation loop. The purpose of these methods was to identify the maximum time in which the modules were installed. After that, visualize the decay curve of the modules' use. It can be seen from this analysis that, by the year 2075, there will be no new photovoltaic modules installed. And, yes, modules installed considering the proposed reuse process, as well as modules that will go through the recycling process.

As seen in figure 4, the total amount of reused and recycled modules begins to decline around the year 2100. This result acquired by the simulation is satisfactory, since a single mass of installed modules is considered. Then, through the reuse stage, circularity is achieved, reaching a time mark for the use of photovoltaic modules in approximately 70 years.

5 FINAL CONSIDERATIONS

This study aimed to demonstrate a model for reusing photovoltaic modules in half a cycle. After the production process, the modules have an average lifespan of 30 years, after this period recycling is applied, using the elements that make up the modules for their respective applications. In addition to recycling, there are solutions for reuse, but these are very scarce as the modules are at the end of their cycle. In some cases there is the possibility of replacing them in half a cycle and applying reuse.

The study consists of a model using the STELLA system dynamics software and applying a simulation to obtain data on modules used, reuse flow, recycling flow and reuse potential of modules in half a cycle.

This result obtained by the simulation is satisfactory, since a single mass of installed modules is considered. Then, through the reuse stage, circularity is achieved, reaching a time mark for the use of photovoltaic modules in approximately 70 years.

For possible future studies, the data obtained in the simulations should be reviewed and a parallel classification process of the modules should be created in half a cycle. In this classification, it would be interesting to use a dynamic variable adding physical and electrical data of the modules, as this way, the model will be more embedded providing a more efficient average forecast.

REFERENCES

CRESESB, C. **Grupo de trabalho em energia solar**. Rio de Janeiro, Brasil: PRC - Prodeem, 2014.

JORDEHI A. R**. Parameter estimation of solar photovoltaic (PV) cells: A review**. Department of Electrical Engineering, Lashtenesha-Zibakenar Branch, Islamic Azad University, Lashtenesha, Iran, 2016.

PANG, S. YAN, Y. WANG, Z. WANG, D. LI, S. MA, W. WEI, K**. Enhanced separation of different layers in photovoltaic panel by microwave field.** Key Laboratory of Green Process and Engineering, National Engineering Laboratory for Hydrometallurgical Cleaner Production Technology, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100190, People’s Republic of China. Innovation Academy for Green Manufacture, Chinese Academy of Sciences, Beijing, 100190, People’s Republic of China. University of Chinese Academy of Sciences, Beijing, 100039, People’s Republic of China. National Engineering Laboratory for Vacuum Metallurgy, Faculty of Metallurgical and Energy Engineering, Kunming University of Science and Technology, Kunming, 650093, People’s Republic of China, 2021.