APPLICATIONS AND MODELS OF THE HYBRID ENERGY GENERATION SYSTEM: LITERATURE REVIEW

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Abstract: Hybrid energy production systems provide greater stability, constancy and reliability to the generation system by implementing different energy sources. However, there are technological and regulatory challenges that need to be overcome. The article aims to present the concept of technology applied at a global level, through a literature review of patents published in the last five years. Identifying hybrid power generation systems with varied configurations and arrangements between energy sources. The high potential for expansion of the hybrid plant can be seen in the creation of technologies and development of control systems, aiming at future consolidation in the energy market.

Keywords: Hybrid Generation; Plant Control Method; Complementary Energy Sources; Renewable Energy.

APLICAÇÕES E MODELOS DO SISTEMA HÍBRIDO DE GERAÇÃO DE ENERGIA: REVISÃO DE LITERATURA

Resumo: Os sistemas híbridos de produção de energia fornecem maior estabilidade, constância e confiabilidade ao sistema de geração por implementar diferentes fontes energéticas. No entanto, existem desafios tecnológicos e regulatórios que precisam serem superados. O artigo tem como objetivo apresentar o conceito da tecnologia aplicado em nível global, através da revisão de literatura das patentes publicadas nos últimos cinco anos. Identificando sistemas híbridos de geração de energia com variadas configurações e arranjos entre as fontes energéticas. Percebe-se o elevado potencial de expansão da usina híbrida, na criação de tecnologias e desenvolvimento de sistemas de controle, visando a consolidação futura no mercado energético.

Palavras-chave: Geração Híbrida; Método de Controle de Usina; Fontes de Energia Complementares; Energia Renovável.

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1. INTRODUCTION

The concept of the hybrid power plant is inclusion on several sources of energy for the electric grid, especially sources complementary, because of their response to changing conditions and requirements. As is the case of plants that unify the generation by wind turbines and photovoltaic panels, added to an energy storage system in batteries. As renewable sources are subject to the laws of nature and natural phenomena that vary over time. Complementing two renewable sources in the same plant becomes interesting, such as local sources of wind and solar energy. Because, when the sun may not be shining at night, reducing the production of solar electricity. This period is the time of intensification in the production of wind power, when the winds are relatively strong. The unification of these elements increases the production the maximum allowed amount of energy, granting stability over time, control over distances, provides a high constancy and reliability of the energy produced by the hybrid plant [1].

Currently, renewable energy sources are gaining ground in the world to produce electricity for the local electricity grid. Aiming at a gradual transformation, with the implementation of a non-fossil energy system. However, for this process to be effective, it is necessary to overcome some challenges and attend the required requirements [1]. The enterprise known as the hybrid power plant attend a market trend to integrate 'complementary' renewable energy sources. The energy storage system more used is electrochemical storage, specifically rechargeable stationary batteries, but other kind energy storage units are also included, for example, mechanical storage (compressed air reservoirs), electrical storage (supercapacitors), thermal energy storage, or chemical energy storage (power-to-gas P2G), or other technologies. The energy storage unit is applied in the system to assist the plant's energy generators. It stores energy during the period of surplus energy and then generates energy during the period when the energy is needed to be supplied to the electrical grid.

Faced with motivating factors for the implementation of hybrid plants, this article aims to contribute with analysis regarding the concept of Hybrid Power Plant, through a literature review with published patents relating to this technology in the last 5 years. Indicating innovative configurations and alternatives to improve the quality, efficiency and reliability of the electric power generation system.

2. METHODOLOGY

This study was developed through a search for patents that include model, arrangement and technologies applied in hybrid power plants around the world. The research was carried out through a priority search, being developed with the support of the Intellectual Property Center of SENAI CIMATEC.

The anteriority search was executed in the period around July 2021, following the steps: identify the databases to be consulted; define the Boolean descriptors and connectors; the inclusion and exclusion criteria of the works; and, finally, analysis and evaluation of all studies included in the review was carried out, producing a synthesis of the information and results found.

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The inclusion criteria for publications were: patents, which addressed the concept and advance of technologies applied in hybrid power plants, published between 2016 and 2020, written in English, and documents available in the whole. All documents published outside the period and in languages other than those defined were excluded.

The research was carried out using the databases available: The Lens; Derwent Innovation; INPI – National Institute of Industrial Property; and ESPACENET – European Patent Office. The literature review used keywords such as Hybrid Plant OR Hybrid Generation; Plant Controller OR Protection Relays; Power Converters OR Electric Power Flow.

3. RESULTS AND DISCUSSION

In Table 1 the keywords were defined through combinations, to delimit results to publications with a higher level of correspondence. It was found a total of 534 files related to hybrid plants.

Table 1. Selection of the patent for the production of the study

DATABASE	CRITERIA TO CHOOSE OF PATENTS		
	KEYWORDS	PUBLISHED IN 2016 – 2020	AVAILABLE IN FULL TEXT
THE LENS	330	193	31
INPI – National Institute of Industrial Property	25	23	0
ESPACENET – European Patent Office	154	106	99
Derwent Innovation	25	8	8

As can be seen in Table 1, many documents were found, so it was necessary to apply some selection criteria. In this way, files published before 2016 were eliminated, obtaining 330 documents. Then, files with unavailable full text were discarded, leaving 128 patents. The researched database (128) was explored in a qualitative way, seeking to obtain within the scope of patents on the technologies applied in the generation and control of hybrid plants in the last 5 years (2016-2020). Thus, it was identified that from the total, only 11 add more content to this article and the other 117 did not meet these requirements. Therefore, timely analysis will be presented in the next topics.

Møller presents a hybrid plant, which the concept is the production of energy that feeds the electricity grid, through a plurality of energy assets. For this patent, the plant consists of two interconnected different renewable energy sources. The first generator unit is wind turbines, while the second generator unit is solar panels, both connected to an energy storage unit, preferably a battery energy storage system

(BES). The hybrid plant contains a controller whose function is to measure and/or receive information from the electrical grid, to communicate with the other elements of the plant, providing electrical energy with greater stability, reducing impacts on the grid caused by faults. The hybrid plant controller consists of modules to derive and regulate a measured value for electrical losses, applying this value in an active power control loop. Control and operations are carried out through a computer program that provides access to data storage, connecting all parts of the plant [1].

The hybrid energy plant, described by Nielsen, consists of two different renewable energy sources, managed by a control system. The generation system has a central power plant controller (CPPC) that uses a communication network, enabling the analysis and application of setpoints to the generation system. The plant's central controller (CPPC) receives data from the generation system. It is configured to produce a modified feedback signal, having as reference the data received from one of the generating units. Through this structure, a model for the operational behavior of the energy generation systems of the sources is built. When analyzing data received from one source, the central plant controller (CPPC) is programmed to produce a modified feedback signal, and apply it to the feedback control circuit of the other source in the plant. Allowing the power generation system to have its operation modeled, according to the feedback signals exchanged between the plant's sources [2].

A method of operating a hybrid power plant from renewable sources is presented by Mendizabal Abasolo. Having as one of the sources, a wind farm, together with one or more other type of renewable energy source, in addition to an energy storage system. The control method has an energy production schedule, based on a set of data, provided by an actual forecast of variables such as: energy produced, climate, energy price and the actual status of the hybrid plant. In this way, it is possible to have a basis in the energy production schedule and definition of the status of the hybrid plant in the future. Allowing a more efficient management of energy generation, according to the schedule provided by forecasting the variables in the future. Using this data as a reference, it is possible to apply energy arbitration. Maximizing the mill's profit, knowing that energy prices vary at different times throughout the day. The increased reliability of the forecasting system allows for an efficient control of the generating elements, as well as the dispatch of the plant's energy production [3].

The invention discloses a fuzzy control method for a hybrid wind-solar plant with storage, which provides electrical power to a microgrid system. In this method explained by He, the power of the hybrid energy storage system and the state of charge of the supercapacitor are used as controller input variables. The controller output is the filter time constant correction value. Providing dynamic modification of the size of the filter time constant and more assertive energy distribution in the hybrid energy storage system. This control reduces the number of battery recharge cycles, smooth the battery charging and discharging process. Generating economic benefits, in the hybrid energy storage system; in addition to granting greater coordination in energy control. The implementation of fuzzy control promotes balance in the power supply for the microgrid system, constant DC bus voltage. A fuzzy control method applied to this hybrid plant power system is proposed, which is based on variable filtering time constant power [4].

The generation system presented by He, contain renewable energy: a photovoltaic module and a wind power module, added by another non-renewable source, a diesel power generation module, in order to maintain a constant generation

during the fluctuations of other sources that depend on external factors. The plant also has an energy storage module, an off-grid inverter, an environment monitoring instrument, an upper computer and a data center. Each element of system of the hybrid micro-grid power generation has a module of controller that can communicate with the host computer through of the CAN bus / GPRS. The module data of controller send information for the PC with energy management system, supplying data uploaded to the data center via GPRS / Internet. The data center storage all data in a cloud artificial intelligence algorithm. The use of this data allows test center experimental data adjustment, evaluation of energy solution strategy, and the management strategy of plant. This data return to the host computer, to apply the appropriate actions on the execution unit [5].

This hybrid power supply, reported by Fan, has different sources, mixing renewable energy, photovoltaic power generation panel; non-renewable energy, a diesel generator; a public power grid, and an energy storage battery. The diesel generator is an emergency system that will provide electrical power to the alternating current bus when needed. The plant's two generation sources, the photovoltaic panels, as well as the public electricity grid, are connected to an alternating current bus, and are intended to supply the load and charge the energy storage battery. At times when there are advantages, analyzing factors as the value of the power consumed by the load, the power supplied by the photovoltaic generation, the charging level of the battery energy storage, and the current price of the electricity supplied by the public grid solar electricity generation. The controller system can decide transmit power to the public electricity grid by photovoltaic generation or storage system in batteries, negotiating the sale of energy with the electric utility. When trading for the sale of energy is not profitable, the energy storage system can store the energy produced by the plant, or use it, transforming its current into alternating current and connecting it to the busbar to supply energy to the load [6]. The hybrid plant configuration allows the system to be interconnected with the external power grid or limit its own generation, such as a microgrid. Ensuring reliability in the normal flow of energy through the adaptability of the electrical supply system, being disposed in different ways, avoiding situations of energy interruption when the public power grid or any other elements of the plants are unavailable [6].

The hybrid renewable energy plant, described by Hsuch, comprising a wind and solar park, stands out for the integration of various technologies for the energy storage system, using lithium batteries, flywheels and fuel cells. To increase the efficiency of the transmission of electrical energy produced by the sources, the supply structure is divided between alternating current (AC) and direct current (DC) loads. To attend the system, the sources are activated using a sequence, starting with solar photovoltaic generation, wind power generation, the fuel cell and the commercial power supply (public electricity grid), and the storage system can supply the plant energy requirement or absorb excess energy through lithium iron phosphate battery units and/or flywheels [7]. The plant's control will be able to act in conjunction with the intelligent energy saving service monitoring system iEN (Intelligent Energy Network), facilitating the management of generation assets. Enabling access to data on the operation of plant elements in different periods, facilitating the management of plant assets in peak and off-peak periods, supporting decisions to store energy when the sale price of electricity is not attractive, and negotiating the supply of energy to the public electricity grid when the sale price is economically attractive [7].

This hybrid energy generation, indicate by Mo, configured to attend the energy demands of a ship. To supply electricity, some elements are combined in this process, photovoltaic generation, diesel power generation, public electricity grid and the battery storage system. However, as a premise of this arrangement, the main source of this system is photovoltaic generation, being responsible for providing power to the batteries of the energy storage system, as well as supplying the energy demand of the load of the ship in question. In situations where both the photovoltaic energy supply and the energy storage system are insufficient to supply the load: If the ship is berthed in a place with access to the public electricity grid, the load can be connected and powered through that grid. If access to the public grid is unable, the diesel power generation system will be activated, assuming the necessary demand for the full supply of energy to the load. This level of hierarchy between the plant's sources, aims to reduce the use of the diesel generator, in this way, the consumption of diesel is reduced and, consequently, the level of pollution produced by it, too. In addition, the photovoltaic energy system promotes greater reliability in the supply of electricity to the ship's load, as it would not be dependent on diesel generators, when these fail or there is no connection to the power line through the public grid [8]. The control system uses data from the plant's elements, through of analysis, the system can manage the plant more efficiently, deciding which source to use, the period of use, whether the battery storage system should absorb or discharge energy, among other resources for better management of the plant [8].

This plant is a hybrid generation system that uses different energy sources extracted from the ocean, presented by Gong. The plant consists of an ocean energy power generation device group, a grid-connected control cabinet group, a bus switchgear, a control station, an energy storage system and a user load. The group of ocean power generation devices comprises a combination of one or more devices that utilize wave energy, tidal current and ocean temperature difference, between other. Each generating device is connected individually to a network control cabinet, this group of control cabinets is connected to the control station respectively. In accordance with this hybrid plant concept, the system's multiple ocean energies are used for power generation, providing more reliable and stable power supply to the load. The energy output is mainly used for load consumption and energy storage, when there surplus can be negotiated with the energy concessionaire, being able to be sold and connected to the external grid in parallel [9].

This renewable hybrid power generation was designed and developed, according to Jun, to keep the power supply system stable in the face of an instantaneous load variation, or in the system in general. The plant is consisting of a renewable energy generation device (RG), a fuel cell system (FC) and an energy storage device (ESS). Through this arrangement is aiming avoid unnecessary equipment costs, and increase the energy storage capacity for long periods, several months, using the hydrogen energy storage system. In an instantaneous load variation, the fuel cell (FC) system exhibits a slow dynamic response. This feature allows for an acceptable system response when disturbed by overload or peak load [10]. The arrangement of this hybrid power system, has the battery energy storage device (BESS) configured to operate within a range of values, as per the output voltage reference on the plant's power bus. The performance of the batteries may be increased when adjusted to keep the battery charge always at maximum, and when resources are invested to increase the system's robustness in the face of grid disturbances, such as instantaneous load fluctuations on the grid. [10].

Fan presented a hybrid generation system that unifies the production of wind energy, solar energy, hydrogen energy storage (fuel cell) and a coal chemical industry. The arrangement is intended for the production of electrical energy, through the junction of renewable energy sources, and a storage system. It also uses the by-products generated by the hydrogen fuel cell energy storage system for the applications of the coal chemical industry [11]. In this system, the hydrogen energy storage unit stands out as one of the main elements of the plant. The electric energy storage process by the wind-solar complementary system, in the hydrogen fuel cell, takes place through the electrolysis of water, generating oxygen gas and hydrogen gas as a product of the reaction. The coal chemical industry uses both oxygen gas and hydrogen gas in its procedures. Therefore, the hydrogen fuel cell is able to provide the coal chemical industry with supplies such as oxygen and hydrogen. In addition to storing energy from the system, to meet the electrical demand of the load when necessary, obtaining an increase in the safety and stability of the plant's electrical supply [11].

4. CONCLUSION

We were able to identify through the patents presented throughout the text, that the concept encompassed by hybrid plants emerges as a strong alternative to solve some challenges faced by renewable and non-renewable energy plants. Renewable source plants have the difficulty of depending on external factors for the production of electricity. However, patents referring to hybrid plants bring as a solution, the union of different complementary renewable energy sources. Allowing diversification of the plant's energy sources, not depending on just one external factor. The inclusion of elements in the plant, such as an energy storage system (batteries, thermal storage, mechanical storage) and electricity generators from non-renewable or renewable sources, aims to make the energy production system more robust. Generating greater reliability, stability and constancy in the energy supply, as it does not depend only on an external environmental factor in the generation of electricity.

In addition to the diversification of sources in the same plant, the hybrid plant has several models for controlling and managing the generation elements. Allowing the manager to configure the plant to negotiate the purchase and sale of electricity for the public grid, with the concessionaire. However, this is still a great challenge for hybrid plant owners, a regulation that covers all parameters for this type of supply of this type of plant. As it is a relatively recent technology, hybrid plants have a high potential for development and maturation process. Hybrid plants present a great opportunity for further studies with the aim of bringing innovations and discoveries about this model of electricity production.

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