A Strategic Method for Steering a Photovoltaic Generator

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Abstract— **There are several forms of electricity generation, first, by burning fuels, such as coal, natural gas or oil, which have an effect on the atmosphere, especially increasing greenhouse gases, or, second, from renewable sources, such as wind, hydro and solar, which are clean and renewable sources of energy. Our work focuses on solar sources, especially photovoltaics; we have treated the steering part of photovoltaic generators using artificial intelligence methods, specifically, case-based reasoning. The system we have built generates actions to be applied to the generator based on its current state and reasoning from previous cases recorded in the case base.**

Keywords- photovoltaic system; photovoltaic generator; steering of photovoltaic system; case-based reasonnig; k-means neighbors.

I. INTRODUCTION

Algeria is one of the sunniest countries in the world. Consequently, there are many programs for the installation of huge photovoltaic (PV) stations [17]. In PV systems, we face three important problems: sizing, diagnosis and fault detection, and tracking the maximum power point. These problems need to be addressed before setting up a photovoltaic generator. Our intervention is in the maintenance, as well as detection of faults of the PV generator; it helps regulate the operation of the generator to achieve its objectives. This is achieved by the application we developed to steer the PV generator using a case-based reasoning methodology and intervenes automatically to regulate the effects of an anomaly.

PV generators connected to the grid are usually located in isolated areas where human intervention is late or absent. The objectives of our system are:

- Improve generator productivity by decreasing the defects of the solar panels. This is done by reconfiguring the generator to achieve maximum production of the non-faulty modules.
- Increase the availability of the generator keeping the generator in partial production state when a failure has occurred.
- Increase the life of the system in the case of partial shading of the module that generates the hot spot and automatically isolates the module and invokes the maintenance team when it persists over time.

The rest of the paper is structured as follows. Section 2 concerns the related works. We present the steering functions and its problematics in Section 3. Section 4 is dedicated to the approach of artificial intelligence followed case-based reasoning (CBR). Section 5 presents the objectives and multiple configurations of the proposed steering system. The deployment of the proposed system with the different stages of CBR and the tests of presented cases are discussed in Section 6. Finally, we conclude our work presenting perspectives in Section 7.

II. RELATED WORKS

Research in the supervision and management of PV systems is increasing not only in Algeria but also in the rest of the world. In the photovoltaic field, most researches are focused on dimensioning, diagnosis, fault detection and maximum power point tracking problematic. Hence, several artificial intelligence methods are used such as fuzzy logic, neuronal networks and genetic algorithms to solve these problematics. In this paper, we address another problematic namely, the photovoltaic field steering, which is not directly addressed in other works. So, in the state of the art, we will mention some research works that solve problematics that have an influence on the photovoltaic steering problematic. We start with fault detection using artificial intelligence techniques. Fault detection is a crucial task to increase the reliability, efficiency and safety of photovoltaic systems. The detection and manual removal of faults in photovoltaic systems is very expensive, and, in some cases, impossible, like the photovoltaic systems of satellites. Therefore, automatic fault detection techniques are required [1].

Several methods are used, because of the non-linear nature of the photovoltaic system and some faults are difficult to detect by conventional protection devices. Zhao et al. [2] proposed in their work a model based semi-supervised learning graph for the detection of faults. The proposed model not only detects defects, but also identifies their possible type. In another work, Zhao et al. [3] developed a decision tree model for detecting and classifying photovoltaic field faults. This model analyzes the current-voltage characteristic (I-V) to make detections.

Artificial intelligence techniques are also used for the detection of faults. Zhihua et al. [4] have used neural networks in their work for the detection of faults. At first, the temperature of the module determines the occurrence of defects in a photovoltaic module. Then, the artificial neuron is used to make the diagnosis and define the type of defect. The input parameters of the neuron are: temperature, current, and voltage, while the output is the detection result. Inside of the fault detection, the maximum power point

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tracking is an important issue in the photovoltaic field. The Maximum Power Point (MPPT) tracking technique is an important requirement in improving the efficiency of power extraction from PV modules. The main goal of all MPPT techniques is to extract the true maximum power of the PV module in any atmospheric condition. However, in the conditions of rapid climate change and partial shading, conventional techniques have not been able to follow the true peak power point. For this reason, artificial intelligence methods have been developed with the ability to search for the true maximum power point with a good convergence speed [5].

Patchara Prakriti et al. [6] have proposed a method of tracking maximum power points using an adaptive fuzzy controller for PV systems connected to the network. From simulation and experimental results, the adaptive blur controller can provide more power than the conventional blur controller. Bahgat et al. [7] presented a maximum power point tracking algorithm for photovoltaic systems using neural networks. According to the authors, the experimental results showed that the photovoltaic plant with MPPT always listens to the maximum power point of the PV module under various operating conditions. The MPPT transmits approximately 97% of the actual maximum power generated by the photovoltaic module.

III. THE STEERING FUNCTIONS AND PROBLEMATICS

A. *The steering of production process*

The steering is the function of controlling the future and immediate behaviour of the production process according to a given process to achieve the production objectives expressed in terms of quality and productivity [8].

The steering is responsible for carrying out the planned production. It must solve all the problems that are not solved by the forecast level (local loads or constraints). It must also take into account all the manufacturing constraints (quality control, maintenance-related downtime, staff qualification level, etc.), all present at this level, and react to hazards so that the planned production be possible.

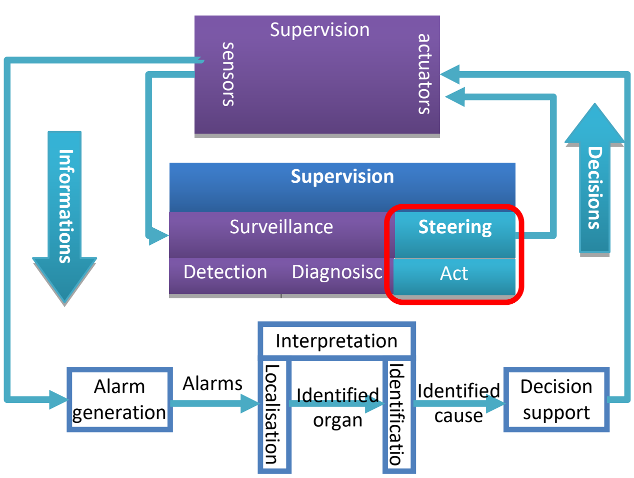

Figure 1. Position of the steering in supervision process [13]

Figure 1 shows the position of steering in the supervision process of production system. It is jointed to action after decision supported by the preliminary steps of surveillance, detection and diagnosis.

We can distinguish three main classes of functions of steering to ensure:

- Communication: with the scheduling function (recovery of forward orders and transmission of order tracking), with the order of the production system (sending orders for launch, control and reception of real-time monitoring), with the other industrial functions (request for intervention, analysis, taking into account urgent orders, transfer availabilities, etc.);
- Data management: concerning products, resources, tasks to be performed;
- Historical and statistical: equipment breakdown statistics, team activity, time spent by batch, by product, etc.

B. *The steering problematics*

Here, we discuss the problems of operating and analysing steering systems [9].

- **Exploitation**: the problem of operating the steering systems can be seen as a particularization of man-machine cooperation problems. In the field of human-machine cooperation, horizontal cooperation is defined as a means of regulating the human activity of supervision by means of a division of tasks between the operator and a decision-making tool. In vertical cooperation, the tool only offers advice to the operator who remains the final decision maker. The difficulty of operating the steering system lies in the division of tasks between the human operator and the material part of the system. Some authors advocate permanently keeping the human operator in the steering loop by regulating his workload.

- **Analysis:** the analysis of a control system uses, at least in the same way as its design and operation, very complex and highly variable interpretative processes. Based on purely quantitative criteria, the difficulty of the analysis is due to the causal and temporal distances between the implementation of the steering system and the resulting performance. On a more qualitative level, the analysis of the steering system is based on the value it brings to the different actors of the production system: better feedback on everyone's actions, facilitation of monitoring and diagnostic tasks, better organization of the workshop, etc.

IV. CASE-BASED REASONNING

Case Based Reasoning (CBR) is an approach for solving and learning problems. A new problem or case is solved by remembering (recalling) similar cases already pre-analyzed and stored in memory. The solution found is then adapted (reused) to the new problem. The new case is then revised or repaired (by the expert or by the use of the general knowledge of the system). This new case can also be learned from the system (memorization) as a new experience [10][11]. The CBR approach reduces knowledge

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acquisition efforts. It allows the use of existing data and can adapt to changes in their environment. Figure 2 illustrates the CBR cycle:

- **Retrieve**: Recovery of previously experienced similar cases (e.g., solution-problem-result triples) whose problem is deemed similar.
- **Reuse:** propose a solution to solve the new problem using information and knowledge of the recovered case.
- **Revise:** aims to evaluate the applicability of the proposed solution.
- **Memorize:** Maintaining the new solution once it has been confirmed or validated.

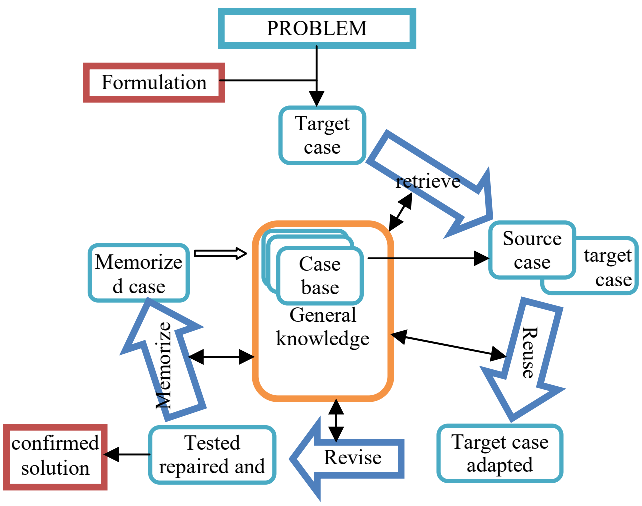

Figure 2. Case-based reasoning process [14]

In many practical applications, the reuse and revision stages are sometimes difficult to distinguish, and many researchers use a single adaptation phase that replaces and combines them. However, fitting into a RAC system is still an open question because it is a complicated process that tries to manipulate case solutions. The cases recorded in the case base have been enriched by general knowledge, which often depends on the domain of the problem [12]. The selection of an appropriate method for each step depends on the problem and requires knowledge in the field of application. In situations where information is incomplete or missing and we want to exploit tolerance for inaccuracy, uncertainty, rough reasoning, and partial soft-truth calculation techniques could provide solutions with traceability, robustness, and low cost.

V. Principles and Multiple Configurations of the Proposed Steering System Using CBR

A. Architecture of the proposed steering system and case presentation

Figure 3 illustrates the global architecture of the developed steering system. It contains a formulation of cases to set them as a vector of attributes, a case management, a history management and an automatic steering (the cycle of CBR).

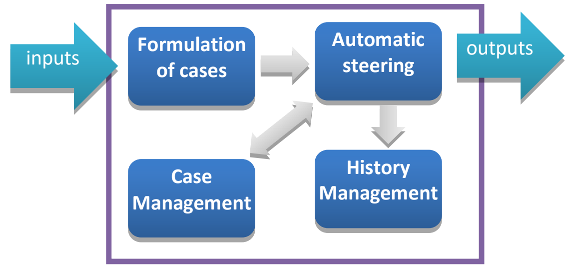

Figure 3. Architecture of the proposed steering system

The case is a state of photovoltaic generator represented by attribute vector to be usable by CBR (Figure 4).

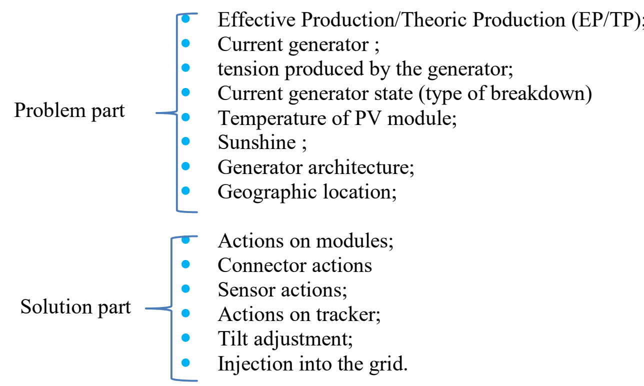

Figure 4. Generator state (target case) attributes

A case is composed of two parts: the problem part and the solution part. The attributes of a case are represented in Figure 4.

B. Principles of the application of CBR process in the proposed steer system

Retrieve: Select the most similar cases calculating the distance between the appeared case and the cases of the base cases. We used the types of distances in a developed system and the user has to choose one of them.

- Distance between blocks,

$$d(x,y) = \sum |xi - yi| \tag{1}$$

- Euclidian distance with weights,

$$d = \sqrt[p]{\sum |xi - yi|^p} \tag{2}$$

The first (1) method only measures the distance between 2 cases; however, the second (2) allows us to give importance to attributes that others and exclude some by giving them a 0 weight because in reality not all attributes have the same importance. It is noted that in the second method the sum of the weights must be equal to one (1) [14]. The calculation is done only on the problem part of the ***case.*** The objective of the calculation of the distance is to find the

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closest cases to the target case (problem), from the base case. We chose the K nearest neighbors method with K=3 to find the 3 closest cases to the target.

Reuse: is the proposal of a solution to solve the new problem by reusing information and knowledge of the three cases found. If the distance is zero (0), the solution is reproduced. If not, an adaptation step is necessary.

Adaptation of the case: The adaptation of the cases consists in giving a coherent solution, one must not find contradictions between the values of the problem part and the solution part. The verification is done using rules of type "if condition then result":

IF <Action on module = Replace and type of failure = Sane>
Then incoherent values

For each attribute of the solution of the nearest case:

- **IF** <the value conflicts with the attributes of the problem part of the target case>
  Then we move to the values of the next case.
- **IF** <all the values of the three cases are in conflict>
  Then the case is recorded in the database of untreated cases.

Revise: It validates the obtained solution, by evaluation with simulation using a model of the generator. After application of the solution:

IF < PE/PT>minimum threshold>
Then the solution is registered in the base.
Otherwise the case is recorded in the database of unprocessed cases.

C. *Generator models*

Calculation of the generated current: The photovoltaic cells could be presented with one diode or bishop model (Figure 5a, Figure 5b).

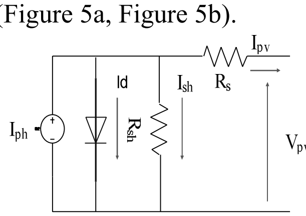

Figure 5a. One diode model [15]

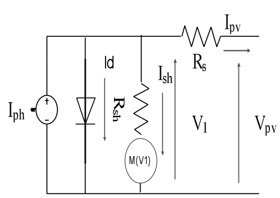

Figure 5b. Bishope model [16]

The bishope model takes the avalanche effect of the cell into consideration by adding to the diode model a nonlinear multiplier in series with the shunt resistor. The user will configure the developed system according to the PV cells used. The electric currents generated are obviously different. These were calculated according to different formulas.

D. *Calculation of current and voltage*

The current and the voltage of the PV generator are calculated by the formulas (3) and (4) respectively.

- $\mathbf{I_{generator} = N_{string} \times N_{module} \times N_{cell} \times I_{cell}}$ (3)
- $\mathbf{V_{generator} = M_{module} \times M_{groupe} \times M_{cell} \times V_{cell}}$ (4)

Where

- $\mathbf{N_{string}}$: number of strings in parallel ;
- $\mathbf{N_{module}}$: number of groups of modules in parallel in a string;
- $\mathbf{N_{cellule}}$: number of groups of cells in parallel in a module;
- $\mathbf{M_{module}}$: number of modules in series in a string;
- $\mathbf{M_{groupe}}$: number of groups of cells in series in a module;
- $\mathbf{M_{cellule}}$: number of cells in series in a cell group;

E. *General operation of proposed steering system*

Figure 6 presents the proposed generic algorithm of the steering system.

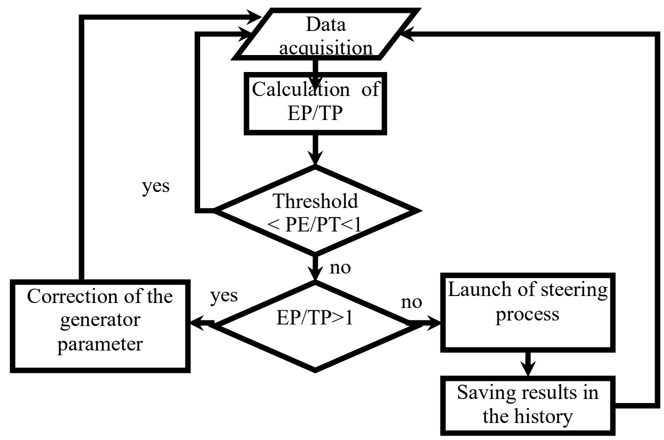

Figure 6. General operation of steering system

The proposed system was developed with LabVIEW (Laboratory Virtual Instrument Engineering Workbench). It is ideal for data acquisition, automation and instrument control. The integrated user interfaces make it easy to use and apply, and, they offer a rapid prototyping.

VI. DEPLOYEMENT OF THE PROPOSED STEERING SYSTEM AND DISCUSSION

The application is essentially composed of the following modules: system status, system settings, model of the photovoltaic cell, test & simulation and historical. Figure 7 represents the status of the PV system (dashboard) over time displaying parameters graphically (tension, current and other parameters).

Figure 7. Dashboard of the PV system

Figure 8 is the interface allowing the setting up (model diode or Bishope, type of distance, number of parallel strings, number of serial cells and all the attributes of the target case) of the PV system.

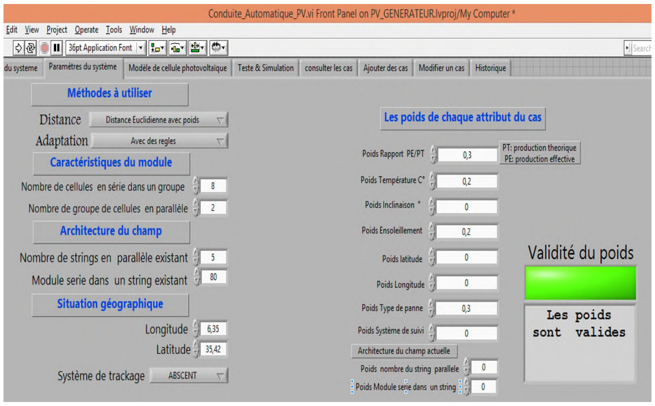

Figure 8. Settings of the PV system

We passed then to the construction of the base case. Table I presents six cases alimenting the base case.

TABLE I. CASES ALIMENTING THE BASE CASE

Attributes	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
PE/PT report	0.6	0.6	0.6	0.72	0.72	0.72
Temperature	32.00	32.00	32.00	32.00	32.00	32.00
Tilt	23.5	23.5	23.5	23.5	23.56	23.5
Sunshine	650	650	650	650	650	650
Latitude	35.42	35.42	35.42	35.42	35.42	35.42
Longitude	6.35	6.35	6.35	6.35	6.35	6.35
breakdown type	Shady	Disconnected connectivity	Module shorted	Sain	Sain	Sain
Tracking system	Absent	Absent	Absent	Absent	workin g	working
Number of strings in parallel	10	10	10	10	10	10
serial module in a string	80	80	80	80	80	80
Action on Modules	Isolate	no	Replac e	no	no	no
Connector action	no	Maintain	no	no	no	no
Action on Sensors	no	no	no	no	no	no
Action on tracker	no	no	no	no	Setting	Repair
Tilt adjustment	no	no	no	Tilt adjustm ent	no	no
Injection into the grid	Injectio n	Injection	Injectio n	Injectio n	Injecti on	Injectio n

Table II represents the attributes of the case to test in their problem part. The solution part is to find using the simulator of the developped steering system.

TABLE II. CASE TO TEST

Attributes	Case 1	Case 2	Case 3	Case 4
PE/PT report	0.58	0.6	0.65	0.65
Temperature	30,00	32,00	25,00	25
tilt	30	23.5	23.5	23.5
Sunshine	600	650	750	750
Latitude	35.42	35.42	35.42	35.42
Longitude	6.35	6.35	6.35	6.35
breakdown type	shady	Disconnected connectivity	Sain	Sain
Tracking system	Absent	Absent	Absent	working
Number of strings in parallel	10	10	10	10
serial module in a string	80	80	80	80

Table III shows the obtained results as a solution part of the case attributes.

TABLE III. OBTAINED RESULTS

Attributes	TestCase 1	TestCase 2	TestCase 3	TestCase 4
Action on Modules	Isolate	no	no	no
Action on connector	no	Maintain	no	no
Action on sensors	no	no	no	no
Action on tracker	no	no	no	no
Tilt adjustment	no	no	*Set the tilt angle to: 65,259900 °*	no
Injection into the grid	Injection	Injection	Injection	Injection

The results of the tests are acceptable. For the cases TestCase 1 and TestCase 2, the obtained solutions are the optimal ones. The most similar case to TestCase 1 is Case 1, so the solution part of this case is applied. The same is true for TestCase 2, the most similar case is Case 2. The result obtained for TestCase 3 is great. The system finds that the most similar case is Case 4, whose solution is tilt adjustment. The system automatically provides the exact angle of inclination based on the situation information geographical location and the current date.

The adjustment of this anomaly is to enrich the case base with this case by assigning the correct solution to it, or assigning a weight to the attribute "tracking system".

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TABLE IV. TEST CASE 4

Attributes	TestCase 4	Case 4
PE/PT report	0.65	0.72
Temperature	25	32,00
Tilt	23.5	23.5
Sunshine	750	650
Latitude	35.42	35.42
Longitude	6.35	6.35
breakdown type	Sain	Sain
Tracking system	working	Absent
Number of strings in parallel	10	10
serial module in a string	80	80
Action on Modules	no	[illegible]
Connector action	no	[illegible]
Action on Sensors	no	no
Action on tracker	no	no
Tilt adjustment	no	Tilt adjustment
Injection into the grid	Injection	Injection

However, the result of TestCase 4 is not optimal. It can be seen that the PE/PT ratio is less than 0.85 and the solution contains no action. So, we analyse how the system handled this case. We found that the most similar case for TestCase 4 is Case 4, so the system takes its part solution is goes to the adaptation stage of the solution. In the tilt adjustment attribute, the system finds a conflict: "tilt angle setting but the tracker system exists and is running", in which case the system proceeds to the next similar case solution and applies the adaptation rules on it. It finds it to be valid, despite the fact that it is not optimal.

VII. CONCLUSION AND FUTURE WORK

Oil is an exhaustible energy, so renewable energies are those of the future. In our work, we have presented the renewable sources available in Algeria and their exploitation, the methods of artificial intelligence used in the supervision and finally the reasoned steering based on cases. The current exploitation of renewable energies is not extensive, but the program launched for the development of these energies gives importance to these energies, especially photovoltaics. In our work, we have illustrated that photovoltaic solar installations require real-time monitoring of their operation to increase their production and availability. This is done by steering. Our steering system generates the right actions to apply to the generator when its state changes using the case-based reasoning methodology. During this work, we found that the use of case-based reasoning methodology is tricky, especially in the choice of type of case representation and similarity and adaptation calculation methods. The richness of the case base has an important influence on the quality of the solutions obtained. The richer the base, the more appropriate the solutions.

As a perspective, we propose to add to this application a generator fault detection subsystem, an automatic optimal reconfiguration subsystem for better production and a system that allows the exchange of cases between the systems implanted in different sites.

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