Creation of a Knowledge Management Model Based on CBR: Application to the Maintenance of Autonomous Solar Photovoltaic Installations

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Abstract---This paper proposes a solution to facilitate maintenance activities associated with stand-alone solar photovoltaic installations in our developing countries. The autonomous photovoltaic solar installation is not connected to the electricity distribution grid. It meets the electricity needs on the one hand, of those who are too far away and who do not have access to the distribution grid. On the other hand, those who wish to overcome the constraints of connection to the electrical distribution grid. Our work focuses on the capitalization of knowledge in maintenance activity. The goal is to propose a model capable of helping maintenance technicians during their interventions by providing them with knowledge elements that will be drawn from a knowledge base. This knowledge base is built from the knowledge collected during previous maintenance activities in a given solar photovoltaic installation.

Keywords---CBR, knowledge management, learning, maintenance, solar photovoltaic

Introduction

The equipment of autonomous solar photovoltaic installations has, over time, become reliable. In addition, the installations are more durable thanks to the quality of the construction and maintenance of the equipment. However, maintaining the functions of the solar photovoltaic energy system can be problematic if maintenance and repair services are not provided. It is therefore important to have well-trained technicians with support to assist them in their daily work in order to preserve these assets. However, according to our field surveys, we have found that maintenance technicians, despite their proven competence, encounter a lot of difficulties during their maintenance interventions. Indeed, they are very often confronted with a lack of documentation of follow-up of the interventions of the installations where they intervene (Andrews et al., 2013; Veliz et al., 2021).

In this article, we propose the construction of an evolutionary knowledge base inspired by the CBR (Case-Based Reasoning). We have chosen the CBR because it favors good knowledge management and the learning of the users. Indeed, in the CBR approach, each problem-solving activity requires finding similar situations in a case base and then adapting them to the new situation. Thus, before each maintenance activity, the intervening technician will be able to have documentation of the history of the breakdowns that he can consult in order to better plan the intervention. After the maintenance activity, he will update the knowledge base with a report that he will have written. In this work, we will show the stakes of the maintenance in the PV systems, we will make then a

bibliographical review on the CBR which is the theoretical base of our remarks, then we will make a presentation as complete as possible of the proposed knowledge base by showing each element which composes it. Finally, we will end this article with the approach used for the writing of the maintenance report which constitutes the knowledge element to be transferred in the knowledge base (Craw et al., 2006; Mudambi, 2002; Pérez et al., 2021).

Maintenance issues in stand-alone PV installations

In many developing countries most populations do not have access to electricity. For facilities located in remote areas off the national electricity grid, solar photovoltaic (PV) power systems can provide the most convenient and least expensive means of accessing electricity. The solar PV system is often the most appropriate way to operate low-voltage electrical equipment and appliances, including electric lights, vaccine refrigerators, water pumps, televisions, and computers, in these areas. Although a solar PV system will produce electricity for 20 to 25 years with little maintenance and good weather resistance, underestimating maintenance can lead to a decline in production performance in the medium to long term with costly interventions when some neglected problems become clear.

However, maintaining the functions of the solar PV system can be problematic if maintenance and repair service is not provided. When any of these elements are missing, or done incorrectly, or done inappropriately in the context, system failure can occur. This is evidenced by the street lighting recently installed in some of Dakar's communes. Almost 80% of the installed streetlights are no longer working. It is not the solar energy that is failing, but rather a bad installation or bad management of their maintenance.

We can safely say that the success of any program of massive dissemination of the photovoltaic sector requires optimization of maintenance systems. This is where the possibility of satisfaction of the users of the sector lies, by maximizing the capacity of the photovoltaic panels to regularly provide the maximum of their capacity. In some projects of solar photovoltaic installations, a technical monitoring system had been instituted. This system had the merit of allowing the analysis of feedback in order to improve the quality of the equipment or to better respond to customer demand. But unfortunately, this system no longer works because it is no longer applied by the local technicians who no longer fill in the datasheets, thinking that everything is in their heads. And yet, the use of feedback is relevant in order to improve the quality of the elements of the solar photovoltaic installations. For better exploitation of this feedback, the quality of these data sheets should be improved (Dave & Koskela, 2009; Gautam & Kaushika, 2002).

We have also noticed that most users adopt unplanned maintenance because for them this method corresponds to lower expenses. This is not without consequences on the management of their installation, indeed, because of the lack of follow-up by the technicians, there is a strong loss of data of the return of experience, capital data to know the reliability of the components, and the conditions of use. The operating histories of the installation, if they are well maintained, constitute a knowledge base that can be used for diagnostic purposes. They can be a means to obtain a representation of the unknown symptoms/defects relationship. From a general point of view, the problem to be solved consists of evaluating the similarity of the vector of observed symptoms to a vector of reference symptoms that we know to be associated with the defect (De León, 2006).

Case-Based Reasoning (CBR)

In the current industrial context, it is necessary to have approaches and tools to help maintenance. These tools must allow to propose new concepts but also to strongly reduce the delays of the activity as long as some choices are not to be made or questioned, in particular when there is a certain recurrence in the activity. In order to have these tools, we can resort to methods based on feedback. These experiences are of particular interest and should be acquired during previous maintenance activities, but also by exploiting the knowledge and know-how of experts.
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Fundamental elements (CBR)

The CBR is a methodology that originates and develops from the works of artificial intelligence and cognitive psychology and is oriented towards problem-solving. It is reasoning by analogy that consists in solving a new problem from previous experiences (known and previously solved problems), each of which constitutes a case. The goal is to use the knowledge from previous cases and adapt it to solve new problems. Each case designates a set of problems associated with its solutions. A "source case" corresponds to a previous experience and can be used as a similar case to solve by analogy a current problem called "target case". The main steps of the CBR are the recollection (selection in the database of a case considered similar to the target problem), the adaptation (resolution

of the target problem based on the recollected case) and then the revision and the memorization (or learning: validation of the newly formed case and eventual storage in the database). In order to better understand the functioning of a CBR cycle, we will start with an example. This example starts from the observation made during the creation of a process. A case in this situation represents the different parameters of a past design (specifications, operating conditions, thermodynamic models, diagrams, ...). In the search for information for the creation of new processes, the engineer can compare his needs with those of past designs summarized for example in the form of a flowsheet. A similar flowsheet can then be used and modified, if necessary, to fit the new situation. In this example, we can see that a CBR system is able to solve new problems by adapting the solutions to past problems (Boral & Chakraborty, 2016).
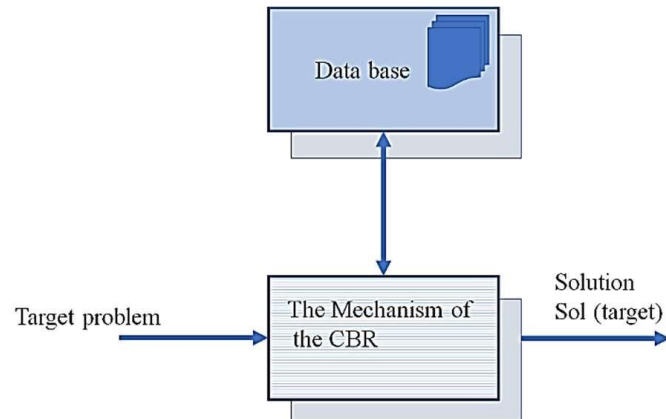

Figure 1. Operating principle of the CBR (d'Aquin et al., 2006)

The CBR cycle

According to Chakraborty & Boral (2017), the CBR cycle can be defined as a methodology capable of reasoning and learning, based on specific knowledge of past problems. The past knowledge is reused to provide a solution to a new problem. In the literature, we find a multitude of models that are used to represent the different sequential steps of the process deployed in a CBR (Mabkhot et al., 2020). In Figure 2, we find an R5 cycle proposed by Finnie & Sun (2003), which is used to model and build a typical CBR system. This cycle is an extension of the R4 model introduced by (Troiano et al., 2016). In the R5 cycle, each R refers to one of the following steps:

- Represent: It consists in shaping the target problem in view of the recollection by completing its description with the help of the domain knowledge.
- Recall: Its objective is to select and extract a source case similar to the target. The key point of this step is the similarity measure. (Target, Case Base) → (source, Sol(source)) ϵ Case Base - Reuse: Based on the remembered case, reuse seeks to solve target. The CBR system adapts the solution of a remembered case to meet the requirements of the new problem. This phase is also known as "case adaptation" and can be formalized by (Source, Sol(source), target) → Sol(target). There are many approaches to adapting Sol(source) to target. Reuse can be as trivial as directly proposing Sol(source) as a solution for target, without any changes (used for decision support or to justify a choice). But most of the time, this adaptation step seeks to define the gap between the source and target problems and then modify Sol(source). Adaptation methods must answer the following two questions: What should be changed in Sol(source)? How should this change be made?
- Review: Following the adaptation, the proposed Sol(target) is tested, by simulation or experimentally, to check its adequacy and relevance to the target. If the test fails, the solution is corrected to eliminate the last discrepancies. Note that these testing and repair steps can be an integral part of the adaptation.
- Remember: If it is appropriate, bring a real added value to the case base, the new resolution episode is stored in the base. This step makes the CBR a self-learning system, which gives it the advantage of extending its coverage of the space of possible problems and of increasing its efficiency. With this step, the problem of the maintenance of the case base and especially of the knowledge management in such a system inevitably arises.
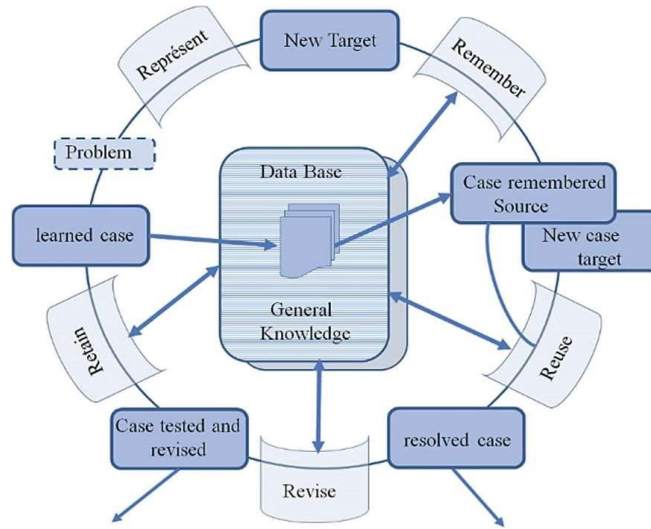
Figure 2. The R5 cycle of case-based reasoning (Veloso, 1994)

Several strategies and mechanisms have been proposed in the literature to meet the needs of each of these stages. We focus here on the similarity search phase. However, it should be noted that even if the CBR allows the development of knowledge-based systems that work quite well and are very successful in the industry (Jabrouni et al., 2013), its engineering remains a difficult problem. Thus, even if it has many qualities, the CBR is not a knowledge-based system that "learns to solve problems by solving problems" because it cannot dynamically evolve its representation of experiences. Three main causes for this limitation are proposed in (Kwon et al., 2018): case model "too well structured and therefore too constrained", the paradox of "fixed knowledge that evolves" and the reductive hypothesis of "it is good for me now so it will always be good for everyone". As for the effectiveness of case-based reasoning (CBR), it is no longer in question when it is necessary to reuse knowledge. Its proven effectiveness in knowledge management and especially in the field of industrial maintenance encourages us to use it in this article.

Presentation of the knowledge base

The knowledge base inspired by the CBR is represented in the model in figure 3. The maintenance technician is required, in the phase of diagnosing a failure, to use the following sub-model and under the control of his department manager. Thus, to enable him to carry out his maintenance activity, he must always look for similar situations in the case database before solving a problem and then adapt them to the new situation.
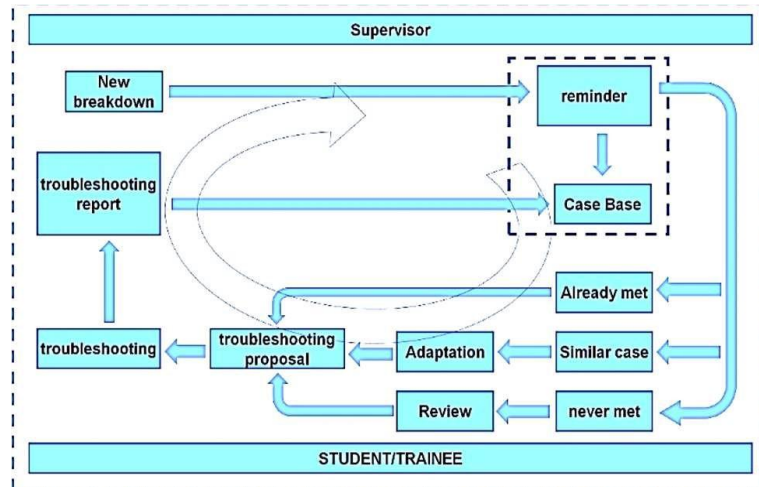

Figure 3. Searching for information in the case database (Gueye et al., 2021)

The case base

A case is commonly a specific problem that has been identified, solved, stored, and indexed in memory with its solution, and possibly the process of obtaining it. The case base is the set of cases of the system, which are given by the user in our system. In the recollection phase, we look for all the previous cases that can help to solve the failure of a system, starting from the description of the problem. This is a knowledge search that will be done in the case base. It is essentially a set of knowledge reconstruction operations allowing to extract the knowledge needed to solve the system failure. This phase of recalling similar cases depends essentially on the representation of the cases, the structure of the case base, the similarity measures, and the accuracy of the expected response. This similarity measure looks for correspondences between the problem descriptors of the source cases (case base) and those of the target case (new cases). The objective of these similarity measures is to find in the case base, the case similar to the current problem in the sense that it is easily adaptable to this new problem. After defining the problem according to a well-normalized description, the recollection module launches the algorithm to search the case base for similar models. In our system, we used the Levenshtein algorithm (Levenshtein, 1966), to estimate the percentage of similarity between the source case and the target case.

Principle of the Levenshtein algorithm

This algorithm, commonly called Levenshtein's distance, measures the degree of similarity between two strings of characters. It is equal to the minimal number of characters that must be deleted, inserted, or replaced to go from one string to the other. It is a distance in the mathematical sense, so in particular, it is a positive or zero number, and two strings are identical if and only if their distance is zero. We also have symmetry properties, and the triangular inequality of geometry is also verified here. We have been inspired by this algorithm to realize the application on Excel which allows us to search for similar cases in the case base. This algorithm of similarity search is implemented in an Excel workbook which contains all the reports of the maintenance activities carried out by the technicians during their passage in a given installation. This workbook is therefore scalable and will represent the case base. Below is an example of a search for a case in the case database. This case base contains maintenance histories on two solar photovoltaic installations.

Table 1
Similarity search in the case base

Please enter your search here				
CODE	**DECLARED FAILURE**			
MF03	Degradation due to heat		xxxxxxx	
code	DIAGNOSED FAULT	SCORE	DATE	Document CR
MF01	Rust by water infiltration		12/10/2018	Doc_maint_MF01
MF02	Solar modules with different performance		08/12/2018	Doc_maint_MF02
MF03	Degradation due to heat	score (100,00%)	09/02/2019	Doc_maint_MF03
AD01	Disconnection of welds		07/07/2018	Doc_maint_AD01
AD02	water penetration into the junction box		15/09/2018	Doc_maint_AD02
AD03	Degradation due to heat	score (50,00%)	19/01/2019	Doc_maint_AD03

These installations are located in a village in the department of Tivaoune in Senegal. It can be noticed that the failure declared "code MF03", which is the subject of the research, gave a better score of 100%. So in the case database, we find that on 09/02/2019 a technician had intervened in this same problem. This phase of determining the similarity leads us to three possibilities: these possibilities are given by the Levenshtein algorithm that we implemented in the case base (Table 1). Indeed a similarity search in the base of cases always gives three possibilities (case never

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encountered 0%, similar case 80% and case already encountered 100%). Below we propose for each case a troubleshooting methodology that the technician in charge of maintenance will use.

- Never encountered case: percentage 0%.
  We are facing a never encountered situation, for its resolution, we propose the following generic diagnosis methodology usable in various application domains (Paquette et al., 2006). It is composed of five principles that together distribute control among the four diagnostic sub-procedures. It allows to generate and test one by one, and systematically, the various components of the target system (Figure 4).
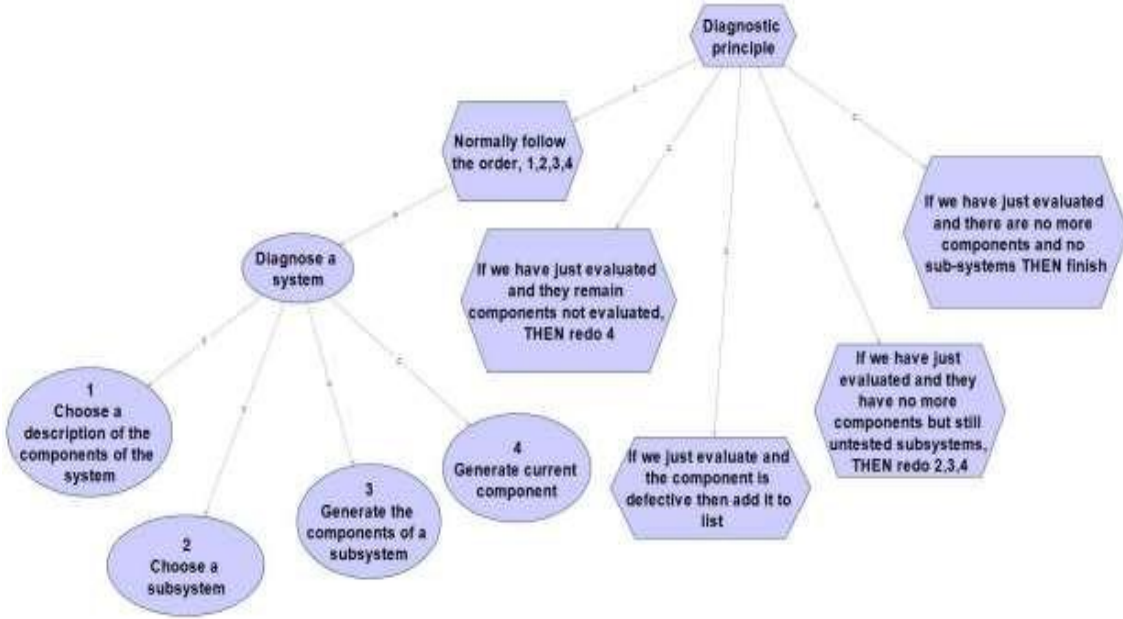

Figure 4. Generic diagnostic methodology

- Similar cases: percentage 80%.
  Depending on the percentage of similarity between the source case and the target case (80% for our system), an adaptation strategy will be implemented, which consists in proposing a solution to the new problem from the solutions belonging to the recalled source cases (De Mantaras et al., 2005). This phase can be done either through human intervention (manual) or in an automatic way using algorithms, methods, formulas, rules, etc. In our case, given the importance that we attach to learning for the improvement of the technician's skills in the maintenance activity, we recommend a manual adaptation for this phase. This adaptation phase consists in transforming the source solutions (Sol(source)) into an appropriate solution Sol(target) and we propose the following resolution approach
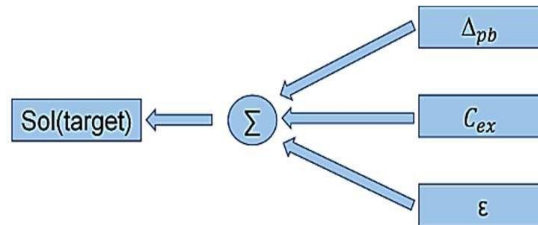

Figure 5. Problem-solving approach for a case similar to 80%

Δpb : Contains all the information about the links between the source and target problems
Cex : The set of experiential knowledge that the maintenance manager (expert) is able to mobilize for solving the target case ε : The experiential knowledge of the maintenance technician The information about the links between

the source and target problems (Δpb) is obtained from the case base. To obtain this information it is sufficient, as mentioned above, to query the case base for a similarity search between a target case and a source case. Once the similarity search algorithm has found one or more similar cases, all the maintenance reports related to this similar case are retrieved through links. It is enough to study these documents to extract the Δpb and this synthesis work will be done by the technician.

The aim is to develop the technicians' ability to identify and classify the characteristics and dimensions of a problem, to compare the elements of the problem, and to find the relationships between them. To implement the experiential knowledge in this relation we will rely on the theory of socialization and externalization of knowledge (Nonaka & Takeuchi, 1996).

- Cases already encountered: percentage 100%.
  In this phase, the target solution is 100% located in the case base, as long as a troubleshooting account of the problem exists. The difficulty here lies in how to solve the new problem from a previous solution. This phase will allow us to encourage metacognitive activities in the technician to better promote his autonomy. This will consist in bringing him to understand, use and master the problem-solving process based on the solution of the source case. As the technician becomes more autonomous, he/she will develop self-management skills that will serve him/her throughout his/her life. Although we encourage the technician's autonomy, the team leader, who is the expert in the field and who has the experiential knowledge that we want to apply to the resolution of the target case, always supervises the technician's activities at each stage.
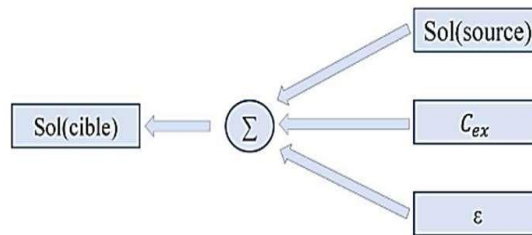

Figure 6. Problem solving approach for a 100% similar case

Presentation of the knowledge base

To create the document to be transferred to the knowledge base, we will use the technique that consists of trying to access the subjective experience of the technician during the maintenance activity (this experience includes the sensory and the emotional, the thought and the gestures that are not yet conscious) of the latter. This necessarily involves verbalizing his activities in the form of a report after each maintenance activity. This developed technique allows to facilitates the expression of this internalized knowledge and tries to access the subjective experience of the subject (Wang et al., 2016; Mouchet et al., 2011; Vermersch, 2006). Since we favor learning in the activity, we have chosen the method of verbalization after the action (Theureau, 2020), quoted by (Madhusudan et al., 2004; Changchien & Lin, 2005). Thus, after each maintenance action, the subject will try to comment on his activity. This report will allow the subject to step back and reflect on the experience, on the activity carried out.

After writing the report, the technician must make a presentation in handwritten form but also orally to the team leader. The oral presentation of the report, once back from the maintenance activity, could play this role of reflection on the experience. This methodology is discussed by (Chiva-Bartoll et al., 2020), "Being aware of one's experiences is nothing more than having them available". The interaction with this expert appears to be the driving force behind the development of thought, which becomes autonomous at the end of the internalization process. (Mohler et al., 2009), thus insists on the relevance of discussing one's experience and having a reflective approach to professional situations in order to produce knowledge.

The report will be a means of communicating to highlight one's perfect mastery of the maintenance activity from start to finish. The entire process, from analysis to problem resolution, will be told and formalized in the form of an articulated story. The style of narration will be borrowed from Patriottta, who in one of his articles described the verbalization of a subject as a double structure of detective stories: first the description of the problem to be solved (by analogy with the crime) and then the description of the process of analysis, of diagnosis leading to the solution (by analogy with the police investigation). He considers that this narration of the plot and this double structuring allow tacit knowledge to be brought out and shared (Patriotta, 2003). This well-developed account will be transferred

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to the knowledge base where a keyword search will allow it to be retrieved when needed. The storage of a new case thus makes it possible to enrich the case base and to increase the experience of the system (Haouchine et al., 2009). Thus the case base evolves as new cases are added to take into account the new solutions found and the way the cases were solved. In all cases, we require, for faithful restitution of the course of the maintenance activity, that the intervention report includes the headings described in figure 7.

Figure 7. The elements that make up the maintenance report

Conclusion

In this article, we have tried to present the knowledge base in a general way. Our main concern was to allow a technician to be at ease during his maintenance interventions in a solar photovoltaic installation. The tool presented allows him to have at his disposal very comprehensive and fairly explicit documentation that will facilitate his maintenance operations. Indeed if we refer to the results obtained during the experiment (see Table 1), on 02/09/2019 a well-written report clearly describing the failure and the methodology used to troubleshoot is stored in the case base under the name "doc.maint.MF03". This document, extracted from the base of cases and analyzed, enabled the technician deployed to the site to correctly repair the fault.

The proposed strategy is centered on the production of a maintenance activity report by the technician, a work done with his team leader. The explanatory interview with his team leader, based on the evocation of one or more reference experiences, allows the emergence of awareness promoting the appropriation of the experience as a knowledge base. This knowledge base is intended for all the technicians of a maintenance team. It should be updated after each maintenance activity by the technician concerned under the supervision of his team leader.

The results obtained in this work have given us complete satisfaction as we have developed and provided a team of maintenance technicians with a tool capable of helping them in their daily maintenance activities. However, this work is not very exhaustive from the point of view result, indeed for the sake of clarity of the tool, we have developed much more the strategy used to develop the case base with documentation (maintenance report), on previous maintenance activities, as faithful as possible. With the data that we obtained in the case base after three years of maintenance activity, we will soon count the exploited to see the beneficial impact of our tool on maintenance activities in autonomous solar photovoltaic installations. Then, we also intend to refine this work by improving the diagnosis of a fault to offer a more efficient model that can detect and locate faults in an autonomous solar photovoltaic installation.

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