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Integrating Parabolic Trough Solar Fields into Computerized Maintenance Management Systems

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Abstract. Computerized maintenance management systems for power plants are not well suited for application in solar fields. They work well for tracking maintenance requirements on the hundreds or even thousands of pieces of equipment in conventional power plants, but they do not work as well tracking the maintenance requirements on hundreds of thousands of identical pieces of equipment found in a solar field. A database application, known as a field status program, is being developed for tracking the maintenance and status of collectors and components in parabolic trough solar fields as a complement to the computerized maintenance management system. This system, patterned after a similar system developed by the KJC Operating Company in the 1990s, provides a valuable tool for the O&M of parabolic trough solar fields. This paper describes the development and application of the tool and the new expanded capabilities that are being added to further enhance the O&M of solar fields.

Keywords: Field Status Program (FSP), Computerized Maintenance Management System (CMMS), Corrective Maintenance, Preventive Maintenance, Predictive Maintenance, Concentrating Solar Power (CSP).

1. Introduction

Over the last 30 years, there have been major advances in the information systems used in the operation and maintenance (O&M) of utility scale power plants. This falls in a class of software referred to as asset management systems or in the case of maintenance, computerized maintenance management systems (CMMS). A typical CMMS software package automates the work management process necessary for identifying, planning, and executing maintenance activities for power plants. “The goal of any work management process is to track all maintenance, repair, and engineering information, including all costs and details, to a particular equipment, item, asset, building/floor/room locator” [1]. A well implemented CMMS tracks all stages of the maintenance effort: problem identification, scheduling repairs, procurement of materials and spare parts, inventory management, planning of the work effort, access to equipment documentation, and interfacing with financial systems and reporting. With the adoption of CMMS software, this work management process is more organized, repeatable, and disciplined because the CMMS enforces workflows and defines input and output data structures. This has resulted in major cost savings and improvements in availability and performance while reducing the staffing required to maintain plants. Figure 1 shows an overview of the typical maintenance work management process.

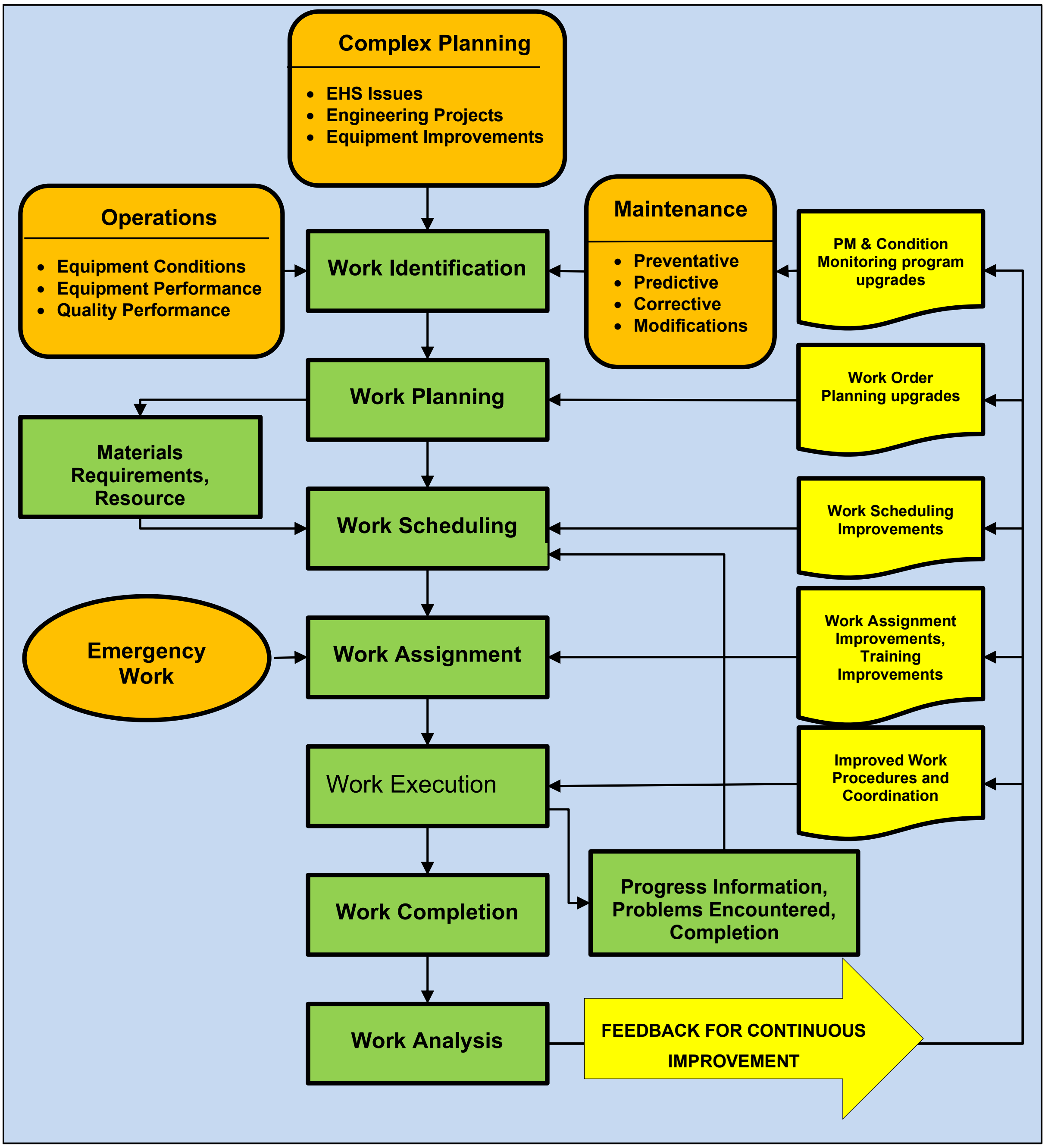

Figure 1. Work management process overview [1].

Maintenance activities fall into three categories: corrective, preventative, and predictive maintenance. Corrective maintenance is when equipment has a failure and must be fixed. This is like having a flat tire on your car and needing to repair it. Preventive maintenance is schedule-based maintenance, such as changing your car's oil every 5000 kilometers. Predictive maintenance uses diagnostics to identify a problem before a failure occurs. For cars, they typically have sensors that if they detect a problem, trigger a "check engine" light. Power plant CMMS's track all three types of maintenance activities. Corrective maintenance activities are often identified by an operator that has a problem operating a piece of equipment. In this case the operator will input a work request into the CMMS. All the normal preventive maintenance schedules are entered into the CMMS proactively so that the system generates a list of scheduled maintenance activities to be performed. Predictive or condition-based maintenance is generated by scheduled inspections, testing of equipment, or monitoring of process variables.

2. Maintenance of solar fields

Using CMMS software to manage the maintenance in concentrating solar power (CSP) plants is considered a best practice [2]. These systems work well for the equipment in the central power block but are not as well suited for managing the maintenance of equipment in solar fields. There are several reasons why conventional CMMS systems are not ideal for managing solar field maintenance.

2.1. Equipment identification

CMMS's typically track maintenance by equipment ID. This works well when tracking maintenance on a pump or valve in a power plant, but the systems are typically not well suited for tracking equipment in large solar fields. A solar field may have hundreds or thousands of individual collectors or heliostats. Solar field maintenance management in parabolic trough plants requires tracking the status of the components on each individual solar collector assembly (SCA), as well as monitoring the status of the mirrors, and the receiver tubes. The solar field in the 250 MW Solana parabolic trough plant, located in Gila Bend, Arizona, USA for example, has 3,232 solar collector assemblies (SCAs), each with its own components that need to be monitored, maintained, and tracked. In total there are almost 100,000 receiver tubes and 900,000 mirrors to monitor and track. In addition, the solar field equipment is spread out over 750 hectares. Tracking mirrors and receivers individually quickly overwhelms a traditional CMMS, creating an administrative burden on the staff and potentially overloading the CMMS software. Typically, in a traditional CCMS, each individual piece of equipment needs to be entered into the system. While this works for 6 high pressure feedwater pumps or 10 HTF pumps the idea of entering equipment ID's for 900,000 mirrors is not practical especially considering that over the life of the project the majority of the mirrors will not require any maintenance. Although CMMS systems can be used to monitor the maintenance of equipment in solar fields, CSP plant operators often rely on other work arounds for solar fields, often defaulting to paper lists and spreadsheets.

2.2. CMMS customization & implementation

Maintenance of collector technology is different from most conventional equipment tracked in CMMS systems. Setting up the CMMS software will likely require customization, which means additional time and cost for implementing these systems. CMMS systems are typically implemented by the O&M organization at CSP plants. It can take a year or more for the O&M company to have their CMMS fully implemented. As a result, the system misses out on a lot of information on failures and repairs that occur during construction, commissioning, and early operation of the plant. This is when design or early failure issues have the largest impact. These can be important issues or events that influence the availability, reliability, and lifetime of solar field equipment.

2.3. Solar field status program

KJC Operating Company (KJCOC) operated the Solar Electric Generating Systems (SEGS) III to VII parabolic trough plants located at Kramer Junction in the 1990s through early 2000s and developed a customized database program referred to as the Field Status Program (FSP) [3]. The FSP used a Failure Reporting, Analysis, and Corrective Action System (FRACAS) methodology to track the failures of solar field equipment. FRACAS is a system that provides a process for reporting, classifying, analyzing failures, and planning corrective actions in response to those failures [4]. The KJCOC FSP enabled the solar field technicians to easily input new failures, identify the cause of the failures, and track repairs. The FSP database was installed on a laptop computer that the solar field technicians carried with them as they conducted their work in the solar field. The FSP had a user interface that showed a graphical depiction of the collector and highlighted any existing problems with the collector so that new failures could be easily identified. When maintenance was completed, the database was updated to show the repaired status. A historical file was created so that all information on failures could be tracked. The program generated summary data so that the status could be reported, or historical failure patterns could be trended. The National Renewable Energy Laboratory (NREL), for example, used the FRACAS data from the FSP to evaluate trends in parabolic trough receiver failures at the SEGS [5, 6]. This helped identify the common failure causes and helped identify the issue of hydrogen build-up in receivers. KJCOC used the FSP to complement their conventional CMMS program used for the plant. The conventional CMMS was used to schedule and track labor and material costs, and the FSP was used to track the location of specific failures and repairs in the solar field. The FSP and the conventional CMMS worked together in a complementary manner. Although the KJCOC FSP proved to be a successful tool to support the maintenance of parabolic trough solar fields, it was never made available to the CSP industry at large.

3. OPTOM project

The U.S. Department of Energy is supporting a new cooperative research effort with Solar Dynamics titled Optimization of Parabolic Trough Operations and Maintenance, or “OPTOM”. This project is looking at ways to improve the O&M of parabolic trough plants through the development of new tools and systems. Solar Dynamics has partnered with Atlantica Sustainable Infrastructures, the operator of the Solana parabolic trough solar power plant, to support this effort.

3.1. Solar field CMMS

One of the objectives of the OPTOM project was to address the need for a CMMS optimized to work for solar fields. The initial concept was to develop a standalone CMMS system for the solar field. Atlantica indicated that they already had a CMMS system for the Solana plant, including the solar field. What they needed was something like the KJCOC FSP that could complement the existing CMMS, rather than replace it. The team had experience using the original KJCOC FSP system and decided to develop an application that reproduced many of the key features and expand on the original concept. The project is developing and testing a prototype FSP software referred to as FieldStatus™ for the Solana solar field. This paper provides an overview of the system development efforts, lessons learned from the development, and a view to where the system might evolve in the future. The project focused on developing a prototype system that could be field tested for the Solana solar field to evaluate the system capabilities, to determine whether the system would add sufficient value and complement the existing CMMS to be worth implementing long term at Solana and other Atlantica plants.

3.2. Field status program framework

Key elements of the new FieldStatus program include the system hardware/software architecture, the solar field equipment hierarchy, the FRACAS coding system, a database for storing collector failure/repair/status information, and custom field and office computer applications.

3.2.1. System architecture

The FieldStatus program is being developed to use the system architecture shown in Figure 2 below. It is made up of a primary database with local access via an on-site corporate network and is extended to a secondary cloud-based system. The cloud-based system provides several important capabilities including offsite data backup and isolated read-only access for external viewing and or further data analysis. In addition to the on-site local primary database, multiple field tablet computers host the FSP application used by the solar field technicians while an office-based PC is used to host the FSP application for management reporting and system management. Both the field tablet and desktop applications utilize a Python-based front-end Graphical User Interface (GUI). Each field tablet computer has a synchronized local copy of the primary database since a real-time database connection while out in the solar field is not possible nor practical. The field tablet computer is the primary means of solar field maintenance data entry by maintenance staff and the desktop application is the primary means of viewing and approving data by management staff.

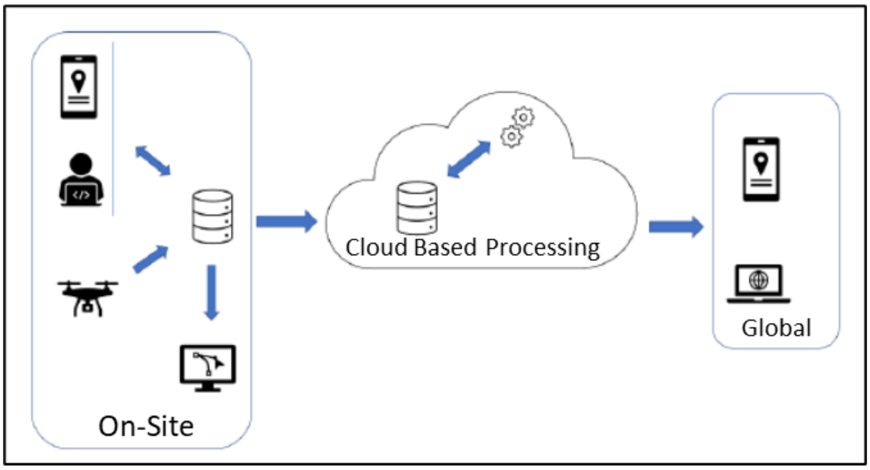

Figure 2. System Architecture for FSP.

3.2.2. Solar field equipment hierarchy

An equipment hierarchy is a numbering system for identifying and locating equipment in the plant. Most plants already have an equipment hierarchy used to identify solar field collectors and components. Figure 3 presents the first two levels of a generalized equipment hierarchy for parabolic trough solar fields. This is the underlying equipment hierarchy used by the system; however, the hierarchy can be easily mapped such that the user only sees the same equipment hierarchy they use at their plant.

3.2.3. FRACAS coding system

A failure reporting, analysis, and corrective action system methodology was developed to track the failures of solar field equipment. This identifies specific failures for each of the components in the solar field. For each component, the FRACAS coding identifies the types of failure that may be seen, the potential causes of the failure, the impacts of the failure, and the type of repair. For example, the parabolic trough receiver tube (aka heat collection element or “HCE”) might have failures of broken glass envelop, loss of vacuum, absorber tube coating defect, bowing of the absorber tube, etc. The cause for a broken glass envelope might be from a broken mirror, a sticking ball joint that bowed the absorber tube, mechanical damage to the

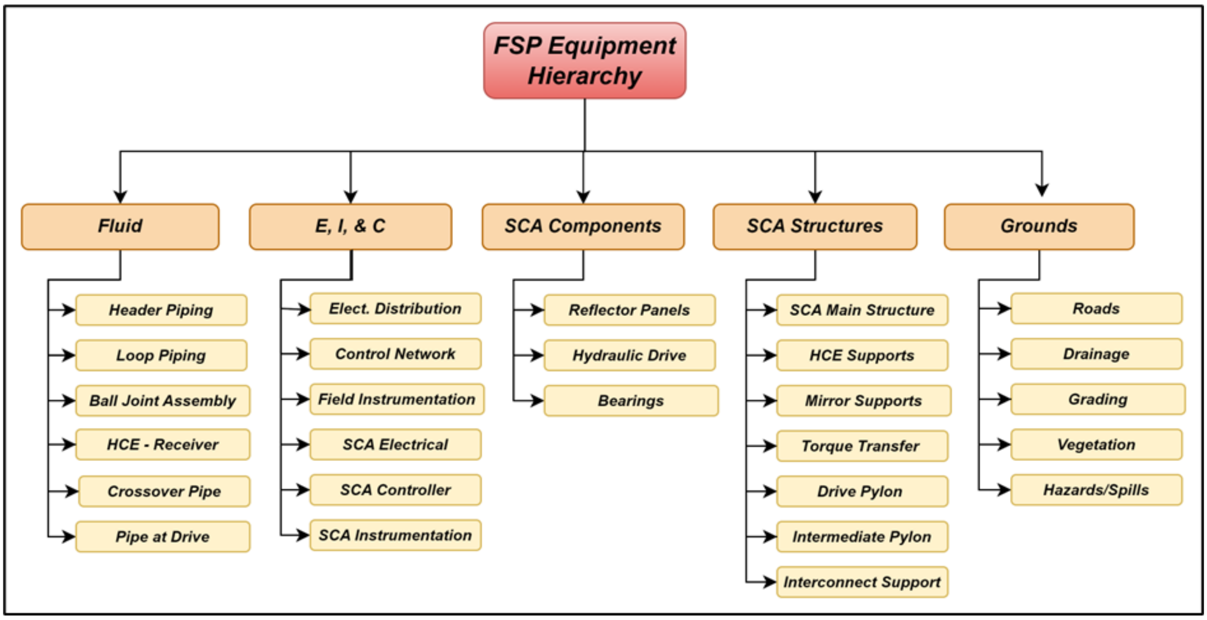

Figure 3. New Equipment Hierarchy for Field Status Program.

collector, etc. Standardized coding enforces uniform reporting and allows for more accurate statistical analysis of failures. But it relies on the field technician to properly identify the failures and causes. It is important to implement a quality process to validate that failures are correctly reported.

3.2.4. FSP database

The heart of the FSP system is a relational SQL database that contains information on the current and historical solar field component failures, repairs, and equipment status. Most people are familiar with spreadsheets and typically default to using a spreadsheet to track equipment, but databases are better suited to track data for maintenance applications over time. In particular, they provide efficient and fast access to large data sets and are well developed for concurrent multi-user data access.

3.2.5. FieldStatus tablet application

The FieldStatus field tablet application is designed to operate on a ruggedized tablet computer that is carried by solar field technicians and operators. The tablet selected for initial testing is the Panasonic Toughbook G2 and was picked for its portability and durability, its ability to function outdoors in the summer heat, its screen with good visibility in direct sunlight, the ease-of-use touch screen, and a long duration battery that will last a full shift without charging. The prototype system runs in Windows, allowing for simplified use during the prototyping stage.

One of the key features of the KJCOC FSP application was the user-friendly interface that showed a graphical image of the collector, allowing component failures that existed in the database to be easily viewed while the solar field technician was working in the solar field. This allowed for efficient identification of new problems and error checking of problems in the database. This is a huge advantage over using a form based interface commoon for conventional CMMS systems. This was identified as one of the most important features to include in the new FieldStatus prototype. Figure 4 shows an example of the collector graphical user interface developed for the Solana E2 SCA. Although many conventional CMMS systems include portable applications, they typically rely on form-based queries or tabular reports to access information. This is a slower and less efficient process for field technicians as they are moving through large solar fields.

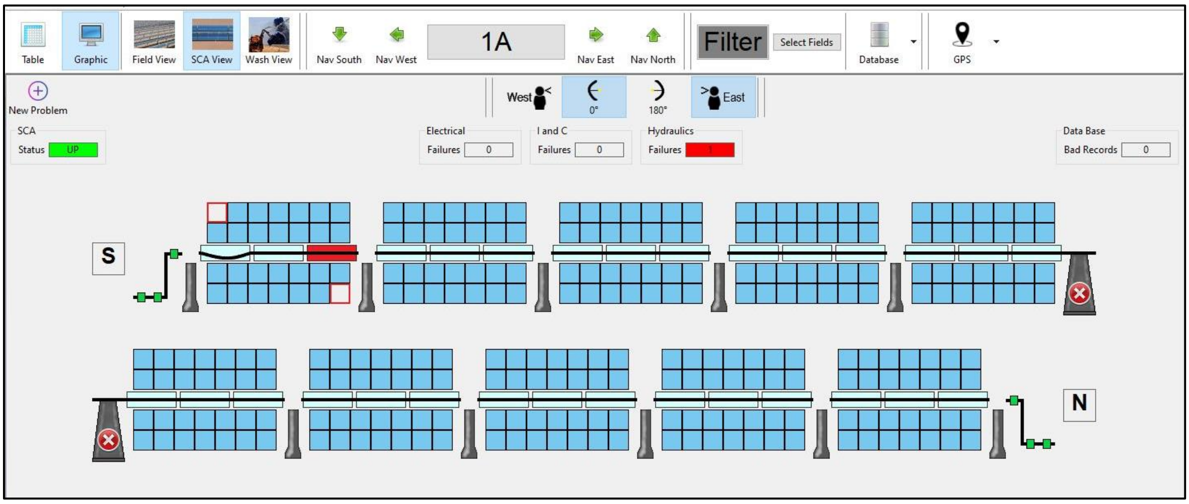

Figure 4. The collector view graphical user interface for the FieldStatus prototype (sample data showing different failures).

The FieldStatus tablet application includes two additional ways to view data, in a tabular format or mapped in a Graphical Information System (GIS) map of the solar field. The tabular data view allows users to view the historical failure and repair data for an individual collector, a section of the solar field, or for the entire solar field. The user can view either the detailed failure and repair data or generate tabular count of failures and repairs. The reporting allows for filtering of data, so that only the problems of interest, the time period of interest, and whether they are open problems or histroical problems that have been repaired, can be inspected. The mapping view allows problems to be mapped out on a view of the solar field.

3.2.6. FieldStatus office application

A version of the FieldStatus application has been developed to support solar field maintenance management. This version focuses more on the planning and reporting aspects of solar field maintenance, as well as FSP administrative features. It is designed to take advantage of the larger displays typically found on desktop computers.

3.3. Enhanced FSP capabilities

The core of the proposed FieldStatus program builds on the experience from the KJCOC FSP. A number of new capabilities and features are being developed to enhance the value of the system to O&M operators.

3.3.1. Aerial drone inspections

Solar fields are spread out over large areas. Experience has shown that periodic surveys of the collectors is needed to identify failures and potential issues. In recent years a significant effort has gone into using aerial drones for various survey activities. They have been used to survey fields to look for broken mirrors and receivers, and to evaluate collector optics. But in recent years, drones are increasingly being used to survey receiver glass temperatures to monitor the build-up of hydrogen in the receiver vacuum annulus. Many plants are repeating the surveys on an annual basis to evaluate the progression of hydrogen buildup. Integration of drone data into the FSP allows historical trending of information gathered.

3.3.2. Mapping

Graphic information system (GIS) technology has been implemented into a map view, allowing mapping of failures or other status information from the collectors to be presented. This can be used to show the location of failures in the solar field for planning or inspections. Figure 5 shows a map of mirror cleaning status.

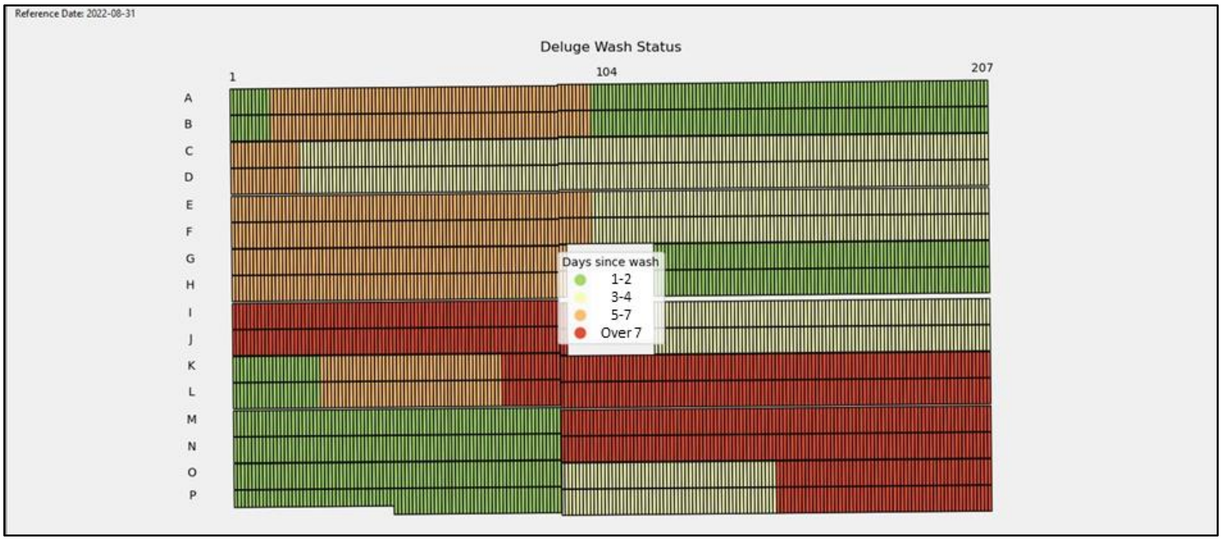

Figure 5. Mirror Cleaning Status Map (FieldStatus prototype with sample data).

3.3.3. Global positioning system (GPS)

The accuracy of GPS units have improved such that they can be used to locate where an individual is in the solar field. This allows a number of potentially interesting capabilities that can be integrated into the FSP. The FSP can automatically pull up information about the collectors around the user freeing them from having to manually select the collector of interest. The system can be used to show the user where they are on the field map. This allows the user's movements through the solar field to be tracked to allow time allocation to particular activities or to conduct efficiency movement studies of staff. If a real time communication link is possible between the tablet computer and the central network, staff locations can be monitored at all times in the plant for improved staff coordination, efficient supervision, and safety in emergency situations.

3.3.4. Monitoring of mirror cleaning

Tracking mirror reflectivity and cleaning efforts are two of the key maintenance challenges in CSP plants [2]. In many facilities, significant effort is expended in monitoring mirror cleanliness in order to prioritize cleaning efforts and to understand the impact of mirror cleanliness on plant performance. The FSP can be used to track mirror cleaning activities, improve mirror cleaning planning, and to improve mirror cleanliness monitoring. As shown in Figure 5, the FSP can be used to track when mirrors are cleaned. This can be used to help optimize mirror cleaning efforts. One approach for prioritizing mirror cleaning is to simply focus the cleaning efforts on the collectors that have gone the longest without cleaning. One interesting potential is to use the FSP GPS capabilities to track mirror cleaning activities, so that the collectors cleaned can be automatically recorded.

Many plants take periodic sample measurements of mirror cleanliness to estimate an average plant mirror cleanliness. But unless a sufficiently large and random sample is taken, including both clean and dirty mirrors, this does not provide a particularly accurate estimate. This approach also cannot extrapolate the data when readings are taken several days apart.

We believe a more accurate approach is needed to track the mirror soiling rates and monitor the days since each collector was cleaned. Then the cleanliness of each individual collector can be estimated based on the days since it was last cleaned to get a average field cleanliness. This type of approach can be implemented into the FSP.

3.3.5. Field inspections

It is often necessary for regulatory reasons to conduct inspections of the solar field. This may be to monitor leaking of ball joints or inspections for protected species. The FSP can be set up to monitor and record historical inspection data for different items. The GPS feature can allow exact locations of identified issues to be tracked.

3.3.6. Reliability data

Although the system is being designed to improve the effectiveness and efficiency of solar field maintenance, one of side benefits is the gathering of data that can be used to monitor the reliability, availability, and maintainability of solar field collectors and components. Although a fair amount of information was known about the reliability of the solar field components in the SEGS plants in large part due to the FSP, very little information is known about the reliability, availability, and maintainability of the newer generation of CSP plants built in recent years. Systems like the FSP are needed to provide the data for industry to understand the issues with the technology to be able to improve it and make it more competitive in the future.

3.3.7. Interface with existing CMMS

In order to maximize value, it is important to understand how the FSP will integrate with the CMMS used for the plant. In the case of the KJCOC FSP, the FSP was treated as a standalone but complementary tool to the CMMS. The CMMS was used to track time charged and expenses for materials and spares, but not to track the work completed on individual SCAs in the solar field. The FSP was used to track failures and repairs to individual SCAs. However, for most CMMS systems, it is possible to create links that allow some level of direct communication between the FSP and the CMMS. This likely requires additional custom programming of the CMMS but can provide improved efficiencies and effectiveness for maintenance. It is essential that the FSP integration with the CMMS maintain the system’s workorder audit integrity. In the case of the Solana CMMS, the notification process workflow in their CMMS provides a safe way to input new failures without compromising CMMS data integrity and can be done using an existing file data input process.

3.4. Future FSP applications

3.4.1. Solar field construction monitoring

As previously indicated, one of the important issues for tracking solar field maintenance is understanding what happens to the solar field during construction, commissioning, and the early operating period. This is when many issues occur due to construction or assembly defects, equipment may be improperly operated, or defective components or infant mortality failures occur. The FSP should be utilized during this period to track the initial assembly, installation and commissioning progress of the solar field. This would allow the system to be fully implemented and operational when the operating company takes over the operation and maintenance of the plant.

3.4.2. Implementation for heliostats

The FSP has been developed and used for parabolic trough collector technology. The system is ideally suited to be used for heliostats. As newer plants are using smaller heliostats, the need for an FSP type system becomes even more important to track failures and repairs.

3.4.3. Solar process heat plants

There appears to be a growing interest in solar industrial process heat (IPH) plants to help decarbonize industrial processes. Solar IPH plants tend to be much smaller in size than CSP plants and are less likely to have dedicated O&M teams to monitor and maintain the solar fields. The FSP has become an important tool for managing and maintaining the solar fields in multiple locations.

4. Conclusions

Although conventional CMMS systems are frequently implemented to track the maintenance of solar fields, they typically do not provide information in a way that can efficiently support the O&M of large solar fields. This paper highlights the potential value of adding a field status program to complement the conventional CMMS system to better support the O&M of large CSP solar fields. A field status program can provide access to current and historical solar field collector and component status, failure, and repair history in a user-friendly graphical user interface can help O&M companies optimize the O&M of solar fields.

Data availability statement

Data or information on the FieldStatus application can be requested from the authors.

Author contributions

Hank Price performed writing – original draft, conceptualization, and supervision. Rick Sommers, Luca Imponenti, and Keith Boyle performed writing – review and editing, and software development of the FieldStatus program. Manuel Diaz Callejero performed writing – review and editing of the paper.

Competing interests

Solar Dynamics is working to develop and provide products and services to support the O&M of CSP power plants.

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