Paladin® Monitoring and Predictive Software for Electric Power Distribution Systems

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Abstract – Electrical power distribution and communication systems are becoming more complex, more compact, and more sensitive to abnormal conditions. A streamlined process for monitoring the health of the system and adjusting to damage or impending failures is needed to reduce reaction time and maintain critical functions. General Atomics and EDSA have integrated the capabilities of a fast system circuit analysis code with the Paladin®[1] software, so as to monitor sensors continuously, reconfigure the system circuit models automatically as the system state changes, compare the system status with analytical predictions in real time, and display status. The initial versions of Paladin have been deployed, and validated at selected Federal Aviation Administration Air Route Traffic Control Centers. The code and its application for electric ships are described.

Key words: Electrical power distribution, health monitoring & control software

1 Introduction

There are several commercial software packages that can analyze complex electrical circuits for power distribution networks. The EDSA power system analysis and simulation package, however, has an extensive database that relates the electrical components in the model to the characteristics of actual hardware components to allow a realistic & accurate model for prediction of system performance. The EDSA/General Atomics Paladin® software package embeds the EDSA simulation engines and logical electrical model, into a real time Supervisory Control and Data Acquisition (SCADA) environment. Paladin collects data from sensors that measure system performance at critical points and changes the EDSA logical model automatically as the component states change (e.g., switches open or close, machines start or stop, etc.) It continuously compares predicted values from the simulated logical model, with the measured values from the sensors. When a difference between a predicted and measured value exceeds a threshold level, the display of system status indicates a change from a “green” to “orange” or to “red” condition and, if warranted, an alarm is indicated so human action can be taken. The entire history of events is recorded for further analysis if desired.

The Paladin system can be modified to use artificial intelligence techniques to reduce reaction times and adjust to damage or impending failures automatically. Plans are underway to implement Artificial Intelligence features into Paladin to allow for an immediate and automatic response for system efficiency optimization or for maintaining critical functions in an emergency situation. This can reduce maintenance costs, maintain critical functions, and/or save lives in battle situations.

The Paladin software system has been successfully implemented at three Federal Aviation Administration (FAA) sites in the USA and is planned for installation at others. It is applicable to any power or communication system, in particular, to a well bounded and defined system such as a ship.

2 Monitoring and Control Concept

The purpose of Paladin is to transform the traditional, passive electrical distribution system SCADA methodology into a diagnostic, predictive, proactive process for system monitoring and control. The approach used by Paladin is illustrated in Fig.1 and can be summarized as follows:

- The real-time data from system sensors placed strategically throughout the distribution system are brought into the SCADA system.
- The electrical distribution system one-line diagram is modeled, in detail, with the EDSA design analysis and simulation software package that can perform real-time power flow, transient stability and harmonics analyses.

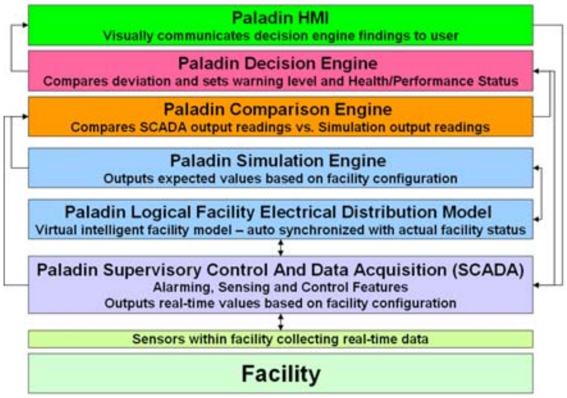


Fig.1 Illustration of the process employed by Paladin in determining the health of the system

- Paladin continuously runs simulations on the embedded logical model and auto-synchronizes the model with the system status so that switch, breaker, and equipment on/off conditions are continuously monitored and the logical model is continuously updated to reflect the system configuration. Note: The logical model database holds a detailed library of component features including performance data, drawings, location, maintenance history, et al.
- Paladin includes an auto-calibration feature that automatically calibrates the logical model to the actual installed equipment load characteristics. This allows a "normal" set of conditions to be defined in the event that the parameters used for the logical model are not 100% reflective of delivered and installed components.
- Paladin compares the sensor data from the physical system to the predicted data from the logical model. The trends in differences are tracked and rates-of-change are determined. The differences between actual sensor and simulation based predicted values are compared to threshold limits. The deviation level is classified as High ("red"), Marginal ("yellow"), or Low ("green") and the deviations are communicated to the Decision Engine for action.
- The Paladin decision engine analyzes the differences and classifications to determine the health and performance status of the system. It determines the alarm condition, activates alarms, and communicates the system status to the human machine interface (HMI).
- The HMI provides displays of the system and its status at various levels of detail, calls attention to alarm conditions, and can be used to perform "what if" analyses to display the predicted system response to a hypothetical operator change in system status (e.g., open or close breakers, turn equipment on or off, etc.) before the action is implemented.

The entire history of system states is also recorded so that an analysis of events leading to an alarm condition can be displayed.

The net result is that health and performance indicators are overlaid on easily recognizable engineering diagrams to allow an immediate understanding of system status. “What if” analyses can be performed to evaluate responses before taking action and details like component features and maintenance records can be easily retrieved from the database. Paladin can also be configured to provide control functions and plans are underway to incorporate AI features to provide an automatic control response to alarm conditions.

3 Application to FAA Power Distribution System

The Paladin software system has been installed at three FAA Air Route Traffic Control Centers (ARTCC). The status of the power distribution system for a site is typically displayed and controlled on large panels at a remote location, for example, as illustrated in Fig.2. This was simulated in a Paladin display as shown in Fig.3, which is virtually identical in appearance to the physical panels, so as to provide easy recognition by operators. Other screens can be easily displayed to allow access to higher or lower levels of status detail, to allow analyses to be performed, to allow historical or data base displays, or to allow management functions.

Fig.2 Typical status and control panel for an ARTCC site. (Courtesy of the FAA)

As examples, Fig.4 shows a top-level screen that summarizes the “red”, yellow,” or “green” status of the power distribution systems at sites across the United States and Fig.5 shows a more detailed screen in which a node on the distribution diagram has been selected and the sensor data for the node is compared with the predicted value for that point.

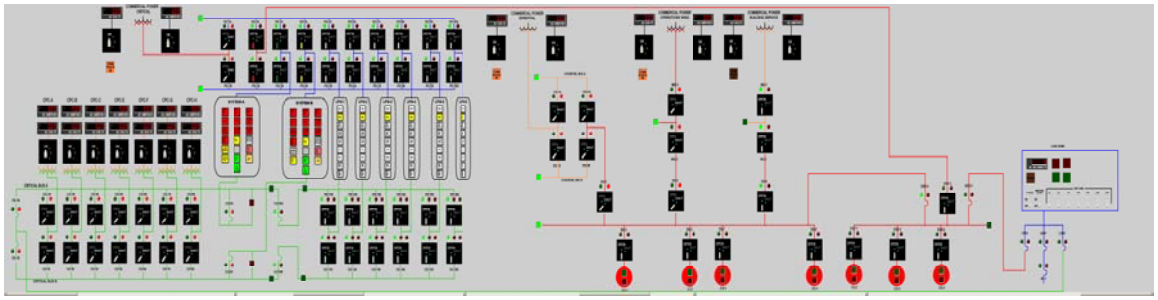


Fig.3 Paladin, on-screen display, simulating the physical control panel in a form familiar to operators. (screen courtesy of the FAA)

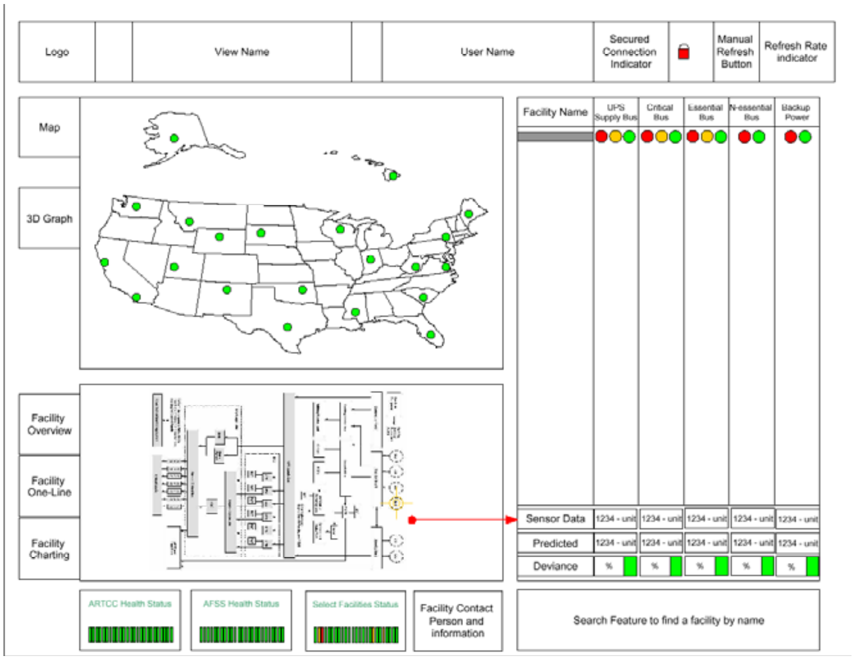
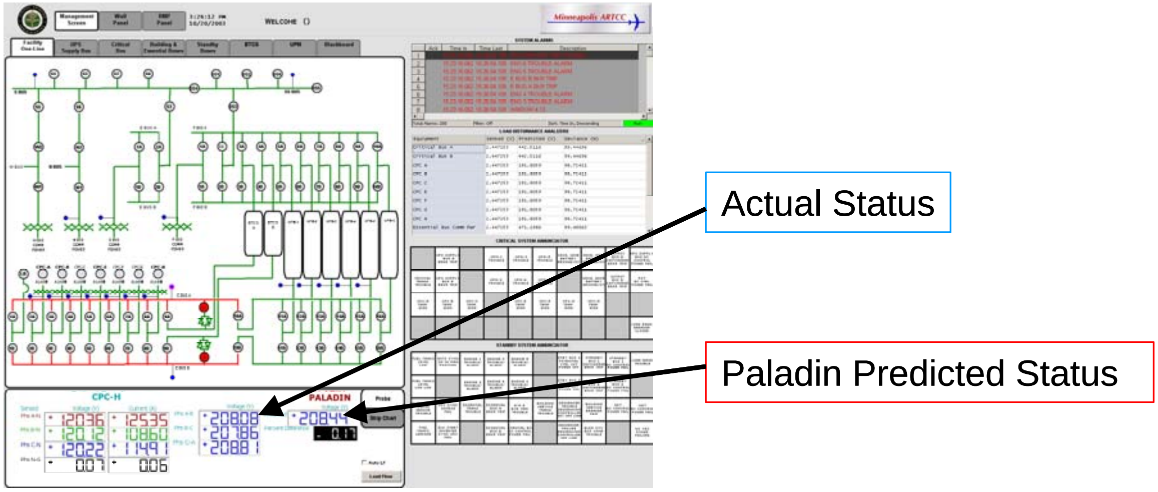


Fig.4 Top level display of "red, yellow or green" status of sites across the USA. (Screen courtesy of the FAA)



Actual Status

Paladin Predicted Status

Fig.5 Typical display of subsystem detailed status with comparison of actual and predicted values at a selected node. (screen courtesy of the FAA)

4 Potential for Application in an Electric Ship

Future electric warships will be driven by multiple electric propulsion motors with direct drive to the propellers. Each motor will have the capability of 20–40 MW depending on the platform, hence, the power required for propulsion at maximum speed will be in the range of 40–100+ MW. At reduced speed, a significant amount of this power will be available for special equipment such as rail-guns, free electron or solid-state lasers, and area denial microwave weapons. At all speeds, there will be requirements for radar, communications, short-range electrical defensive weapons, and ship services. The net result is that the prime movers and generators must supply a wide range of loads with various, individual, AC or DC requirements. In order to accommodate the range of conditions, zonal electric power distribution concepts, as shown in Fig.6, are being considered. General Atomics has built one zone of equipment that has been successfully tested and is installed at the Naval Surface Warfare Center, Carderock Division, Philadelphia. It provides ~2MW of continuous power conversion capability. Two more zones are under construction by GA and are planned for test on the RV Triton, a UK research vessel [2].

Fig.6 illustrates, as an example, a set of turbine generators providing power to parallel buses at 4160 Vac. Part of this power is provided to the propulsion motor drive which converts it to the appropriate AC or DC current and voltage to control the torque and rpm of the electric propulsion motors.

The ship is also divided into zones, which are supplied with power, in parallel, to a transformer/rectifier (PCM-4) in each zone. The PCM-4 converts the power to about 1000 Vdc to supply two DC-DC converters (PCM-1) in each zone. The PCM-1's supply power to the local DC loads at up to about 800 Vdc. Part of the output from the PCM-1's is routed to the PCM-2, DC-AC inverter, which supplies local AC loads at about 450 Vac. The combination of multiple zones and parallel bus-work provides a highly redundant system capable of being optimized for efficiency under a given set of operational conditions, or capable of routing power around failed elements to supply critical loads according to a prioritized list in the event of an emergency.

The use of the Paladin software in a well defined system such as an electric ship would be a natural application and a great advantage. It would allow the continuous monitoring of sensors and comparison to predicted state variables to allow the health of the electric distribution system components to be displayed. Variations from the norm would lead to calculated differences which would

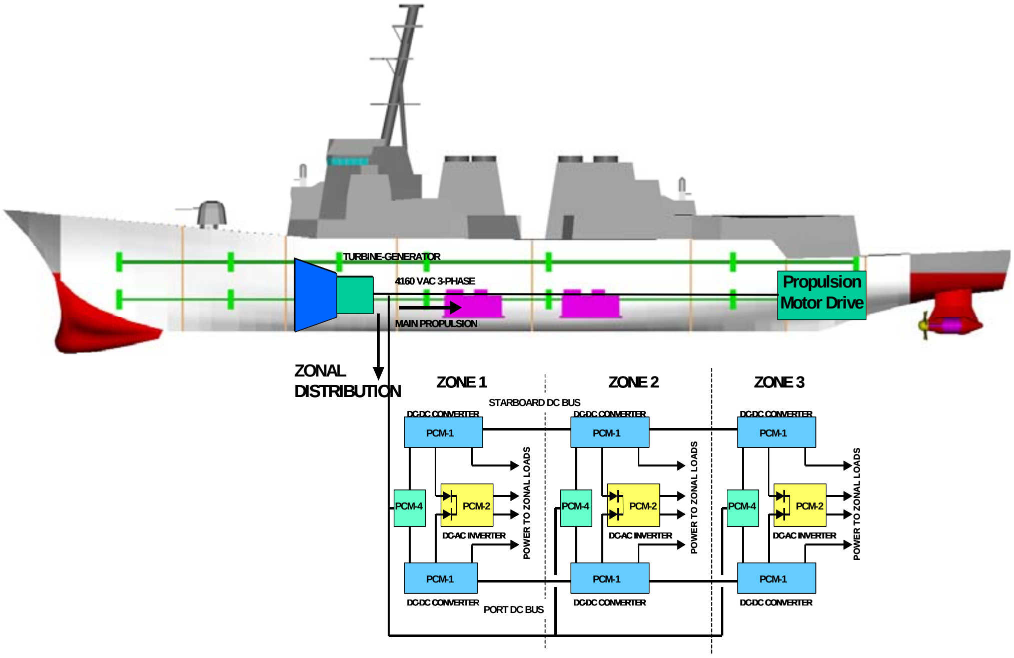


Fig.6 Illustration of a ship with an electric drive and a zonal distribution system

automatically trigger alarms to call attention to an impending maintenance condition, or a failure. “What if” analyses could be performed to allow an action to be evaluated before it is implemented by an operator to provide an assessment of the expected improvement in performance or of the mitigating action in the event of a failure. With AI features, Paladin could perform assessments of the system state and trends in the event of component degradation or failure, then automatically implement an action to maintain continuous power to critical functions.

5 Conclusion

Electrical power distribution and communication systems are becoming more complex, more compact, and more sensitive to abnormal conditions. An automated process for monitoring the health of the system and adjusting to damage or impending failures through Artificial Intelligence is needed to reduce reaction time and maintain critical functions. General Atomics and EDSA have taken the initiative in this process by integrating the capabilities of a fast system circuit analysis code with the Paladin software, so as to monitor sensors continuously, reconfigure the system circuit models automatically as the system state changes, compare the system status with analytical predictions in real time, and display status using alarm thresholds when the state changes from “green” to “orange” to “red” conditions to alert human operators. System operational history is recorded continuously for display and further analysis.

Plans are underway to implement Artificial Intelligence features in the Paladin software package. This will provide immediate, automatic, reaction to selected changes in state to allow optimization of system operational efficiency or to alter the system configuration in the event of a component failure or impending failure. In the extreme event of sudden component loss (e.g., accident, extreme weather or act of war), the AI features could assess the extent of damage and control the system reconfiguration to maintain critical operations by bypassing damaged segments.

The initial versions of Paladin have been developed, deployed, and validated at selected FAA ARTCC sites.

References:

[1] Paladin is a registered trademark of EDSA Micro Corporation.

[2] J. Zgliczynski, et al, The development of integrated fight-though power modules for at-sea testing on board the RV Triton, presented at 7th Inter Naval Engineering Conference & Exhibition, Amsterdam, March, 2004.