

EPS TDS
Electric Power Systems
Time Dependent Simulation Tools
For Verification and Validation of Complex EPS Applications

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A group of computer code simulation tools has been created to predict the time dependent behavior of electrical power systems used in aerospace and satellite applications. These tools can also be used to simulate accurate power systems behavior in virtually all other power system applications and architectures, including vehicles, aircraft, solar powered facilities, power plants, and nuclear generating stations. It should be noted that although these tools can be used in many classified projects and programs, that the models and codes themselves as used are not classified. Only the input and output data used in the codes may be considered to be classified. Also, many models used in the codes may be considered to be proprietary. Any such models or data would then be allowed to be used only by those agencies that have legal access to that proprietary data. Generic models and user generated models can also be used whenever necessary.

NEED AND APPLICATIONS

There is a clear and definite need for the ability to accurately simulate the time dependent behavior of the variables in an electrical power system (EPS) during the life of the system, and also during specific system transients. In aerospace satellite systems, the voltage and current in the EPS is needed to be known in order to determine the state-of-charge of the batteries during periods of charging and discharging. This is extremely important in space applications, as many battery cells will not be able to be recharged if they discharge beyond a certain point.

BACKGROUND

The EPS TDS models and tools were inspired from the Power Tools Suite (PTS) models and tools that were developed at the Lockheed Martin Space Systems Company over the past several years. The development and use of those PTS models and tools has been documented in several conference papers and presentations that have been presented and published to the public during the past several years. A collection of these publically available PTS papers and presentations can be found at: http://www.padrak.com/pts_pgb/.

The newer TDS models and codes have been developed and written completely independently of the PTS effort at Lockheed Martin. The TDS models and codes also do not contain any proprietary or restricted data, equations, models, coding, or information.

COMPUTER PLATFORM – EXCEL

The TDS tools package is written entirely in Excel Visual Basic, and uses only the Excel computer code application as released by Microsoft Corporation. The use of these “macro commands” is exactly equivalent to the writing of code in FORTRAN, C, C++, or BASIC. It allows fast and accurate numerical simulation with the added capability of using the worksheets and workbooks unique to the Excel application. It also allows the use of these tools without the need of any special computer application code or license, such as needed for FORTRAN, MATLAB, and Simulink. In addition, the use of tabulated data and non-linear numerical simulation with iteration loops allows for the convergence of EPS variables throughout the system, which may be impossible to simulate using other application codes and models.

EPS SIMULATION STRATEGY

The entire Electric Power System (EPS) is simulated by a collection of EPS Components, which are in turn connected by wiring. The entire EPS could then be considered to be composed of major components, such as: a solar array, a battery, diodes, resistances, wiring, switching circuits, and several loads. Each major component is considered to be composed of several sub-components, arranged in either parallel or series, possibly with different cells at different states. The wiring of a group of sub-components determines the model of the major component. The wiring of the major components determines the design or the architecture of the entire EPS.

The normal computer simulation technique is to define the input conditions required by the EPS, and to then determine the output conditions at the end of each time step during the simulation. Major input requirements at each time step would include the power required by each load and the input conditions to each major component; such as the amount of light and the angle of the light striking each solar array cell, and the temperatures of each cell and component. Initial conditions for each battery cell would also include the state-of-charge, temperature, and any other given initial conditions. The resulting output variables would include the new state-of-charge in each battery cell, the voltages produced in and by the battery, the voltages present on each solar array cell, and the currents in each part of the entire EPS.

EPS PARAMETER MODELING

Each EPS Component Model is represented by a “lumped parameter model”, which models and simulates the operation of that component for the input operating regions specified. For short time durations, on the order of milliseconds, this model may consist of individual electrical components, such as resistors, capacitors, inductors, and solid-state microchips. In most cases, however, the simulations are concerned with transient behavior over the duration of weeks, days, hours, and minutes. For these cases, each component would be modeled by equations or tabular data that recreates and duplicates the actual measured response of the component. This is the method used in the current TDS component models. This technique allows long mission transients over the order of 7 to 10 days to be easily simulated by as little as one minute time steps in a very short amount of actual computer time. The results of these calculations are thus accurate for overall component and system behavior. Fast transients, such as rapid current spikes and impedance effects, should be separately analyzed using other models and applications, such

as PSPICE. These applications, however, usually require thousands of time steps to simulate just one second, and are not suited for long term transient simulation or mission analyses.

A specific advantage of TDS is its ability to model the solar array and the battery by several unique sub-components. The solar array is designed to be any number of wings, each wing being composed of any number of strings, and each string having any number of cells. It is assumed that the cells in each string are the same type, with different types in different strings, and each cell could be at different temperatures. The battery is composed of any number of stacks of cells, with each stack composed of any number of battery cells of any type. Each battery cell can be at a different state-of-charge and at a different temperature, and each cell can be degraded or dropped out of the battery at any given time. The user specifies the construction of each component using input data. Initial conditions and other data are then required for each solar array cell and each battery cell. In this manner, very complex and multiple solar array wings can be modeled, as well as batteries of any cells in series, and stacks in parallel configuration.

EPS ARCHITURES

Various EPS architectures can be simulated by the manner in which the sub-components and components are wired together. Various configurations can be modeled, all of which would be able to use the same EPS Component Models. In this way, for example, both battery-dominated and preset constant-voltage bus architectures can be simulated. The numerical solution iteration techniques used allow accurate simulations and results for any architecture configuration.

SIMULATION NUMERICAL ACCURACY AND TECHNIQUES

The TDS tools use double precision accuracy, as provided in Excel. During the simulations, within each time step, iteration loops are also used to calculate the voltages and the currents to their required “converged” values. This method allows the addition and use of non-linear EPS Component Models, such as solar array cells and diodes, as well as any user defined connection of the components to create any desired architecture.

VERIFICATION AND VALIDATION OF MODELS AND RESULTS

The EPS Component Models use equations and tabulated data to fit the given behavior of that component in the given range of conditions. Each model is individually tested, and the results are displayed, to insure that each model produces the intended results and actually reproduces the given or documented behavior as obtained from testing data. This verifies the use of the model for that component. Performing simulations with that component in use with other components against known results are used to validate the accuracy and performance of the models. In this manner, the validated models can then be used to accurately predict future system behavior.

TABULATED AND PLOTTED RESULTS

The results of any EPS variables can be tabulated at any time step during the simulation. The data are stored in Excel spreadsheets. This allows the automatic creation of plots for each system variable of interest. In addition, a user interface is provided which allows the user to select any

portion of the time domain of the results, and to plot the data for that given range of time. This allows the user to see both the plotted results of the entire simulation, and to “zoom in” on any selected time domain ranges of interest.

DOCUMENTATION

User’s manuals are being completed that fully describe the use and the application of the tools for several EPS applications. All of the EPS Component Models used in the tools are fully documented, including results of the use of the individual models.

EXPANDABILITY

The TDS tools are easily expandable by including additional EPS Component Models and by adding additional EPS architectures. When necessary, unique EPS architectures can be used in separate Excel files to model the system behavior for various applications. All of the EPS Component Models are available for use in any of the EPS Architecture Models.

FUTURE PLANS

The EPS TDS models and codes are currently being used to simulate the behavior of aerospace satellite systems, both for orbital missions and deep space missions. The tools are very useful for sizing power systems for proposals, design reviews, mission operation, and predicted mission behavior. It is also expected that the tools will be very useful for mission verification and validation, and will provide an on-orbit ground simulation tool to predict system behavior. This will be extremely useful in analyzing future “what-if” operational behaviors.

Additional models and data are also being created to allow the simulation of any given power system, including vehicles, electric vehicles, automobiles, airplanes, fighter jets, unmanned submersibles, solar powered homes, electrical generating stations, and nuclear plants. User input would then determine the models and the EPS architectures to be simulated.

AVAILABILITY

The EPS TDS computer code tools package is available under non-exclusive licensing arrangements at a very reasonable cost. Training and consulting can also be arranged. After the initial training, most of the support and service can be performed via email and over the internet.

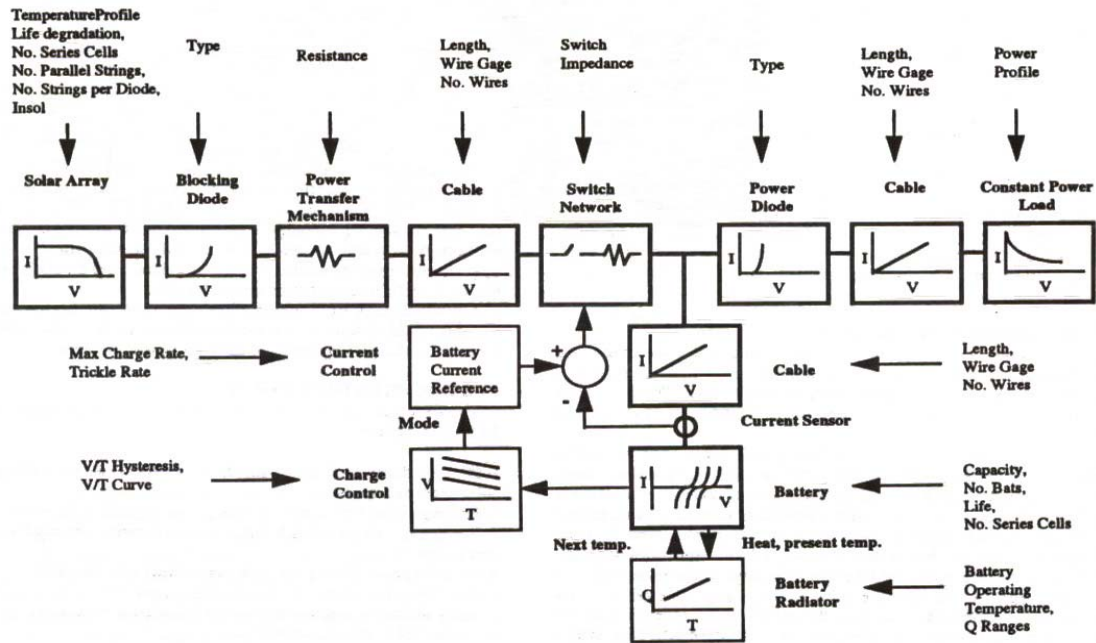
FOR ADDITIONAL INFORMATION

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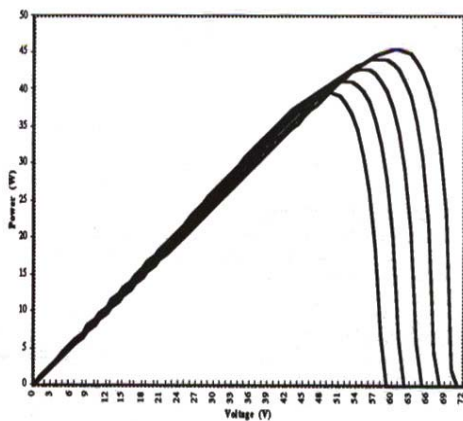
TDS and PTS SAMPLE RESULTS

Sample results are presented below that show the modeling of an EPS, EPS Components and a simulated satellite mission. These results are shown from the publically released PTS presentations. The results from the TDS code simulations are very similar, although the exact models are different from those used in the PTS simulations. [http://www.padrak.com/pts_pgb/]

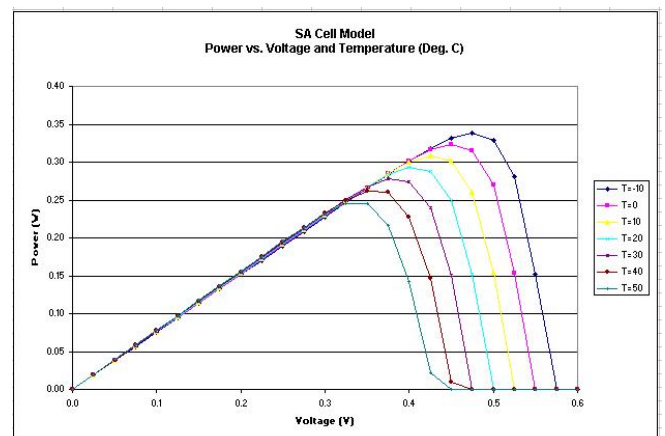
EPS Architecture Dynamic System Simulation [IECEC 1997]



Solar Array Cell Components [IECEC 1997, and IECEC 2009]

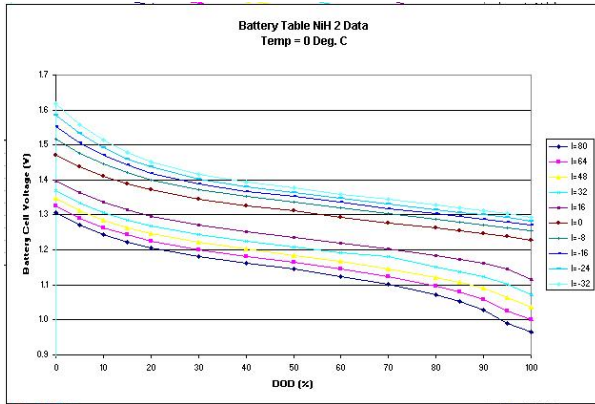


Solar Array Cell Model, Power vs. Temp C, Effects of Temperature on Power

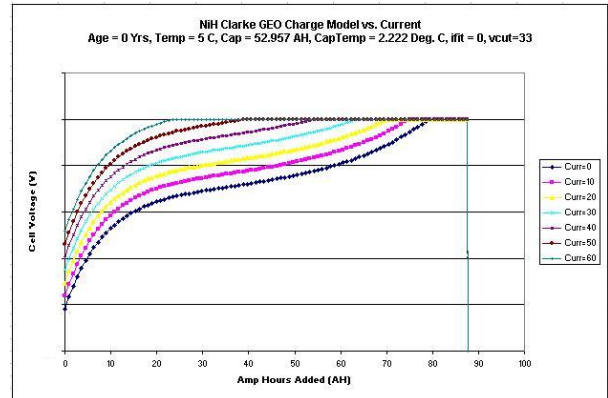


Solar Array Cell Hughes Model, Power vs. Temp C, Effects of Temperature on Power

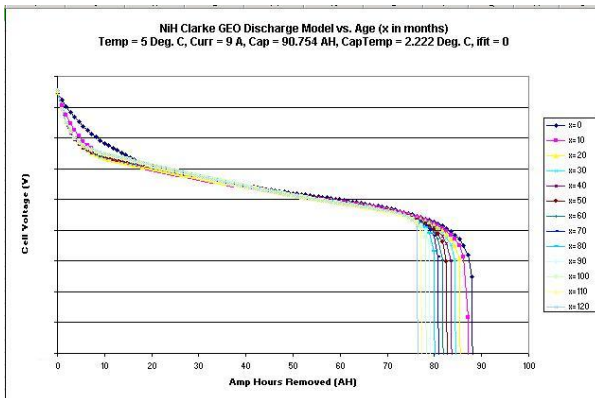
Battery Cell Components



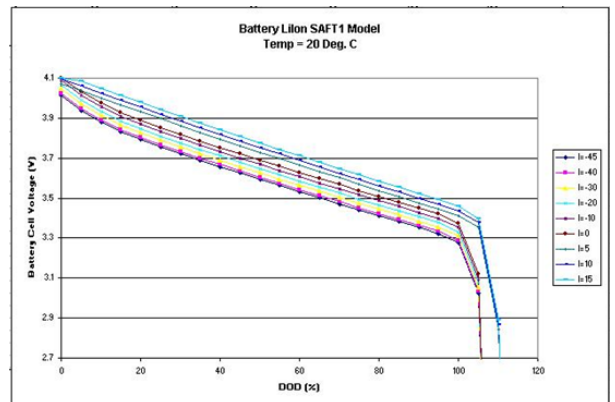
Typical NiH Battery Voltage Characteristics at BOL Conditions [IECEC 2010]



Battery Charge Model, Effects of Capacity and Charging Current [IECEC 2009]

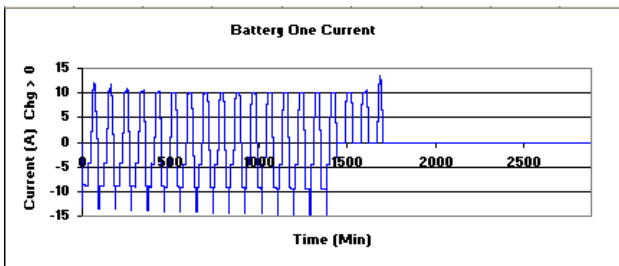


Typical NiH Battery Discharge Model, Effects of Capacity and Age [IECEC 2009]

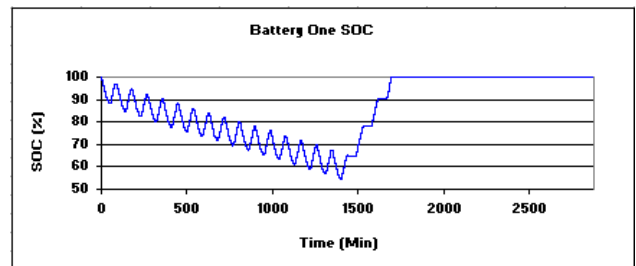


Typical LiIon Battery Voltage Trends at BOL Conditions [IECEC 2010]

Simulated Geosynchronous Satellite Multiple Orbits LiIon Battery Charging Profiles



Sample LEO Simulation of 48.4 Ah LiIon Cells – Battery Current [IECEC 2011]



Sample LEO Simulation of 48.4 Ah LiIon Cells – Battery State-of-Charge [IECEC 2011]

Further information and clarification is available at: www.padrak.com/ennead/.