Bridging the Gap: Understanding User Input Options on Inverter Black Box Models

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***Abstract*— Renewable energy sources are driving increased demand for inverters. Their complex control algorithms often remain hidden within "black box" models. This research will investigate the black box models from four inverter manufacturers and document their user-configurable setpoints. Comparisons will be made between different manufacturers to determine if there are any commonalities between them and which inverter model has the most user-friendly experience.**

We will start by analysing documentation on black box input setpoints, including variable naming conventions, units of measurement, and permissible adjustment ranges. Our findings will unveil insights into future user-configurable setpoints, highlighting similarities and differences in variable naming and operational impact. The hope is that manufacturers will adopt intuitive, user-friendly naming conventions and functions in the future, simplifying customization and understanding.

The extent to which current setpoints and documentation differ among manufacturers remains uncertain. While some manufacturers are anticipated to offer fine-grained control, others may restrict adjustments to higher-level settings. The ultimate determinants for ease of use and comprehensibility of setpoints will play a crucial role in shaping the user's ability to customize inverter performance effectively.

This research bridges the gap between the inner workings of inverter black box models and evolving user needs. By examining four leading manufacturers, we will provide insights into customizable setpoints, facilitating informed decisions and efficient inverter deployment across future applications. This will give protection engineers the ability to tune their inverter models to work in conjunction with protective relays, allowing for more complete and reliable protection schemes.

***Keywords:* Black Box, EMT, Simulation, Settings, Documentation, Inverter, IBR**

I. Introduction

As renewable energy resources become more prevalent in our power system, more and more protection and system study engineers will need to understand the correct way to model the inverters that make renewables possible. Nearly all inverter manufacturers are protecting their intellectual property by creating black box models, an equivalent model of their inverter with the proprietary inner workings hidden from the consumer. Because of this, comprehensive documentation of the correct way to model and implement inverter black box models in EMT modeling software is critical in helping engineers understand their capabilities and how to implement them in simulations correctly. This paper covers the documentation of four different types of inverters, examining their documentation and comparing how well they convey the necessary information.

II. Inverter Types and Limitations of the Research

All four inverters investigated can run in both grid forming and grid following modes. The data used in this paper's research was received over the last four years of project work with these manufacturers. As the data within the documentation is privileged, no specifics will be given on inverter capabilities, and some data may be outdated.

III. EMT Model Configuration

How well the documentation supplies information on getting started is crucial to successfully integrate the black box model into an EMT simulation. With the complexity of the software available and the many different files, inputs, compilers, and configurations an inverter can use, a clear explanation of how to get the black box up and running can make the job of the engineer much easier. Below are summaries of how each of the four manufacturers explains how to get started.

Inverter 1 has some very solid model initiation documentation. It provides a decent guide through compiler requirements, time step requirements, and how to navigate the file structure and import into an EMT program. It delivers fundamental instructions for initiating the black box model, with diagrams to support the instructions.

Inverter 2, unfortunately, falls short by not furnishing a comprehensive guide on getting started with the black box model. This absence of introductory information is a notable drawback, particularly for users unfamiliar with the model. The omission creates a potential learning curve, making Inverter 2 less user-friendly than its counterparts. While experienced users might easily navigate it, those seeking detailed guidance may find the lack of comprehensive documentation limiting.

Inverter 3 is the best choice, offering the most detailed documentation with very clear graphics. Its comprehensive guide covers applicable compilers, included and required files/external software, workspace and project loading, instance creation, time step requirements, linking library objects, and configuring between 32 and 64-bit operations. Inverter 3 surpasses the other inverters, providing information on simulation snapshots and configuring simulations with multiple instances of the inverter. Many steps of the guide include screenshots of what the user will see when working in the EMT program. With its user-friendly approach and detailed descriptions of inverter features, Inverter 3 stands out as the most descriptive and best choice.

Inverter 4 effectively outlines model prerequisites, basic I/O configuration, and compatible compilers. It does not provide much on how the actual model setup will work, so users seeking a clear understanding of model prerequisites will be disappointed.

In summary, Inverter 3 takes the lead with its detailed guide, allowing users at various proficiency levels to navigate the model easily. Its extensive coverage and user-friendly design make it the most versatile and appealing option among the four. Inverter 1 is a close second but lacks some of the ease-of-understanding features provided by Inverter 3. Inverter 4 is a bare-bones approach that leaves much to be desired. Inverter 2 provides no assistance, which should be considered an unacceptable omission given the complexity of this topic.

IV. EMT Model Configurable Setpoints

The next step in comparing these different inverters is exploring how well they explain their setpoint and configuration files. All four of these inverters have several functions that control inverter behavior, and each has several parameters that can be modified to fine-tune function behavior. How clearly these configurable setpoints are explained and in what context is very important for the end user to understand how to properly run an EMT simulation.

Inverter 1 presents an extensive table containing numerous external data points that can modify its behavior. This large table approach, while informative, is not very conducive to understanding how to enable specific features. Navigating through the large table of setpoints can overwhelm users, and the lack of context of the setpoint’s purpose can be confusing. The exhaustive table requires time and effort to extract the needed information.

Despite the overwhelming nature of the setpoint table, Inverter 1 does offer information on the various features and functions the inverter is capable of, including graphics to illustrate the effect of the function. However, the fact that these functions are divorced from most of their setpoint descriptions in the documentation can lead to confusion.

Inverter 2 presents setpoint descriptions and ranges in the function section to which they are relevant. This format provides the benefit of not overwhelming the user by dividing up setpoints and related functions. The documentation also provides some reasoning behind each feature. The visual aids included in the function sections are helpful, but some are very low resolution, making them somewhat difficult to read.

Inverter 2’s documentation succeeds in helping users understand the rationale behind each feature. It also provides information on setpoints in an easier-to-digest way, separating them by the function they modify. However, not all functions are presented in the same way, and some functions and associated setpoints read like a wall of text, which can be difficult to navigate.

Inverter 3 again stands as the best option. Its user-friendly and clear format distinguishes it, providing all relevant information on each function in one section. This inverter lists each feature, explaining the why behind its use. It describes the setpoints associated with the function and their ranges and typical values. It also incorporates graphs of the inverter response with default values to illustrate how the function works.

Inverter 3 is the most accessible choice, appealing to users at varying proficiency levels. It offers not just a list of features but a detailed guide, ensuring understanding and ease when modifying inverter behavior. The inclusion of graphics and detailed explanations helps the learning experience greatly.

Inverter 4 adopts a table format similar to Inverter 1. Listing setpoints provides a convenient reference for users, but it suffers the same drawback as being separate from the descriptions of the functions they modify. The documentation also does not provide much information on the functionality of the features. While an experienced user may not need to know the reasoning behind some functions, Inverter 4 may pose challenges for users less familiar with the why of inverter operating modes. The documentation, though clear, lacks the detailed explanations found in Inverter 1.

Inverter 4 provides users with a simple overview of its features, providing little background information or handholding. The lack of feature descriptions could limit the reader's understanding, but it will serve as a quick reference for those with prior knowledge.

In summary, Inverter 1 provides a detailed presentation of data but risks overwhelming users with its presentation. Inverter 2 takes a difficult-to-read approach with a wall-of-text format, potentially leaving users wanting more depth. Inverter 4 offers a quick reference but is less valuable without a certain baseline of knowledge. Inverter 3 excels in user understanding, as it details each feature with clear explanations, graphics, and examples.

The choice among these inverters goes beyond features—it involves the learning experience. Inverter 1 overwhelms with its abundance, Inverter 2 lacks depth, and Inverter 4 assumes prior knowledge. However, Inverter 3 stands out as a user-friendly option, helping users understand the how and why of inverter operating modes and features.

V. EMT Internal Setpoints vs. Parameter File Setpoints

Each of the four inverters has both a configuration file that can be imported, and in-model setpoints that can be modified by changing the values sent into the black box. A table of these EMT internal setpoints can be found in Figure 1.

	Inverter 1	Inverter 2	Inverter 3	Inverter 4
V_ref	✓		✓	✓
F_ref			✓	✓
I_ref	✓		✓	✓
P_set	✓	✓	✓	✓
Q_set	✓	✓	✓	✓
V_set	✓	✓		
F_set		✓		
PF_set	✓			
V_droop		✓		
F_droop		✓		
Mode set		✓	✓	✓
Start/Stop		✓		✓

Fig 1. EMT Internal Inverter Parameters

The EMT internal configurable setpoint descriptions are listed below.

V_ref: Voltage reference input into the inverter for grid following mode

F_ref: Frequency reference input into the inverter for grid following mode

I_ref: Current reference input into the inverter for grid following mode

P_set: Real power output setpoint for grid forming mode

Q_set: Reactive power output setpoint for grid forming mode

V_set Voltage output setpoint for grid forming mode

F_set: Frequency output setpoint for grid forming mode

PF_set: Power factor output setpoint for grid forming mode

V_droop: Voltage droop multiplier to influence droop control

F_droop: Frequency droop multiplier to influence droop control

Mode set: Setpoint to change between grid forming, grid following, or other modes available in the inverter

Start/Stop: Enable/disable the inverter

When compared to the EMT internal setpoints, the parameter file has significantly more control setpoints. Table 1 shows the comparison of EMT internal setpoints to configuration file setpoints.

	Inverter 1	Inverter 2	Inverter 3	Inverter 4
EMT internal setpoints	8	8	7	13
Configuration file setpoints	~230	~31	~150	~70

Table 1: Setpoint comparison from I/O and Parameter files

The approach for the configuration files is generally the same across all four inverters, and setpoints are modified in an external file that is then linked to the EMT simulation. Inverters 2 and 4 have a single file that can be externally modified and will automatically be referenced when the simulation starts. Inverters 1 and 3 can have multiple configuration files set externally, and the user can select the correct one inside the EMT model. This selection is made in the user interface and must be done before initializing a simulation.

VI. What Works and What Doesn't?

What works best between the four inverters?

1. Clean formatting: Formatting that is not too overbearing but helps the user differentiate sections and setpoints.
2. EMT model creation support: A description of how to take the black box model files and correctly get them into an EMT simulation. This includes descriptions of how to have a correctly set up EMT program that will work with the black box model, as well as describing the different ways the black box model can be used (snapshots, multiple inverters, etc.).
3. Setpoints/Functions being paired: Function descriptions immediately followed by the relevant setpoints.

4. Clear graphics: High-resolution graphics that can be read easily and provide value to explaining a function or feature.

What doesn't work between the four inverters?

1. Large tables of setpoints: Listing all setpoints in a single table and having the functions they modify in a different section.
2. Walls of text: Limited/no formatting that clearly shows where the documentation changes to a new function and sentence-only descriptions of the functions and their setpoints.
3. No EMT model creation support: Having no support at all on how to set up the black box model.

VII. Conclusion

Of the four inverters, inverter 3 has by far the best documentation. It provides a very detailed explanation of how to get the black box model up and running, pairs its functions with its setpoints intuitively, uses high-resolution graphics to support explanations appropriately, and fully explains functionality.

Inverter 1 comes in second. It adequately explains how to set up the black box model, lists all relevant setpoints, and provides graphics to support the explanations. The functions are explained well on how they modify inverter behavior. However, the single table of setpoints approach and the setpoints being separate from their functions can be confusing. Also, most of the graphics are low resolution and some of the information they should be conveying is unreadable.

Inverter 4 places third. It provides a simple explanation of how to set up the EMT model with the black box that gets the job done but leaves much to be desired. The single table of setpoints separate from the function descriptions does provide the necessary information, but, like inverter 1, it can be confusing and difficult to navigate.

Inverter 2 is last. While it does have some positive qualities, such as having inverter setpoints and functions paired appropriately, it presents as a wall of text for half of its length. There are some well-formatted tables in some areas, but overall, it is difficult to navigate and understand. The omission of a description of model initiation and requirements is very detrimental to the user.

Documentation that prioritizes clean formatting, solid explanations for all inverter functions, intuitive pairing of functions and setpoints within the documentation, and high-resolution graphics that aid in inverter setup and function explanations are the traits that make inverter documentation work best.

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