Data Article

Online database of Power Hardware In-the-Loop tests

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A R T I C L E   I N F O

Article history:
Received 4 November 2019
Received in revised form 24 December 2019
Accepted 6 January 2020
Available online 11 January 2020

Keywords:
Power Hardware in-the-Loop (PHIL)
Online database
Digital real-time simulator (DRTS)
Power amplifier (PA)
Rapid prototyping
Smart grid test bed

A B S T R A C T

The online database presented in this article provides information about Power Hardware In-the-Loop (PHIL) tests to allow the reproducibility of the experiments. The data were collected through published papers and manufacturer data sheets. The database is hosted on an open subversion platform, which allows a continuous improvement of the data. Furthermore, a GUI interface has been developed to ensure the integrity of the database and its traceability. The access to PHIL test data will facilitate reliable findings for the reproducibility of PHIL experiments.

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1. Data

Power Hardware In-the-Loop (PHIL) is a test system technique which combines the system simulation flexibility with the fidelity of complete hardware test. It is based on a Digital Real-Time Simulation (DRTS) that communicates with a Power Amplifier (PA), which exchanges real power with the
Hardware-Under-Test (HUT). This data article describes a database which contains information about PHIL tests, organized in eight different interconnected dynamic tables. The Unified Modeling Language (UML) representation of these dynamic tables is shown in Fig. 1. The variables contained in every table and their description are shown in Tables 1–8.

The database is implemented in Microsoft Access [2]. This software provides the possibility of dynamic classification of all available parameters of Power Hardware In-the-Loop (PHIL) tests, allowing the organization of the information without requiring programming skills. Furthermore, a user management system (Fig. 4) and a GUI interface (Figs. 5–7) are included to add, modify and update the online database. It also offers the possibility of showing information as a table or as a form, and users can copy and paste data to other database software to process them.

2. Experimental design, materials, and methods

A significant number of PHIL test reports have been collected from the scientific literature. The main data were extracted from these publications for reproducibility purposes. Some representative examples of these publications gathered in the database are [3–8]. The information of PHIL systems used in the tests was completed by extracting data from manufacturer datasheets and from PHIL review articles [9–16]. Publications with insufficient information were excluded.

Summary statistics of one of the most important variables included in the database are presented in Figs. 2 and 3. If any paper describes two or more tests, in which the same HUT type has been test or the same system has been simulated [7,8], it only counts once.
Fig. 1. UML representation of the database entity-relationship model.

### Table 1
Variable description of “HUT Device” table.

| Variable          | Type         | Description                                                                 |
|-------------------|--------------|------------------------------------------------------------------------------|
| Id                | Integer      | Item Identifier                                                              |
| Device            | Categorical  | Name of the device                                                           |
| Company-University| Categorical  | Name of the company, university and/or research centre which develops the item, taken from the dynamic table “Companies_Universities” |
| Added_By          | Categorical  | User who adds the item                                                       |
| Add_Date          | Date         | Date of the item addition, in dd/mm/yyyy format                               |
| Revision_Date     | Date         | Date of the last revision of the item, in dd/mm/yyyy format                   |
| Permission_User   | Categorical  | Users who have the permission to modify the item                             |
| Last_Modification_Date | Date         | Date of the last modification of the item, in dd/mm/yyyy format              |
| Last_modification_By | Categorical | User who made the last modification                                          |

### Table 2
Variable description of “HUT Types” table.

| Variable          | Type         | Description                                                                 |
|-------------------|--------------|------------------------------------------------------------------------------|
| Id                | Integer      | Item Identifier                                                              |
| HUT               | Categorical  | The different types of Hardware Under Test (HUT) used in the experiments: Circuit Breaker, Car: FTP-72 driving cycle, Nonlinear circuit, Linear Circuit, SFCL (Superconducting Fault Current Limiter), OCR (Overcurrent relays), Smart Transformer (ST), Battery Energy Storage System (BESS), Distributed Energy Storage Systems (DESS), PV Inverter, Virtual Synchronous Generator (VSG), High Speed Generator, AC/DC power conversion module (PCM), Voltage Source Converter (VSC), Electric Drive, Physical Analog Subsystem (PAS), Generator, Statcom, Wind Inverter, Battery Inverter and House. If it is not defined in the test, it is selected “not shown” |
In order to increase the comprehension and traceability of the items in the database, some non-categorizable fields have been added. A field called “Notes” has been added in every table, with the purpose of adding some extra information which is interesting for the readers. Furthermore, a web link of the item has been added in Tables 5–8. Moreover, the “Paper” table (Table 6) includes a “Summary”, “Why and what for”, “Results” and “Conclusions” to add the subjective information of the paper. The table “Power Amplifier” (Table 7) includes a field “attachment” where the datasheet of the system can be added.

Several methods have been considered in order to ensure information integrity, to increase readability, and to update the information periodically. These methods are described in the following subsections:

2.1. User management

The database allows modification after its publication. A user management system has been implemented to prevent anonymous database editing. The registration is done via email, with every

| Table 3 |
| Variable description of “Simulated System” table. |
| --- |
| | Variable | Type | Description |
| Id | Integer | Item Identifier |
| Simulated System | Categorical | The different systems simulated in the Digital Real-Time Simulator (DRTS) in the experiments: Lithium Battery, Short-Circuit, Grid Voltage, Electric Ship, Electric Grid, PV, Wind Turbine, Electric Motor/Generator, Gas turbine generator, On Load Tap Changer (OLTC). If there is not a specific system, the field is empty |

| Table 4 |
| Variable description of “Test Objective” table. |
| --- |
| | Variable | Type | Description |
| Id | Integer | Item Identifier |
| Test Objective | Categorical | The main objective of the described test: Check PHIL Behaviour, Test HUT and/or Test Simulated System. If there is no main test objective specified, the field is empty |

| Table 5 |
| Variable description of “Companies_Universities” table. |
| --- |
| | Variable | Type | Description |
| Id | Integer | Item Identifier |
| Company-University Name | Categorical | Full name of the company, university or research centre |
| Research_Center | Binary | 1: yes, the item is a research centre 0: no, the item is not a research centre |
| University | Binary | 1: yes, the item is a university 0: no, the item is not a university |
| Company | Binary | 1: yes, the item is a company 0: no, the item is not a company |
| Added_By | Categorical | User who adds the item |
| Add_Date | Date | Date of the item addition, in dd/mm/yyyy format |
| Revision_Date | Date | Date of the last revision of the item, in dd/mm/yyyy format |
| Permission_User | Categorical | Users who have the permission to modify the item |
| Last_Modification_Date | Date | Date of the last modification of the item, in dd/mm/yyyy format |
| Last_modification_By | Categorical | User who made the last modification |
user having a unique username and password to enter the application. Only registered users are able to add new information to the database. Furthermore, only users with special rights can modify the information. Consequently, the database records the date and authorship of every addition/modification. Finally, a "guest" user allows non-registered users to read the database. Fig. 4 shows the login window to enter to the online database.

2.2. Database GUI

Fig. 5 shows the database GUI. It has three main groups: check, add and modify information. Each group allows users to check, add or modify the reports, Power Amplifiers (PA), Digital Real-Time Simulator (DRTS), Companies/Universities and Hardware-Under-Test (HUT) device tables respectively. All users can access the items in the check information group. However, to enter the other two groups it is necessary to be registered in the database.

Fig. 6 shows the PHIL tests report table which holds all the information included in the reviewed publications and it is accessed by the “Table Reports” button in the database GUI (Fig. 5). Fig. 7 shows the “form” to change PA data, which is opened by clicking the “Modify Power Amplifier” button in the database GUI (Fig. 5).

### Table 6
Variable description of “Papers” table.

| Variable                  | Type       | Description                                                                 |
|---------------------------|------------|-----------------------------------------------------------------------------|
| Id                        | Integer    | Item Identifier                                                             |
| Year                      | Integer    | Year of publication                                                         |
| Title                     | Categorical| Name of the paper                                                           |
| Authors                   | Categorical| Authors of the paper                                                        |
| Company-University        | Categorical| Companies, universities and/or research centres which carried out the test. |
| Step Time (μsec)          | Numerical  | Real-time simulation step-time in μsec                                      |
| DRTS                      | Categorical| Digital Real-Time Simulator used in the experiment. These data are taken from |
| Test Power (kVA)          | Numerical  | Maximum power achieved during the test in kVA                               |
| Interconnection Method    | Categorical| Type/s of interconnection method between DRTS and PA: Analog signals,      |
| Algorithm                 | Categorical| Algorithm/s used during the test: Ideal Transformer Model (ITM), Transmission |
| Power Amplifier           | Categorical| Power Amplifier used in the experiment. These data are taken from the       |
| HUT Type                  | Categorical| Type of Hardware Under Test (HUT) used in the experiment. These data are     |
| Simulated System          | Categorical| System simulated in real-time in the Digital Real-Time Simulator (DRTS).     |
| Test Objective            | Categorical| Main goal of the experiment. These data are taken from the dynamic table    |
| HUT Device                | Categorical| Specific device used as a Hardware Under Test (HUT) in the experiment. These |
| Added_By                  | Categorical| User who adds the item                                                       |
| Add_Date                  | Date       | Date of the item addition, in dd/mm/yyyy format                             |
| Revision_Date             | Date       | Date of the last revision of the item, in dd/mm/yyyy format                  |
| Permission_User           | Categorical| Users who have the permission to modify the item. Only the registered users  |
| Last_Modification_Date    | Date       | Date of the last modification of the item, in dd/mm/yyyy format              |
| Last_modification_By      | Categorical| User who made the last modification                                          |
| Variable                        | Type         | Description                                                                 |
|--------------------------------|--------------|-----------------------------------------------------------------------------|
| Id                             | Integer      | Item identifier                                                             |
| Model                          | Categorical  | Model name of the Power Amplifier (PA). If the brand of the PA is specified but not the model, the name of the brand with the label “(no model)” has been included in the database |
| Power (kW)                     | Numerical    | Maximum power of the PA in kW                                              |
| Voltage BW (Hz)                | Numerical    | Maximum bandwidth of the output voltage in Hz                              |
| Current BW (Hz)                | Numerical    | Maximum bandwidth of the output current in Hz                              |
| Accuracy (pct)                 | Numerical    | Output accuracy of the PA in %                                             |
| Width (mm)                     | Numerical    | Width of the PA enclosure in mm                                            |
| Height (mm)                    | Numerical    | Height of the PA enclosure in mm                                           |
| Depth (mm)                     | Numerical    | Depth of the PA enclosure in mm                                            |
| Weight (kg)                    | Numerical    | Weight of the PA in kg                                                     |
| Power density (kW_div_dm3)     | Numerical    | Power density of the PA in kW/DM3                                          |
| Specific Power (kW_div_kg)     | Numerical    | Specific power of the PA in kW/kg                                          |
| Voltage Range (V)              | Numerical    | Range of the output voltage of the PA in V                                 |
| Current Range (A)              | Numerical    | Range of the output current of the PA in A                                 |
| Efficiency (pct)               | Numerical    | Efficiency of the PA in %                                                  |
| Voltage Ripple (pct)           | Numerical    | Maximum ripple of the output voltage of the PA in %                        |
| Price (€)                      | Numerical    | Price of the PA in €                                                       |
| Slew Rate (V_div_µsec)         | Numerical    | Slew rate if the PA in V/µsec                                               |
| Delay (µsec)                   | Numerical    | Delay between the input and output of the PA in µsec                        |
| Communication                  | Categorical  | Type/s of communication with the DRTS: analog, digital and/or optical link |
| Quadrants                      | Integer      | Quadrants in which the PA can operate: 1,2,3 and/or 4.                     |
| Modularity                     | Categorical  | Degree of combination of several power amplifiers: serialize, parallelize or nothing. |
| Power Factor                   | Numerical    | Power factor of the PA in cos φ                                            |
| Portability                    | Categorical  | Portability of the PA: rack format, wheels, forklift openings or nothing.  |
| Security                       | Categorical  | Protections of the PA: overtemperature, overvoltage, overcurrent, emergency stop or not show |
| Standards                      | Categorical  | Standards accomplished by the PA: IEC/EN 50178, IEC/EN 50581, IEC/EN 61000-2-2, IEC/EN 61000-4-4, IEC/EN 61000-4-5, IEC/EN 61000-4-8, IEC/EN 61000-4-11, IEC/EN 61000-4-13, IEC/EN 61000-4-14, IEC/EN 61000-4-17, IEC/EN 61000-4-27, IEC/EN 61000-4-28, IEC/EN 61000-4-29, IEC/EN 61000-4-34, IEC/EN 61000-6-2, IEC/EN 61000-6-4, IEC/EN 60146-1-1, IEC/EN 60529, IEC/EN 61131-2, IEC/EN 61496-1, IEC/EN 61800-3, IEC/EN 62040-2, SEMI F47-0706, VDE 0126/EN 50438 |
| Company-University             | Categorical  | Companies, universities and/or research centres which develop the PA. These data are taken from the dynamic table “Companies-Universities” of Table 5 |
| Added_By                       | Categorical  | User who adds the item                                                     |
| Add_Date                       | Date         | Date of the item addition, in dd/mm/yyyy format                            |
| Revision_Date                  | Date         | Date of the last revision of the item, in dd/mm/yyyy format                 |
| Permission_User                | Categorical  | Users who have the permission to modify the item                           |
| Last_Modification_Date         | Date         | Date of the last modification of the item, in dd/mm/yyyy format             |
| Last_modification_By           | Categorical  | User who made the last modification                                         |
| Variable               | Type             | Description                                                                 |
|------------------------|------------------|-----------------------------------------------------------------------------|
| Id                     | Integer          | Item Identifier                                                             |
| Model                  | Categorical      | Model name of the Digital Real-Time Simulator (DRTS)                        |
| Company-University      | Categorical      | Companies, universities and/or research centres which develop the DRTS. These data are taken from the dynamic table “Companies-Universities” of Table 5 |
| Hardware               | Categorical      | Hardware used to run the simulation: CPU, DSP, GPU and/or FPGA              |
| Host OS                | Categorical      | Operative System of the host: windows or Linux                             |
| Target OS              | Categorical      | Operating System of the target: Linux based, QNX, Red Hat, VxWorks, QNX RTOS, Optimized Real-time kernel, FPGA |
| Application Software   | Categorical      | Software used to model and run the simulation: Matlab/Simulink, RSCAD, RT-Lab, Hypersim software suite, AdvantageDE |
| Communication, Protocols, Interfacing and I/O | Categorical | Supported communication, protocols, interfacing and I/Os of the DRTS: Gigabit Ethernet, Dolphin networking, IEC61850, C37.118, DNP3, Shared memory, Third party I/Os, Optical fiber, Fast back plane, Global bus hub, TCP/IP, Analog and digital I/O, PCI, PCIe, PXI, PMC, IEEE 1284C, Serial, UDP/IP, CAN, J1939, SFP |
| Application            | Categorical      | Type of application of the DRTS: Power systems, Real-time simulation of power electronics, Control and automotive systems, Multi-domain simulation, HIL testing, Specialization in avionics and maritime, Control system and/or Rapid prototyping |
| ADC bit                | Integer          | Number of bits of the DRTS ADC                                              |
| ADC delay              | Numerical        | Delay of the DRTS ADC in μsec                                               |
| Minimum Time Step (μsec) | Numerical   | Minimum time step of the DRTS in μsec                                       |
| Added_By               | Categorical      | User who adds the item                                                      |
| Add_Date               | Date             | Date of the item addition, in dd/mm/yyyy format                             |
| Revision_Date          | Date             | Date of the last revision of the item, in dd/mm/yyyy format                  |
| Permission_User        | Categorical      | Users who have the permission to modify the item                            |
| Last_Modification_Date | Date             | Date of the last modification of the item, in dd/mm/yyyy format              |
| Last_modification_By   | Categorical      | User who made the last modification                                          |

**Table 8**

Variable description of “DRTS” table.

**Fig. 2.** Percentage of the different HUT types used in the database tests.
2.3. Database host

The database is uploaded to GitHub [1], which is an open-source version control system. It gives the possibility of changing and updating the database in an orderly manner, preventing the database from becoming outdated. However, since the Access database must be updated in GitHub as a binary file, only the main branch of the database could be useful to users. This form of centralised management enables better organised control of the database updating process. Consequently, this supervision technique will provide a third-party revision to prevent mistakes and any attempts of cheating.
Fig. 5. PHIL database user interface. Three menu bars are available: check, add and modify information.
Table Reports

in the database GUI (Fig. 5), which contains the PHIL test manuscripts information of the database.

Modify Power Amplifier

| Id | Company-University | Model | Power (kW) | Voltage (V) | Current (A) | Efficiency (%), Effectiveness (%) | Power Density (kW/Divervolts) | Power Factor | Added_By | Revision_Date | Last_Modification_Date | Last_Modification_by | Add_Date | Security | Notes |
|----|-------------------|-------|------------|-------------|-------------|---------------------------------|-----------------------------|--------------|----------|--------------|------------------------|---------------------|----------|----------|--------|
| 1  | Regatron           | TC.GSS.32.600.RVR.S | 32 | - | - | 600 | 66 | 0.761 | 0.99 | E.Garcia | 11/06/2018 | E.Garcia | 28/01/2018 | Overtemperature, overvoltage, overcurrent, emergency stop |

Table 7. “Modify Power Amplifier” in the database GUI (Fig. 5), which gives access to the Power Amplifier data change form.
Acknowledgements

This research was funded by the CERVERA Programme of CDTI, the Industrial and Technological Development Centre of Spain, under the research Project ENERISLA (CER-20191002).

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2020.105128.

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