Adaptation of AC load bank system for programable resistive loading and testing of diesel generators

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Abstract—**The paper presents adaptation of a commercial AC load bank system modified to deliver controlled load to the diesel generators in order to prevent generator wet-stacking. The described solution involves increasing the existing load resolution from 6*53 kW to a resolution of 56 steps with 5.7 kW, making an approximate total load of 319 kW. The load can be controlled in steps of ±5.7 kW, ±17 kW, and ±51 kW. Measurement of electrical quantities was realized with PM51100 power meter. For the purpose of recording electrical quantities, a RecMod2021 device using Modbus communication protocol was developed. The RecMod2021 is programmed to read the PM51100 registers and log read quantities to the belonging SD card. The format of the recorded electrical quantities was adapted for later graphical representation and analysis of the power supply quality, as well as the stability of the generator automatic voltage regulation (AVR) system under various load scenarios.**

Keywords- load bank; mobile generators; wet-stacking; programable load; PM5110; data logging, Arduino;

I. INTRODUCTION

The market for mobile power generators has seen record sales due to the global energy crisis and rising electricity prices. The fear of potential power outages in the future is the main driver behind this unexpected demand for mobile diesel generators. In response to this increased demand, many manufacturers have ramped up production of mobile generators. These portable power sources provide a reliable backup energy solution for both residential and commercial customers. They can be used in a variety of settings, including construction sites, events, and emergency situations.

The health of diesel generators depends mainly on proper and timely maintenance. Another important factor that can affect a diesel generator's performance over its lifespan is its operating regime. Specifically, when a diesel generator is run at no or light load for extended periods, a thick, dark liquid may begin to drip from the exhaust system. This dripping substance, known as "wet stacking," can negatively impact the generator's operation. Wet stacking, depicted in Fig. 1, occurs when unburned fuel, carbon particles, and accumulated moisture gather around the exhaust system components. This may happen for various reasons, but is often caused by running the engine at light loads for a prolonged period of time, resulting in incomplete combustion of the diesel fuel [1].

In order for a diesel engine to run at maximum efficiency, it has to maintain an exact air-to-fuel ratio just like all other internal combustion engines. It also has to maintain a designated operational temperature to have a complete fuel burn. However, when the diesel engine is operated on light loads, it does not attain the designated operating temperature. Operating below the designated operating temperature as well as allowing the generator to stay unused for long periods of time is what results in wet stacking which inevitable leads to following issues:

- Expense: Excessive wet stacking shortens the life of engine, resulting in premature (and costly) replacement.
- Pollution: Many urban areas limit smoke emission levels which are produced by wet stacking.
- Power: The carbon deposits that occur because of wet stacking affect the engine's maximum power rating. An engine affected by wet stacking will operate at a lower power than it was designed to achieve.
- Maintenance: An engine affected by wet stacking will require much more maintenance than one that is appropriately exercised.

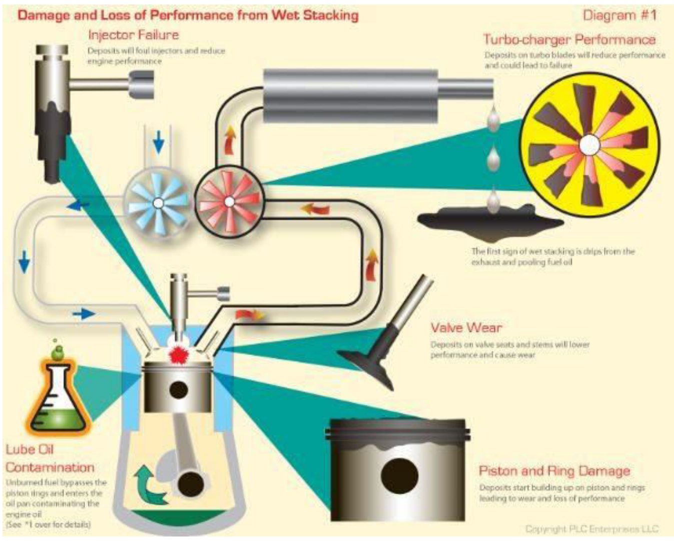

Figure 1. Damage and loss of performance from Wet-stacking [2]

Due to its harmful effects, wet stacking is being recognized by the organizations that write codes for standby generator set systems, such as the National Fire Protection Association (NFPA) and others. They require maintaining the exhaust temperature at a certain limit and generator loaded by not less than 30% of its name plate. Rather than exercising diesel generator with a light or no load at all, it is recommended that operators run their generators for a few hours at least 75% load in order to avoid wet stacking. Operating generator at this load allows the engine to reach the appropriate temperature needed to effectively burn the fuel entering system.

One of the most common solutions in wet stacking prevention are load bank systems. These systems serve as an appropriate resistive load of the generators forcing them to work close to rated operating point subsequently reaching rated temperature of the generator. This paper presents an adaptation of a commercial load bank system with integrated possibilities to appropriately load and test diesel generators. The modified solution is able to deliver programable load to the generator with small steps, as well to monitor and record basic electrical quantities during the generator examination and testing.

II. AC LOAD BANK SYSTEMS

A practical solution that can fit any design is to provide a permanent resistive load bank with self-control based on the exhaust temperature on the connected load and engage its different stages according to the requirement until either the required exhaust temperature is reached or the generator is loaded up to the minimum loading level. The load bank solution remains applicable in some cases if used temporarily during a regular maintenance procedure, where it is considered as a general cure for wet stacking to load generators - based on its type 85% for standby and prime rated, and up to 100% for continuous rated – up to 4 hours after every 100 hours of low load operation (30 or 40%) [3], [4].

In most cases, load bank systems work in parallel with regular load. Depending on the current consumption or the generator operation temperature, load bank system monitors and apply additional load, if necessary, with the aim to load diesel generator at least 60—80% and keeps it running with temperature able to deal with wet stacking. As load elements, usually finned or fin strip tubular heating elements are used inside the load bank (Fig. 2).

Figure 2. Air finned and fin strip tubular heating elements types (on the left) and example of the air heating load bank system (on the right)

Parallel connection of these heating elements is controlled by an integrated controller, usually PLC, which control appropriate resistive load to the generator. PLC can be programmed to monitor actual load and consequently rise its load with a goal to reach defined percentage of the rated load (at least 75%).

III. ADAPTATION OF HILLSTONE LOAD BANK SYSTEM

A. *The original Hillstone load bank system characterisitics*

The 3 phase Hillstone load bank [5] with overall capacity of 319 kW at 230V per phase is shown in Fig. 3.

Figure 3. Hillstone load bank 3 phase AC, 400V, 319 kW

Inside of this load bank makes 24 air finned single phase heating elements evenly distributed inside with following characteristics:

- 18 big heating elements (5600 W at 230V), and
- 6 small heating elements (950 W at 230V).

Load control of this Hillstone load bank was realized with *Millenium 3* PLC with relay outputs controlling 6 contactors. Each of these 6 contactors was turning on set of heating elements (3 big and 1 small heating elements per phase) with overall power of 53 kW at 400V as can been seen in Fig. 4. Thus, the load could be changed in 6 steps, 6 x 53 kW. During the operation, heat generated by heating elements is transferred to surrounding with forced air convection provided by integrated fan of 1.5 kW located at the front of the load bank.

Figure 4. Main 6 contactors with connected set of heating elements

The main lack of the described load bank is that the load could be only controlled in steps of 53 kW making this load bank unsuited for generators with rated power less than 100kW. Additionally, the controller was programmed to monitor current load of diesel generator and automatically introduce additional load with ±53 kW on order to reach defined percentage of the load bank full load.

B. Realised modifications on the Hillstone load bank load set

The modification criteria for the existing Hillstone load bank system were as follows:

- Enable load control in steps smaller than 53kW, which would allow for testing of low power generators under more precise load control;
- Enable monitoring of actual load in terms of corresponding electrical power supply quantities (active, reactive and apparent power, line and phase voltages, currents, power factor, frequency, THD);
- Enable time-stamped recording of electrical power supply quantities and their appropriate graphical representation for subsequent analysis.

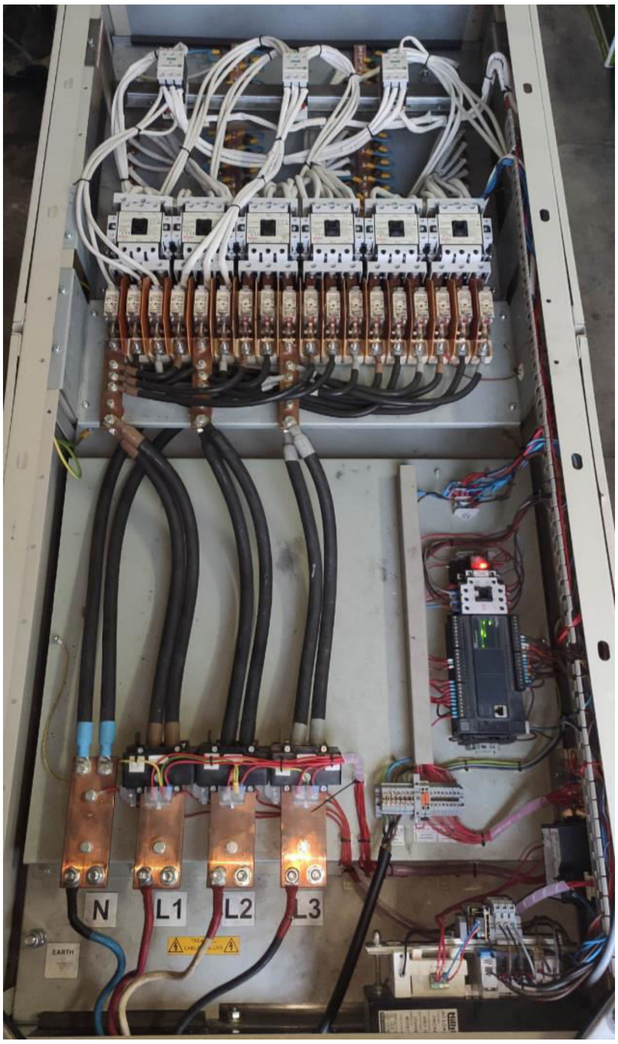

Figure 5. Added contactors for smaller load step, phase busses with installed current transformers, PLC, and protection.

The first part of the modification task required the disconnection of all heating elements and their reorganized configuration. To achieve smaller load steps, the heating elements were reorganized as follows:

- **5.7 kW** (3ph*950W*2) – 1 contactor connected to 2 heating elements of 950 W per phase.
- **11.4 kW** (3ph*950W*4) – 1 contactor connected to 4 heating elements of 950 W per phase.
- **17 kW** (3ph*5600W*1) – 1 contactor connected to 1 heating elements of 5600 W per phase.
- **34 kW** (3ph*5600W*2) – 1 contactor connected to 2 heating elements of 5600 W per phase.
- **51 kW** (3ph*5600W*3) – 5 contactors, each of them connected to 3 heating elements of 5600 W per phase.

Three additional contactors responsible for three new load intensities were added (as shown in Fig. 5). These contactors are responsible for the newly defined load rates of 5.7 kW, 11.4 kW, and 17 kW. One of the remaining 6 contactors is connected to a 34 kW, while the other 5 contactors are connected to a 51 kW heating element set. The introduced reorganization of the heating elements using 9 contactors allows for 56 load steps of 5.7 kW, resulting in a total capacity of 319 kW for the load bank.

C. Load control, monitoring and recording

The load control, using 9 contactors, is implemented using the TM221C40R Modicon M221 PLC with relay outputs. The control panel introduce 6 push buttons that allow the operator to increase or decrease the generator load in small, medium, and large steps of 5.7 kW, 17 kW, and 51 kW, respectively (as shown in Fig. 6). This allows for more precise control of the generator load, with any load up to 319 kW being set with a resolution of 5.7 kW. In cases where high power generators need to be tested or the generator's response and automatic voltage regulation (AVR) stability at large load steps need to be examined, there are also push buttons with ±17 kW and ±51 kW load steps available. In this case, a high load step, for instance 2x51=102 kW, can be set by pressing two times consecutively +51 kW button. The relay outputs of the M221 PLC are programmed to minimize the number of switching operations required to reach the set power. A 0.2 s deadtime is added between two successive push button operations to avoid imperfect contact operation. Block structure of modified Hillstone load bank is shown in Fig. 7.

Figure 6. Control panel with power meter PM5110 series.

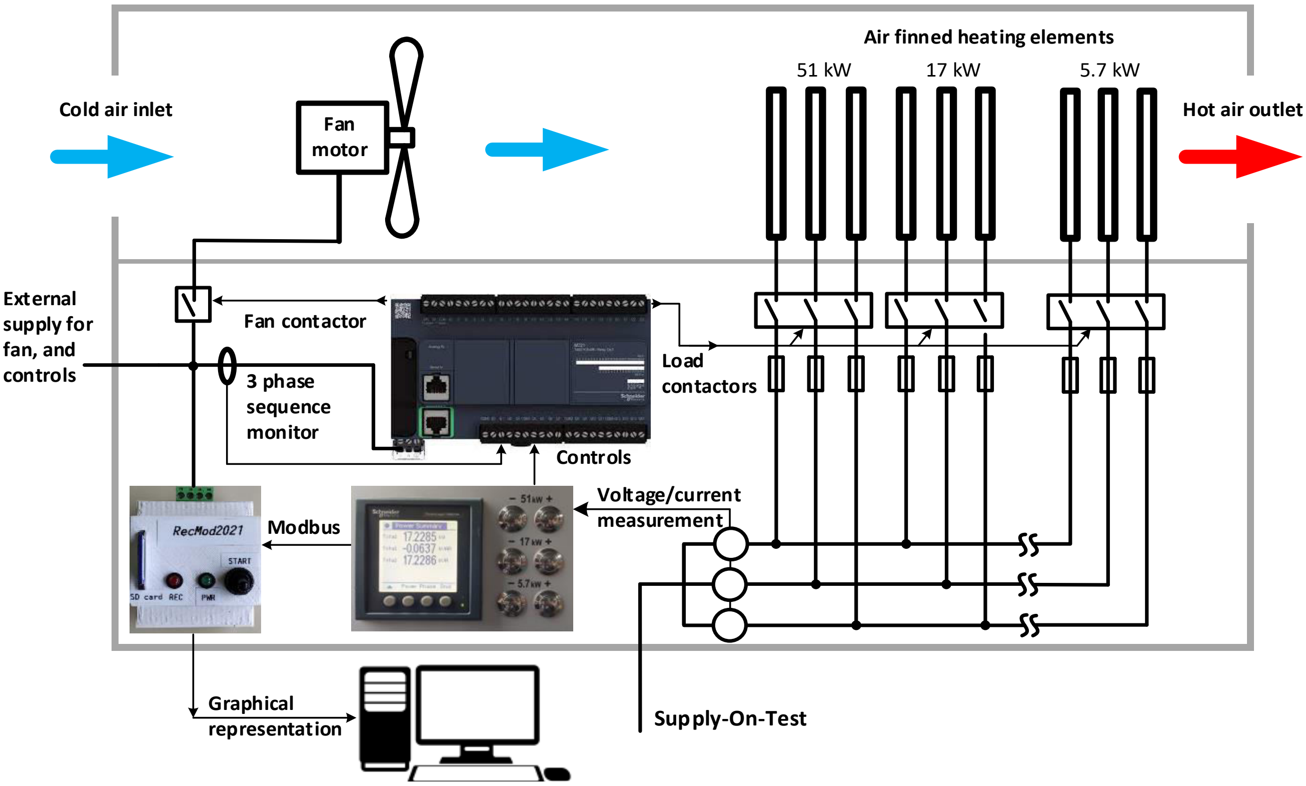

Figure 7. Block structure of modified Hillstone load bank

Monitoring of electrical quantities during the load test is provided by 3 busbar current transformers 500/5 A, and the PM 5110 series power meter which is capable of monitoring all three power components, power factor, energy, voltages, currents, frequency, and THD up to the 15th harmonics. The PM 5110 has Modbus RTU and ASCII 2 communication protocols with RS485 port support, which are used to read and save the electrical quantities measured by the PM5110. A specially designed RecMod2021 logging device has been developed for these purposes [6].

The RecMod2021 logging device is based on an ATmega168 microcontroller located on an Arduino Nano board. The microcontroller communicates with the PM5110 panel meter as a Modbus master [7] using the RS485 module. The received data is stored on an SD memory card, which is connected to the microcontroller using the SPI protocol. A simplified structural diagram of the realized RecMod2021 logging device is shown in Fig. 8 (up right).

The user can start recording of electric power quantities at any time during load bank operation by turning the START switch ON, which periodically appends PM5110 data to a CSV file on the SD card. The acquisition period is configurable and is currently set to one second, which is the shortest due to the slow communication speed over the RS485 line. The real-time clock values are read in unsigned integer format, while the electrical values are read in 32-bit floating point format. When the user stops the recording using the switch, the current logging file is closed and the file number is incremented in the EEPROM, so the new recording will be appended to a new CSV file. After the recording SD card can be removed, and appropriate CSV file can be copied to PC and plotted.

Although, saved electrical quantities can be plotted in various application that uses CSV for the graphical representation, the CVS pattern of stored data in this case is adjusted for display using the original software ACLoadView. After starting the ACLoadView software and loading the data stored on the SD card, a graphical display of all measured electrical quantities is obtained, as shown in Figure 9.

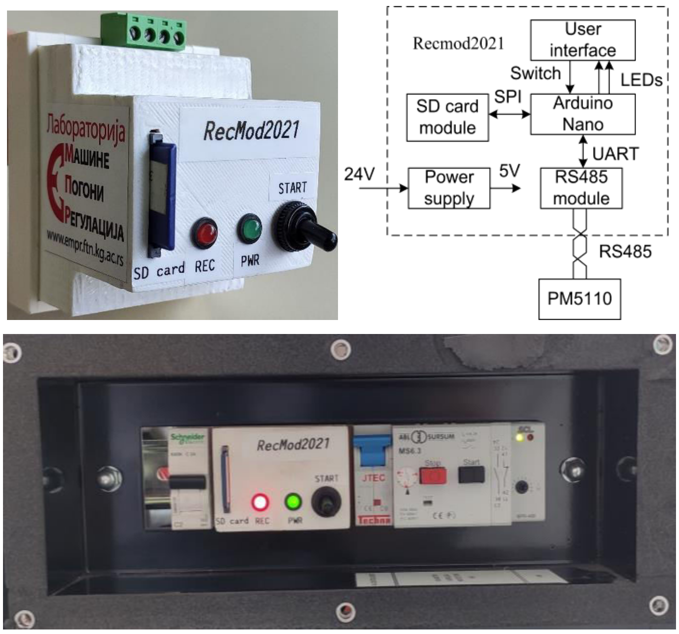

Figure 8. Developed RecMod2021 device with its block diagram (up) and installed RecMod2021 device in operation (down).

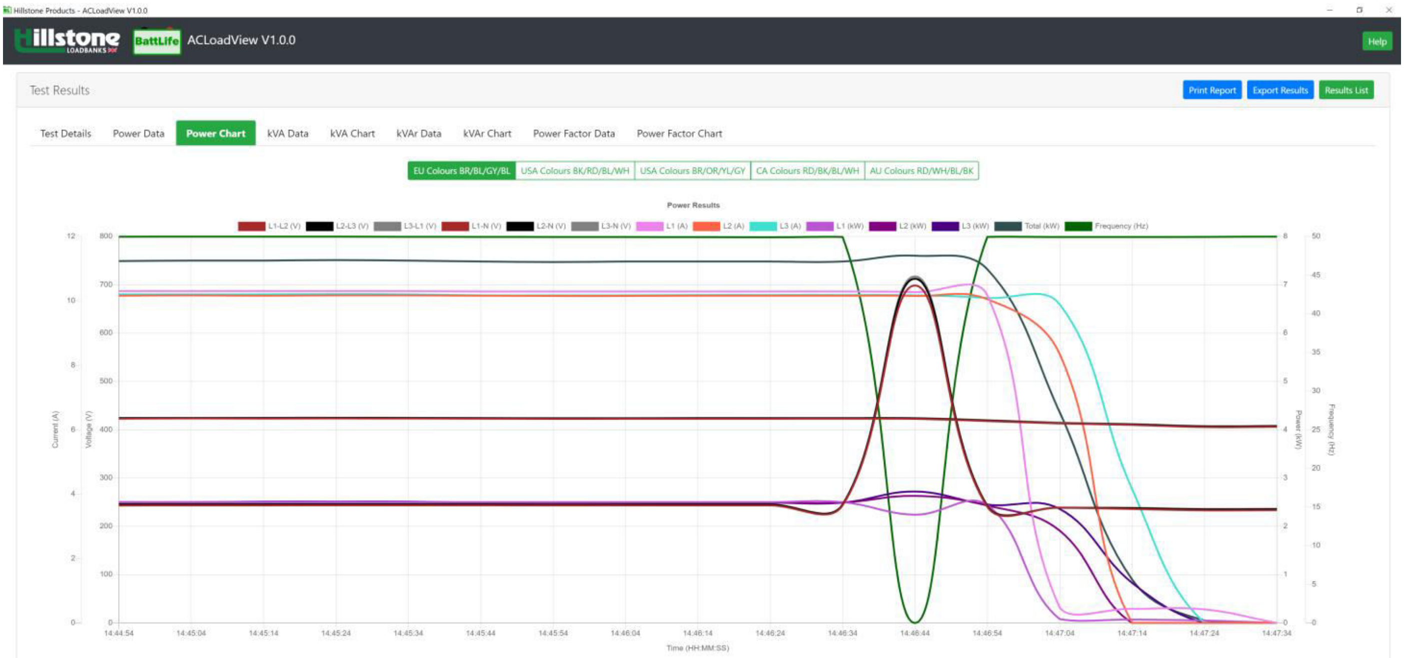

Figure 9. Graphical representation of recorded electrical quantities

Fig. 9 displays the time evolution of various electrical quantities that can be selected and shown or hidden by choosing the corresponding colour on the top of the graph. This feature allows for easy analysis of the AVR response to sudden load changes and identification of potential generator malfunctions. During the generator load test all three power components, power factor, and generator frequency could be plotted, enabling examination of their interdependence.

After analysing the test results, the ACLoadView allows for printing a report with basic test details, numerical and graphical test results, in the form of a PDF document. This report can be joined with the accompanying generator's documentation as a proof of the tested generator's performances under various load and real-world testing conditions.

IV. Summary

The paper presents modifications of the commercially available load bank with the aim of increasing the resolution of the applied load and recording characteristic electrical quantities with the ability of their graphical representation. The original six levels of 53 kW load have been replaced with 56 new levels of 5.7 kW. In addition to ±5.7 kW, load control is enabled in increments of ±17 kW and ±51 kW by simply selecting the appropriate pushbutton. The measurement of electrical quantities is carried out with the PM 5110 power meter, while recording is performed with the RecMod2021 device. The RecMod0221 device is specifically designed to allow data to be written to an SD card in a format adapted for graphical display in the ACLoadView software. The implemented system allows for simpler and more accurate control of the generator load with the ability to record and analyse characteristic electrical quantities. The possibility of graphical representation (of recorded electrical quantities during the test) enables further analysis of the delivered power quality and overall AVR stability at different levels of load as well as the identification of potential malfunctions. After the preformed load test, it is possible to generate a PDF report with the test results in order to confirm the diesel generator health and performances. The price of the proposed system is at least twice as inexpensive in comparison to other commercially available alternatives when compared to the identical system potentials and features.

Acknowledgment

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, and these results are parts of the Grant No. 451-03-47/2023-01/200132 with University of Kragujevac - Faculty of Technical Sciences Čačak.

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