Modeling and Analysis of the Impact of Second-life Components on PV-Battery-Diesel Microgrids

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***Abstract*—The rising popularity in current and future use of electric cars has triggered discussions on recycling used batteries. To give a second life to these batteries in low-power applications can contribute to the environmental and financial sustainability. This work presents a mix of simulations and experiments to analyze the net performance impact of legacy batteries in a photovoltaic (PV) microgrid. The simulation model parameters are tuned using the behavior obtained from the real batteries. In doing so, the battery model behaves like a practical aged battery. Thus the results can be trusted and may further determine the impact in a hybrid PV-battery-diesel microgrid. In addition, the energy management system (EMS) is adapted to the evolving dynamic behavior of the batteries. This way, the EMS can learn from its environment and estimate the state-of-age of the legacy batteries. From these estimations, the EMS adapts its own control to balance the limitations of the legacy batteries with the system's energy requirements and engage the batteries based on their health. Such a low-cost solution could significantly reduce the storage cost of electrification systems and delay toxic lead recycling.**

Over more than 100 years, still a dark planet. The well-populated countries in Asia and Africa still have no access to electricity [1]. One of the main reasons for the lack of basic rural electrification is the issues associated with the traditional large grid expansion, which is costly and impractical in hard-to-reach areas. Another one is the non-availability of low-cost microgrids, a big reason for less consumer participation and revenue generation. Thus setting up a rural microgrid is also a financial risk for the investors.

Microgrids are basically the philosophy of power generation very close to the load. It is an excellent scheme to generate and consume power at the local level [2]. The cost can be significantly reduced by giving a second life to the discarded batteries. It is done by capacity restoration and to serve the load based on their remaining health capabilities [3].

The battery second use in the potential low power applications is shown in Fig. 1. The test bench is as shown in Fig. 2. It is used to automate the data collection and test supervision. As depicted in Fig. 3 and Fig. 4, these experiments are conducted to get the dynamics of a real battery and use this information for tuning the battery model parameters. The battery's 2RC electrical equivalent circuit is used as a balance between complexity and accuracy. One of the key challenges is to adaptively parameterize the battery model to reflect the true dynamics to simulate the impact in a legacy microgrid for at least two more years. In Fig. 4, batteries can be discharged based on their remaining health capabilities, which is determined by the coefficients of individual current limitations of each battery ,*i.e.*, $\alpha_W, \alpha_A, \alpha_F$. Also, $\beta = i_{batt}/i_{load}$, and $\delta_W(weak), \delta_A(avg)$, $\delta_F\ (fresh)$ are strength factors of each battery. A key challenge in this work is automated parameter estimation and its update in the energy management system (EMS) to evolve with the availability of PV power and remaining health capabilities of the storage batteries.

Key outcomes of the work:

- Parameterize simulation models (batteries, diesel) based on the real data from experiments.
- EMS to adaptively evolve with the degraded performance of the aged equipment.
- Legacy microgrid cost vs performance analysis for at-least two years of service in a rural area.
- To put into evidence that second-life equipment could be used for the cost reduction of rural microgrid.

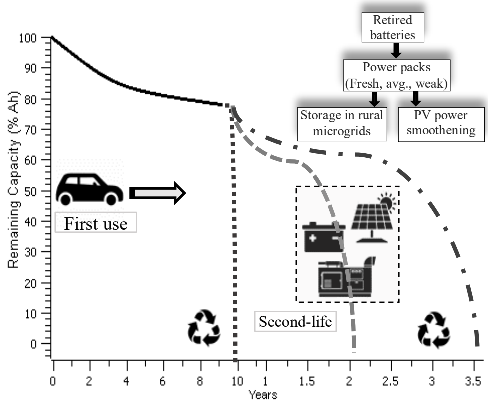

Fig. 1. Applications of legacy batteries.

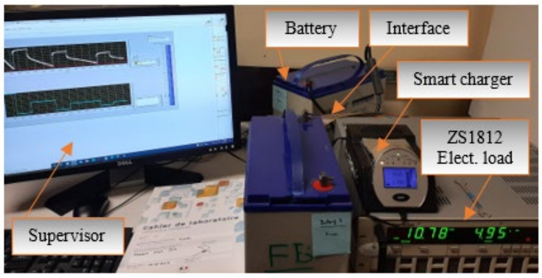

Fig. 2. Experimental bench for battery tests.

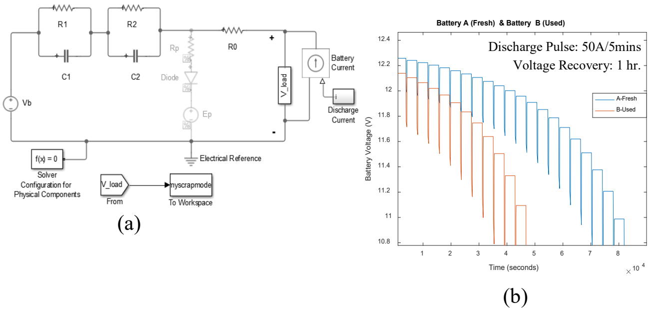

Fig. 3. (a) Battery simulation model, (b) discharge response.

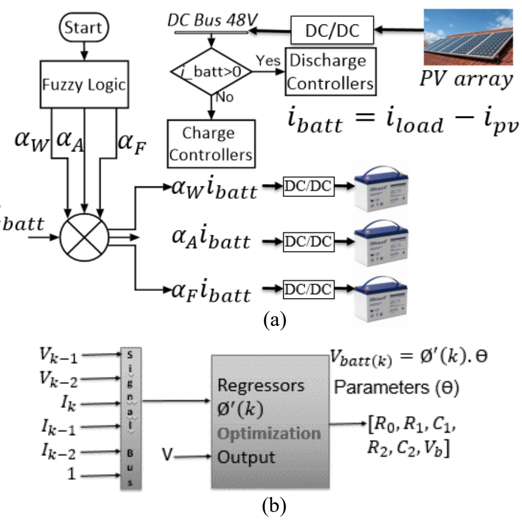

Fig. 4. (a) Battery management, (b) battery parameter extraction and optimization.

[1] IEA, World Watch Institute, NASA.
[2] T. Alharbi, K. Bhattacharya, and M. Kazerani, "Planning and operation of isolated microgrids based on repurposed electric vehicle batteries," *IEEE Trans. Ind. Inform.*, (15), no. 7, pp. 4319–4331, Jul. 2019.
[3] K. U. Jan, A. Migan Dubois, D. Diallo, W. Uddin, M. Nasir, and I. Khan, "Reuse Legacy to Repower the Microgrids–An Affordable Solution for Test and Restoration of Repurposed Lead Acid Batteries" *In Proc. of IEEE 2nd International Conference on Smart Power and Internet Energy Systems—SPIES'2020*, Bangkok, Thailand, pp.1-6, Sept. 2020.