2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)

# Lifetime Enhancement of Li-Ion Batteries used for Ancillary Services

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2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) | 978-1-7281-5672-9/20/$31.00 ©2020 IEEE | DOI: 10.1109/PEDES49360.2020.9379486

***Abstract*—In recent past, ancillary services gained attention in grid management due to increased intermittent Renewable Energy (RE) integration into the grid. Battery Energy Storage Systems (BESS) are attracted more popularity for the usage of ancillary services support due to its faster response. Since the deployment of various battery technologies are under the pilot stage and not take on large scale installations across the globe, the cost of the BESS is quite expensive. Also, these battery systems have restrictions of operation for a limited number of life cycles. Given the economic aspects and limited life cycle operations, it is essential to utilize the battery systems optimally, efficiently and cost-economically. In this paper, a new algorithm called Dynamic Frequency Regulation (DFR) is proposed which is based on the prediction and historical operating data along with live data profiles. It helps to enhance the life of the battery systems by ensuring the necessary requirements of ancillary services applications. The proposed algorithm simulated through MATLAB and the results are compared with real time Conventional Frequency Regulation (CFR) output of the Li ion battery integrated with the 22kV feeder located at Power grid Puducherry. The life of the battery system is enhanced by 80% more compared to the CFR methodology. Further, the proposed algorithm shall be implemented on real-time grid-connected $LiFePO_4$ BESS of 500KW/250kWh capacity established by POWERGRID at Puducherry, India.**

***Index Terms*—Ancillary services, Dynamic frequency regulation, Battery Energy Storage System, capacity degradation**

## I. Introduction

The higher quantum of the Variable Renewable Energy Source (VRES) penetration into the grid enables the increase in the requirements of the ancillary services support to ensure the balance and reliability of the grid. Battery Energy storage systems (BESS) are the best alternative resources to provide effective ancillary service support due to its fast response, higher ramp rate and modularity in size [1]. Due to its technical merits, BESS are being used for various applications like Electric Vehicle (EV), standalone Microgrids (MG), Solar and wind integrated grid systems and exclusive grid applications such as frequency regulation, energy time shift, renewable energy capacity firming, etc. [2]. BESS provides self-healing property to the grid by acting as both generator and load depending upon the requirement of the grid [3].

Lithium-ion group batteries are attracted more attention compared to other technologies due to its faster response and higher energy and power densities [4]. In respect of grid applications, these battery systems majorly used for frequency regulation which is one of the leading ancillary services supports [5]. Apart from the merits, the main drawbacks of the battery storage systems are the limited life cycle operations. Also, the cost of the battery storage systems is quite expensive due to limited production/usage in large scale grid applications. Hence it is necessary to use these resources optimally, efficiently, cost-economically without effect in the ancillary service requirements. Extensive research being carried out for energy management, optimal usage and improvement in efficiency of BESS linked applications. Energy management of battery systems used in electric vehicles presented in [6]. [7] Presents battery lifetime enhancement through controllers for standalone PV systems. Lifetime enhancement of batteries used in EV through converters presented in [8]. [9] Presents energy management and lifetime enhancement of BESS used for micro grid applications. [10] Presents lifetime enhancement of batteries based on the forecast for rooftop solar battery systems. [11] Presents lifetime enhancement by optimal usage by forecasts and battery degradation for standalone microgrid applications. However, the lifetime enhancement of large-scale battery systems used for ancillary service applications has not presented so far.

In this paper, a new algorithm called dynamic frequency regulation proposed to enhance the life of the battery systems used for frequency regulation application. The proposed algorithm works based on the prediction and scheduling of historical data along with live data profiles. Real-time grid frequency profiles have been considered to evaluate the proposed methodology. Simulation results presented and capacity degradation and lifetime estimation made for both methodologies for variations of real-time grid frequency profiles. The proposed algorithm shall be implemented on $LiFePO_4$ battery storage system of capacity 500KW/250kWh in the place of CFR which is installed by POWERGRID at Puducherry.

## II. INDIAN POWER SCENARIO AND ANCILLARY SERVICES

Indian power grid is one of the worlds largest synchronized power networks with more than 370 GW of installed capacity serving about more than 1.25 billion population. In the recent couple of years, the Indian power generation witnessed tremendous growth in renewable energy integration due to technological advancements along with the huge changes in the electricity policy framework. The Ministry of New and Renewable Energy (MNRE), Government of India (GoI) promotes various activities including installation of green energy resources solar, wind etc. for power generation and the contribution of energy from the RE sector is about 25 % of the total capacity as on date. The Government of India has set an ambitious target of adding 175 GW (100 MW solar and 60 MW wind) capacity of renewable energy into the grid by 2022. The intermittent nature of renewable energy (Wind and solar) may pose threat to the grid network in terms of reliable operation, power quality, voltage regulation and stability etc. in view of these upcoming challenges, ancillary services are gaining attention for effective grid management [12].

Ancillary services are essential grid support services as part of power system operation and maintenance. It provides services for quality, reliability and security of the entire grid network. The major ancillary services are Frequency regulation, energy time shift/peak shaving, voltage regulation an black start etc. [13]. Traditionally, these ancillary services support provided by the generators as the requirement of these applications were limited. Due to increased solar and wind energy integration into the grid, the scenario of ancillary service support has entirely changed. It needs faster response systems as per variations in the RE generation and also energy time shift as the non-availability of solar generation during night hours. The major applications of the ancillary services can be listed as

- Frequency Regulation
- ETS / Peak Shaving
- RE firming
- T and D Enhancement
- Micro grid Applications
- Generation enhancement
- Regulatory compliances
- Energy cost control

## III. CONVENTIONAL FREQUENCY REGULATION (CFR)

Frequency regulation is one of the ancillary services that entail moment to moment reconciliation of the difference between the supply and demand. It is necessary to maintain the grid frequency in a specified band to ensure the stability and reliability of the grid. As per Indian Electricity Grid Code (IEGC), the allowable variation in the frequency band is 49.7Hz to 50.05Hz without any penalty. In the real-time grid frequency profiles, it has been observed that the grid frequency operates below 50Hz for the majority of the time. Hence, the operating limits of the CFR have been considered for optimal operation as per the flow chart mentioned in Fig.1. If the grid frequency is higher than the upper cut off frequency (FH), then the BESS charge from the grid and if the grid frequency varies below the lower cut off frequency (FL), then the BESS discharges to the grid. If the frequency varies in between threshold limits, BESS charge/discharge based on battery SOC to maintain the optimum SOC for further grid applications.

As the grid frequency varies continuously, charging / discharging operation of the battery system also changes accordingly. Figure 2 depicts the real-time charging/discharging operation of battery and their SOC along with the grid frequency on a typical day under CFR application of the BESS ($LiFePO_4$ Battery of 500kW/250kWh) at the POWERGRID Puducherry, India. From the figure, it is clear that when the variation in frequency from the allowable band is higher the battery will discharge or charge accordingly with maximum power capacity. The abrupt charging and discharging of battery increases the stress in the battery and which in turn accelerates the degradation of the capacity of the battery system. During the CFR application, the BESS exchanges 4 to 5 cycles of energy per day as per the real time frequency variations at this sampled BESS pilot site.

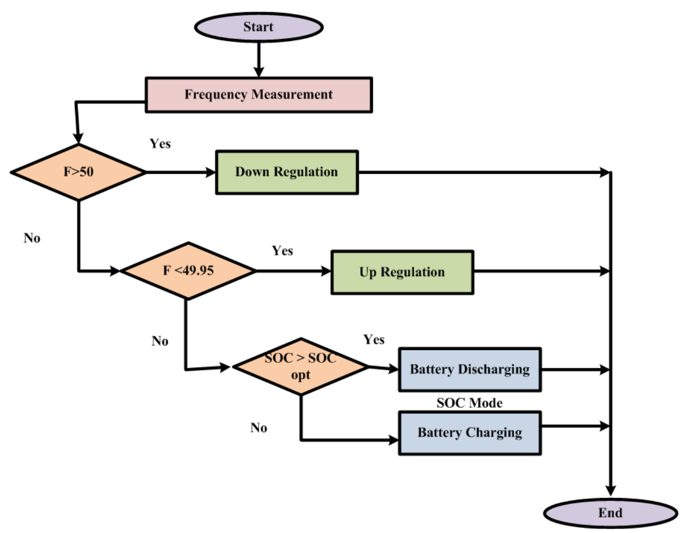


Fig. 1. Conventional Frequency Regulation Flowchart

Calculation of capacity degradation and the lifetime estimation of the battery energy storage systems under any application are very essential and important for grid ancillary services. In general, the capacity degradation of any battery system is due to cyclic aging which depends on its operation and calendar aging due to storage. As the BESS operates continuously for grid applications, capacity degradation due to storage is negligible. Hence, the capacity degradation calculated for cyclic aging using equation (1) [14].

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$$Cfade(nc, T, cd) = 0.00024{*}e^{0.02717T}{*}0.02982{*}cd^{0.4904}{*}nc^{0.5} \quad (1)$$

Where, nc is the number of cycles, T is temperature in Kelvin, cd is cycle depth or depth of discharge (DOD) in percentage

The capacity degradation of the BESS is estimated as 7.21% per year and the lifetime of the system estimated as about 4 years if it is operated under conventional frequency regulation application continuously.

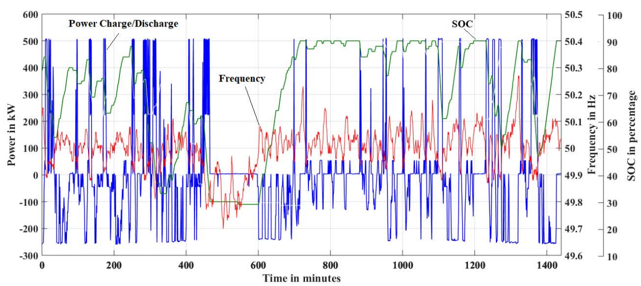


Fig. 2. Variation of Power and SOC w.r.t Frequency during Conventional Frequency Regulation

## IV. PROPOSED DYNAMIC FREQUENCY REGULATION

Dynamic frequency regulation (DFR) can provide frequency regulation support by optimizing the battery response. Here the DFR algorithm is based on the historical as well as the real time grid frequency data. The detailed flow chart of the proposed DFR algorithm is given in Figure 3. Based on historical frequency profiles, the charge/discharge operations are divided into fixed time slots/intervals per day. Energy charge or discharge for each particular time interval is pre-calculated to cap the overall number of charge or discharge operations during the day. DFR ensures that the battery parameters like operating voltages, temperatures, SOC and DOD etc. are in the permissible limit to enhance the lifetime of the battery.

Based on real-time grid frequency, rate of change of frequency, battery SOC and other critical parameters, it divided into three modes of operation under proposed dynamic frequency regulation:

1) Mode-I: Charge/Discharge power based on SOC and other BESS parameters
2) Mode-II: Charge/discharge based on real time grid frequency variations
3) Mode-III: fast charge / discharge based on f/t and SOC

The DFR algorithm is simulated using MATLAB and system parameters are taken from the 250kWh/500kW $LiFePO_4$ battery energy storage system which is integrated with a 22kV medium voltage distribution feeder. The frequency fluctuation from the feeder as well as the battery parameters are monitored and recorded using the SCADA system. The field data as well as the system parameters of the existing BESS installation is used to formulate the simulation of DFR. The frequency band is not static in DFR like in FR, as it defines different threshold frequencies for each slot depending upon the number of variations in that particular slot. The energy discharge per day is already defined and accordingly the selection of the frequency band for each slot is calculated. The amount of energy discharge to the grid by the battery is limited by the amount of energy allocated to the particular slot. Hence the energy discharge of the BESS is less compared to the conventional frequency regulation.

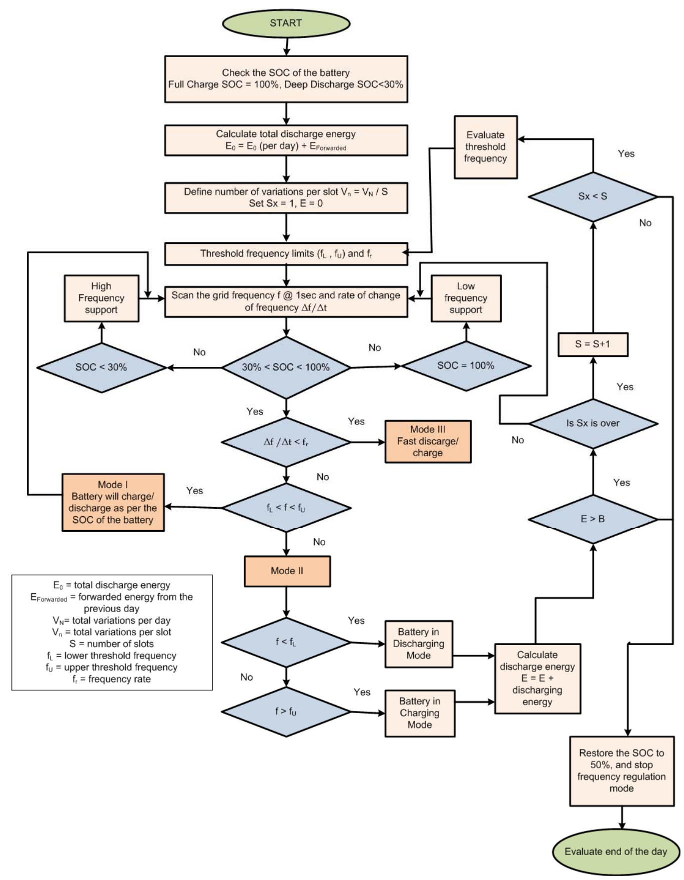


Fig. 3. Dynamic Frequency Regulation Flowchart

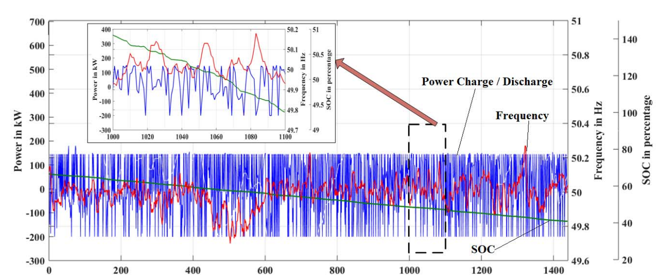


Fig. 4. Variation of Power and SOC w.r.t Frequency during Dynamic Frequency Regulation

## V. RESULT AND DISCUSSIONS

Dynamic frequency regulation is simulated based on the real time parameters, which is taken from the pilot Battery Energy Storage System project installed in Puducherry, India. The 250kWh/500kW $LiFePO_4$ BESS is integrated with the 22kV feeder. The BESS consists of Battery modules, Power Conversion System (PCS), Battery Management System (BMS), Power Management System (PMS) and Bay Control Unit (BCU). Each $LiFePO_4$ cell is of 3.2V and 80Ah capacity. 1728 cells are arranged in four clusters of series and parallel connections to achieve a DC bus voltage of 691.2V. PCS works as bidirectional AC/DC converter and a voltage regulator, while BMS is responsible for monitoring the battery parameters like cell temperature, voltage etc. All control logics are performed by PMS and the BCU collects the data from different field devices and communicates with SCADA for monitoring and controlling the entire system.

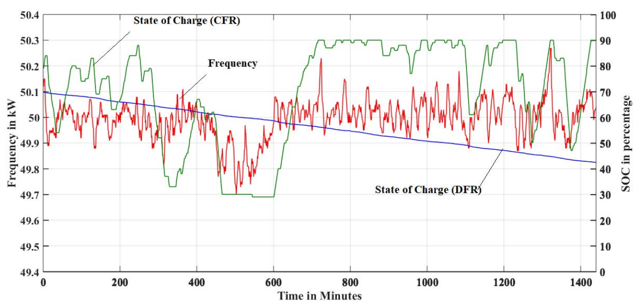


Fig. 5. SOC variation for CFR and DFR

Figure 4 shows the charge and discharge pattern as well as the variation in SOC of the BESS w.r.t to grid frequency under the proposed dynamic frequency regulation. As mentioned above, the battery system utilized optimally based on variation in grid frequency, availability of SOC and rate of change of frequency (f/t). The battery energy charge and discharge is comparatively low compared to CFR and hence the SOC of the battery also changes accordingly. Total energy exchanges per day are 2.05 cycles and 1606 cycles for one year. Capacity degradation during DFR calculated using equation (1) as 5.172% for year and lifetime estimated as 6.54 years. Hence, the lifetime of the BESS enhanced by 80% compared with conventional frequency regulation operation.

The proposed dynamic frequency regulation algorithm is verified through MATLAB modeling of grid connected BESS and compared with conventional frequency regulation. Real-time grid frequency data and operational limits of the battery system have been considered for the simulation. Capacity degradation and lifetime estimation is evaluated for both applications. As the battery system responds to real-time frequency, the rate of power discharge from the BESS is more during CFR compared to DFR. The proposed DFR algorithm optimizes the BESS utilization by considering historical profiles of grid frequency and SOC. It operates in three different modes based on real-time grid frequency, rate of change of frequency, availability of SOC and other BESS parameters. Fig 5 shows the variation of SOC for both applications w.r.t to variation of real-time grid frequency. The discharge power is more during CFR application which results in an increase in temperature, increase in stress on the battery and reduction in life of the battery system.

- In the case of CRF, it has been estimated that the average energy exchange per day is around 4.4 cycles and capacity degradation estimated as 5.4% per year and total lifetime estimated as 3.64 years.
- The battery life enhances during DFR by optimum usage and total energy exchange per day is around 2.45 cycles. Capacity degradation estimated as 3.057% per year and total lifetime estimated as 6.54 years.
- Lifetime of the BESS enhanced from 3.64 years to 6.54 years which is almost 80% increase in battery life with proposed DFR algorithm.

TABLE I
LIFE OF BESS UNDER CFR AND DFR APPLICATION

| Sl.No | *Description* | *CFR* | *DFR* |
|---|---|---|---|
| 1 | Energy exchange per day (no. of cycles) | 4.4 | 2.45 |
| 2 | Energy exchange per year (no. of cycles) | 1606 | 895 |
| 3 | Capacity degradation per year (%) | 5.4 | 3.057 |
| 4 | Lifetime in years | 3.64 | 6.54 |

## VI. CONCLUSION

The importance of ancillary services increases in grid management due to increased intermittent Renewable Energy (RE) integration into the grid. Energy storage system is one of the best alternatives to provide ancillary service support. Due to faster response and modularity in size, Battery Energy Storage Systems are more focused on these types of applications compared to other energy storage systems. The major drawbacks of BESS are limited life cycle operation and also the cost of the battery systems is quite expensive nowadays. Given the economic aspects and limited life cycle operations, it is essential to utilize these battery systems optimally, efficiently and cost-effective. In this paper, a new algorithm called Dynamic Frequency Regulation (DFR) is proposed which is based on the prediction and scheduling of historical data along with live data profiles. It helps to enhance the life of the battery systems by ensuring the necessary requirements of ancillary service applications. Capacity degradation and lifetime estimation along with simulation results presented for both conventional frequency regulation and proposed dynamic frequency regulation. It is estimated that the lifetime of the battery system can be enhanced by 80% with the proposed DFR algorithm. Further, the proposed algorithm shall be implemented and validated in real-time grid-connected $LiFePO_4$ BESS of 500KW/250kWh capacity by POWERGRID at Puducherry, India.

### ACKNOWLEDGMENT

Authors are thankful to the management of POWERGRID for granting permission for presentation of this paper. Views expressed in the paper are of the authors only and need not necessarily be that of the organization in which they belong.

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