BATTERY SWAP STATION PARTICIPATION IN MICROGRID UNIT COMMITMENT

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ABSTRACT

In these years, Battery Swap Station (BSS) is suggested as a new aggregator unit which can satisfy Electric Vehicle (EV) users by fast refuelling time and also help distribution system operator by giving more degree of freedom in EVs' load shifting. Really, in MicroGrid (MG) concept with Renewable Energy Sources, BSS enrolment will be more valuable due to power intermittency. But, adding BSS to MG will make Unit Commitment (UC) of MG as a so complex problem. This research paper will solve the defined problem in detail to make BSS presence as a reasonable solution for EVs' demand challenges. In this respect, the issue will be intersected to two layers operational field. Also, batteries lifecycle concerns will be addressed as a key component in decision making over two scenarios. It is a suitable solution for governments who failed in applying EV in their countries.

INTRODUCTION

Due to new environmental politics, EVs should catch their popularity in the nearest future, this is while EVs' shortcoming in satisfying citizen is the most conventional challenge for them. Slow home refuelling process of EVs made them as a dreamy object in future. Fast DC charging was the solution which presented in the last decade but this will set Distribution Network (DN) under stress of such huge load. On the other hand, smart charging will decrease cost and disturbance of large penetration of EVs, but this made EVs as a restricted technology for its users. Recently, it seems that BSS will be as a trade-off between EVs charging strategies.

Within the above context, the motivation factors by this paper supported by issues related to managing BSS nearby other components of DN. BSS adds more degree of freedom to operation program of DN. Smart charging restrictions can be assigned to Distribution System Operator (DSO) without any barriers for end DN consumers. BSS is a new EV aggregator with high a possibility of load shifting. Foremost, this will be a near-term solution in the active distribution network with Renewable Energy Sources (RES) to compensate their intermittency. Explicitly, the authors evaluate BSS impact in UC problems of MG in the interconnected mode of the grid operation for profit calculation.

Adding BSS as a new element to the classic format of UC will increase the complexity of decision while modernizing it. That's really caused by considering BSS which belongs to the state grid, in this respect, all of the EV charging constraints in aggregator bed should be taken in to account by MG System Operator (MGSO) in UC problem, the research paper executes resource schedule and BSS smart charging simultaneously. The interconnected MG can participate in the upstream grid power market, BSS charging and discharging process will help MGSO in maximizing its profit. A two-layer optimization method is applied to reduce time compiling of the processor and increase accuracy. The decomposition method will intersect the process in two parts (i.e. internal and external layer of optimization). In the internal layer, the capacities of charge for BSS and its customers demand will be adopted to manage BSS in charging and discharging in interaction with MG. The internal layer result will be sent to the upper layer. After this, the external layer will execute UC program to maximize the whole profit from MGSO point of view. Also, battery Depth of Discharge (DoD) impact will be evaluated over two case studies.

INTERNAL LAYER: BSS OPERATOR AREA

BSS unit objective function will be as (1), it includes three objective functions which has been weighed by w_1, w_2 and w_3 depending on their importance.

$$\mathrm{MIN}\{\sum_{T}[\mathrm{w}_1\sum\nolimits_{i,g}\mathrm{sht}_{i,g}^{t}+$$
$$\mathrm{w}_2(\frac{\mathrm{pc}_s^t}{\sum_{T}\mathrm{pc}_s^t}\mathrm{l(t)}P_{new}^{t}+\frac{\mathrm{pc}_b^t}{\sum_{T}\mathrm{pc}_b^t}(1\text{-}\mathrm{l(t)})P_{new}^{t})$$
$$+w_3|(\mathrm{P}_{wind}^{t}\text{-}\mathrm{P}_{wind}^{t-1})\text{-}(\mathrm{P}_{load}^{t}\text{-}\mathrm{P}_{load}^{t-1})+(\mathrm{P}_{BSS}^{t}\text{-}\mathrm{P}_{BSS}^{t-1})|]\} \quad (1)$$

In the first term aims to minimize battery depleted capacity in swap time where $sht_{i,g}^{t}$ is the percent of depleted capacity in battery i from g group at the swap time. In the second term a new power profile which follows constraints (5) introduced as P_{new}^{t} to the upper layer, this minimizes the upper layer load profile regarding the market condition in each hour, where pc_b^t and pc_s^t are the price of energy buy and sell respectively. $l(t)$ is a binary variable (1 when P_{new}^{t} is positive load, 0 when P_{new}^{t} is negative load). Lastly in the third term BSS operator is responsible for scheduling the station hourly charging and discharging power regarding a demand response progress which hopes to flat grid profile in respect to Wind Turbine (WT) generated power and hourly non-controllable load profile. P_{BSS}^{t} is the hourly BSS power that is exchanged between grid and BSS, it can be obtained by subtracting BSS hourly discharging power ($P_{BSS}^{dch}(t)$) and charging power ($P_{BSS}^{ch}(t)$): $P_{BSS}^{dch}(t) - P_{BSS}^{ch}(t)$. P_{wind}^{t} and P_{load}^{t} are the wind and conventional load of the grid. Consequently, BSS should consider the following constraints:

BSS power balance constraints

BSS as a separate mediator unit has its own power balance, that's because that BSS is responsible for EVs demand by itself as shown in (2), it should manage to charge its batteries to match hourly demand in a day. The most complexity of BSS participation is added by constraint (3) to classic format of UC, the BSS power balance under the force of package structure for energy exchange should be monitored in every single battery.

$$\sum_{i} sp_{i,g,t} = D_{g,t}^{EV} \tag{2}$$

$$\begin{aligned}\mathrm{SoC}_{i,g,t} =& ((\eta \mathrm{G2B}_{i,g,t} - \mathrm{B2G}_{i,g,t}/\eta)/\mathrm{B}_{g}^{cap} \\ &+\mathrm{SoC}_{i,g,t-1})(1 - sp_{i,g,t}) + \mathrm{SoC}_{i,g,t}^{init} sp_{i,g,t}\end{aligned} \tag{3}$$

$$\mathrm{SOC}_{\mathrm{i,g,t-1}} + \mathrm{sht}_{i,g}^{t} \geq \mathrm{sp}_{i,g,t} \tag{4}$$

$sp_{i,g,t}$ is the binary variable it will be equals to 1 when the battery swap. $D_{g,t}^{EV}$ is the hourly demand for battery reported by the number of requested EVs in hour t with g battery type. $SoC_{i,g,t}$ is the battery State of Charge where i is set index for battery and g set index for battery group, also $G2B_{i,g,t}$ and $B2G_{i,g,t}$ define the battery statement in charging from the grid and discharging mode to the grid in t time interval. The charger efficiency is η and the battery SoC is normalized by battery group capacity B_{g}^{cap}. $\mathrm{SoC}_{i,g,t}^{init}$ is the initial battery SoC. Also, as it has been noted before we try to increase the SoC of batteries to full percentage capacity in swap time and minimize battery shortage is defined in (4).

As it was mentioned in the (1) in this layer a new load profile will be reported to MGSO, so the upper layer is only responsible for the decision about MicroTurbines (MTs) and the participation in upstream grid power market to satisfy the P_{new}^{t} and maximize the total profit. P_{new}^{t} obeys the following constraint (5).

$$\mathrm{P}_{new}^{t} + \mathrm{P}_{\mathrm{BSS}}^{dch}(\mathrm{t}) + \mathrm{P}_{\mathrm{wind}}^{t} = \mathrm{P}_{\mathrm{BSS}}^{ch}(\mathrm{t}) + \mathrm{P}_{\mathrm{load}}^{t} \tag{5}$$

As a security constraint, the new power profile offered to MGSO should limited by $\mathrm{P}_{m}^{\max}$ the maximum production of MTs and $\mathrm{P}_{grid}^{\max}$ the maximum power that is permitted to exchange between MG and the upstream grid.

$$-P_{grid}^{\max} \leq P_{new}^{t} \leq P_{grid}^{\max} + \sum_{m} P_{m}^{\max} \tag{6}$$

Battery statement limitation

$$0 \leq \mathrm{G2B}_{\mathrm{i,g,t}} \leq B_{g}^{cap} \mathrm{a}_{\mathrm{i,g,t}} \tag{7}$$

$$0 \leq \mathrm{B2G}_{\mathrm{i,g,t}} \leq B_{g}^{cap}(1 - \mathrm{a}_{\mathrm{i,g,t}}) \tag{8}$$

$$\mathrm{G2B}_{\mathrm{i,g,t}} \leq B_{g}^{cap}(1 - \mathrm{sp}_{\mathrm{i,g,t}}) \tag{9}$$

$$\mathrm{B2G}_{\mathrm{i,g,t}} \leq B_{g}^{cap}(1 - \mathrm{sp}_{\mathrm{i,g,t}}) \tag{10}$$

(7) and (8) prevent the simultaneous charging and discharging for a typical battery by using $a_{i,g,t}$ auxiliary binary variable. (9) and 10) show that the battery stock is empty and there is no battery to charge or discharge.

The station ability to charge and discharge

This constraint is limited by the total batteries which exist in the station.

$$P_{BSS}^{ch}(t) = \sum_{i,g} G2B_{i,g,t} \tag{11}$$

$$P_{BSS}^{dch}(t) = \sum_{i,g} B2G_{i,g,t} \tag{12}$$

Rated power of charger equipment in BSS

$$\eta \times \mathrm{G2B}_{i,g,t} \leq \mathrm{P}_{rated}^{ch} \tag{13}$$

$$\frac{\mathrm{B2G}_{i,g,t}}{\eta} \leq P_{rated}^{ch} \tag{14}$$

P_{rated}^{ch} is the rated power of the chargers in BSS.

Reserve for daily start time

$$SoC_{i,g,t=0} = SoC_{i,g,T} \tag{15}$$

T is the Period of the case studies. The fully charged batteries at the start of a day support BSS for match EVs demand.

EXTERNAL LAYER: MGSO AREA

In this section, the MGSO responsibility will be formulated. This is the upper layer optimization loop in the pre-mentioned issue.

Objective function

The total objective function for the problem is defined in (16).The first term is the cost of transferring power between MG and the upstream grid, power selling to the main grid will be positive, inversely power purchasing will have a negative value, the second term is the MT units operation cost in power generation cost. The third term is the revenue of MGSO in providing power to the common daily load (i.e. daily MG load by ignoring EV load), EV load will be provided by BSS unit directly and the last term includes a fixed fee will be paid to the MGSO by EV owners. (Note that BSS is dependent on MG)

$$MAX \left\{ \begin{aligned} &\sum_{t=1}^{24} \{(\mathrm{P}_{grid}^{t}(\mathrm{b(t)pc}_{b}^{t} + \mathrm{s(t)pc}_{s}^{t}) - \\ &[\sum_{m=1}^{M} FC(P_{m}(t))]u(m,t) \\ &+ P_{load}^{t}\,\mathrm{pc}_{d}^{t} + (\sum_{i,g}(sp_{i,g,t} \times Fee)\} \end{aligned} \right\} \tag{16}$$

Where P_{grid}^{t} is the energy exchange between MG and upstream grid (negative for buy from and positive for sell to upstream grid). $b(t)$ and $s(t)$ are the binary variable decision for buy and sell there will be equals to 1 when the buy and sell happen. $u(m,t)$ is the binary variable for turn-on of MT m in hour t (1 for on 0 for off). P_{load}^{t} is the conventional hourly load of MG at pc_{d}^{t} price. *fee* is the fixed fee for swap battery gathered from EV owners versus each swap. $P_m(t)$ is the power production of MTs. Also, the solution should satisfy the bellow constraints:

The Constraint for MG Power balance

$$\sum_{m}(\mathrm{u(m,t)}\times \mathrm{P}_{m}\,\mathrm{(t))}=\mathrm{P}_{new}^{t}+\mathrm{P}_{grid}^{t} \qquad (17)$$

Microturbine limits

The generation range of each MT is limited by (18).

$$P_{m}^{\min}\leq P_{m}(t)\leq P_{m}^{\max} \qquad (18)$$

The decision of off/on status of each generation unit needs for checking minimum/maximum duration of continuously off/on limitations.

$$(\mathrm{T}_{m,t-1}^{on}\text{-}\mathrm{MUT}_{m}\times(\mathrm{u(m,t\text{-}1)\text{-}u(m,t))}\geq 0 \qquad (19)$$

$$(\mathrm{T}_{m,t-1}^{off}\text{-}\mathrm{MDT}_{m}\times(\mathrm{u(m,t)\text{-}u(m,t\text{-}1))}\geq 0 \qquad (20)$$

Where MUT_m and MDT_m are the minimum up/down time for MT m. $T_{m,t}^{on}$ and $T_{m,t}^{off}$ are the duration of continuously on/off time of unit m at hour t.

Security constraint limit

The maximum power interaction between MG and upstream grid will be limited due to the interconnected line, transformer and breakers capacity.

$$P_{grid}^{t}\leq\left|P_{grid}^{\max}\right| \qquad (21)$$

CASE STUDY

The MG consist of 5 wind turbines and 2 microturbines. Some research proves that output power of wind turbine is a function of wind speed [1]. Wind speed historical data was gathered from the National Renewable Energy Laboratory (NREL) website [2]. In this study hourly conventional load, market prices, wind system and MT parameters are derived from [3]. The fuel cost of MT is modelled as quadratic cost function [4]. The efficiency of chargers is considered 90%. It is assumed that the initial SoC of the battery is following normal distribution function $N(0.5,0.4^2)$ [5]. The fixed fee for swap $70 according to [6]. As there is no historical data for at least one existing BSS the data for EVs demand is derived from [7] with Fig. 2 Probability Distribution Function (pdf) for arrival time to station for three battery group 15kWh, 18kWh and 20kWh that has been matched to the data. Number of battery stocks is set to 100 for each group with 10% as reserve and 6.6 kW/h charging and discharging power rate. w_1, w_2 and w_3 weighing factors are considered 0.5, 0.35 and 0.15 respectively. Maximum energy is permitted to exchange between MG and upstream grid is set to 100 kW. Each optimization layer is a Mixed Integer Nonlinear Programming (MINLP) implemented in GAMS 24.8.3 mature software, by LINDO solver for internal layer optimization and BONMINH for a final decision in the upper layer. All the simulations were run on a laptop with Intel (R) Core (TM) i5-4200U 2.30 GHz and 4.00-GB RAM, Microsoft Windows 7.

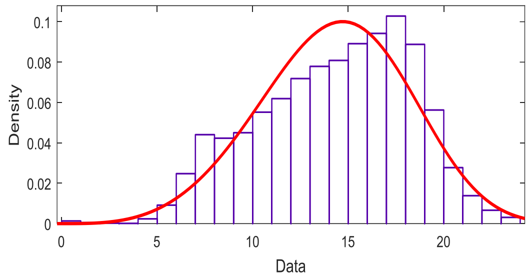

Fig 1. The data and pdfs of the end time of daily travel

The proposed approach is applied in two scenarios over a 24 hours period by modifying discharging allowance threshold: **case1-** no limitation and **case2-** with q=0.7 as a ratio for battery SoC. One of the most items which can affect BSS optimal operation and limits its interaction with DN is the battery lifecycle which reduced when the Depth of Discharge (DoD) go lower than q ratio [8]. On the other hand, it is beneficial since diminishing battery degradation effect.

RESULT AND DISCUSSION

The BSS operator decision on MG power flatting is presented in Fig.2 and Fig.3 which manages BSS charging and discharging power ($\mathrm{P_{BSS}}$) according to price factor (Positive values for charging and negative for discharging), giving the MG operator a new load profile defined as $\mathrm{P_{new}}$. The result shows the correct treatment of BSS, during peak hours 16-21 as generator unit and off-peak hours are the right time for charging and storage rolls. Although the charging chance occurrence goes down during the peak, the BSS enrollment as a source has been limited by the allowance ratio for discharge in case2, this lead to higher power profile to it.

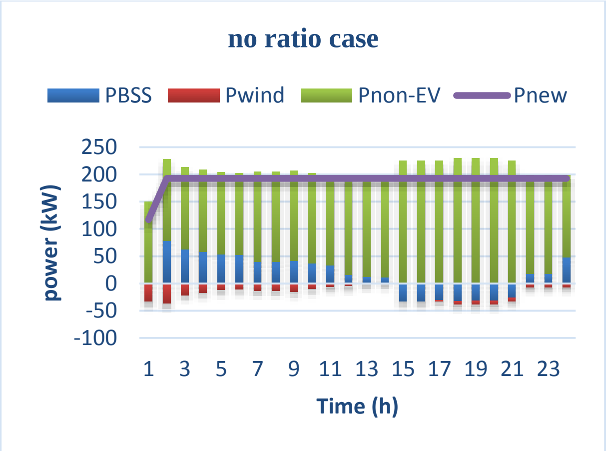

Fig 2. The Internal layer result for power flatting in case1 (P $_{\mathrm{new}}$)

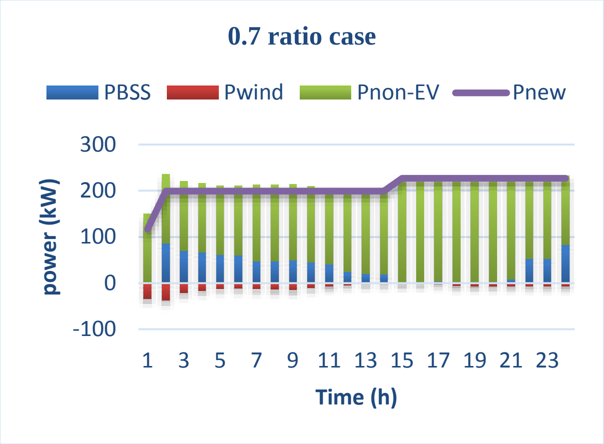

Fig 3. The Internal layer result for power flatting in case2 (P $_{new}$)

Table1. Daily total profit in each case

	total profit ($)
case-1	10016.97740
case-2	9874.92404

$P_{non\text{-}EV}$ demonstrates the hourly conventional load (except EVs). Wind generation has shown as negative load. Then, in Fig.4 and Fig.5 the final unit commitment output is shown (P_m is the generated power by each microturbine), it is explicated that the station enables MG to sell its extra power to the upstream grid during peak and purchases energy from the upstream grid during off-peak due to a lower price (P_{grid} is the energy exchange, negative for buy from and positive for sell to upstream grid). It can be understood that, as there is no limitation for battery discharging in case1, it generally can cover its load without any dependency to the upstream grid. Consequently, in case2, MG needs to supply itself by buying energy, this finally causes less total profit to case2 comparison with case1 (See Table.1). So BSS interaction with power grid is still under the force of battery technology but it leads to reasonable answers in EVs load management for efficiently load shifting and is an easy method for implementing smart charging strategy without any stress for EV users and also MGSO.

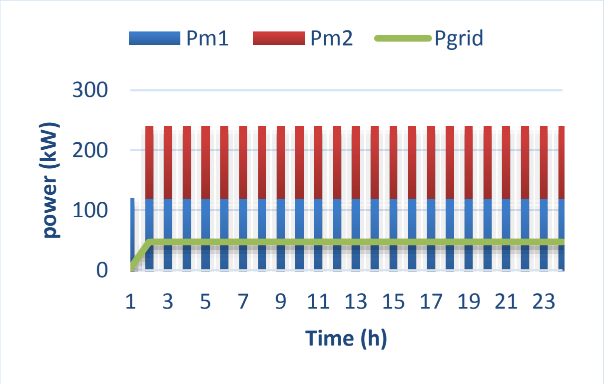

Fig 4. The external layer result for UC in case1

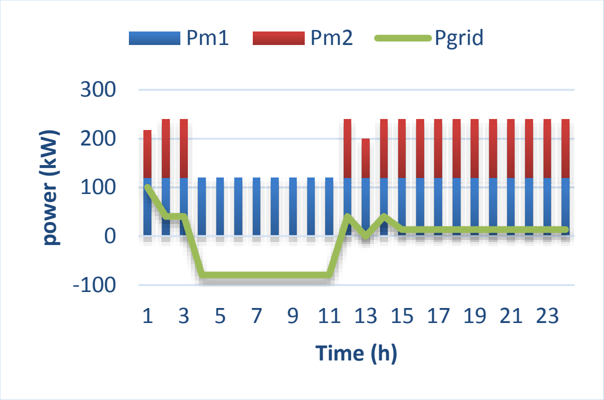

Fig 5. The external layer result for UC in case2

CONCLUSION

A detailed UC model by considering different constraints related to BSS is presented in this paper. The model decomposes the problem in two sections by scheduling BSS according to energy price, the conventional load of MG and the power intermittency of wind turbines. Depending on market condition BSS can be a benefit to confronting EVs demand even there is a threshold for allowance to discharge or not, but the pre-mentioned parameter can impact the degree of freedom in BSS operation and finally the MG operator.

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