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INTEGRATION OF WIND AND SOLAR POWER TO A DC MICROGRI

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***Abstract*: Operational controls within the microgrid are designed to maintain the integration of the wind and solar power. The dc microgrid is propounded to comprise a wind energy conversion system (WECS), a photovoltaic array (PV), battery energy storage system (BESS) and supercapacitor (SCAP). Droop control for power electronic converters connected to battery storage which is a function of the storage state-of-charge (SOC) and can become asymmetric is developed and tested. Supercapacitor and battery are modeled with an energy management strategy in a hybrid storage system. SCAPs are featured for peak power demand, and batteries supply the power in the steady state. Untapped wind and solar are supporting to deliver to electric vehicles (EV) and the main AC grid.**
***Index Terms: Wind energy, Photovoltaic array, Battery Storage, supercapacitors, droop control, electric vehicle*.**

I. INTRODUCTION

2015 was an unrivaled year for the wind power generation as annual installations reached the 60 GW and new wind power with capacity of 63 GW were brought on-line. The growth of wind power is increasingly operated by its economical pricing, as well as because it improves price stability and energy security that is progressively making the major development of urban areas in the world unlivable. In this paper, the energy system proposed to resolve both issues related to transportation sectors and electricity. One probable solution is a microgrid that can be vertically integrated with the harvesting of renewable wind and solar energy occurs at the top of the building. The wind and solar generation connected to electric vehicle (EV) charging stations are supplied to ground level via a microgrid where multilevel energy storage plays a role in maintaining the balance between supply and demand. The significance of an urban integration within buildings is the usage of rooftop energy storage for contributing EV fast charging at the ground level, this result in emission-free EV transportation in urban areas and the grid-friendly integration of the microgrid with the rest of the power system main grid. The integration of the wind and solar energy resources on a rooftop was also explored in [3]. It was established that the integration of the wind and solar energy results in reduced local storage requirements [4]. A multilevel energy storage, where a supercapacitor provides fast power fluctuation compensation and cache control to smoothen the transients experienced by a battery with higher energy capacity [5], [6]. Microgrids or integrated systems have been shown to be an effective formation for distributed renewable generation, storage and loads [7]–[12]. Recent research has considered that the droop control maintained the dc link voltage that correlates the dc link voltage to the power output of controllable resources. This paper showed the droop characteristic of the battery as a function of the expected state of charge (SOC) according to its real time SOC versus operational optimization set point. The proposed operational optimization is further determined in that it deals with intermittency associated with renewable generation forecast, constraints, emission and EV fast charging.

II. LAYOUT OF THE DC MICROGRID

The microgrid is included a photovoltaic system (PV), a wind energy conversion system (WECS); a battery energy storage system (BESS) and a supercapacitor. Because the wind and solar energy sources are random, a multilevel energy storage system is therefore integrated into the system to reduce usage of electricity from main AC grid, minimize the operation cost and reduce the emission of the system also. Multilevel energy storage system can also provide is load-frequency control, voltage control, providing a reserve, capturing excess renewable generation and increasing the value of generated renewable energy by shifting the usage time in an economically optimized way.

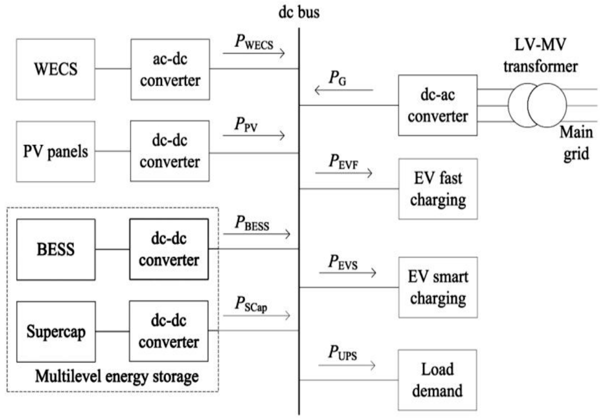


Fig-1 outline diagram of the DC microgrid

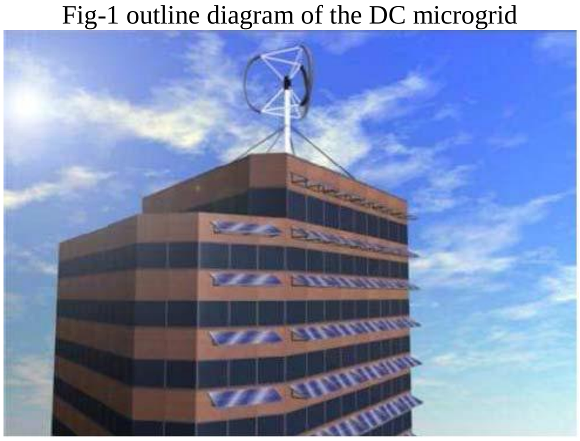


Fig. 2 Vertically integrated structure for the wind and solar power generation for microgrid

WECS is connected to the dc bus through an AC/DC converter. Both energy storage system is integrated to the dc link via a bi-directional dc/dc converter. The supercapacitor has much less energy capacity than the BESS. Rather, it is compensating the fast fluctuations of power and so results in cache control as explained in [19].The dc microgrid is interfaced to the AC grid through a DC/AC converter and a transformer. Multilevel energy storage can manage the intermittent and volatile renewable power outputs supplying uninterruptible power supply (UPS) service to loads when demanded is a main function of the urban microgrid. EV fast charging provided a stochastic load to the urban microgrid. A vertical axis wind turbine may be installed on the rooftop of a building as shown in Fig. 2. PV panels can be also located on the rooftop of the building. Such or similar configurations benefit from a local availability of abundant wind and solar energy. The fast charging station is introduced for public access at the ground level. User-defined constraints should be within the limit for smart charging for EVs parked in the ground level of the building.

III. OPTIMIZED OPERATION STRATEGY OF THE DC MICROGRID

A. Solar and Wind Power Generation Forecast

- Power generated from the wind and solar is available for hourly intervals. An uncertainty in forecasted power decides the energy capacity of multilevel energy storage system which is also known.
- Load profile of Electric vehicle fast and smart charging are known.
- Several parameter of the battery for example SOC (state of charge), depth of discharge (DOD), power and charging and discharging efficiencies are known.

B. Energy Reserve Allocation for Operation of DC Microgrid:

In the BESS, the main energy constraints are positive and negative energy allocation. According to operation schedule, BESS storage capacity assessment is shown in Fig. 3 The positive energy reserve (+ reserve), negative energy reserve (-reserve), depth of discharge (DOD) and operational area, are assigned for optimized operation in the BESS. The constraints of BESS have used for maintaining the balance between the power generation and load demand in real-time operation. To regulate uncertainty between renewable energy generation and power demand, the battery provided specific amounts of positive and negative reserves allocation [15]. Intermittency of generation can be determined with the help divergence between forecasted power and actual output power. An agreement between cost and advantage of allocating the reserves can promote to an establishment of optimal size.

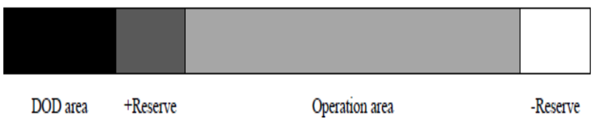


Fig.3 Battery storage allocation for optimized scheduling

C. Formulation of Optimized Scheduling of Microgrid

The main objective of the formulation of optimization is to minimize schedule the cost of the DC microgrid in integrated system and supply UPS service in self-governing mode. The minimization of the objective function can be achieved as follows:

$$F(P_G, P_{EVS}) = \sum_{i=1h}^{T} C_{1kWh}(i) \times P_G(i) \times \tau_h + \sum_{i=1h}^{T} C_{1kWh}(i) \times P_{EVS}(i) \times \tau_h + \sum_{i=1h}^{T} EPBF \times \overline{EMS} \times P_G(i) \times \tau_h \qquad (1)$$

where F is the objective function which is used to minimize P_{EVS} and P_G, T is the optimized scheduling horizon, τ_h is the time step for 1 hour for optimization, the energy cost for 1 kWh energy represented by C1kWh, PG is the power supplied by the grid, PEVS is the power used for smart charging for EVs, EPBF has defined the emission penalty bonus factor for CO2. In this objective function, PEVS and PG are to be optimized with the help of three-term, the first term is the energy cost, the second term defines the EV cost for smart charging, and the third term indicates the emission cost.

The power exchanges from the main grid introduces a boundary limitation to the optimization

$$P_{G-} \le P_G(t) \le P_{G+} \qquad \forall t \in T \qquad (2)$$

Where P_{G-} and P_{G+} are the lower and upper boundary of grid interface power respectively.

Battery power has to be within the boundary condition to the optimization

$$P_{BESS-} \le P_{BESS}(t) \le P_{BESS+} \quad \forall t \in T \qquad (3)$$

Where P_{BESS-} is the lower limit of the power flow from battery to dc link and P_{BESS+} is the upper limit of the power flow from dc link to the battery .

Power available for EV charging must satisfies the following boundary condition

$$0 \le P_{EVS}(t) \le P_{EVS+} \quad \forall t \in T_{EVS} \qquad (4)$$

Where P_{EVS} represents the EV charging power available for smart charging and T_{EVS} is the time period available for smart charging.

Balance equation of the power must satisfy at all simulation time periods

$$\overline{P_A}(t) + P_{BESS}(t) + P_G(t) - P_{EVF}(t) - P_{EVS}(t) = 0 \quad \forall t \in T \qquad (5)$$

Where $\overline{P_A}(t)$ is the average power generated from the wind and solar. P_{EVF} is the power available for EV fast charging.
For battery, the main objective function for optimization is the SOC of the battery. Battery constraint can be expressed as follows

$$E_{BESS-}(t) \le E_{BESS-0} - \sum_{j=1\min}^{t} \Delta E_{BESS}(j) \le E_{BESS+}(t) \quad \forall t \in T \tag{6}$$

Where E_{BESS-} is the lower limit of the energy capacity of the battery, E_{BESS-0} is the energy capacity available in initial, ΔE_{BESS} is energy discharged to the dc link from the BESS per minute and E_{BESS+} is the upper limit of the BESS for energy capacity.
The upper and lower boundary of BESS for energy capacity to the optimization can be defined as follows:

$$E_{BESS-}(t) = EC_{BESS} \times (1 - DOD) + EC_{PR}(t) + EC_{UPS}(t) + EC_{EVF}(t) \quad \forall t \in T \tag{7}$$

$$E_{BESS+}(t) = EC_{BESS} - EC_{NR}(t) \quad \forall t \in T \tag{8}$$

Where DOD is the depth of discharge of BESS, EC_{PR} is the positive energy reserve and EC_{NR} is the negative energy reserve of the battery.
EC_{UPS} is the energy capacity required from the battery for the local loads and EC_{EVF} is the EV fast charging energy capacity.
The energy discharged from the battery to the dc link is determined by

$$\Delta E_{BESS}(t) = \begin{cases} \dfrac{P_{BESS}(t)}{\eta_{dis}} \times \tau_{\min}, & P_{BESS} \ge 0 \\ P_{BESS}(t) \times \eta_{ch} \times \tau_{\min}, & P_{BESS} \;\pi\; 0 \end{cases} \tag{9}$$

Where η_{ch} and η_{dis} are the charging and discharging efficiencies of the battery. $\tau_{\min}$ represents the time step for 1 minute.

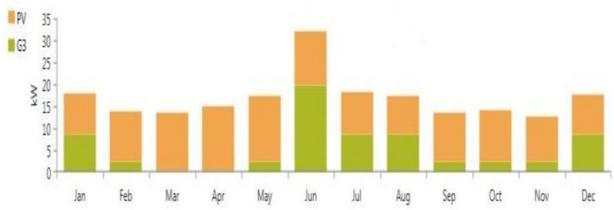
IV. DROOP CONTROL OF BESS

In this segment, the continuous operation of the microgrid in the interconnected and self-governing modes is examined. In the interconnected method of operation, a droop control is achieved for the BESS. Droop control for power electronic converters connected to battery storage which is a function of the storage state-of-charge (SOC)**.**The droop control attribute of the BESS electronic converter is chosen on the premise of the deviation between the improved and ongoing SOC of the BESS, as computed in Section III. In autonomous mode of operation, the BESS is in charge of keeping the voltage of the dc link in a characterized range.

V. VERIFICATION BY SIMULATION

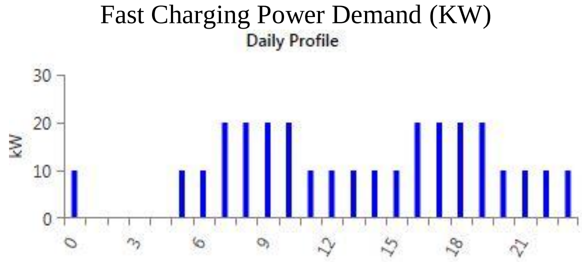
The proposed operational technique for the urban microgrid in day-ahead planning and ongoing operation is verified by simulation results. HOMER programming performs different simulations with a specific end goal to acquire the optimized hybrid results [24]-[28]. For the day-ahead scheduling, the technique presented in this paper is implemented and verified in MATLAB
The optimized results of a vertically incorporated urban microgrid with sustainable power source gathering as appeared in Fig. 2 and EV charging on the ground is verified for the accompanying presumptions.
1) A vertical axis twist turbine with a generation capacity of 45 kW is introduced on the housetop.
2) Photovoltaic panels with a capacity limit of 60 kW are mounted on the building.
3) A battery storage with the capacity limit of 738 kWh, the power rating of 50 kW, and charging and discharging efficiencies of 0.95 and 0.90, separately, is set on the ground floor of the building. The DOD of the BESS is 80% of the most extreme power limit, which gives a minimum discharge to SOC of 25 kWh.

Renewable Power Generation (KW)



(a)

Fast Charging Power Demand (KW)

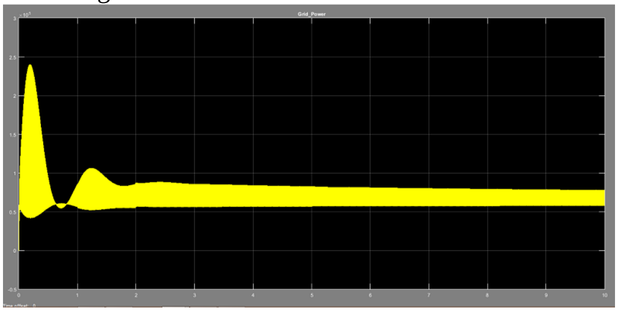


(b)

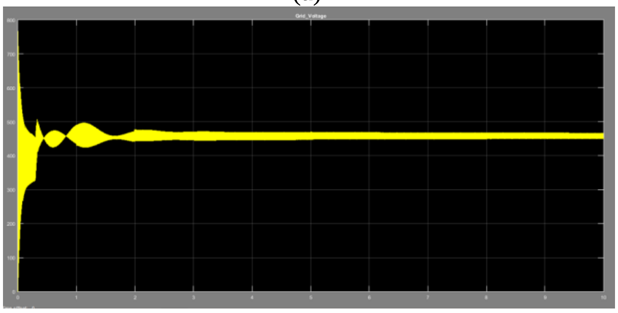
Fig. 4. Case study: Inputs. (a) Average wind and solar power forecast profiles. (b) Fast charging profile of electric vehicles.

4) A storage capacity of a supercapacitor with a limit of 12 kW is introduced.
5) The BESS and a supercapacitor together form a multilevel energy storage system, where the supercapacitor gives energy cache control for dynamic [19].
6) A grid interface with the limit of 50 kW is provided.
7) The power generation of the wind and PV-based have appeared in Fig. 4(a).
8) A quick charging station to serve one EV at any given moment is given. The charging capacity is 20 kW. The simulation result of fast charging profile is given in Fig.4(b).
9) Charging and discharging characteristic of supercapacitor are shown in fig.6.

10) Charging and discharging characteristic of the battery are shown in fig.7.



(a)



(b)

Fig. 5. Case study: Assumptions of the simulation. (a) Power generated at dc bus. (b) dc bus voltage profile

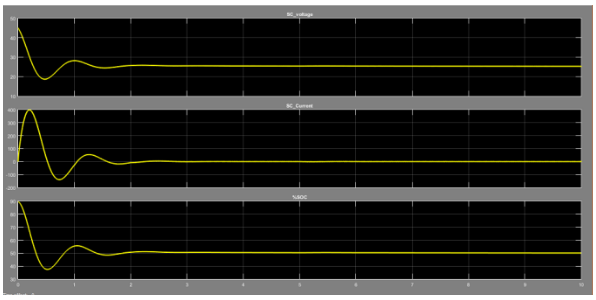


Fig. 6 Supercapacitor charging and discharging characteristics

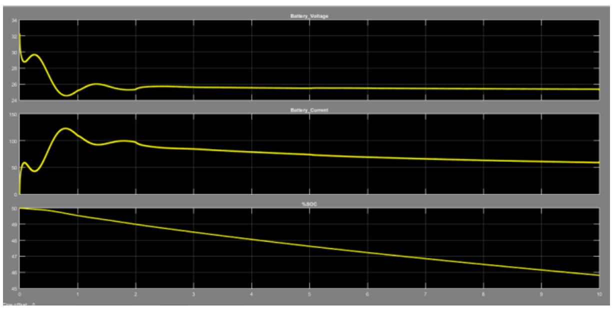


Fig- 7 Battery charging and discharging characteristics

With the help of asymmetric droop characteristic of the BESS, the multilevel energy storage does not provide compensation of renewable forecast fluctuations and the dc fast charging EV. So, the grid droop control is also operated, and the main grid gives power to EV for the fast charging demand. The BESS supplies steady state power due to the supercapacitor, which absorbs the fast fluctuations. The dc bus voltage drops to around 450 V which is used for dc fast charging of electric vehicle as shown in Fig. 5(b.

VI. CONCLUSION

The integration of the wind and solar power for dc microgrid has been proposed. The optimized scheduling of microgrid and various power-electronics based converters was developed, and the operation of the different component of dc microgrid was explained through simulation. Integration of various renewable energy resources was controlled as a result to minimize CO_2 emission and cost of an operational optimization. The uncertainty in the aggregate wind and solar power generation forecasted which is used to specify the energy reserve capacity of the battery energy storage system. The supercapacitor connected parallel to the battery to configure a multilevel energy storage system. The storage system plays a vital role in compensating fluctuations in renewable power and supporting the power demanded for fast charging. According to the microgrid paradigm, the autonomous mode is also possible to support UPS when there is no connection to the main grid. Fast charging is not available during such period and power supply shifts to local loads. With the help of power electronics technology, it is possible to enable to connect all the energy resources with the dc microgrid. The control strategy present here is voltage–power droop characteristic which is modified according to the result of the operational optimization. Multilevel energy storage that plays a key role in controlling dc bus voltage and supplying adequate energy reserve. In case of an urban microgrid, the vertical integration offers to harvest of renewable solar and wind power on the top of a tower building and energy supply to local loads and electric vehicle charging on the ground level of this building. This structure contributes to resolving the issues related to the transportation of energy and nearly co-locating the power generation resources and supply. This paper presents the optimization for the power of resources and dc bus voltage control achieved by adaptive voltage–power droop control through power electronic converters that joins together all the resources. The emerging energy system supplies local loads and electric vehicle fast and smart charging. Renewable energy resources reduce CO_2 emissions and effective cost of the energy system.

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