

# Dynamic Demand Balancing Using Demand Side Management Techniques in a Grid Connected Hybrid System

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**Abstract-**This paper confers the control strategies in balancing the dynamic demand (DD) considering a grid connected hybrid system using Demand side management (DSM) techniques. Power generation and energy needs of consumers will always be uneven; there exists a mismatch between two terms. The hybrid energy system (HES) that carries the best features of both conventional and non conventional energy resources supplies unstable power. This instability is due to the renewable energy system (RES) penetration which is highly intermittent and non reliable. This instability also causes phase shift in voltage and current waveforms causing reactive power penetration to the electric grid leading to voltage/frequency imbalance. By means of DSM control strategies the power in the grid is made reliable with improved quality. Using proper switching tactics with Power electronic controllers for Synchronizing devices, the lead lag active and reactive power is controlled with variable connected load. The entire creature of control is integrated with the smart meters. Modeling and simulations were done in MATLAB/Simulink. The simulations were presented to evaluate the dynamic performance of the hybrid system under proposed demand balancing methodology.

**Keywords** Demand side management, Dynamic demand, Hybrid energy system, Grid connected Hybrid system, Renewable energy system.

## 1. Introduction

Renewable Energy has been one of the rising trends in the field of Energy engineering. Renewable energy system has its source over the renewable resources such as solar, wind, tidal, wave, biomass etc. Power extraction through tidal and wave energy is bounded due to less availability, lack of technological improvements. Due to this rationale the energy extraction by renewable is principally emphasized with solar and wind resource. Both these resources exhibits eco-companion benefits and find a trendy development in research and development field. The intermittent nature of solar and wind resources creates large obstruction in the process of power squeezing. In this case, it is hard to balance the local loads due to absence of precious characters such as stability and quality in the power supply [1]. Enhancement developed in the process of onsite energy production minimizes the losses during the transmission and distribution [2]. On site generation also provides extreme benefits to the utility as it bear up the DSM program implementation directly. Dynamics on both source side and demand side for sizing the RES unit

was comparatively done in [3]. Similarly the balancing models for dynamic power in future scenarios were resolved in [4].

The solar PV and diesel hybrid system impinges in off-grid areas for the most part with no battery storage. The reliability in the power supply to the system by DG set which offer optimal power to the load [5]. Control strategies of hybrid distributed generation units with rated configuration for Wind power, Hydro power, PV array, CHP units and battery storage to improve the efficiency during grid connected operation being analyzed to ensure the drastic performance of distributed generation [6]. Dynamic behaviour of a stand-alone hybrid power generation system of wind turbine, Micro turbine, solar array and battery storage by [7] proves the distinct behaviour of the hybrid system at different status. A DSM model with a pre-paid metering system for hybrid RES is proposed in [8]. The core idea of the proposal is controlling the demand of the consumers with some functions, restricting the consumption proportionality to the monthly available resources. The proper sizing of the PV/wind system with techno-economical proposal presented in the work [9] overshoot an intended

destination for improving non-intermittency quality of distributed resources.

Hybridization of the renewable energy resources requires an integrated control unit to compete an autonomous hybrid energy system for stand-alone applications [10]. The feasible solution relating the penetration percentage of the RES in the Hybrid power system should give tolerance values to meet the demand through the available resources [11]. The changes in wind velocity and daily load of the consumer are harder to deal. The effective strategic decisions discovered for planning and implementation of DSM important to have stable electricity supply [12, 13]. A DSM program highlights the necessity of load management and Energy conservation, for both electric utilities and consumers. So effective strategic planning should be laid to ruin the concept of demand for electricity. Different load profiles for stand-alone photovoltaic systems exhibits variety of load-loss probability effects [14]. The optimal solution for DSM problem with a case study was terminated using mathematical formulations in [15]. The main objective of these formulations is to manage the load factor near to unity, and to have a small peak under certain note. The balance between the power supply and power consumption, determines the energy need in demand which can estimated online for scrutinizing power flow into the system. Optimal frequency detection is performed throughout the entire system for supplying quality power during transients. As the load factor of the system gets closer to a value nearer to unity, the demand side measure is on track to make a way of success to reach the destiny of DSM.

## 2. Dynamic Demand and Demand Response

Power factor on the utility grid is monitored and the control parameters guiding the entire utility system is optimized, considering switching of personal and intermittent load. Ease of balance is achieved by optimal switching of load and generation unit, thereby reducing critical power mismatches. Matching the individual appliance operating cycle through advanced and delayed switching of concerned appliance by the utility can aid to get rid of failures such as regional power cut, peak demand power quality issues.

Altering the utility intentions over the customers consumption chart results in riding out customers load timing, instantaneous load demand level and the total energy consumption. The DSM actions in plenty can rule off energy meter for different system operations. The individual appliance operating cycle(AOC) expressed in terms of parameters such as time of use ( $t_u$ ), power consumed ( $P_c$ ), average power consumption ( $P_{c-avg}$ ), power delivered ( $P_d$ ) and the average output power ( $P_{d-avg}$ ).

$$AOC = \frac{t_u}{P_c} (P_{c-avg}) + \frac{t_u}{P_d} (P_{d-avg}) \quad (2.1)$$

The system operating cycle (SOC) is expressed using source side dynamic parameters such as time duration of power generation ( $t_g$ ), power generated for corresponding time period ( $P_g$ ), the average power generated ( $P_{g-avg}$ ) and the demand side dynamic parameters such as the time duration of power received ( $t_r$ ), power received by the connected load for corresponding customer consumption time chart ( $P_r$ ), average power consumption period ( $P_{r-avg}$ ). The SOC could be expressed using those relations as stated in below equation (2.2)

$$SOC = \frac{t_g}{P_g} (P_{g-avg}) + \frac{t_r}{P_r} (P_{r-avg}) \quad (2.2)$$

In this study mathematical models were developed and substitutions related to private utility system consumption charts were done to estimate the operating cycle. Considering the importance of operating cycle to rule over future smart grids the source and demand side power generated and received power was collected dynamically within distinct time range. The difference in power generation and power consumption dictates the power loss across the system. After successive substitution of parametric values there shows a surprising two results i.e. for minor losses the SOC cycle will be low and for major losses the SOC will be high. There raises a constraint again to run the system under optimal condition to keep up best SOC range. The calculated SOC values give preference to work the entire utility system within optimum operating cycle range for effective operation and performance.

## 3. Data Collection and Scrutinization

In order to prove the strategy for balancing dynamic demand, the data was collected considering both load side and source side dynamics. Details and descriptions of data collection are given below.

### 3.1. Customer Electrical Load Profile

An electrical load profile acquired from a neighbourhood residential sector, receives power from the grid also consists of renewable energy system in play which could be used in the analysis for DD balancing. In order to own a stable power supply to the load during power shortage, intruded Captive diesel generator (CDG) within the system can offer a support. For solidity a battery backup on the side of generating unit of RES could be furnished, comprising an excellent grid-connected Hybrid system. Momentary values about all the typical load demand connected with in the system and related information have gathered for execution.

### 3.2. Renewable Resource Profile

In order to set up the real-time control strategy for balancing demand, the data relating both load side and source

side dynamics could be acquired. This for when establishes a chance to discover optimal operating frequency and safe voltage potential. A dial to discover all those values requires the localized solar irradiation and wind speed.

3.3. Solar Energy Resource Data Profile

The incident solar irradiation is collected in the neighbouring site at Trivandrum with a global location of latitude 8.48 N, Longitude 76.95 E, and Elevation 64 MASL. The data were collected for each 10 minutes for several days and averaged. The localized solar irradiation from morning 6pm to evening 6pm is tabulated. Minimum values of

irradiation hitting the panel were found in the morning and evening sessions.

3.4. Wind Energy Resource Data Profile

The wind speed data brought together from the neighbouring impoverished village named Muppandal (latitude 8°15' N, Longitude 77°32' E) that is highly benefited with wind resources near to the resident. The data for each 10 minutes of distributed wind resources being aggregated, for several days and averaged. Scrutiny of load profile, and wind speed data, and the solar irradiation data

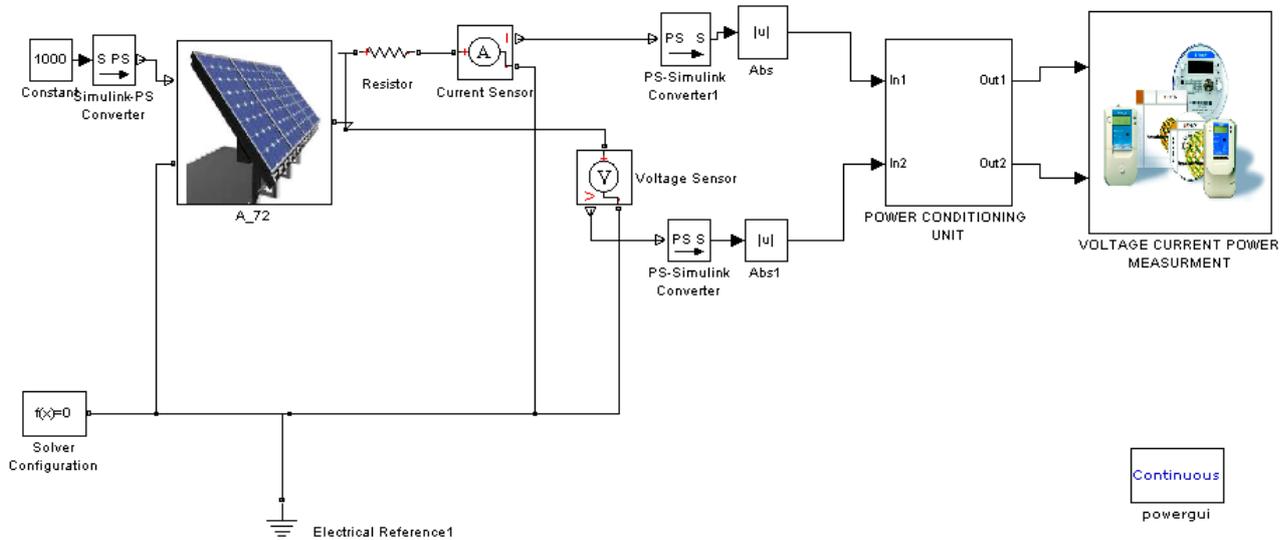


Fig. 1. Solar energy system – Simulink Blocks in MATLAB

have reckoned in MS Excel for varying time. Increased fluctuations in the wind speed have deemed throughout the day which is continuously monitored and charted.

4. System Modeling

4.1. Solar PV System Modeling

Fig.1. shows the solar PV system modeling in MATLAB manifest. The modeled solar energy system comprises of multiple subsystems that of solar cells to a greater extent strapped in series and parallel furnished with a rated power of 100 kW. The solar cell is primarily a current source device which interconnects the voltage source inverter with the aid of I-V Sim-scape interface block. The inverter composed of IGBT devices connected in the universal arm bridge mode activated by six pulse sources to the gate port. The inverter consists of IGBT devices connected in the universal arm bridge mode, triggered with six pulse sources to the gate port. The total system connecting the feeder through a linear transformer with proper grounding helps to decrease the asymmetric fault currents between the phases. The

measured irradiance value yielded to each solar cell placed inside each subsystem of the solar array. The solver parameter block used to solve the configuration linked with the model.

4.2. Wind Energy Generator System Modeling

The wind energy system modeled with an asynchronous machine coupled along the system to compensate the negative VAR produced due to secondary load as shown in fig. 2. The asynchronous generator is parameterized using the d-q equivalent circuit. The phases of the stator terminal voltage aligned with the direct axis, by which all the rotor variables contemplated in the rotor side [12]. The wind power unit is supplying three dynamic loads namely Base Load, primary load and secondary load of range 25 kW, 50 kW and variable 500 kW respectively. The d axis and q axis voltages on the stator side described by the following equations;

$$V_d = E'_d - R_s I_d - X'_l I_q \tag{4.1}$$

$$V_q = E'_q - R_s I_q - X'_l I_d \tag{4.2}$$

The output of the wind generator comprises of two power components namely, active power component and reactive power component. Under steady state operation, their values estimated using the below equations as depicted.

$$P_e = \text{Re}\{V_t I_A^t\} \tag{4.3}$$

$$Q_e = \text{Im}\{V_t I_A^t\} \tag{4.4}$$

The d-axis and q-axis voltages on the stator side had taken as reference of excitation system for the synchronous condenser. By using a discrete frequency regulator, switching the secondary load have made possible connected with the feeder.

4.3. DG Set Modeling

The DG unit designed as similar as the wind machine by considering synchronous machine parameters only. A governor was employed for the variant controls of synchronous machine, with speed and power as regulating parameters. The excitation system managed by a control unit receives power from the stator terminals. Thereby, calculation

of field excitation for the synchronous machine, estimating the d axis and the q axis voltage is measured at the stator terminals.

4.4. DSM - MDC unit modeling

The MDC unit represents a large proportion of the electricity bill in residential sector. By switching off the non essential loads during the peak hours be an economical and smart idea. MDC unit have responsive demand values regarding the load management of residential sectors. When

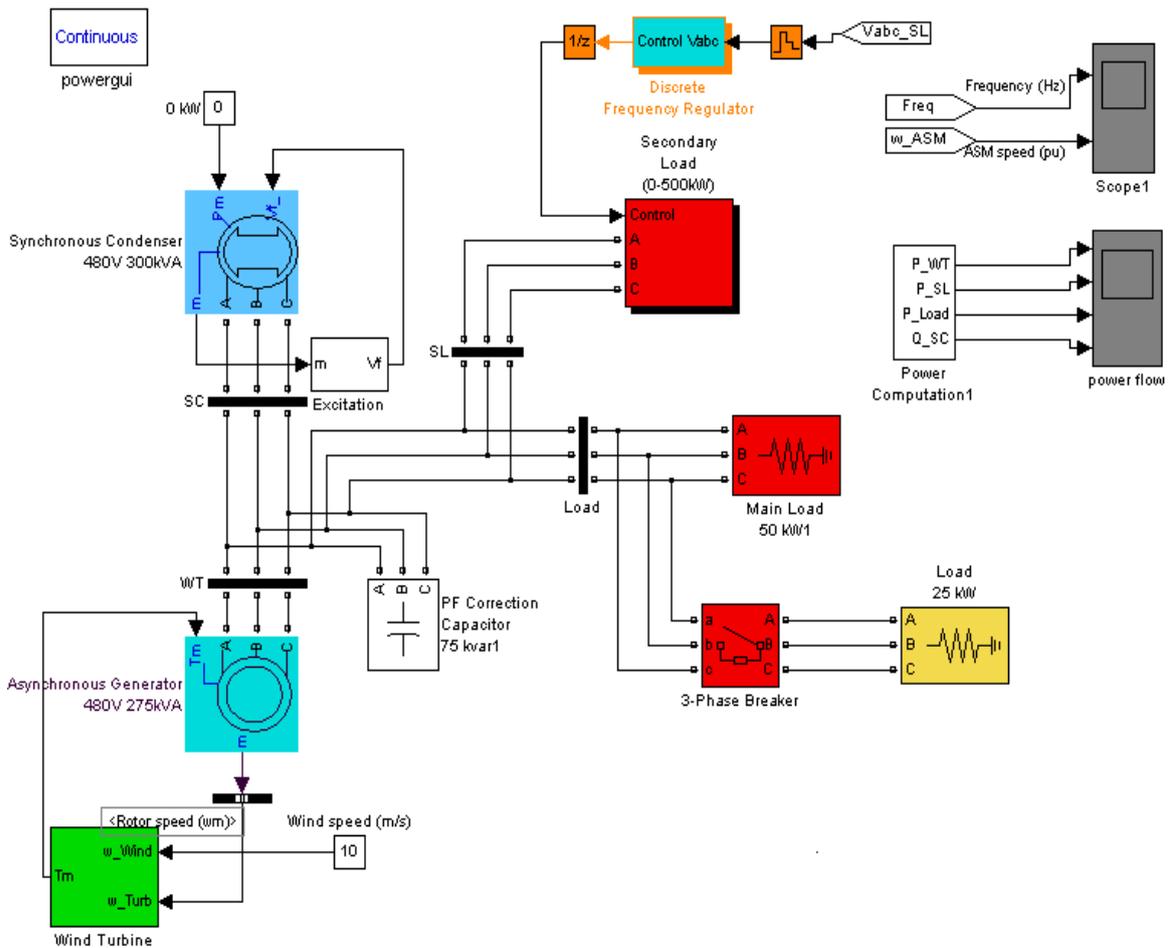


Fig. 2. Wind energy system – Simulink blocks in MATLAB.

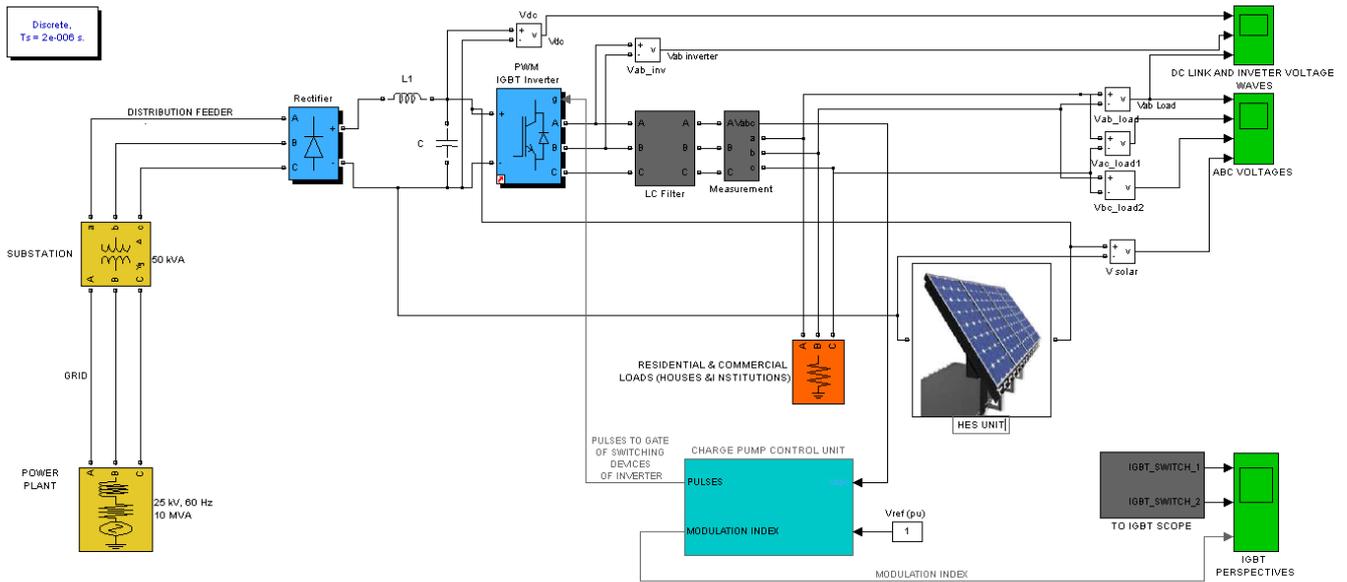


Fig. 3. Wind energy system – Simulink blocks in MATLAB.

the demand raises an indication is provided by the MDC unit. It readily switches ON/OFF the non-essential load which is already programmed in it through logical sequence using microcontrollers. MDC unit should be installed with safe electrical contactors with appropriate control resident to demand side region. The non-essential load is turned ON when the load profile approaches a base line value. Also the load sharing and peak clipping operations were performed by DSM-MDC unit. The entire hybrid energy system creature and its control during its operation with power transmission grid are shown in fig. 3.

### 5. Power Computations and Analysis

The residential power demand depicted in fig. 4. Power induced from the 100 kW solar power generators from locally gained solar resources is pictured in fig. 5. The power induced is calculated through equation, which requires solar irradiation data, panel area and panel efficiency [7].

$$P_{pv} = \eta_{pv} \cdot A_{pv} \cdot G_t \tag{5.1}$$

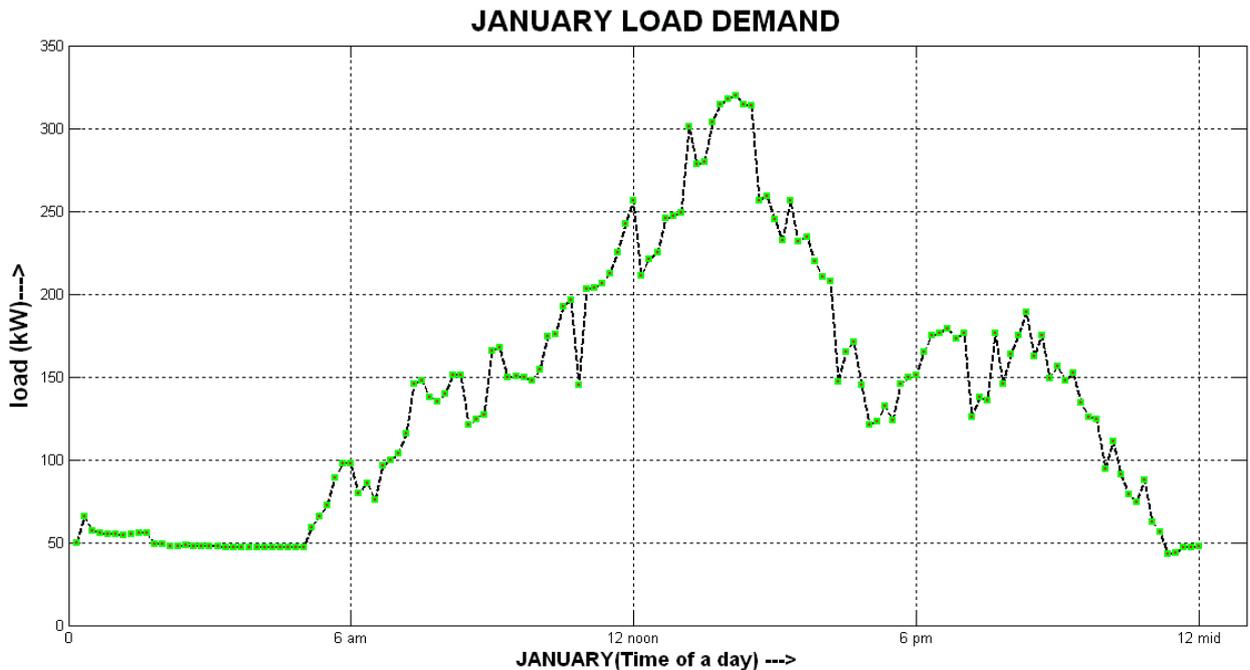


Fig. 4. Localized Residential Customer Demand Curve.

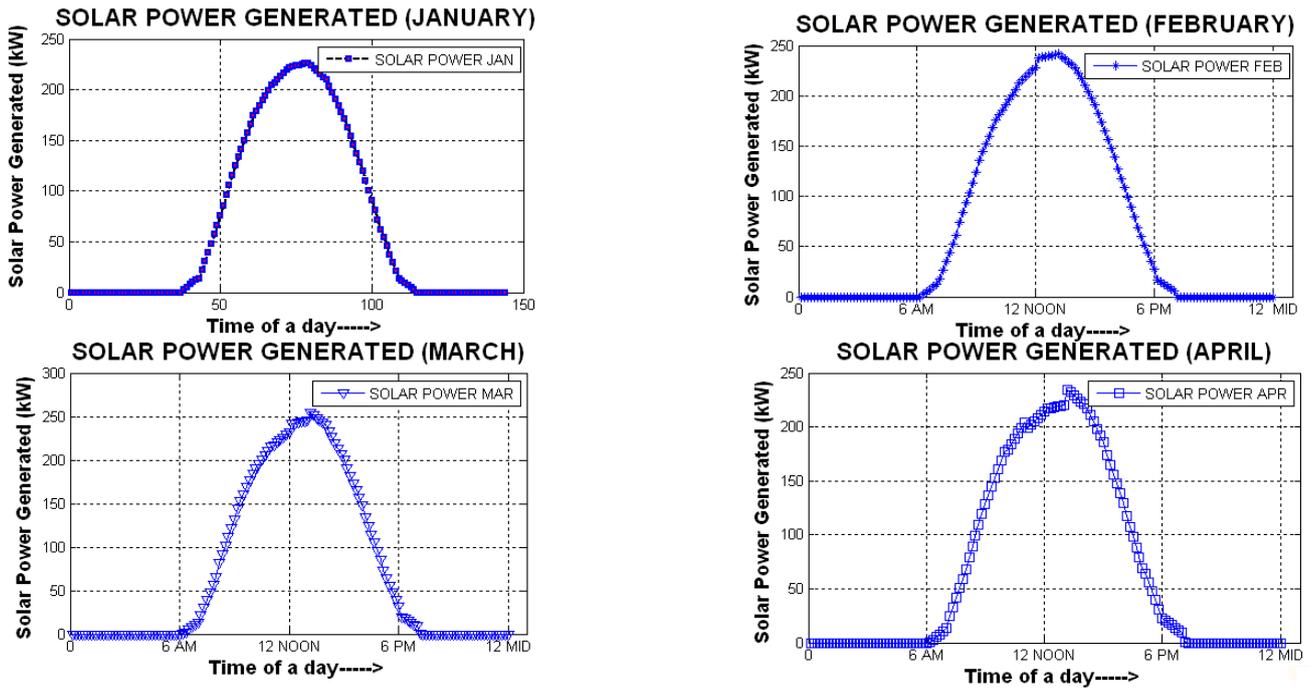


Fig. 5. Generated Solar Power vs. Time of a day.

The generated wind power is calculated for the wind machine having rated capacity of 220 kW and the generated power is simulated using suitable MATLAB functions. The average power generated for twelve months in an annual year and the daily-monthly average power is calculated for all months in a year and the six month averaged wind power is pictorized in fig.6. The excess electricity produced by the HES unit without DG set, is driven to grid with varied time period and the unmet part is conferred from the grid. Observations during the survival of renewable energy system shows that the

reliability is low due to frequently varying nature of the renewable resources as seeking as in charts in fig. 7 and 8.

$$P_w(V) = \begin{cases} \frac{V^2 - V_{cin}^2}{V_{rat}^2 - V_{cin}^2} P_r; & V_{cin} \leq V \leq V_{cin} \\ P_r; & V_{rat} \leq V \leq V_{cout} \\ 0; & V \leq V_{cin} \text{ and } V \geq V_{cout} \end{cases} \quad (5.2)$$

The path shown in improvement of system reliability considerably increases the use of filtering units. If diesel generator is coupled during operation, uninterrupted stable

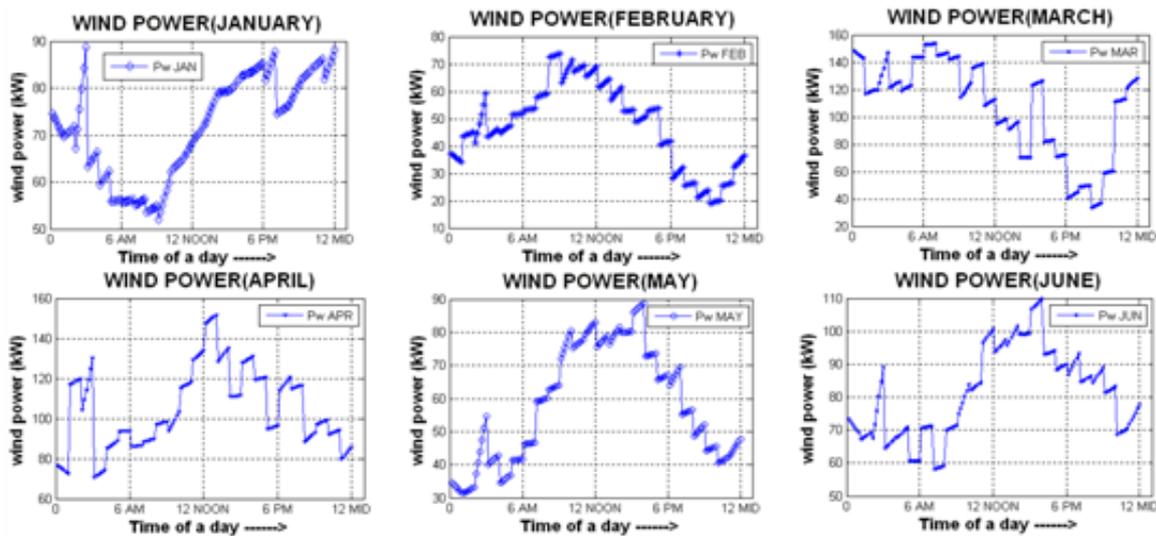


Fig. 6. Generated Wind Power vs. Time of a day

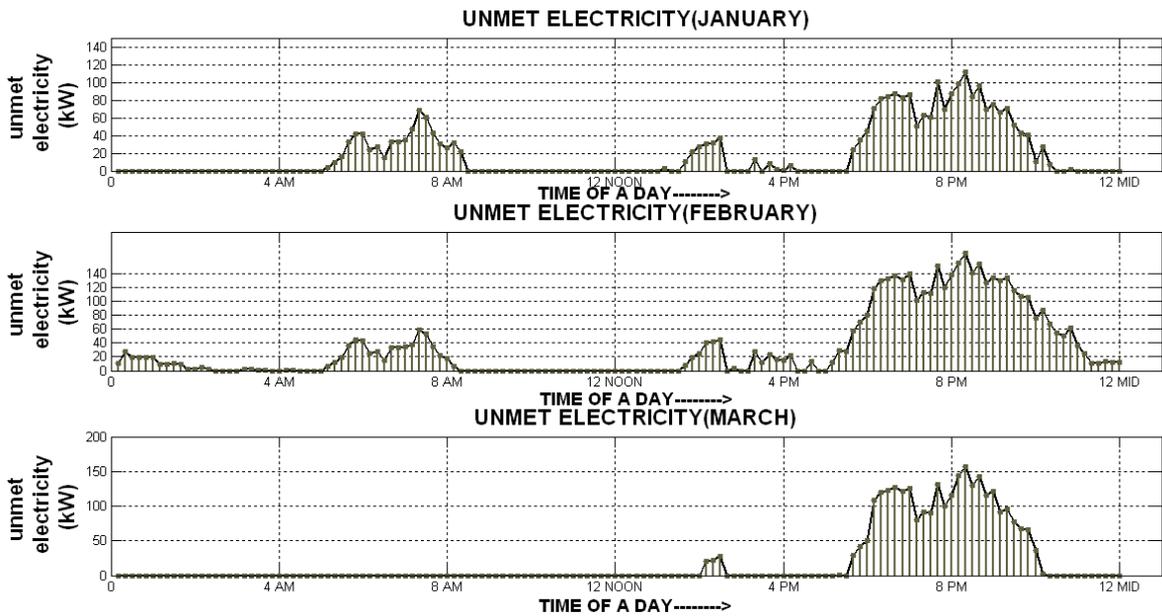


Fig. 7. Computed unmet electricity of the residential load sector

power with better reliability is obtained from the HES unit using optimal power tracking system.

Addition of multiple energy resources generate surplus power which is transmitted to the grid by the aid of appropriate power electronic technologies incorporated with the entire system. Implementation of DSM measure over the corresponding residential demand unit is scrutinized and charted in fig. 9. Scrutinization of power quality is made to be prominent during the power injection to grid for improving transmitting efficiency. The harmonics are filtered using the frequency control unit incorporated with load frequency controller. Any distortion in power injection may lead to small adverse effects on the grid, so the injected power is scrutinized for each time intervals.

Demand side control measures are implemented through MD controllers by disconnecting nonessential loads during peak hours. The controller is aided to shutoff the non-essential loads not met by renewable energy system above a reference set value. The energy conservation measure through adopted energy efficient devices and considerable power reduction is viewed in the load profile which is shown in fig.10. Valley filling measure is equipped along the controller to enchant energy use during off-peak hours which is shown in fig.11. Energy Conservation ratio (ECR) opted for all devices is an innovative concept indulged in implementing the energy conservation measure. As a result of load shifting, the maximum demand reduces and follows a track nearer to the average demand. Obviously the load factor gets close to the unity which means the demand side

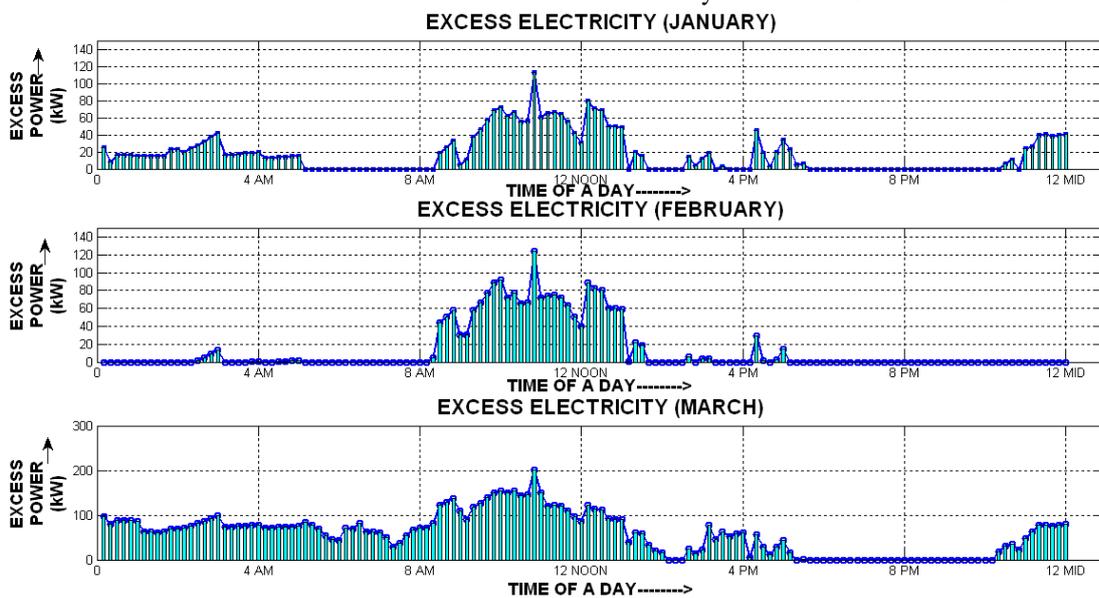


Fig.8. Computed Excess electricity of the residential load sector.

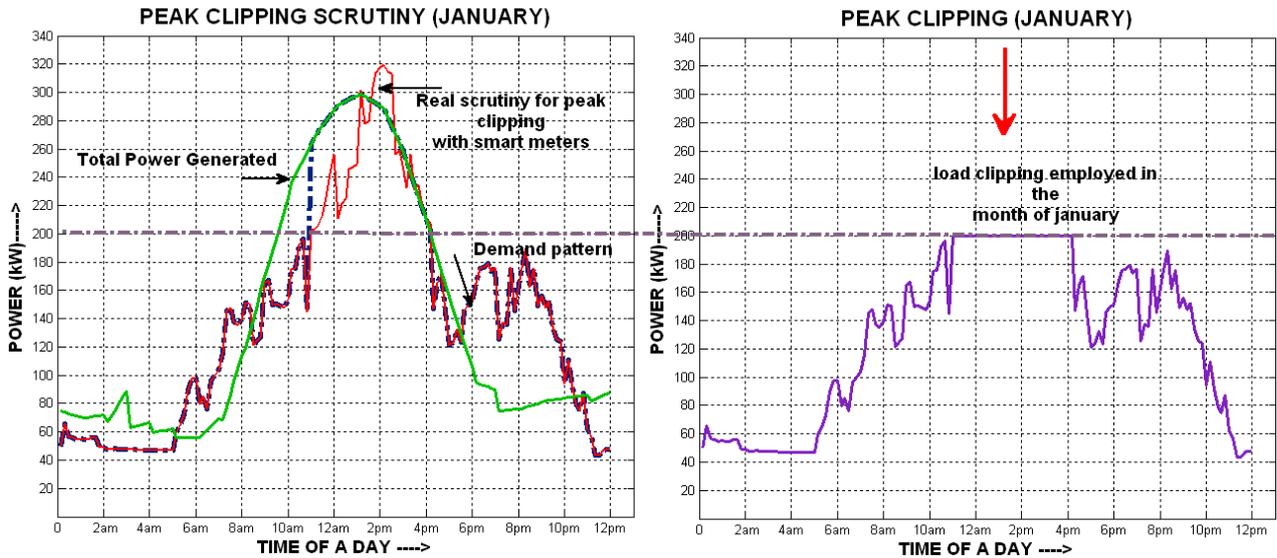


Fig. 9. Implementation of DSM Measure over the residential Load Profile.

measure is on track to reach the destiny for attaining objectives of demand side management.

## 6. Results and Discussions

In this paper the simulated system is been consistent with wind power generation system owning a rated capacity of 200 MW. In addition there is a neighbouring solar power generation system relatively having a rated capacity of 100 MW, and a DG backup of higher rated capacity including the total installed capacity of the customer unit. The unpredictable load characteristics of customers were assorted by steering operators and controllers through meaningful generative power predictions linked with DSM controllers governing entire system.

### 6.1. DSM Mechanism For DD Balancing

Algorithms are depicted in order to implement the balancing system using DSM techniques. The sizing of solar and wind energy system is based on the assessment of the customer load profile. By finding unmet and excess electricity through proper investigation made over demand assessment, there is in need of a unit to guide entire energy system. Such guidance is provided by optimal energy guidance unit which divides unmet and excess electricity from the customer energy demand. The energy guidance system gives the sense of leading and lagging power demand information. The electricity shortage (Unmet Electricity) is taken from the power grid by HES unit. Fig.12. manifest the AOC within deterministic operating ranges represents low values during higher power consumption and higher AOC

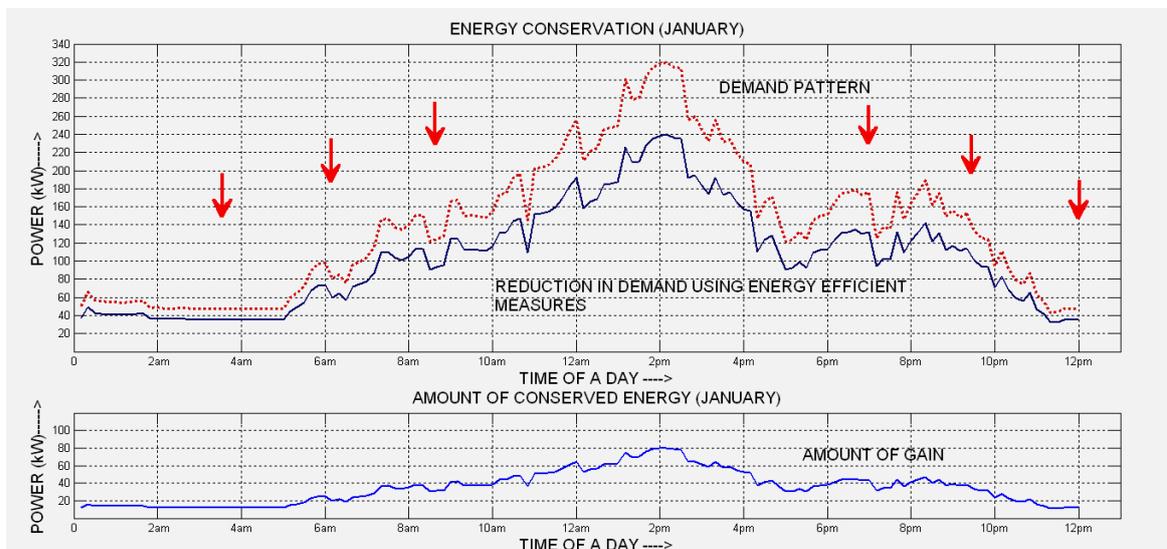
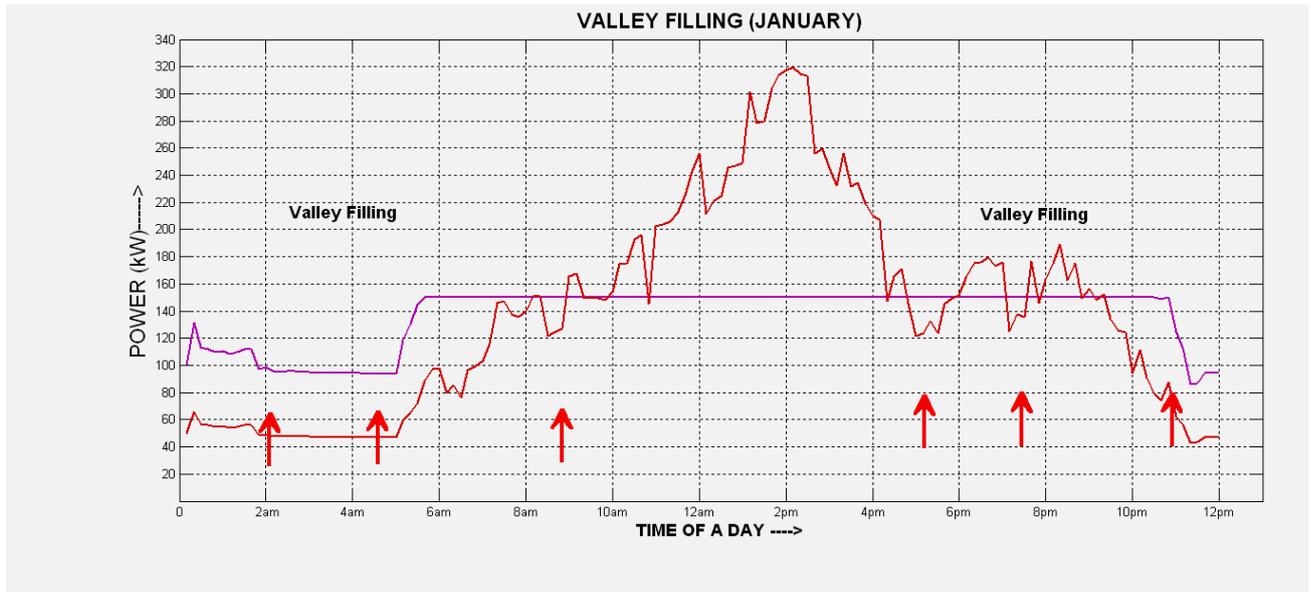


Fig. 10. Energy Conservation measure adopted in Residential load sector

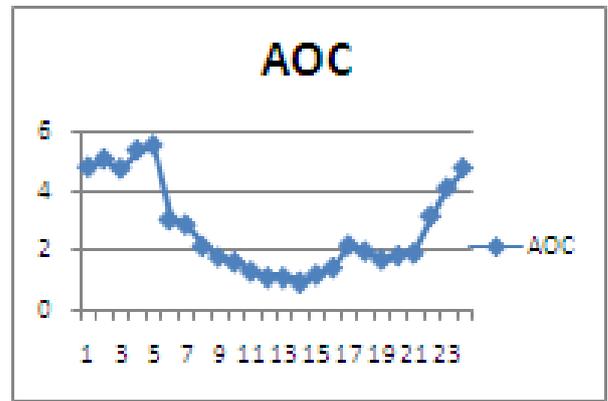


**Fig. 11.** Valley filling technique opted in Residential load sector

values for lower power consumptions for the corresponding residential load profile. Suel-Ki Kim & et al., dynamically modeled and controlled Grid connected HES with versatile power transfer who does not focuses the Demand side power distribution, management and control. This absentia is fulfilled in the paper by implementing the DSM measure using supervisory controls in the customer part. Through dynamic demand balancing steady state performance of individual energy system is kept at optimum acceptable levels. These acceptable limits can be varied by utility and the customers while carrying out DSM measures which comparatively not highlighted by Francois. While making a deal with dimensional HES, the dynamic power balancing for future scenarios, operating cycle should be evaluated for both generation and consumption unit. The comparative analysis indulging dynamic power balancing and demand balancing is effective, when estimating the system operating cycle is done which being absent in the statement of Jayakrishnan R. Pillai et al.

**6.2. Operating Cycle**

Renewable energy system sizing analysis is prominently executed using demand side and source side dynamics in [4] entirely guided by the state of charge (SOC). The strategy is comparatively good but resolution data regarding residential data lacks balancing identity between the utility and customer’s which is concentrated in this paper. Mathematical formulation of DSM problem with its optimal solution is deduced by Hussein. A. Attia, in which energy conservation is formulated with minimum cost that doesnot guide any appliance operating cycle. Without any estimation of individual appliance operating cycle energy conservation ratio can’t be predicted by Attia. The work carried out here



**Fig. 12.** Actual Operating Cycle of residential unit

concentrates on estimation of energy conservation ratio in relation with appliance and system operating cycle.

**7. Conclusion**

In this paper, the control strategies for balancing the dynamic demand in a grid connected hybrid system have been proposed. The top aim of this paper is to enhance the greatest use of solar and wind power by maintaining uninterrupted power to the customers guided by system operating cycle. The smart meter interfaced between the grid control unit and the RES control unit, sequentially check the amount power generated by the RES unit and power consumed from the grid. The controlling of power mismatch was performed by the aid of a sound energy storage unit. The reliable electricity supply in the entire system is opted through exact technical control using energy conservation and valley filling methods.

The operating cycle of the private utility system to estimate the entire system performances were calculated. Considering the importance of operating cycle to rule over

future smart grids the source and demand side power generated and received power were tabulated and after successive substitution of parametric values there shows a surprising two results. For minor losses the SOC cycle will be low during higher power consumption values, and for major losses the SOC will be high during lower power consumption values. The constraint makes it possible to run the residential system under optimal condition with preserved best SOC values. The detected result gives preference to use the entire utility system within optimum operating cycle range for effective operation and performance.

## Appendix

Parametric Values adopted for the simulation study are as follows:

- 1) Wind generator
  - a) Rating :100kVA
  - b) Rated Voltage: 240 volts
  - c) Frequency: 50 Hz
  - d) Stator Resistance: 0.016p.u.
  - e) Stator Inductance: 0.06p.u.
  - f) Rotor Resistance: 0.016p.u.
  - g) Rotor Inductance: 0.06p.u.
  - h) Mutual Inductance : 3.5p.u
  - i) Inertia constant : 2
  - j) friction factor: 0
  - k) pole pairs: 2
- 2) PV Array (for1 panel)
  - a) Rating : 140 Wp
  - b) Open Circuit Voltage ( $V_{oc}$ ): 22.49V
  - c) Short Circuit Current( $I_{sc}$ ): 8.51 A
  - d) Voltage at Maximum power: 17.89V
  - e) Current at Maximum power: 7.83A
  - f) System Voltage: 1000V
  - g) Total rating: 100kW (for 715 panels)
- 3) Diesel generator
  - a) Nominal power: 325 kVA
  - b) line-to-line voltage: 240V
  - c) frequency: 50Hz
  - d) Rotor type: Salient-pole
  - e) d-axis reactance ( $X_d$ ): 1.56p.u
  - f) q- axis reactance ( $X_q$ ): 1.06p.u
  - g) stator resistance ( $R_s$ ): 0.0036p.u
  - h) d-axis time constants ( $T_d$ ) : 3.7 sec
  - i) q- axis time constants ( $T_q$ ) : 0.05 sec
  - j) Inertia coefficient(H): 1.07p.u
  - k) Friction factor (F): 0p.u
  - l) Pole pairs (p): 2 p.u
- 4) Battery storage unit(for 1 unit)
  - a) Battery type : Nickel-metal-hydride
  - b) Nominal voltage : 200V
  - c) Rated capacity : 180Ah
  - d) Maximum capacity : 200Ah
  - e) Nominal discharge Current : 13A
  - f) Full charge voltage : 235.5932V
  - g) Internal Resistance : 0.30769 $\Omega$

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