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ScienceDirect

Procedia Technology 21 (2015) 41 – 48

Procedia Technology

SMART GRID Technologies, August 6-8, 2015

Real Time Active Power Ancillary Service using DC Community Grid with Electric vehicles and Demand Response

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Abstract

The introduction of restructuring the electric power system has led to the scenario, making the customer a significant market/player. This has also made the maintenance of reliability and stability in the power system a financially crucial task. .Self-sustainable community grid is a realization of reliable and stable system at a base level as individual households with solar photovoltaics or other renewable system can sustain itself even if the power grid fails. In this paper, active power imbalance ancillary services provision for the grid using a DC community grid, stabilizing the electric power system is proposed. A community of 100 houses with individual solar installation along with a centralized DC-wind turbine and EV charging station compose the grid that is considered. Different cases of energy imbalance and corresponding system behavior are simulated in MATLAB environment and obtained results indicate that the proposed system ensures a better reliability for the power grid by using the ancillary services.

Peer-review under responsibility of Amrita School of Engineering, Amrita Vishwa Vidyapeetham University

Keywords: Ancillary services; DC community Grid; EV Charging; Three phase Inverter

1. Introduction

The integration of renewable energy is increased worldwide in last decades surpassing a share of 25% of world power generation capacity [1]. They are no longer considered only as alternative sources of energy but also as instruments to reduce negative health and environmental impacts associated with fossil fuels and greenhouse gases, improving educational prospects, creating new job opportunities, reducing poverty and enhancing energy security. Due to the restructuring of electrical power system, the power sector becomes more competitive and market oriented.

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Peer-review under responsibility of Amrita School of Engineering, Amrita Vishwa Vidyapeetham University
doi:10.1016/j.protcy.2015.10.007

Customers become a significant commodity by having a choice to select utilities according to their performance such as power quality, services and reliability. There comes the ancillary services to ensure quality and reliability of the supply system. But owning an ancillary services for any entity is very difficult, expensive and needed only for a very short period. FERC [2] categorized mainly six services that can be considered as ancillary services. They are mainly scheduling and dispatch, reactive power and voltage control, loss compensation, load following, system protection and energy imbalance.

Nomenclature

DC	Direct Current
EV	Electrical vehicle
$P_s(t)$	Maximum power produced by the solar panel at time *t*
$I_s(t)$	Solar radiation at time *t* (kW/m^2)
η_s	Solar panel energy conversion efficiency (%)
A	Area of the solar panel (m^2)
T_o	The nominal temperature in degree Celsius (^{o}C)
P_w^k	Electric output power from wind turbine at kth hour (kW)
P_r	Rated power of wind turbine (kW)
v	Wind velocity at kth hour (m\sec)
Vin	Cut in velocity for the wind turbine
$Vout$	Cut off velocity for the wind turbine

The different characteristic of ancillary services, type, operational difficulties and international different practices of using ancillary services are discussed in literatures [3-5]. Since ancillary services are of short term operation, different literatures investigates the role of renewable energy in the ancillary services market like solar, wind etc [6-9]. Due to climate conditions, these types of renewable sources will fail to meet the agreed services. The installations of these renewable sources will cause also huge financial burden for utilities. To tackle this problem, unconventional sources of energy like batteries, fuel cells and electric vehicles are used[10-12]. But life of these type of sources is a big concern and maintenance should be frequently done which requires a lot of man hours. A pumped storage ancillary services [13] also has come in literature in simulation model of Taiwan power system.

The community grid is a state of art term proposed by NREL to define a community whose all loads are met with renewable energy sources. If a system has renewable energy sources like solar, wind and electric vehicles, through proper coordination control, it can be transformed into community grid. Mariam L et.al [14] proposes a new terminology community grid which consists of a number of houses with wind based micro generation system. This paper defines a method to develop sustainable electric system, with the proposed community micro grid, without changing any rules and regulations. Zhu J et.al [15] proposed a community grid with energy management within grid. The supply and demand should match within the system. The load curtailment is also one's choice by giving preferences to particular load. The role of battery management system in a community grid is explained in literature [16].

Patterson B [17] has proposed the DC micro grid, its advantages and challenges of making a complete DC home micro grid. Moreno-Munoz A et al [18] proposes a distributed DC UPS for the solution of Power quality problems and energy efficiency problems. This paper illustrated that the efficiency of DC UPS system is 5 to 15 % more than that of an AC UPS system in an IT enabled building.VossosV et al [19] has analyzed the efficiency of residential building when it is converted into DC house than the conventional AC distribution house. They analyzed the data of 14 states in USA which used 380 V and 24 V voltages for DC distribution at home. There is a 33 % saving when the AC equipment are replaced with DC equipment.

Summarizing, a self-sustained system is a necessity for providing ancillary services while owning one can be expensive and require maintenance. Hence, this paper proposes a community grid based ancillary service provision system, absent in previous literatures. Also the community grid proposed is a DC system, incorporating the pros of DC power distribution and hence an efficient community grid. The system considered comprises of DC components including loads, batteries, electric vehicles and sources like solar PV and wind turbine. The ancillary services considered here include load following and energy imbalance categories.

2. Methodology

As mentioned before, the community is interlinked with each other using a DC microgrid or DC-Community grid. Though the houses in the system have both AC and DC loads, the in-house inverters are tasked with the providing AC power to the AC loads as and when required.

2.1 System description

The system considered include a variety of load and/or source components like, home loads, batteries, electric vehicles, solar PV, wind DC generators etc. in addition to grid interaction(Fig 3).

2.1.1 *Houses*

The community considered here comprises of 100 houses and are classified into three groups, Group A, Group B & Group C, based on the electric loading levels. A load curve mentioned in [14] has been used as a reference load curve in this paper too. Group A, homes are the heaviest loads while Group B and Group C, are lesser. Houses belonging to the classification Group B are assigned the load curve from the above mentioned literature while the ones in Group A and C have load curves corresponding to 120% and 90% of load in Group B. Table 1 shows the community grid system details.

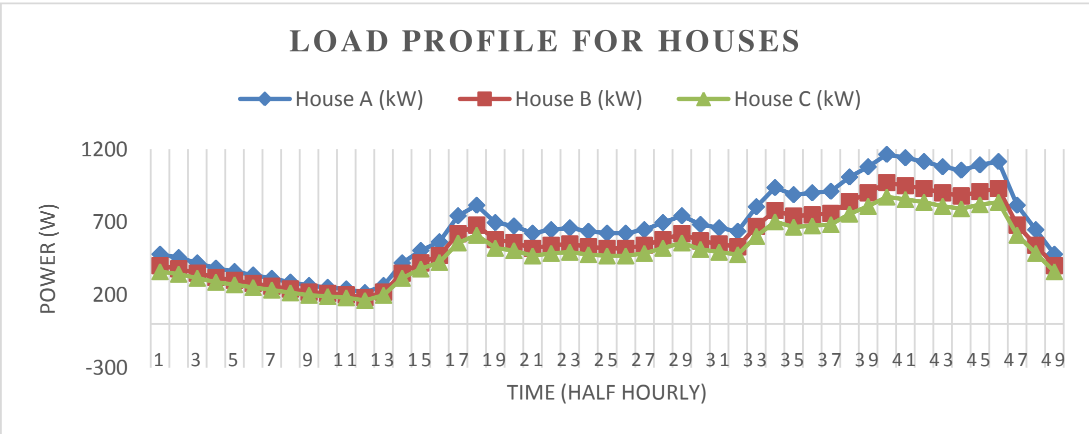


Fig.1. Daily load curve for Group A, B and C

Out of the 100 houses, there are 50 houses of Group A, 20 of Group B and 30 of Group C. The daily load curve of the houses in Group A, B, C given in Fig 1.

2.1.2 Battery and EV

Out of the 100 houses in the considered community, 20 houses are assumed to be equipped with battery for back-up purpose. The battery used in Group A houses are of capacity 12 V, 2400 Ah while the ones in other two groups of houses have capacity 12 V, 1200 Ah. The battery provide back-up power for the house in case of inadequate generation along with providing opportunity for sharing power with other houses by injecting the power back into the DC grid. An EV charging station is also present in the system providing 12 charging points. The home batteries and EVs provide immediate energy in case of power shortage in generation or for the ancillary purpose.

2.1.3 *Sources*

Solar photovoltaic (PV) system and Wind power generation system (WS) with wind turbines attached to DC generators have been used to power the community grid. The houses are to have mandatory PV systems installed for contributing towards the community power generation. Based on the classification of the houses, the solar installation of three different sizes have been allotted to each of the three groups. The houses in Group A are allotted to have a PV panel of size 3 kW, while the ones in groups B and C are allotted with sizes 2 kW and 1 kW, respectively.

Table 1. Community grid-system details

House Type	Grp A	Grp B	Grp C
Number	50	20	30
Peak load (kW)	58.2	19.4	26.19
PV size (kW)	3	2	1
WS size (kW)	100 kW centralized		
Battery size (Ah)	2400	1200	1200
Battery number	10	5	5
EV	12 charging points, 2400Ah		

A centralized WS of 100 kW has also been installed for powering the community. Real time data of solar and wind power generation are given in Fig.2.

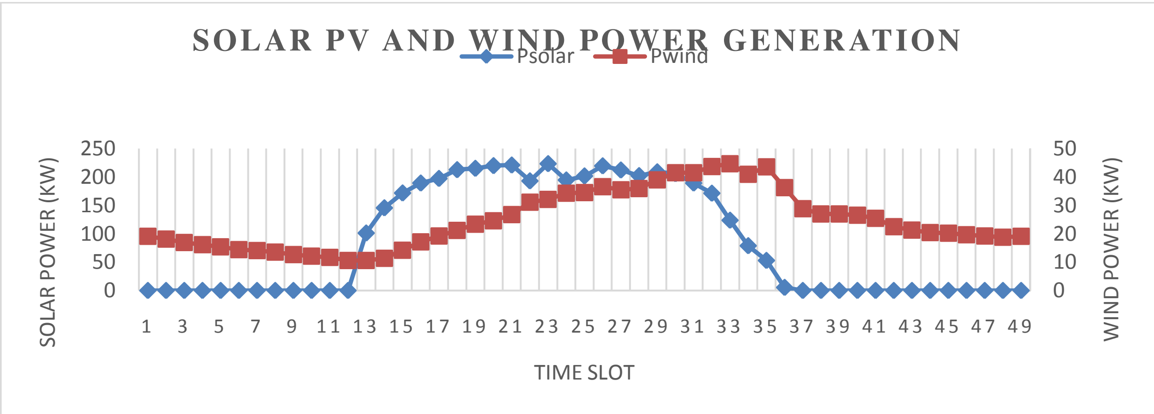


Fig. 2. solar and wind data in AIT, Thailand on 9th Feb 2015

The load curve, solar data and wind data are all taken in half hour intervals or 48 time slots. Solar and Wind data have been procured from the power measurement station in Asian Institute of Technology, Thailand. Solar power is calculated from Eqn.1 taken from [20].

$$P_s(t) = \eta_s . A . I_s(t)\{1 - 0.005(T_o - 25)\} \quad (1)$$

Electric power generation from a wind turbine, as a function of wind velocity, is modelled as a piece-wise function as given by Eqn. 2 and Eqn.3 [21]. Fig. 3 shows the DC community Grid under study.

$$P_w^k = \begin{cases} 0 & v \leq Vin \;\&\; v \geq Vout \\ P_r * vel^k & Vin \leq v \leq Vr \\ P_r & Vr \leq v \leq Vout \end{cases} \quad (2)$$

$$vel^k = \frac{v - Vin}{Vr - Vin} \tag{3}$$

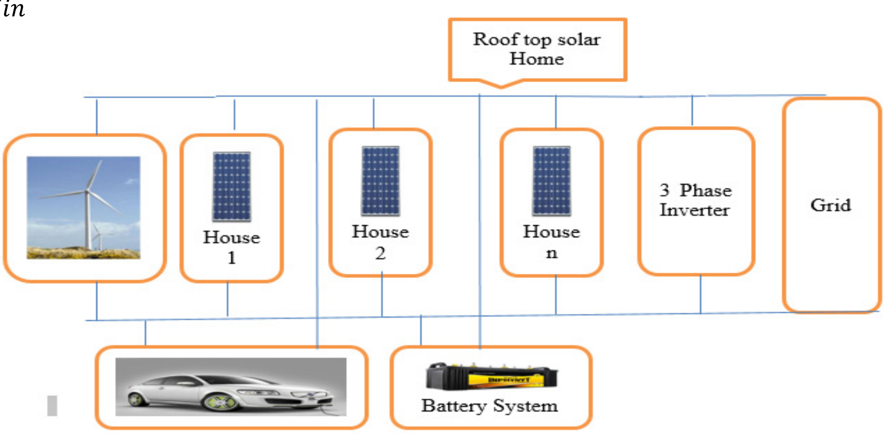


Fig. 3. Block diagram representation of DC community Grid

2.2 *Dispatch Algorithm*

This section describes the dispatch algorithm used for implementing the community grid operation. This dispatch problem considers 10% of the load as losses for a realistic approach. Random values between 0.3 and 0.9 are assigned as initial battery state of charge (SOC) for home battery as well as EVs. At every half hour slot, the net power generation, in Eqn.4, is evaluated to estimate the excess power generated that can be transferred into the grid. Similar to the interrupt signals in case of microprocessors, ancillary request from the grid is given to the dispatch algorithm and the feasibility is checked. The algorithm for the dispatch problem is given below.

1. Read system data: Load, solar radiation, wind speed.
2. Initialize/read (if available) SOC values for battery and EVs.
3. Initialize time slot as 1.
4. Compute the PV and wind generation, and net power generation.
5. If the net power generation is negative, go to step 5, else continue.
   - 5.1 If ancillary request is placed, go to step 6, else continue.
   - 5.2 Sort home battery units and EVs in ascending order of SOC
   - 5.3 If sufficient generation, start charging battery and EV from top to maximum SOC else go to 4.4.
   - 5.4 Distribute generation among least SOC battery and EV equally
   - 5.5 If generation still in excess, inject to grid or dissipate in dump load, else no injection.

6. Power generation does not satisfy community load.
   - 6.1 Sort battery and EVs in descending order of the SOC.
   - 6.2 Extract power from highest SOC battery and EV until their SOC is 0.5
   - 6.3 Check for sufficiency of power. If sufficient, break; else, go to step 6.1.
   - 6.4 If maximum power is extracted and insufficiency remains, take power from grid or curtail.
7. Ancillary request for next time slot placed.
   - 7.1 Calculate net power generation.
   - 7.2 If sufficient for ancillary, break; else continue.
   - 7.3 Sort battery and EVs in descending order of the SOC.
   - 7.4 Extract power from highest SOC battery and EV until their SOC is 0.5
   - 7.5 Check for sufficiency of ancillary power. If sufficient, break; else, go to step 7.3
   - 7.6 If insufficiency in power for ancillary supply remains, go to step 7.6.
   - 7.7 If power required for ancillary supply greater than 50% of current community load, continue; else, go to step 7.9

7.8 Curtail 50 percent of load from different house groups and inform electric power grid authorities of inefficient power. Break.

7.9 Curtail amount of load from different house groups.

8. Repeat steps 4 to 8 till all time slots are analysed.

2.3 Three phase voltage source inverter

Three phase Voltage source inverter is used for the injection of active power to the grid. All the members in the community are connected to a common DC link of voltage 380 V.A centralised inverter is used to connect this community grid with the national grid. By using the equation (4) the active power can be controlled by changing the load angle value δ where v_s and v_g are the voltage of inverter and national grid respectively and x is the reactance between them.

$$Ps=\frac{v_s v_g}{x}\sin\delta \quad (4)$$

The reference power signal will be indicated by the system operator. The three phase inverter operation is as follows: The voltage and current from each phase of the grid is taken using sensors and converted to two phase static quantities from three phase rotating reference frame values. This is to decouple the active and reactive power and controlling will be easy. The phase of the national grid is obtained from PLL and PQ controller will produce triggering signals to the PWM block from the P reference and two phase static values of current. Here in PQ controller, Q reference is taken as zero to control only real power.

3. Results and Discussions

The dispatch algorithm described in the previous section for the grid connected operation has been applied to the community grid system described. The solar generation systems though installed mandatorily, the results below are procured assuming that only 70% of the houses are currently active in the community grid participation. Here a case of increased ancillary demand from 150 kW to 200 kW from the grid is only considered.

The grid makes a prompt request to increase the ancillary support from 150 kW to 200 kW in ancillary support. The operation of the concerned in this environment shall be a crucial factor towards the performance assessment as this poses an opportunity for significant financial gains than the previous case. From Fig.4 shows that all the storage units are in at the minimum SOC level. Hence no more power can be extracted from the same. A deficiency of power exists even after draining the storage units, leading the system to the final option of load shedding.

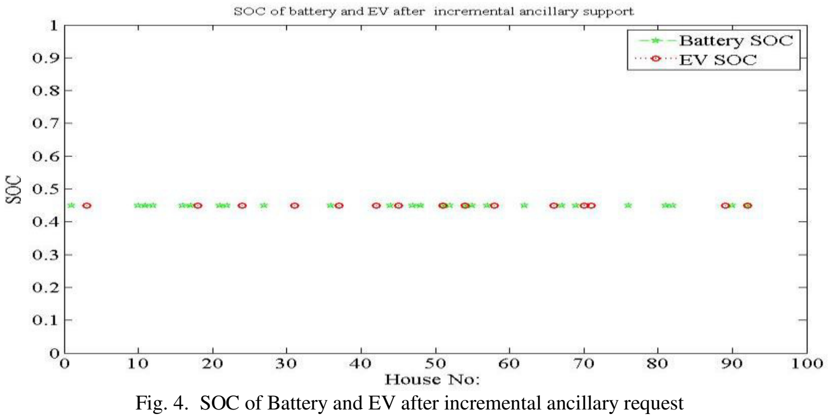


Fig. 4. SOC of Battery and EV after incremental ancillary request

A load of 15.433kW is to be shed in order to meet deficiency in ancillary support requirement and this provides the community with the opportunity to act as controllable load entity and obtain certain financial incentives by cutting down the power consumption a little.The grid operator shall alter the power reference signal based on the ancillary requirement and the inverter control system will sense this change and send a control signal based on which the output power injected into the grid by the inverter will be in accordance with the set point decided by the grid

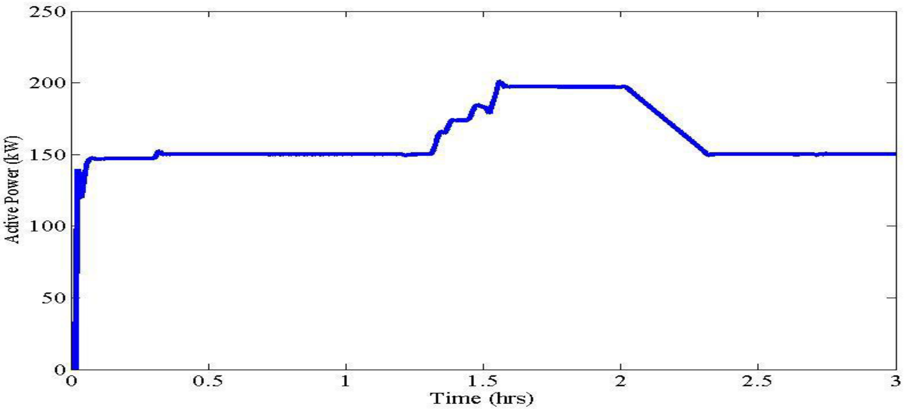
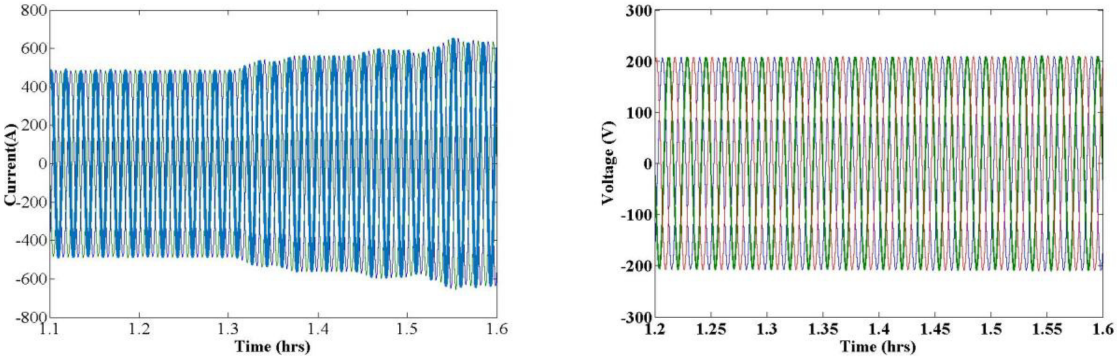


Fig. 5. Increase in ancillary power requirement from the grid



(a) (b)

Fig. 6(a) Inverter output current waveform; (b) Inverter voltage waveform

operator. Fig.5 shows the community grid providing ancillary power of 150 kW to the main grid and after a certain time, as the grid demand increases, the ancillary requirement moves to 200kW. In Fig.6a, the change in the inverter current with the change in the injected power into the grid is shown. The voltage is maintained at the grid voltage which is shown in Fig.6b.

4..Conclusion

A DC-community grid, using Solar PV and Wind power generation system, providing active power ancillary support has been studied in this paper. The system uses home batteries and EVs to render netter performance and improving the reliability of the system. The system operation while all the system components are active has been found to be injecting into the grid a net energy of 190.4 kWh in a single day. Solar power was found to be the prominent power generation source than the wind counterpart. Active power ancillary service provision for the main grid has been analysed for two cases, and in both the cases the system showed good compatibility while maintaining satisfactory operating conditions within the community. The presented system provides 200 kW of unscheduled ancillary power for by making use of the storage units and curtailing internal load of 15.433 kW and provides 150 kW of scheduled ancillary service without any load curtailment. Though promising the system could be made better making use of other sources than wind systems.

Acknowledgement

The authors thank Energy Field of Study at Asian Institute of Technology, Thailand, for providing the technical data and financial aid for fulfilling this work.

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