Plugging ofInverter Loads in Micro-Grid to EnhancePower System Stability

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Abstract: **Implementation of various incentive-based and time-based load management strategies has great potential to decrease peak load growth, customer electricity bill cost and also improves the steady state stability of a power system. In recent years, usage of inverters in domestic, commercial and industrial consumers is increased drastically. However, high penetration of inverter battery loadin to the grid may cause high peak loads at different times of the days. Using advanced metering and automatic chargers makes it possible to optimize the charging cost, and release generation capacities to provide sustainable electricity supply. Using an appropriate encouraging program is a simple way for inverter owners to manage their energy consumption and shift the time of charging to proper time of the day; and therefore, to reduce their electricity bill. With this objective, this paper proposes a method to plugging inverter battery to grid based on loadability of power system and voltage stability limits in a distribution network. Using this new methodology for plugging inverter battery loads (IBL)is aim to improve grid voltage profile, maximum demand and reduces energy losses in distribution network.**

A new analytical approach is adopted in this paper to visualize the impact of demand-side management (DSM) on system losses and voltage stability. The proposed methodology is tested on 33-bus radial distribution network with 24 hr based random varying load curve and this methodology also includes both active and reactive power compensation to improve stability. DSM includes only commercial and industrial consumers for this analysis i.e. those with more than 10kVA storage capacity.

Keywords: **Inverter Battery Loads (IBL), BIBC and BVBC Load flows, Voltage Stability.**

I. INTRODUCTION:

DSM is the process of planning, implementation and monitoring of those utility's activities that are designed to influence the period of use of electricity and the amount of loads in consumer premises so as to achieve desired peak load reduction. The reduction of the peak load is one of the objectives of DSM to avoid new generation capacity addition and helps utility to reduce their operational cost and environment to be free from excess carbon foot prints [1]. However, there are six objectives in the context of DSM: peak clipping, valley filling, load shifting, flexible load curve, strategic conservation and strategic load growth [2]. Rapid industrialization and growing urbanization in developing countries like India needs huge amount of power which cannot be met by present generation capacity. In spite of continuous growth in the power generation over years, the gap between demand and generation is growing every year.To bridge the gap between supply and demand, construction of new generation plants are required. But it is a costly affair and also causes climate changes due to greenhouse gas emissions. Hence, there is an urgent need for the utilities to focus on DSM options to save fuel for power generation and in turn, benefits customers in the form of reduced energy bills [3]. Effective DSM implementation involves planned cooperation between utilities and consumers to adjust load curve resulting in benefits to the utility, consumers and society at large.

Various forms of demand side management (DSM) programs are being deployed by utility companies for load flattening amongst the residential power users. These programs are tailored to offer monetary incentives to electricity customers so that they voluntarily consume electricity in an efficient way. Thus, DSM presents households with numerous opportunities to lower their electricity bills. However, systems that combine the various DSM strategies with a view to maximize energy management benefits have not received sufficient attention. This study therefore proposes an intelligent energy management framework that can be used to implement both energy storage and appliance scheduling schemes. By adopting appliance scheduling, customers can realize cost savings by appropriately scheduling their power consumption during low peak hours. More savings could further be achieved through smart electricity storage. Power storage allows electricity consumers to purchase power during off-peak hours when electricity prices are low and satisfy their demands when prices are high by discharging the batteries. For optimal cost savings, the customers must constantly monitor the price fluctuations in order to determine when to switch between the utility grid and the electricity storage devices. However, with a high penetration of consumer owned storage devices, the charging of the batteries must be properly coordinated and appropriately scheduled to avoid creating new peaks. This paper therefore proposes an autonomous smart charging framework that ensures both the stability of the power grid and customer savings.

The main objective of this paper is scheduling and proper utilization of already existing storage devices of large commercial utilities. Proper scheduling of commercial battery storage loads cuts the peak demand on power system. Reduction of peak demand will reduce the reserve capacity of power system in order maintain proper reliability. It also improves the transient stability by fast switching of battery storage. Switching scheduling of battery loads connected to grid is carried based on daily load curve by using smart metering [4].

Complete utilization of stored energy during the peak hours is not accepted by utilities in order to maintain proper security we need to maintain required reserve at each utility. In this study 30% of their capacity is maintained as reserve for emergency purpose and 70% is used during peak load hours.

Commercial Inverter loads in Vizag city:

Utilities	no.of utilities	Capacity of each
Shopping malls	12	1200kWh
Corporate banks	18	200kWh
Engineering colleges	14	2000kWh
Hotels	12	200kWh

II. DISTRIBUTION LOAD FLOWS:

1. Bus Injection to Branch Current (BIBC) matrix:

For distribution systems, ati^{th}bus complex load isexpressed by equation (1) And the correspondingequivalent current injection is given by equation (2)

$$S_i = P_i + jQ_i \quad (1)$$

$$I_i = \frac{S_i}{V_i} \quad (2)$$

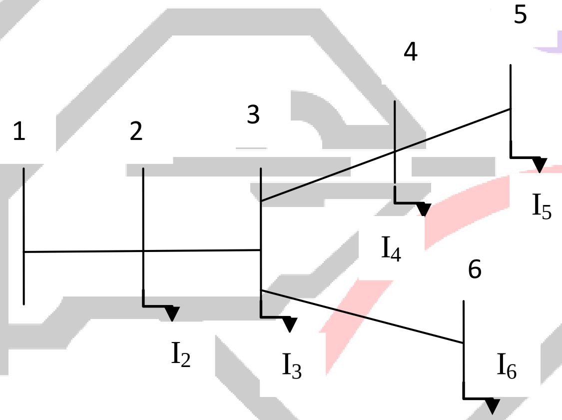

Fig.1

The vector of current injections for the above samplesystem is given as below

Bus No.	2	3	4	5	6
Current Injection	I_2	I_3	I_4	I_5	I_5

For the system shown in Fig.1, apply Kirchhoff'scurrent law (KCL), the branch currents can be expressedin terms of equivalent current injections as

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \quad (3)$$

$$B_2 = I_3 + I_4 + I_5 + I_6 \quad (4)$$

$$B_3 = I_4 + I_5 \quad (5)$$

$$B_4 = I_5 \quad (6)$$

$$B_5 = I_6 \quad (7)$$

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix}$$

The above branch current equations canbe rearrangedin the generalized form as below

$$[B] = [BIBC][I] \qquad (8)$$

2. Branch Current to Bus Voltage (BCBV) Matrix:

The relationship between the branch currents and busvoltages are expressed as

$$V_2 = V_1 - B_1 Z_{12} \qquad (9)$$

$$V_3 = V_2 - B_2 Z_{23} \qquad (10)$$

$$V_4 = V_3 - B_3 Z_{34} \qquad (11)$$

$$V_5 = V_4 - B_4 Z_{45} \qquad (12)$$

$$V_6 = V_3 - B_5 Z_{36} \qquad (13)$$

On Substitution of (9) & (10) in (11), the voltage at bus4 is given by

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \qquad (14)$$

Similarly, the other bus voltages can be rewritten as

$$V_3 = V_1 - B_1 Z_{12} - B_2 Z_{23} \qquad (15)$$

$$V_5 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} - B_4 Z_{45} \qquad (16)$$

$$V_6 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} - B_4 Z_{45} - B_5 Z_{36} \qquad (17)$$

Equations (9), (14), (15), (16), (17) can be rearranged asbelow

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix}$$

$$\Delta V = [BCBV][B] \qquad (18)$$

Now, substitute (8) in (18) and the resulting equation is expressed as

$$\Delta V = [DLF][I] \qquad (19)$$

Where [DLF] represents distribution load flow matrix given as

$$[DLF] = \begin{bmatrix} Z_{12} & Z_{12} & Z_{12} & Z_{12} & Z_{12} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23}+Z_{34} & Z_{12}+Z_{23}+Z_{34} & Z_{12}+Z_{23} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23}+Z_{34} & Z_{12}+Z_{23}+Z_{34}+Z_{45} & Z_{12}+Z_{23} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23}+Z_{36} \end{bmatrix}$$

From the above DLF matrix, the following useful observations are used in developing the proposed topological and primitive based distribution loadflow method.

It has been mentioned in the earlier sections about the BIBC, BCBV and DLF matrices, which were explained in the paper [5]. Consider a sample radial distribution system as shown in the Fig. 1 for the formation of the above matrices

3. *Formulation of voltage stability measurement:*

Voltage stability has become a major concern in modern power system scenario. The threshold point of voltage stability is determined from voltage stability analysis. Some techniques, i.e. nose curve technique, V–Q sensitivity analysis, Voltage Stability Index (VSI) are helpful to measure voltage stability of the system or to find out critical buses in the network. Among different techniques, VSI based method has emerged as very fast and effective tool for off-line voltage stability analysis.

***VSI by Shin*:**

In Shin et al. have formulated a VSI from a simple power system with two buses and later the developed VSI is applied on large system with many buses. The developed VSI to voltage stability of general radial distribution network was defined as

$$VSI = 0.5 \times V_1 - \left(P_{leq} \times r_{eq} + Q_{leq} \times x_{eq} \right) / V_1 \qquad (20)$$

Where V_1 is the sending end voltage of reduced single line network. Authors have identified that approaching of VSI towards zero can result voltage collapse by transferring power at critical point through the distribution line

III. RESULTS AND ANALYSIS:

In this study, the system was run for three different random consumption behaviors on standard IEEE 32-bus system.

Case1: 24 hours randomly generated load without inverter load and reactive power compensation.

Case2:24 hours randomly generated load with inverter load without coordination and with reactive power compensation.

Case3:24 hours randomly generated load with stability based inverter load scheduling and reactive power compensation.

1. *Uncoordinated Charging*:

Large number of inverters charging occurs during the same time, especially during the peak load condition, then the resultant peak due to extra inverter load will be significantly raised. Uncoordinated charging not only increases the peak regulation capacity demand, but also gives rise to a series of problems, such as power quality deterioration, loss increase and stability of power system.

Case1: Total energy loss during the day without inverter load and without reactive power compensation is 5.2516e+003 kWh and minimum voltage is 0.8204p.u (BUS-17) from Fig.2 (a) at 7.00PM. With reactive power compensation energy loss is 2.8386e+003kWh and minimum voltage is 0.9357p.u (BUS-17) at 7PM. from Fig.2 (b).

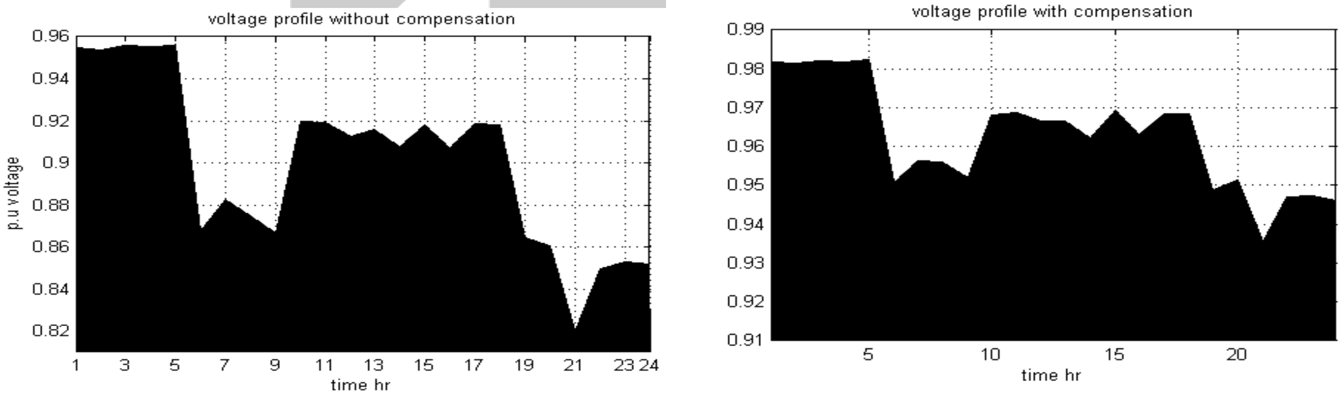

Fig.2 (a) Fig.2 (b)

Fig.2 (a) & Fig.2 (b) Minimum bus voltage during day without and with compensation

2. *Coordinated Charging Control Scheduling onPower Grid:*

Smart charging or coordinated charging depends on advanced metering infrastructure and hardware and software support from smart grid communication technology therefore, using the floatingprice and incentive policies to guide users to avoid peak charging in the short term will be an easy, effective control measures. In this paper, scheduling of inverter loads completely based on stability and energy losses. Hear inverter battery delivers or absorbs power based on stability, during the peak load hours it delivers power to grid and absorbs during off peak period.

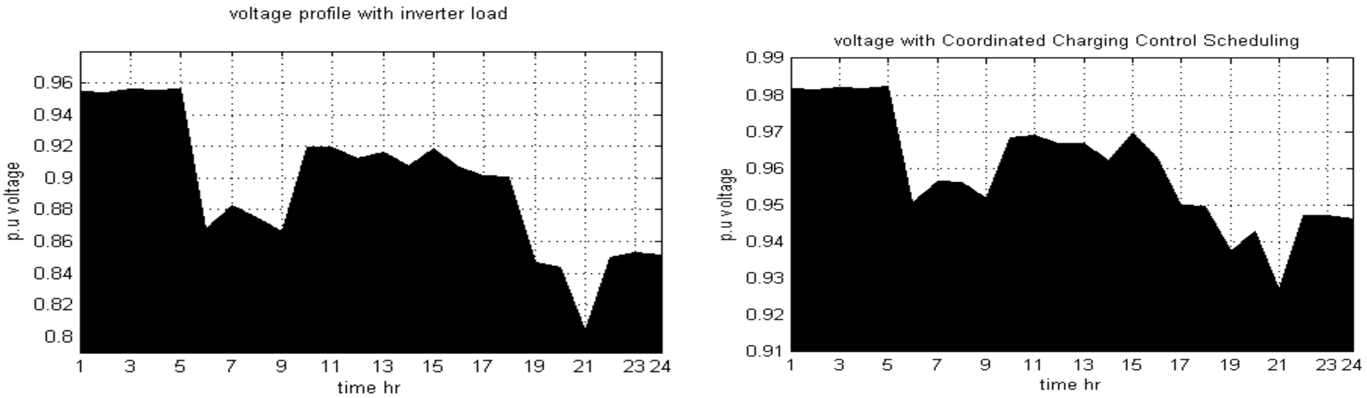

Fig.3(a) Fig.3(b)

Fig.3(a) & Fig.3(b) Minimum bus voltage during day without and with VAR compensation

Case2: Energy loss during the day with uncoordinated Charging of inverter load and without reactive power compensation is 5.8685e+003 kWh and minimum voltage is 0.8041p.u (BUS-12) from Fig.3(a).at 7.00PM. Uncoordinated charging with reactive power compensation energy loss is 3.1523e+003 kWh and minimum voltage is 0.9271p.u (BUS-12) at 7PM. from Fig.3(b).

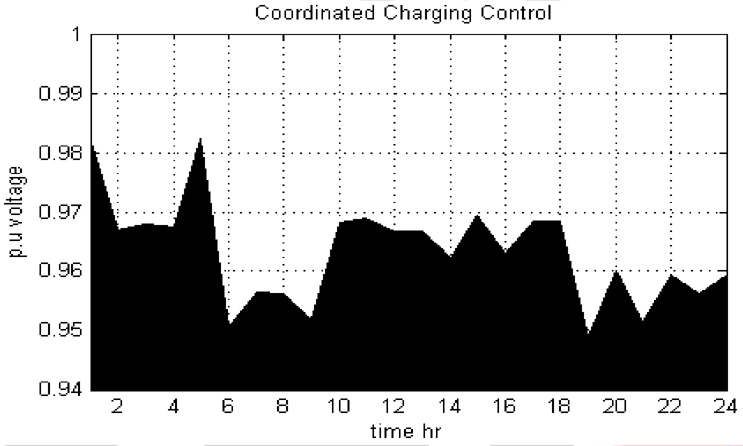

Fig.4. Coordinated Charging with reactive power compensation

***Case3**:* Energy loss during the day with coordinated Charging of inverter load and with reactive power compensation is 2.3370e+003kWh and minimum voltage is 0.9490p.u (BUS-14) from Fig.4.

IV. CONCLUSIONS:

In this paper steady state performance of IEEE 33-bus is analyzed with 24 hours based randomly generated load using BIBC load flows and week buses are identified and ordered based on stability index. Reactive power is injected at week buses and inverters loads are scheduled to local distribution network with the help of daily load variation at buses (load curves) and voltage profile. Energy loss per day without compensation and un-coordinated charging is 5.2516e+003 kWh and energy loss per day with compensation and coordinated charging is2.3370e+003kWh. Compared to un-coordinated charging 55% of energy loss saving is possible with coordinated charging.

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