Use of Battery Banks to Meet the Peak Demand in Off-grid Micro Hydro Systems

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Abstract –*Use of batteries as energy storage devices in electrical power systems is becoming popular with the recent development of the battery technology. At present number of off-grid systems with a single source of generation are in existence in the country. Usually, the source of generation of these systems is micro hydro generator. The growing maximum demand of these small systems cannot be met by the micro hydro generator. Poor load factor is one of the other issue faced by these systems. This paper present use of batteries to solve these problems faced by the off grid systems. Since the operation of the batteries changes the power flow in the system the batteries have been allocated so that the increment of power loss is minimized. Investigation was carried out for one of the micro-hydro power operated off grid system. The capacity of batteries, number of units, charging and discharging periods has been identified. The location of batteries in the system and the loss reduction and load factor improvement after installation of the batteries have been presented at the end of this paper.*

Keywords: *load curve, peak load, off-peak load, load factor*

1 INTRODUCTION

Daily load curve in electrical systems varies with the time and the peak occurs only a certain period of time of the day. The load factor of the load curve in the systems where the domestic consumers are dominated is poor. From recent past the use of energy storage devices (ESD) in electrical systems has been significantly increased due to various reasons. The ESD are being successfully used for the levelling of load curves which brings economical benefits to the systems. With the advancement of battery technology the use of batteries as ESD in electrical systems becomes more popular.

In order to ensure reliable supply to the consumers with the required quality both power stations and loads are interconnected forming grids or network. At the mean time there are off grid systems which cater for isolated group of consumers. These consumers are isolated as they are geographically far away from the national grid. Generally, these off-grid systems have comparatively less number of consumers with a single source of generation. At present these off grid systems are in operation in number of areas of the country. The source of generation of these systems is micro hydro generators. However, these generators cannot meet the growing peak demand of the system. Therefore restrictions are imposed to the consumers to use the electricity especially during the peak hours. As a solution to this problem batteries can be used together with the generator to meet the peak demand.

The batteries are charged consuming power from the system during the off peak hours and discharged delivering power to the system during peak hours. This also helps to improve the load factor of the system. At present different methods are used to store the electrical energy in bulk. .

Another advantage of use of batteries is that there is no restriction in locating them in the system. In contrary to this the energy sources such as hydro, coal, wind, solar are confined to a particular place depending on availability of fuel, water, transportation of fuel etc. This advantage gives the flexibility to locate them closer to the loads as well. The use of batteries in the system effects to the power flow through the network and network losses. As there is no restriction on location of the batteries they can be allocated to minimize network losses.

2 BATTERIES AS ESD

In batteries electrical energy is produced as a result of chemical reaction. This reaction happens during both charging and discharging periods. Energy stored in batteries when the demand is low and the stored energy is released when the demand is high.

Batteries produce DC voltage and the system operate in AC since there need to be have a AC/DC conversion. Schematic view of connection of battery to the system bus via AC/DC conversion is shown in figure 1. The control system is required for the successful operation of the batteries both normal and abnormal conditions. It controls power flow between battery and the system bus in both directions. A battery bank is a collection of two or more batteries for a particular application. Batteries can be connected either series or parallel. When the number of batteries are connected the either the voltage or amperage of the whole unit is increased and therefore the output power is increased

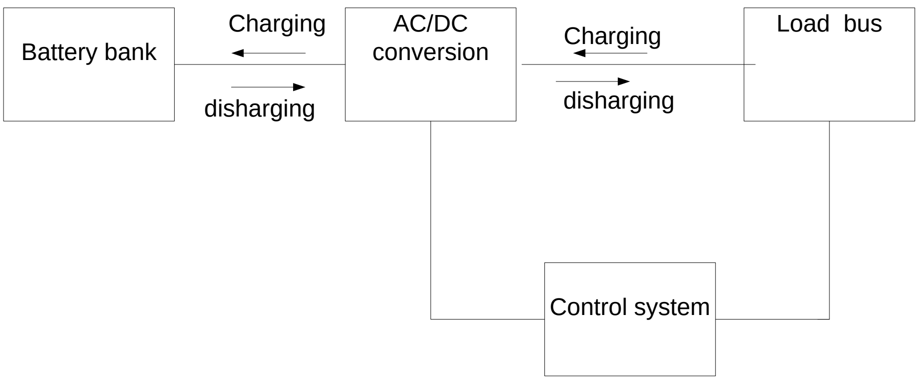

Figure 1 Connection of the batteries to load bus

During last two decades the use of battery banks as storage devices in electrical systems become has been increased significantly. This is due to the less capital investment, less installation time, and reverse time when compare with other types of ESD such as fly wheel energy storage devices, compressed air energy storage devices and pumped storage plants.

2.1 Battery Maintenance

Maintenance of batteries is essential for increase their life time. Some of following actions are maximize the life of the batteries [7].

a) Battery life will be shorter when more discharge. Therefore it should be avoid repeated deep discharging of batteries. If batteries are deeply discharged every day, it should increase the size of the battery bank.

b) Rated temperature of a battery is about 70°-75° C. Therefore it is needed to keep batteries at rated temperatures.

c) Difference charges of batteries in a battery bank may reduce the life. It should be maintain same charges in all the batteries in the bank.

d) Inspection of batteries should do from time to time.

2.2Battery Charge controllers

Battery charge controller regulates the rate of electric current when charging and discharging the batteries. Advantages of use of charge controllers are prevent overcharging and may protect against overvoltage, monitor battery temperature. It may also prevent deep discharging of a battery.

There are two types of charge controllers.They are series and shunt. When batteries are fully charged, series controller disconnects the current flow into batteries. A shunt charge controller diverts excess electricity to ashunt load, when batteries are fully charged.

There are two types of charge controllers used in off grids, PWM (Pulse-Width Modulation) and MPPT (Maximum Power Point Tracking).

Charge controller size can be determined by using power coming to the batteries and voltage of the battery bank.

3 METHODOLOGY

Generally, the use of batteries for the peak shaving of load curve of electrical system is a complex problem which focuses on solving three main problems:

1. Determination of total optimum capacity of battery bank for the given system
2. Determination of economical capacity of each unit of battery bank
3. Determination of optimum locations for the battery bank

The net capacity of battery bank for the given system is determined with the help of load curve. Generally, the capacity of battery bank can be decided by considering the difference between peak and off peak loads. Maximum capacity also decided by considering generation over loading limit. The batteries should be charged during the off-peak period and discharged them during the peak load. The use of batteries reduces the net capacity of the generators required during the peak hours.

Nominal parameters of the batteries also are of importance. Generally, the batteries are specified using its nominal capacity and energy storage. After charging the batteries the part of the energy is lost and therefore the energy available to release during the discharging mode is less than the charging mode. Usually, the amount of energy available for the discharge is around 70% - 80% of the energy stored during the charging mode. This can be considered as efficiency of the storage device.

The allocation of batteries is same importance as the determination of battery capacity. When the batteries are allocated in the system, power flow through the network will be changed. There will be additional power flow through the network during charging and discharging mode. Hence this affects to the overall efficiency of the system. This additional power loss due to installation of batteries can be minimized by optimally allocating batteries in the network.

There can be two options of allocation of batteries.

a) All the batteries are located at the place of generation. In this situation during the charge of batteries there is no additional power loss in the network. During the discharging period there will be additional power flow through the network. Hence power loss is expected to be greater than without batteries due to the increase of power flow during the peak hours.
b) Batteries are allocated near the load centers. In this situation power flow through the network is changed in both charging and discharging modes. During the charging mode the power flow is increased as the power need flow from the generator to the locations where the batteries are located. As the charge of the batteries takes place during off-peak hours the additional power loss due to charging batteries is less. On the other hand, during discharging period power flow increment is minimum as the batteries are located near to the loads. Therefore, the additional power loss due to energy storage devices can be minimized by optimizing the locations of batteries

3.1 Loss Reduction

A single phase distribution line is shown in figure 2. The load at the receiving end of the line receives power from the generator G through distribution line having impedance of (R_L+jX_L). A battery bank is also connected to the receiving end of the line through a AC/DC converter. The capacitive effect of the line and losses of the converter are neglected.

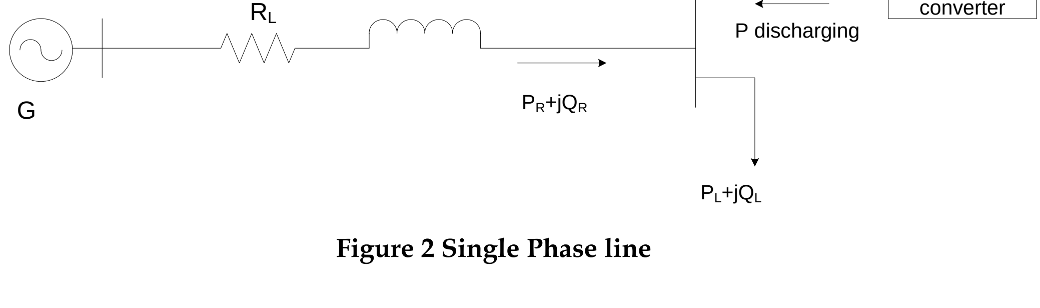

Figure 2 Single Phase line

When the batteries are not in operation power loss of distribution lineΔP is expressed as

$$\Delta P = \frac{{P_R}^2 + {Q_R}^2}{|\underline{V}_R|^2} . R_L \qquad (1)$$

Where P_R, Q_R– Single-phase active and reactive power flow at the receiving end

When the batteries are in operation the power loss of the line will be different from above as the active power flow through the line is less or greater depending on the mode of operation of the battery.

During the charging period additional power flows through the line to charge the batteries at the receiving end. Let the total single-phase power required by these batteries are P_{charge}. Then power loss during this charging period,

$$\Delta P_{charging} = \frac{(P_R + P_{charge})^2 + {Q_R}^2}{|\underline{V}_R|^2} . R_L \qquad (2)$$

Then, change in power loss due to charging batteries

$$\Delta\Delta P_{charging} = \Delta P_{charging} - \Delta P$$

After substituting from (1) and (2) and further simplification

$$\Delta\Delta P_{charging} = \frac{(P_R + P_{charge})^2 - {P_R}^2}{|\underline{V}_R|^2} . R_L \qquad (3)$$

During the discharging period power flow through the line will be less by the amount of discharging power. Let this amount to be $P_{discharge}$. Then power loss during this discharging period,

$$\Delta P_{discharging} = \frac{(P_R - P_{discharge})^2 + {Q_R}^2}{|\underline{V}_R|^2} . R_L \qquad (4)$$

Then, change in power loss due to discharging batteries

$$\Delta\Delta P_{\mathrm{discharging}} = \Delta P_{\mathrm{discharging}} - \Delta P$$

After substituting from (1) and (4) and further simplification;

$$\Delta\Delta P_{\mathrm{discharging}} = \frac{\left(P_R - P_{\mathrm{discharge}}\right)^2 - {P_R}^2}{\left|\underline{V}_R\right|^2} . R_L \qquad (5)$$

Due to the operation of the battery there is an increase of loss during the charging period and decrease of loss during the discharging period. The power loss has nonlinear dependence with the power flow through the line and therefore the net power loss can be reduced by optimizing the allocation of batteries

3.2 Methods of allocation

a) All the batteries are allocated in one of the nodes First the capacity of the battery banks will be determined. Energy loss of the system of the day is calculated after allocating all the battery banks at each and every node separately. The final decision on the location of the battery banks is made based on the minimum energy loss of the system.

b) Battery banks are allocated at different nodes. The batteries are installed one by one. After installation of a module by considering minimum energy losses the load curve will be corrected and then the subsequent battery will be installed. The process will be continued till the installation of all the batteries.

The batteries are allocated applying both methods and the batteries are placed in the locations where the net energy losses become minimum.

4 RESULTS AND DISCUSSION

The above method was applied to select and allocate the batteries in one of the off-grid system which covers Kudawa village in Rathnapura district. The village does not have access to the main grid and an off-grid system was in operation. The source of energy of the system is micro-hydro power plant with the rated capacity 15 kW. The present situation is that the capacity of the plant does not sufficient to meet the electrical demand of the villagers. Therefore the use of electricity by the villagers is restricted especially during the peak hours. Further expansion of the plant is not possible due to limited amount of water. As a solution to this problem, it is suggested to allocate batteries in the system.

4.1 Network data

This distribution system mainly consists of lighting loads and domestic appliances such as heaters, refrigerators etc. There are twenty two domestic loads that are fed by the generator through the distribution system. The domestic loads which are closer are considered as one node and network simplified to a system consisting 12 nodes. The single line diagram of the system is shown in figure 3.

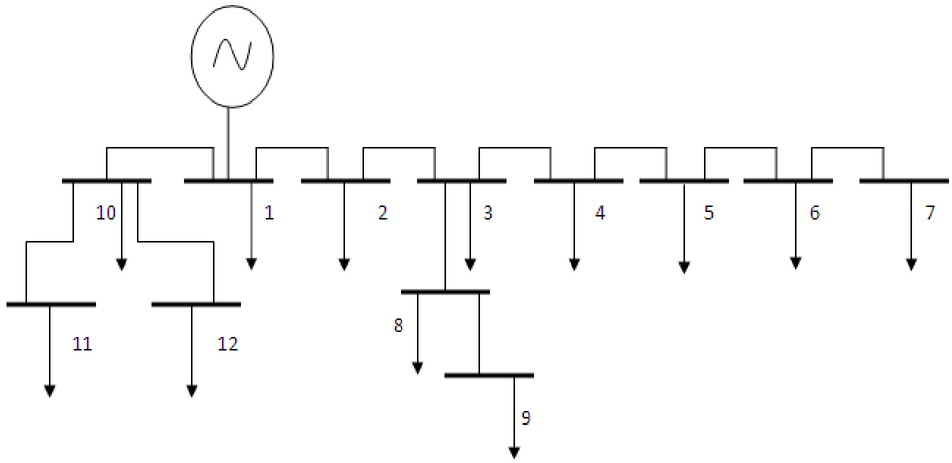

Figure 3 Simplified Single line diagram of the distribution system

4.2 Generator data

Design capacity of the generator is 15 kW. Observation results shows maximum output of this plant is about 7 kW under the flow rate conditions. In order to provide reactive power required by the loads of the system, capacitor banks have been installed. Frequency control of the generator is done with the help of balaster load. The balaster consists of eight coils (each 2 kW).The eight heating loads on and off automatically to make the balance between generation and load which varies with the time.

4.3 Load data

Main load of the consumers are light loads. Other than lighting loads refrigerators, televisions, rice cookers, radios, blenders, irons and etc are used by these consumers. Assuming that the loads remain unchanged during one hour the load variation throughout the day is presented in a step curve as shown in Figure 4.

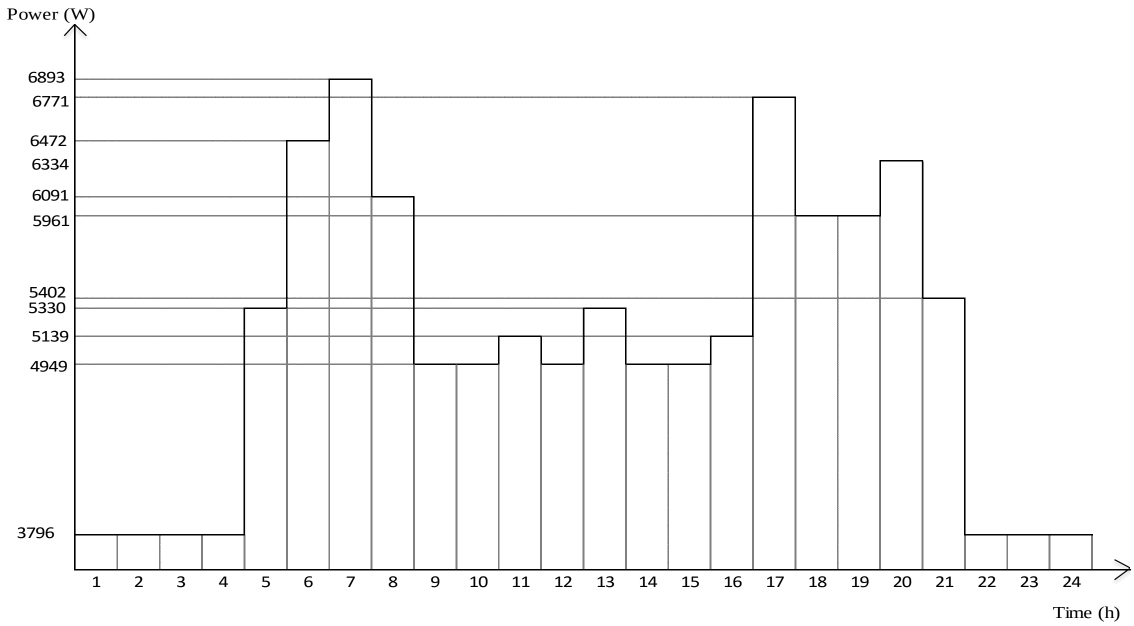

Figure 4 Daily load curve of the village

Summary of result of Load Flow calculation without battery at peak and off peak are given in table 3.

Table 3 Summary of Load Flow calculations

Description	Peak_7.00 a.m.		Off Peak_10.00 p.m. to 4.00 a.m.	
	W	VAR	W	VAR
Load	6430	2108	3665	1223
Generation	6882	0	3794	0
Shunt	0	-2358	0	-1294
Loss	452	250	129	71

4.4 Charging and discharging periods

Considering step curve shown in fig.4. Possible operation schedules of the batteries are determined as given below:

Charging : 22.00 hrs to 4.00 hrs
Discharging : 5.00 hrs to 8.00 hrs and 17.00 hrs to 21.00 hrs

4.5 Determination of Battery capacity

Battery bank capacity was determined by considering maximum and minimum demand of the system. The difference between maximum and minimum load is 3204 W(=7000-3796). This power can be used to charge the batteries. Considering power losses during charging and discharging modes and the commercial available capacities, the total battery capacity for one hour charging is taken as 2400 W. In order to store the maximum power during whole seven hour period of charging, the fourteen numbers of 12 V, 100 AH batteries were selected. The load curve after installation of batteries is shown in figure 5

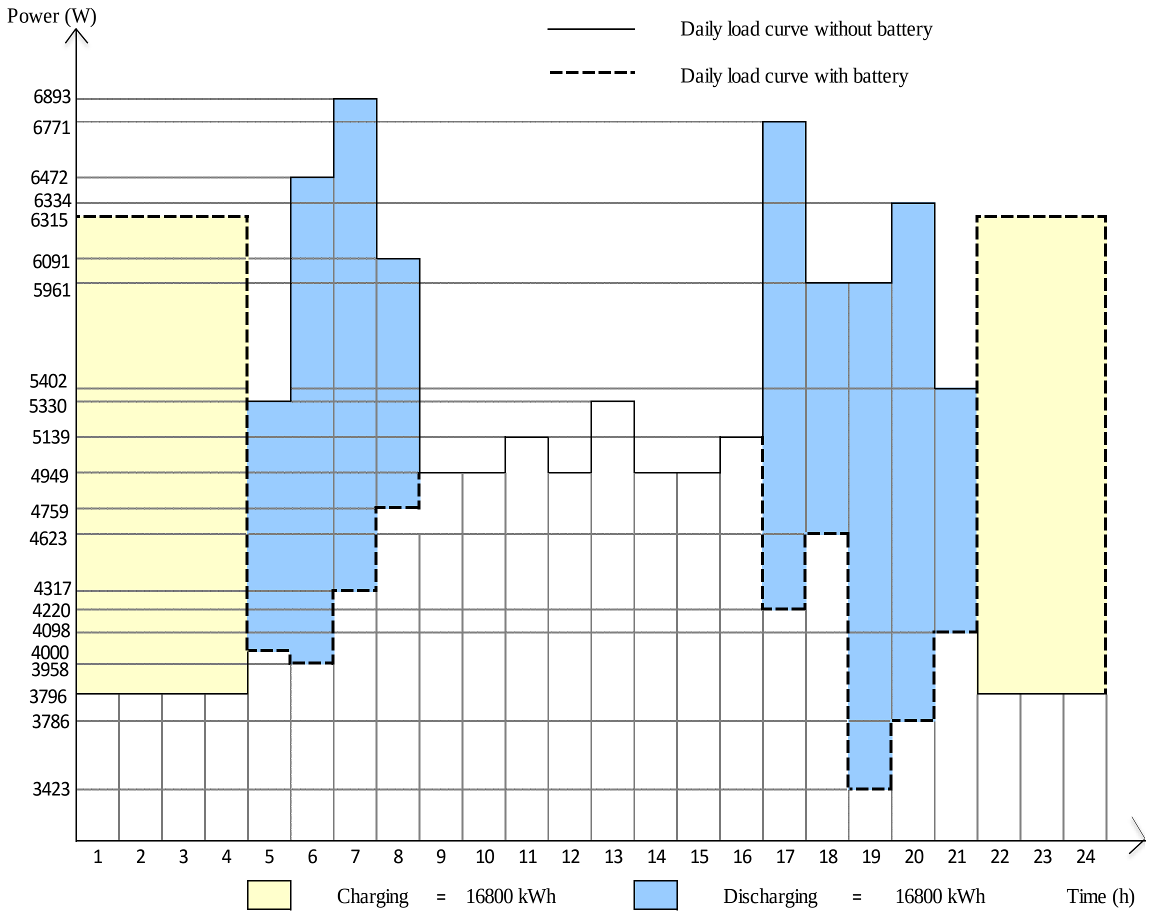

Figure 5 Load curve after installation of batteries

4.6 Location of batteries and loss reduction

The methods (a) and (b) mentioned above have been applied in allocating batteries in the system. The results are given in tables 4 and 5 respectively

Table 4 Energy losses when all the batteries are in one node

2400 W Battery Bank at Node	System loss during charging (Wh)	System loss during discharging (Wh)	Total Loss (charging and discharging periods) (Wh)
1	903	2861	3764
2	1988	1601	3589
3	2366	1243	3609
4	2968	893	3861
5	3024	888	3912
6	3073	888	3961
7	3122	899	4021
8	2828	1288	4116
9	2828	1327	4155
10	1015	2902	3917
11	1064	2950	4014
12	1113	2993	4106

Table 5 Power losses when batteries are at different nodes

1200W Battery Bank at Node	**1200W Battery Bank at Node**	**System loss during charging (Wh)**	**System loss during discharging (Wh)**	**Total Loss (charging and discharging periods) (Wh)**
1	2	1365	2131	**3496**
1	3	1526	1912	**3438**
1	4	1750	1660	**3410**
2	3	2156	1392	**3548**
2	4	2394	1146	**3540**
3	4	2611	1004	**3615**

Minimum total system losses at this situation reported when the 1200W (12V, 100 Ah) battery bank at node 1 and another 1200W (12V, 100Ah) battery bank installed at node 4.

There for the most suitable locations for the batteries for the system are nodes 1 and 4. In this approach the losses per day has been reduced by 9,4% in compare with the losses when all the batteries are located at node 1

As a result of allocation power delivered by the generator during the peak hours has been decreased from 6893 W to 4317 W.

a) This is an advantage during the dry session when the generator cannot deliver its full capacity.

b) If the load during the peak increases it can be met with parallel operation of generator and the battery.

The load factor (ratio of total energy consumption per day to energy consumption if the maximum demand would have been continued for 24 hours) before the installation of the batteries was 0.73 and this has been increased up-to 0.84 after installation of the batteries

Minimum node voltage during charging is node 7 of 215.53 V (0.9371pu)

Minimum node voltage at during discharging at peak is node 7 of 214.84 V (0.9341pu)

Total energy stored 16800 Wh. 2400 W capacity discharge by the time of 6.00am, 7.00am, 5.00pm, 7.00pm and 8.00pm. Only 1200 W at node 4 discharge by the time of 5.00am, 8.00am, 6.00pm and 9.00pm. Load curve with and without batteries is shown in fig. 5.

4.7 Voltage Profile of the power system

Voltages of nodes for existing system and after allocation of batteries is shown below table

Table 6 Voltages at nodes in existing system and system after allocation of batteries

	Voltage (V)			
Bus	**Off-peak Without batteries**	**Peak Without batteries**	**Charging**	**Discharging at 7.00am**
1	230.00	230.00	230.00	230.00
2	224.07	218.20	222.07	220.27
3	222.23	214.87	219.58	217.60
4	219.83	211.39	215.92	215.44
5	219.70	211.12	215.76	215.17
6	219.56	210.91	215.63	214.98
7	219.46	210.79	215.53	214.84
8	222.13	214.61	219.49	217.37
9	222.11	214.59	219.47	217.35
10	228.97	229.95	229.79	229.95
11	228.92	229.93	229.75	229.93
12	228.87	229.91	229.68	229.91

As it can be seen above voltage at nodes has been improved during the peak loads after installation of the batteries. The voltage during the off peak hours are reduced after installation of the batteries as there will be additional power flow through the lines to charge the batteries.

3 CONCLUSIONS

1) Battery allocation in the system increases the generated capacity of the system and will solve problem in meeting the increasing demand of the system. The restrictions that has been imposed to the consumers due to limited power generation may shifted up to a certain level due to installation of the batteries
2) The amount of power that can be delivered during the dry session also will increase due to the allocation of the batteries.
3) The allocation of the batteries closer to the loads will give addition advantage due to loss reduction in the system.
4) The battery allocation also improves the quality of the system such as voltage due to reduction of the voltage drop of the system.

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