MODEL PREDICTIVE CONTROL SYSTEM DESIGN FOR ENERGY MANAGEMENT WITH OPTIMAL USAGE OF BATTERY ENERGY STORAGE SYSTEM

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ABSTRACT

For smart grid infrastructure development, in next coming years, storage will be a solution for maintaining balance between supply and demand, and intermittency in renewable generation such as PV, wind etc. In distribution system peak saving and load leveling are two major applications of storage. In this paper, state variable model is proposed for discharging and charging the batteries incorporating power exchange between supply and demand. Smooth power supply is aimed to achieve from the proposed model. The model predictive control scheme is proposed to predict optimal power exchange to BESS and the stored energy with defined Depth of Discharge (DOD) in batteries. The proposed scheme maintains optimality and stability on different time intervals on charging and discharging conditions. The simulation work is carried out on real and practical electricity consumption data.

Keywords: Model Predictive Control, Load Profile, Battery Energy Storage, Peak Demand

I. INTRODUCTION

Day by day in future power system application of energy storage system is increasing while the energy storage technologies are becoming economically justifiable. Batteries having lifetime equivalent to PV cells and wind power generators could be produced in near future. Energy storages have many diverse powerful applications in distribution network as renewable energy smoothing or ramp control, load shifting and time of use management, peak shaving, and frequency regulation, spinning reserves, outage management, power quality, voltage and VAR support. Significant network infrastructure is needed due to large variations in the grid profile occur because of periods of high local energy generation followed by periods of high power demand. Battery Energy Storage System (BESS) is helpful in the condition while excessive energy is produced by solar power and wind power plant. Excessive power can be dumped in storage system to avoid the distribution grid overloaded with generation. Battery storage and energy management will become complementary to each other in future power system and will helpful in reducing monthly cost of energy, improving energy security and protecting customers from substantial gain/losses of utilities [1] – [8].

As far as conventional generators are concerned, due to slow ramp up time of the bulk conventional generation, they are unable to respond to spikes in demand quickly in real time. Energy storage can mitigate the said problem in real time. Storage has now become a constituent part of microgrid –energy islands that can cater the demand while grid power is interrupted, unsecure and expensive. Power systems generally face major problems as unpredictable peak power demand and intermittency of generations. Systematically deployed energy storage can balance energy in future power system while incorporating microgrids [14] – [15]. Load following is an ancillary services of grid operations. Load following up/down operations are generally done by generation while varying its output by operator. Generation at part load and varying the generation, rather than operating generator at constant design output, result in increased air emissions and fuel requirements, and need for generator variable maintenance [5]. Storage, compared to generation, is a suitable option in load following with its functional capabilities as charging/discharging. Storage can produce partial output as needed and is very quick in its response when different values of energy, in both direction, is required. In load following application, storage must be reliable in transfer of energy. As far as storage market is concerned, the energy stored in storage which is employed for load following, should be purchased at existing wholesale market price [8]. Storage follows the longer (hourly) changes in electricity demand and the discharging time may be between minutes to hours.

In some cases, replacement of transmission lines is the only feasible solution but ESS can be a potential solution to this addressable problem. Maximum benefits can be achieved if storage is pushed and installed close to loads, as managing the variability existing in scattered small scale distributed generation, improving overall grid reliability and integrating plug in electric vehicles. Energy storage system facilitates the microgrids, smart grids and renewable generation to achieve their full potential [13]. The major challenges in implementation of energy storages are high cost, problem in deployment and non-standardization of storage technologies [9].

While smoothing solar and wind power generation fluctuations a suitable control strategy is required to be implemented in such hybrid power system. Also the control strategy is able to maintain the predefined levels of SOC (state of charge) of battery [8], [9]. Authors of paper [15] suggested storage system to be used in electricity trading in lieu of load management. A model is suggested which optimizes charge-discharge time allocation to maximize profit in the system. The state of charge of batteries depends on state of charge of batteries on previous moment and sequence of generated power and load demand level from previous interval. At any moment, state of charge of storages should be within upper and lower limit so that to avoid shortening their life or even their destruction, thus storage should be limited with overcharging or over discharging at any moment. Battery management unit (BMU) is the part of BESS and controls the charging and discharging of battery storage [8], [12].

Model predictive control predicts the future output variables with dynamic model of process and current measurements. In each iteration, it solves an defined optimization problem based on current measurements of system states and calculates future control actions. In receding control strategy, only the first step of the control actions is implemented [16] – [17]. Now a day, MPC is being implemented in power system problems to predict the future behavior of the system [14], [15]. In this paper, the aim is to smooth the assumed PV generation and tracking the reference demand profile while predicting the optimal power exchange between system and BESS. A state variable model and model predictive control approach for this process are proposed to estimate the optimal future power exchange to the BESS and then finds the energy stored in future time intervals with assumed DOD.

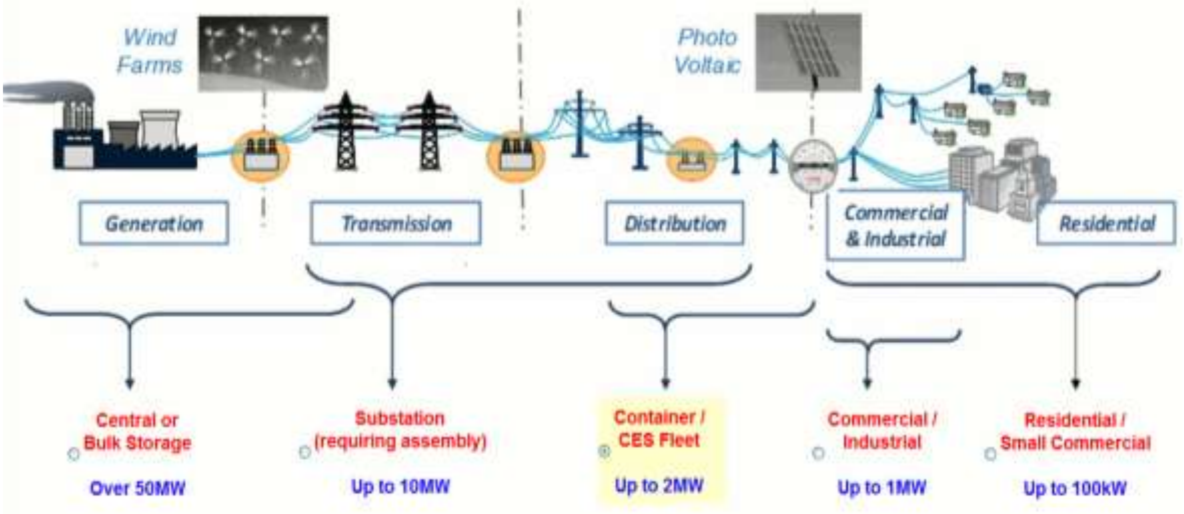

Fig.1 Possible Locations for Grid-Connected Energy Storage

II. A REVIEW OF STORAGE TECHNOLOGIES

Different types of energy storage systems are used to store the electrical energy such as pumped hydroelectric storage, compressed air energy storage system, fuel cell, solar fuels, superconducting magnetic energy storage, flywheel, flow battery, capacitor, thermal energy storage, battery etc. In the power distribution system, mostly, battery energy storage system (BESS) is used along with renewable power generations such as wind, PV etc. These are best suited to uncertain load changes in the system and respond in very less time in charging/discharging operations. During charging/discharging process energy is stored or released with reversible electrochemical reactions. Different technologies in battery energy storages have been developed, out of those, prominent ones are lead-acid, nickel/cadmium, sodium/sulfur, vanadium-redox flow batteries [10] – [11].

2.1 Lead Acid Batteries

Lead acid batteries are oldest of all battery technologies, invented in 1859 by Gaston Plante. Although these batteries are widely used in different applications such as power quality, UPS, and some spinning reserve applications, but the usage in energy management is very limited due to short cycle life (500-1000 cycles) and low energy density (30-50 Wh/kg). Performance of the batteries decreases as the high power is discharged, so at MW scale, these are used in a few commercial applications.

2.2 Sodium/ Sulphur

Na/S batteries are type of molten metal batteries which are having high energy density, high charge/discharge efficiency (89-92%), and long cycle life. The typical life cycle of these batteries is approximately 2500 cycles. The batteries work efficiently as the round trip efficiency is 90%. The major drawback of these batteries is that during chemical reaction process, high operating temperature, 300^{o}C-350^{o}C, is maintained. Around the world, the total installed capacity of these batteries is approximately 300MW, suitable for 6 hour of daily peak shaving, and these are manufactured, mainly, in Japan.

2.3 Nickel/cadmium

In 1899 the nickel/cadmium batteries were invented by WaldmerJugner. Later in mid 20th century, the research was done on sealed nickel-cadmium batteries. Among the rechargeable batteries, nickel-cadmium is the popular choice in power tools, portable devices, emergency lightening, UPS, telecoms, medical equipments and generator starting applications due to its high density (50-75 Wh/kg), robust reliability, and near maintenance free operations. In large scale energy storage applications, the nickel-cadmium batteries were sized as 27 MW for 15 minutes, 40MW for 7 minutes.

2.4 Lithium Ion (Li-ion) batteries

The cathode and anode in the batteries are made of lithiated metal oxide ($LiCoO_2$, $LiMO_2$, $LiNiO_2$ etc.) and graphite carbon with a layer structure, respectively. There is transfer of lithium ions between the two electrodes through the electrolytes made up of lithium salts (such as $LiPF_6$), during charging and discharging operations. Li-ion batteries have different advantages over other batteries such as high efficiency almost 100%, high energy density (75-200 Wh/kg) and increased cycle life (~10000 cycles). But the major drawback is the high cost due to special packaging and internal overcharge protection circuits. These batteries have wide range of applications at scale of low power, in portable electronic devices, medical equipment, electric vehicles, electric tools etc. There are limited applications at scale of MW. As the research is going on to cut down the manufacturing costs, these batteries will capture the high power market of grid applications.

2.5 Flow batteries

Flow batteries are two electrolytes system in which the electrolytes are liquid energy carriers and placed in two different tanks. The electrolytes are pumped through the two cell stacks separated by a membrane and electrical energy is obtained from chemical reaction in the electrochemical cell. In flow batteries, commonly used energy storage materials are iron, vanadium, zinc and bromine. Capacity of storage, which is scalable, is determined by the quantity of electrolyte in the reservoirs, and its power limit, by the size and number of electrodes in cell stacks. The flow batteries are rated to provide high power and high storage capacity for usage in electrical grid system. The major drawbacks of the batteries are that these are bulky and not portable. Based on type of electrolytes used, such as vanadium redox, zinc bromine and iron-chromium, three different types of flow batteries are in use. Chemical reduction and oxidation reactions happen in redox flow batteries during charging and discharging operations. One big advantage, in redox flow batteries, is the separation between power and energy and, hence, optimized and economic storage system is available for each application in range of kWh to 10's of MWh. Zinc-bromine batteries are hybrid redox flow batteries in which the power and energy ratings are not fully decoupled. The total energy storage capacity of ZnBr batteries depends on both the stack size (electrode area) and size of electrolyte storage reservoirs. Integrated ZnBr are tested by utilities in transportable and distributed applications such as community energy storage, up to 1MW/3MWh.

III. BATTERY DYNAMICS

During charging/discharging operations battery follows following dynamic equation [9], [12].

$$\frac{dE_{bat}(t)}{dt} = P_{bat}(t) \quad (1)$$

where$E_{bat}(t)$ is stored energy (Wh) in battery and $P_{bat}(t)$ (W) is charging/discharging rate at time$t$. $\Delta E_{bat}(t)$is change in energy stored, as shown in following equation.

$$E_{bat}(t+1) = E_{bat}(t) + \Delta E_{bat}(t) \quad (2)$$

IV. ENERGY STORAGE APPLICATIONS

Energy storage system finds applications in multitude of different services, incorporating cost reductions, of electric grid. Energy storage system is employed to support ancillary services in grid reliability and other value added services as voltage control and power factor management. Energy hub of different resources are managed to use at different time with employment of energy storage. The energy storage decouples the generated power which is self-produced or purchased. Most of the vendors have started to design the energy storage with communication facility to interact the energy management system to balance the supply and demand. BESS is generally used in power quality, distribution storage, peak shaving and intermittent renewable energy support applications. There are applications of energy storages at different levels of electrical system. Different types of large scale energy storage are installed at generation, transmission and distribution levels.

4.1 Generation level

Traditional large scale storages are installed far away from load centers and used in energy price arbitrage, capacity firming, and curtailments reductions. To meet the maximum demand, which occurs for a few hours in a year, uneconomical and carbon inefficient generation units have to start, in spite of regular generation. Also, bulk traditional generation have slow ramp up time and hence, they are unable to response fast to spikes in real time demand. To address these bottlenecks in the system, energy storages are planned to be installed and power plants are designed based on average demands not on peak demands. With energy storage system usages it has been feasible that the large utility generation plants such as nuclear power plants are operated at full capacity for economic reasons. Pumped hydroelectric storage (PHS) is large scale energy storage, implemented to store the energy, in form of hydraulic potential energy, depending on difference of heights of two reservoirs and volume of water stored and this potential energy is converted to electricity during peak hours. Compressed air energy storage (CAES) is another large scale energy storage option and works on the principle of conventional gas turbine generation. During low demand, energy is stored in the form of compressed air in an air tight vessel and the energy, as required, is extracted from this compressed air [9] – [12].

4.2 Transmission and Distribution Level

In transmission and distribution system, with placement of energy storage, operators are able to manage fluctuating and dynamic behavior of electricity in very efficient and effective manner. With incorporation of storage capability in transmission and distribution system, operators find resilience in transfer of uninterrupted power supply to end users. Under smart grid infrastructure, for the future power system, modular storage are transportable and can be deployed at a part of the network and redeployed at some other part to capture energy at low loads and deliver while there is congestion. Storages, having high density and long cycle life can provide cost effective operation in grid management. With the employment of energy storage, DSOs find more flexible distribution grid and size of distribution grid is reduced. Demand response is an integral part of the smart grid, distributed storage can facilitate and/or enable demand response with different schemes so it will probably become a crucial element of the smart grid [5].

4.3 End Users Level

At end users level the battery energy storages are used in peak saving, time-of-use energy cost management, off-grid supply, electric vehicles. Customers who are consuming electricity based on TOU (time of use) electricity pricing are able to reduce electricity related cost with approach known as retail energy time-shift. In this approach, energy is stored during off peak period i.e. when the demand is low and, hence, price of electricity is low. When the demand and price of electricity is high, this stored energy is used in different end usages, instead of purchasing high priced electricity. So customers can manage their electricity bills by using energy storages. Community energy storage is a concept related to utility owned energy storage placed near to end users. Community energy storage (CES) is an important concept to deploy, utility owned, low capacity distributed battery energy storage system near customers in spite of installing one or large units of energy storage. In such a case, for example, instead of installing 2 MW of battery energy storage at utility substation, it is possible to deploy 20 kW of utility owned small, modular and distributed 100 units of batteries near different consumers having total demand as 20 kW. Power electronic converter of each unit is capable to produce 20 kVARS reactive power to support the voltage control [13]. Under smart grid infrastructure, it is possible to implement community energy storage system to integrate large number of small generating units such as wind power, PV system (i.e. rooftop) etc, located near end-user points. For the future power system, different BESS at customer level should be aggregated to support the electrical grid and this approach should be standardized [1], [2].

The storages of energy find various applications in delivery of electrical energy from generation to end users and these can be deployed at any of subsystems of the power system. A value chain diagram, as shown in Fig. 1, depicts where and what are the applications in power system. At distribution level, the BESS is used in load leveling and peak shaving applications. With advancement in technologies and reduction in cost of installation, and operational and maintenance, the battery energy storage systems are emerging as powerful tool in, day-by-day, balancing of demand and supply at substation and end users level.

V. SIZING OF STORAGE

Storage size requirement is expressed in pair of power and energy capacities, imperative to balance multi directional power flow in each time interval. Power balance requirement is fluctuating power injections (increments) into and absorptions (decrement) from bulk power system [6]. Main points which are to be considered in deciding the size of energy storage are the operational constraints in the system. Size of the battery is fully utilized if it is designed based on 100% of depth of discharge (DOD) of battery. In such a case, battery will be cycled from state of full charge to full discharge [7]. As to improve life of battery and good economic purposes, it is requisite to upsize the battery to a DOD less than 100%. While designing the size of BESS, the main points to be considered are minimum and maximum values of SOC, preventing deep discharge and avoid exceeding converter power limits [9]. As capital cost of BESS depends on size, hence, smaller size is preferred in order to have economical feasible solution. So, there is trade of between energy storage cycle life and capital cost requirements.

Table I. Relationship betweenDOD, Battery Capacity and Life-Cylce [7]

Sr.N.	DOD	Battery Capacity (MWh)	Life-cycle (years)
1	0.05	11,748	240
2	0.10	5,874	82
3	0.15	3,906	43
4	0.20	2,937	27
5	0.25	2,350	18
6	0.30	1,938	12
7	0.40	1,468	7.5
8	0.50	1,175	5.0
9	0.75	781	2.7
10	0.85	691	2.3
11	0.95	618	2.0

VI. SOLAR PV SYSTEM

Output power of solar PV system depends primarily on solar irradiance and temperature. PV system connected to distribution system, contains a set of series-parallel electrically interconnected solar panels which produce dc output voltage, an inverter circuit to convert input dc voltage into three phase AC output, filters to get output, free of high frequency harmonics from unfiltered output from inverter and control system for dc voltage control, inner current control, MPPT control and PWM signal generator. In current control scheme, there is protection against overload and external faults. With lag-lead controller, actual output dc voltage tracks the dc voltage reference. The PV system must be equipped with maximum power point tracker (MPPT) in power conversion process so that maximum power output is obtained [19]. The output of the PV system is obtained from the following expression:

$$P_{PV} = I\eta_{pv}\eta_{red}S_{pv} \quad (3)$$

where$I$ is the sun irradiance (W/m^2), η_{pv} is solar panel efficiency, $\eta_{red}$is efficiency reduction factor due to orientation and shades, S_{pv} is the total area of the installed panel.

VII. PROPOSED MODEL PREDICTIVE CONTROL

In this paper following control system model is proposed which estimates the optimal charge/discharge operation of storage while obtaining the smooth power supply to the load demand.

$$z_1(k+1) = g(k) - u(k) \quad (4)$$

$$z_2(k+1) = -z_1(k) + z_2(k) \quad (5)$$

$$y(k) = z_2(k) \quad (6)$$

Where at k-th sampling interval, $r(k)$is total power generated which includes local generation and grid supply, $p(k)$ is the power exchange with batteries, , $z_1(k)$ is the net smooth power supply required , $z_2(k)$ is the electrical load demand.

In general form the model is simplified as

$$Z(k+1) = A_Z Z(k) + B_{Zg} G(k) + B_{Zu} U(k) \quad (7)$$

$$y(k) = C_Z Z(k) \quad (8)$$

Where

$$A_Z = \begin{bmatrix} 0 & 0 \\ -1 & 1 \end{bmatrix}, \; B_{Zg} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, B_{Zu} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, C_Z = [0 \quad 1]$$

7.1 Augmented State Variable Model

An integrator is embedded to suit the current state variable model to model predictive control design [17].

$$Z(k+1) - Z(k) = A_Z[Z(k) - Z(k-1)] + B_{Zg}[G(k) - G(k-1)] + B_{Zu}[U(k) - U(k-1)] \quad (9)$$

$$\Delta Z(k+1) = A_Z \Delta Z(k) + B_{Zg} \Delta G(k) + B_{Zu} \Delta U(k) \quad (10)$$

$$y(k+1) - y(k) = C_Z[Z(k+1) - Z(k)] \quad (11)$$

$$y(k+1) = C_Z A_Z \Delta Z(k) + y(k) + C_Z B_{Zg} \Delta G(k) + C_Z B_{Zu} \Delta U(k) \quad (12)$$

$$\begin{bmatrix} \Delta Z(k+1) \\ y(k+1) \end{bmatrix} = \begin{bmatrix} A_Z & 0 \\ C_Z A_Z & 1 \end{bmatrix} \begin{bmatrix} \Delta Z(k) \\ y(k) \end{bmatrix} + \begin{bmatrix} B_{Zg} \\ C_Z B_{Zg} \end{bmatrix} \Delta G + \begin{bmatrix} B_{Zu} \\ C_Z B_{Zu} \end{bmatrix} \Delta U \quad (13)$$

$$y(k) = [0 \quad 0 \quad 1] \begin{bmatrix} \Delta Z(k) \\ y(k) \end{bmatrix} \quad (14)$$

Augmented simple model is

$$X(k+1) = AX(k) + B_g \Delta G + B_u \Delta U \quad (15)$$

$$y(k) = CX(k) \quad (16)$$

$$where, \quad X(k) = [\Delta Z(k) \quad y(k)]^T$$

Let k=t is the sampling instant at which information of state variable vector $X(t)$ is available .The future control trajectories in N_c time intervals is as given below.

$$\Delta G(t), \; \Delta G(t+1), \ldots\ldots\ldots, \Delta G(t+N_c-1)$$
$$\text{and } \Delta U(t), \; \Delta U(t+1), \ldots\ldots\ldots, \Delta U(t+N_c-1)$$

Future state and output load demand variables in N_p prediction intervals are as given below.

$$X(t), X(t+1), \ldots\ldots\ldots\ldots\ldots X(t+N_p-1)$$
$$\text{and } \; y(t), y(t+1), \ldots\ldots\ldots\ldots\ldots y(t+N_p-1)$$

All variables on prediction and control horizon are definedin form of vectors.

$$Y = [y(t+1) \;\; y(t+2) \; \ldots\ldots y(t+N_p)]^T \quad (17)$$

$$\Delta G = [\Delta G(t) \; \Delta G(t+1) \ldots\ldots\ldots \Delta G(t+N_C-1)]^T \quad (18)$$

$$\Delta U = [\Delta U(t) \; \Delta U(t+1) \ldots\ldots\ldots \Delta U(t+N_C-1)]^T \quad (19)$$

Above equations can be written in compact form.

$$Y = FX(t) + \Phi_g \Delta G + \Phi_u \Delta U \quad (20)$$

Where

$$F = [CA\ CA^2\ ....CA^{N_p}]^T$$

$$\Phi_g = \begin{bmatrix} CB_g & 0 & 0 & .... & 0 \\ CAB_g & CB_g & 0 & .... & 0 \\ CA^2B_g & CAB_g & CB_g & .... & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ CA^{N_p-1}B_g & CA^{N_p-2}B_g & CA^{N_p-3}B_g & .... & CA^{N_p-N_c}B_g \end{bmatrix}$$

$$\Phi_u = \begin{bmatrix} CB_u & 0 & 0 & .... & 0 \\ CAB_u & CB_u & 0 & .... & 0 \\ CA^2B_u & CAB_u & CB_u & .... & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ CA^{N_p-1}B_u & CA^{N_p-2}B_u & CA^{N_p-3}B_u & .... & CA^{N_p-N_c}B_u \end{bmatrix}$$

7.2 Cost Function and Optimization

Effect of intermittent supply from local distribution generation is mitigated while the balance between supply and demand is maintained and the difference is minimized. Cost function is formulated as given below.

$$J = (R_s - Y)^T (R_s - Y) + \Delta U^T R \Delta U \rightarrow \min \qquad (21)$$

$$J = (R_s - FX(k) - \Phi_g \Delta G - \Phi_u \Delta U)^T (R_s - FX(k) - \Phi_g \Delta G - \Phi_u \Delta U) + \Delta U^T R \Delta U \qquad (22)$$

To minimize the above cost function it is to be differentiated with respect to ΔU and equated to zero i.e.$\frac{\partial J}{\partial \Delta U} = 0$ and thus following condition is obtained.

$$\Delta U = (\Phi_u^T \Phi_u + R)^{-1} \Phi_u^T (R_s - FX - \Phi_g \Delta G) \qquad (23)$$

7.3 Receding Control Horizon

First computed control value is taken in RCH such as

$$\Delta U(t) = [1 \quad 0 \quad \cdots \quad 0] \Delta U$$

Receding horizon control policy is simple and considered at some time interval *t* and extended to the finite time interval *T* in future. In receding control horizon policy following steps are to be performed. In RCH first model for prediction is formed and current estimates are obtained for unknown quantities and then these quantities are replaced with the estimates at time interval under consideration *t*. Optimization problem is solved to obtain input control trajectories at future time intervals subject to predicted dynamics and constraints. The input u_t is retained and considered for estimation of unknown quantities and optimization at next step and then u_{t+1} is retained and the process of computing input values is continued till final time interval.

VIII. CASE STUDY

Feeder connected to 33kV/11kV transformer no. 3 of main substation caters the major demand in IIT Kanpur. Hourly current data of year 2013 is considered for finding the feasibility of installation of storage with 2MW PV arrays existing in the campus. The proposed model predictive control strategy is implemented for energy management scheme with optimal usage of BESS with PV. Hence, it is possible to avoid overloading of feeder and transformer in the distribution system. It is imperative to do planning and design process before installing storage system.

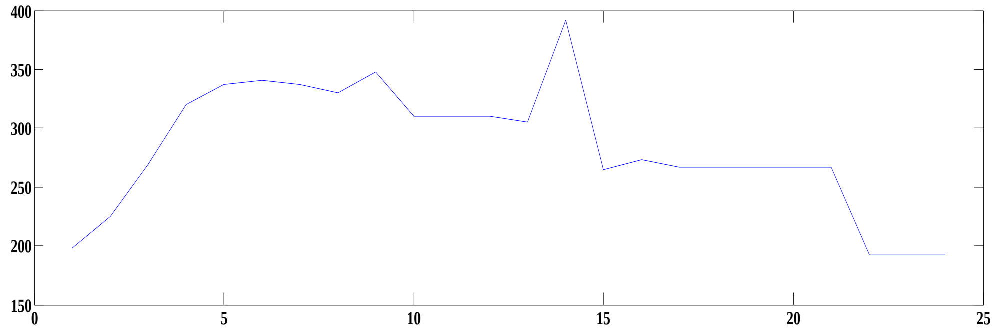

Fig.2. Load Profile Having Maximum Peak Demand (July 17, 2013) (X-Axis: Time (Hrs) And Y-Axis: Current (A))

Load profile of day of maximum demand in year 2013 is July 17, 2013 and assumed as desired load demand profile, fig. 2, for model predictive control strategy. The maximum demand on this day was 392A at 8PM. MW loading is obtained by multiplication of different values of voltages and power factor at different interval. Maximum demand in MW on this day is 4.2689MW. Load profile of that day is first considered for implementation of peak load management with PV plus storage while implementation of model predictive control scheme. Heuristically, it is identified that 1MW/2.5 MWh batteries system with 80% Depth of Discharge (DOD) is rated to implement the model predictive control approach.

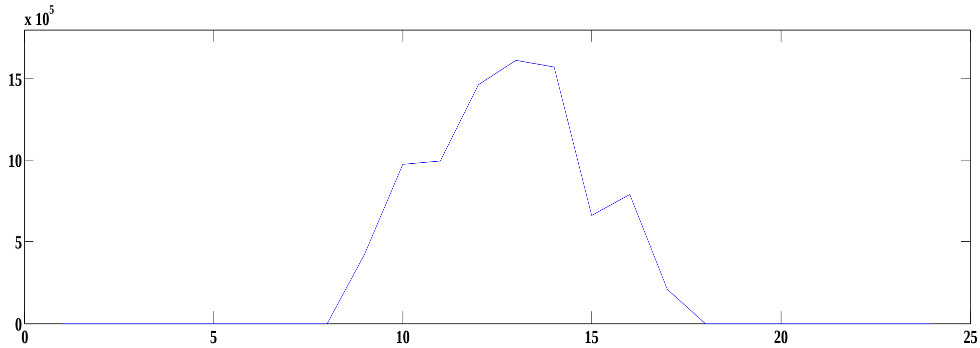

Fig.3. 80% Generation of Installed 2MW PV System (x-axis: Time (hrs) and y-axis: Power (W))

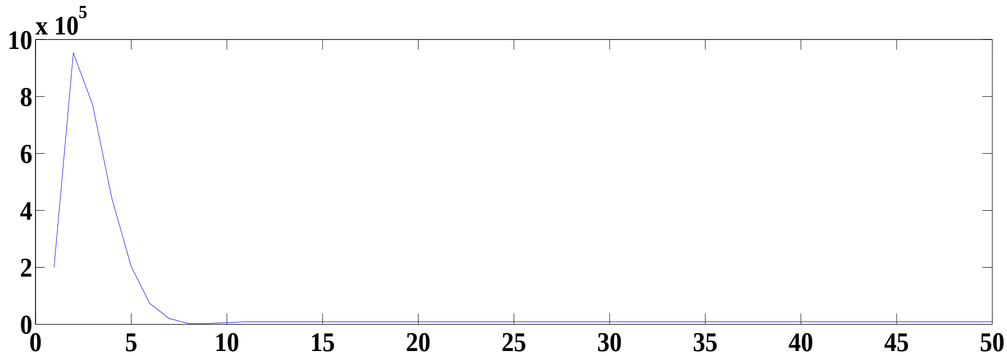

Fig.4. Predicted Power Exchange at 10 AM (x-axis: Simulation Steps and y-axis: Power Exchange (W))

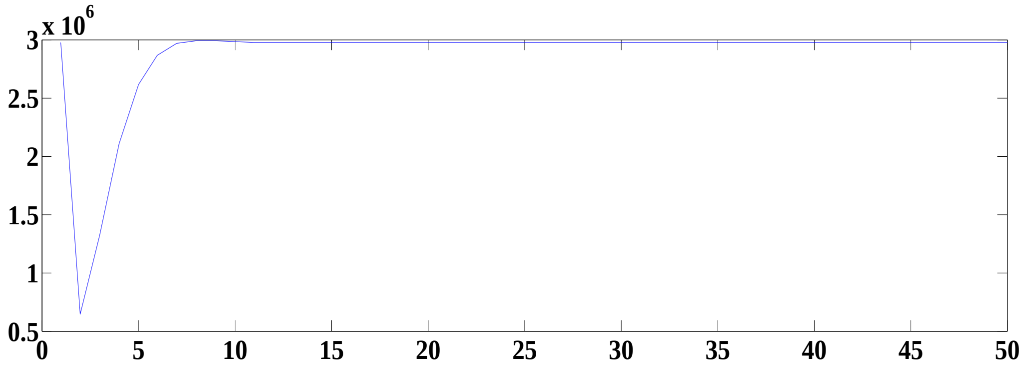

Fig.5. Tracking of Desired Load Demand 10 AM (x-axis: Simulation Steps and y-axis: Demand (W))

8.1 Model Predictive Control Approach Implementation

Hourly load profile data is considered as target values for the model predictive control scheme. Model predictive control scheme is implemented for optimal operation of PV with batteries to cater the desired load demand. In each hour, electricity consumption and total generation are assumed constant. In each hour optimal and stable power exchange with storage is predicted and hence during each hour optimal energy remained in storage with 80% DOD is found. The BESS should act quickly in response to changes occur in grid supply, PV generation and also in demand. The predicted power exchange by MPC helps in improving the fast action of BESS. The approach avoids the peak load demand at main grid so overloading of the system and increased distribution losses at peak demand is prevented. Stable and optimal operation of PV with storage is obtained for different interval and shown time 10 AM in fig.4 and fig.5.

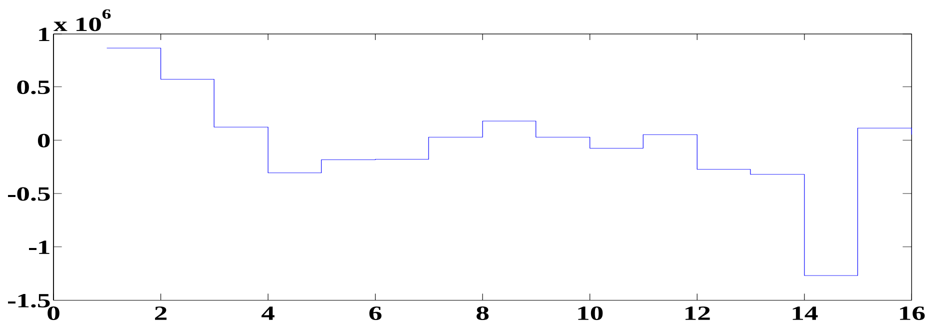

Fig.6. Predicted Power Exchange at Different Time Intervals (X-Axis: Time (Hrs) And Y-Axis: Power Exchange (W))

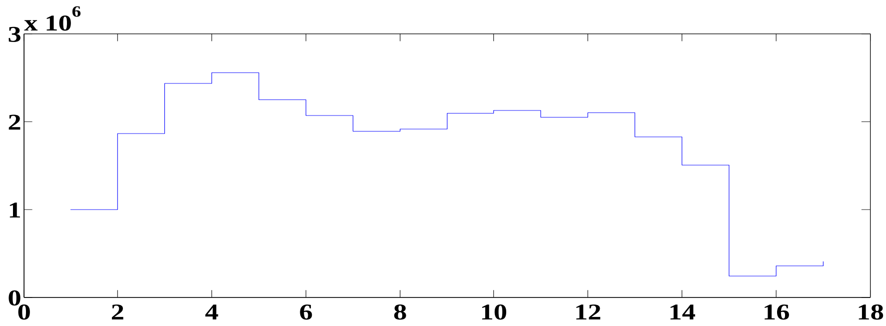

Fig.7. Predicted Stored Energy At Different Time Intervals (X-Axis: Time (Hrs) And Y-Axis: Energy (Wh))

Optimal power exchange and remained energy as predicted by proposed model predictive control scheme and state variable model at different intervals are shown in following figures fig.6 and fig.7.

V. CONCLUSION

In this paper, an overview of storage technologies and applications of BESS have been highlighted. In the proposed state variable model the smoothed power supply is obtained with applications of BESS. The reference demand is assumed as load profile of July 17, 2013 in the load pattern data of IIT Kanpur. The proposed model predictive control scheme is successfully implemented to predict optimal power exchange and stored energy on BESS with 80% PV generation and reference demand.

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