REDUCING BATTERY STORAGE REQUIREMENT FOR THE EFFICIENT OPERATION OF RENEWABLE GENERATION THROUGH THE COORDINATED CONTROL OF SYSTEM ELEMENTS

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Introduction

Using battery storage to smoothen out power fluctuations due to the the random generation patterns of wind and solar power plants is common in today's practice. However storage, especially battery is still quite expensive and as such the use of battery as storage has significant impact on the economics of wind or solar energy generation. Despite the high cost, battery has many advantages as a device of energy storage due to its ability to act fast and high energy density. Hence it is vital to ensure the minimum use of battery for a given application without compromising the system performance expected.

Presently, most power system elements are controlled using system frequency and voltage deviations as input signals. The advances in Information Communication Technology (ICT) enable information exchange near real time. As such by establishing appropriate ICT infrastructure, it would be possible to obtain more information such as active power generated or consumed by an element, battery Status of Charge (SOC) and the locations and types of devices connected to system at a given instance.

The work presented here shows how effectively the availability of information can be used to reduce the battery capacity requirement for the efficient operation of wind power plants without introducing significant power fluctuations.

Method

For the purpose of study, a small subsystem, a part of a large power system and consisting of four types of elements, as shown in Figure 1, is considered. The types of elements considered are thermal and wind generators, battery storage, controllable loads and fixed loads. This small system is assumed to be connected to the main grid through an interconnection. The objective of the control is to avoid the power fluctuation introduced by wind generators from getting into the main grid through the interconnection without compromising energy produced by the wind plant.

For the sake of simplicity, devices, alike, are represented by aggregated models here as shown in Figure 2.

For the purpose of formulating the

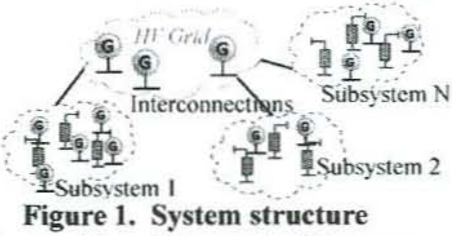


Figure 1. System structure considered for control Purpose

control problem assume that the operable ranges of various devices are as given below:

Thermal generator power – $[P_{Gmin}, P_{Gmax}]$
Battery power – $[P_{Bmin}, P_{Bmax}]$
Battery SOC - $[S_{Bmin}, S_{Bmax}]$
Controllable loads power – $[P_{Lmin}, P_{Lmax}]$
Wind generator power - $[P_{Rmin}, P_{Rmax}]$

Assume also that, $P_G(t)$, $P_B(t)$, $P_L(t)$, $P_R(t)$, $S_B(t)$ denotes thermal generator output power, battery output power, power consumed by loads, renewable generator output power and battery SOC respectively at time t.

Further assume that the unit cost of changing operating power of thermal generator, battery, load and renewable generator and of changing SOC of battery storage are at time t as $C_G(P_G(t))$, $C_B(P_B(t))$, $C_L(P_L(t))$, $C_R(P_R(t))$, $C_S(S_B(t))$ respectively.

Consider that $P_{K'd}(t)$ and $P_{K'}(t)$ are denoting the desired value and actual value of power imported to subsystem from the rest of the system at time t respectively.

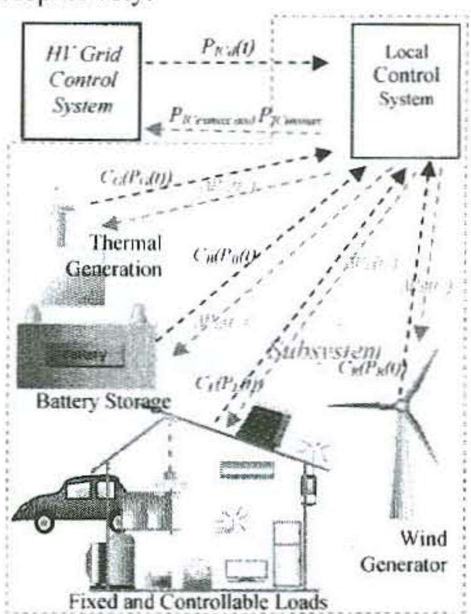


Figure 2. Study system and information flow

The deviation of interconnection power flow from the desired value is given by:

$$\Delta P_{K'}(t) = P_{K'd}(t) - P_{K'}(t) \qquad (1)$$

In order to make $\Delta P_{K'}(t)=0$, the best power adjustment pattern of each controllable devices is computed by solving the optimization problem described by equations (2)-(6).

Let $\mathcal{C}_S$ be the set, consisting of all controllable devices. Let $t+$ is $(t+\delta t)$ where δt is time required to compute and transmit $\Delta P_i(t+)$s to controllable devices.

$$Min \sum_{i \in \mathcal{C}_S} \{\Delta P_i(t_+).\ C_i(P_i(t))\} + \Delta S_B(t_+).\ C_B(S_B(t)) \qquad (2)$$

Subjected to

$$P_{imin} \leq P_i(t) + \Delta P_i(t_+) \leq P_{imax} \text{ for all } i \in \mathcal{C}_S \qquad (3)$$

$$S_{Bmin} \leq S_i(t) + \Delta S_i(t_+) \leq S_{Bmax} \qquad (4)$$

$$\Delta S_B(t_+) = f(\Delta P_B(t_+)) \qquad (5)$$

$$\sum_{i \in \mathcal{C}_S} \Delta P_i(t_+) = \Delta P_{K'}(t) \qquad (6)$$

The details of this method could be found in Liyanage et. el. (2009).

Results

Table 1 shows the study system parameters. Three operating modes, only battery controlled, all elements controlled except thermal generators and all elements controlled, were considered for simulation studies. Figures 3 (a), (b) and (c) show the variation of total wind energy loss as a

Table 1. Study system parameters

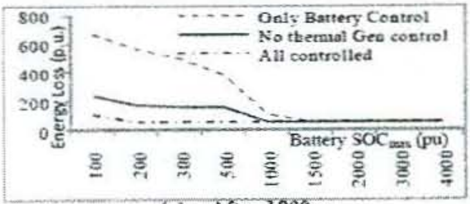
Element	Operating Ranges (p.u.)
Fixed capacity Loads	8
Controllable Loads	3.0 – 1.0
Thermal generation	4.8 - 3.2
Renewable Gen.	6.0 - 0.0
Battery power	2-(-2)
Maximum Battery energy storage* (minimum is 0 p.u.)	100,200,300, 500, 1000, 1500,2000, 3000,4000
Interconnection power flow (import)	2

function of battery storage for three operating modes after 1800s, 3600s and 5400s respectively. Figure 4 shows the variation of interconnection power flow as a function of time for battery SOC corresponding to 500 p.u. for the same three operation modes. Figure 5 shows the wind power generation in three operation modes when battery maximum SOC is 500 p.u.

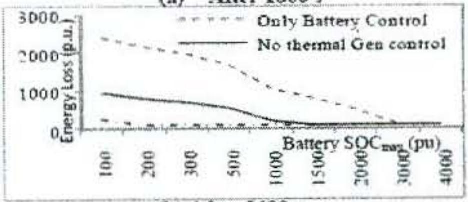
Discussion and Conclusions

Figures 3(a)-(c) clearly demonstrate that the coordinated control can reduce the battery requirement for the efficient operation of wind generation which is random in nature. The reduction is significant for the test system studied. Furthermore results shown in Figures 4 and 5 demonstrate that the proposed control method can reduce the power fluctuations in the interconnection and can capture more wind energy respectively.

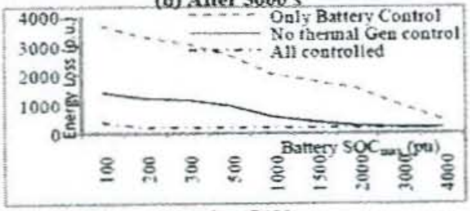
Simulation time interval was 4s with a



(a) After 1800 s



(b) After 3600 s



(c) After 5400 s

Figure 3. Total Energy Loss

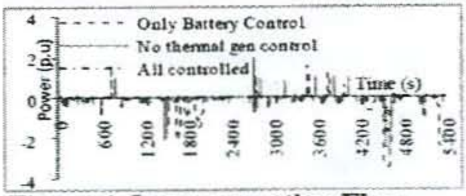


Figure 4. Interconnection Flow Deviation

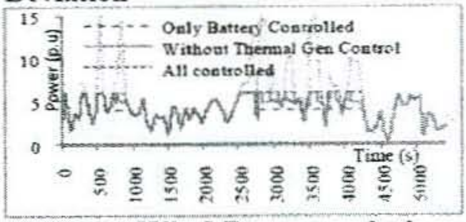


Figure 5. Wind Power variation (SOC_{max} = 500 pu)

References

Kensuke Kanekiyo (2009). Japan Energy Brief, No.2, The Institute of Energy Economics Japan, July 2009.

Liyanage, K. M., Yokoyama, A., Ota, Y., Nakajima, T. and Taniguchi, H. (2009). Efficient operation of renewable sources in ubiquitous power networks through the coordinated control of system elements, Proceedings of IEEJ Technical Meeting, Sept. 2009, PE—09—161.