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Survey on the Proposal of High-rise Building Embedded Pumped Storage as a New Dispersed Energy Storage and Water Conservation for Building Micro-grid and Large Cities

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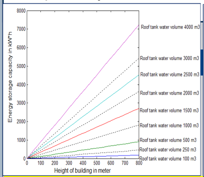
Introduction

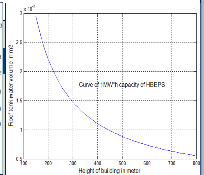
Since the proposal of High-rise Building (HB) Embedded Pumped Storage (HBEPS) being proposed in 2013, an economic viability and optimal sizing study has been completed which assumes HBEPS as a building owner electricity payment saving tool to take full advantage of utility TOU tariff structure, the developed daily optimal operation model can be using MILP to achieve the global optimum solution. The cost pump/turbine main machines are made based on market investigation and the available initial investment range is estimated to check whether it can cover the pipe/water tank/civil works in 8-10% annual interest rate and 10-12 return years based on the maximum daily saving; conventional design has been made including the guaranty calculation and transition process simulation; further survey has being made to investigate the similar thought from patents, dissertation and papers, available reports or talks; a group experts from state grid, conventional Pumped Storage Hydroelectricity (PSH) design institute, building design institute, machine manufactory, university, etc., are invited or visited to query, argue or suggest this proposal. A few fundamental techniques are gradually focused, and the roles of HBEPS for building dispersed resources (BDR) and building micro-grid (BMG), and smart city (SC) are more and more clarified. In MWh scale, HBEPS is very attractive for BDR/BMG/CSG. With its particular and unique utilization of height potential energy concomitant with the man-made high-rise building, HBEPS could never be taken to compare or compete with electrochemical storage techniques theoretically.

HB Resources and Potential in the World

From the statistical data, total number of building with height above 90m has reached more than 17383, 1/3 of them is located in China, USA has more than 2000. It is estimated that China has the HBEPS potential of 7.2GMWh, and USA 2.4GWh, respectively.



The energy storage capacity of HBES with roof water tank volume and height of buildings



The height of building vs. roof tank volume to achieve 1 MW*h capacity of HBEPS

Roles in BDR/BMG/HB

As dispersed energy storage system (DESS) to copy with intermittent DR like BIPV and BIWP when HB tied or isolated with utility grid. UPS;

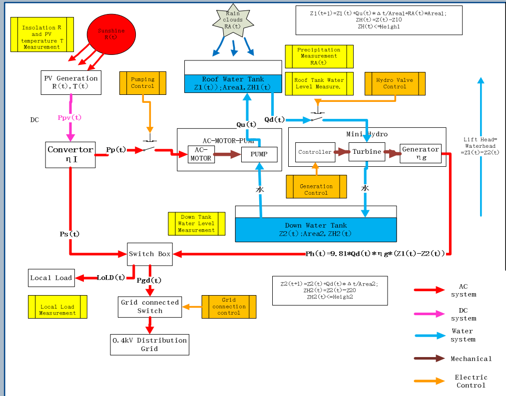
Roof and façade rainfall collection and energy recovering. Grey water energy recovery.

Fire protection/Anti-Terrorism

Roles in CSG/SC

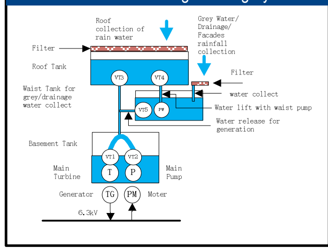
As black start power supply source, and peak shaving tool, DESS for City Smart Grid;

As water conservation tool for rainfall/storm water collection and conservation for smart city.

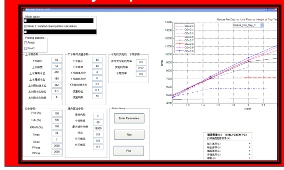


- The survey of high rise building in the world for using its ignored potential resource
- The discovery of such scheme in building DR / building MG/ building electrical power/ energy/water system, as well as in city smart grid and smart city
- The discovery of its technical solution as well economic evaluation with case studies

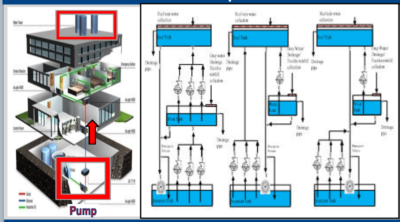
Multi-tanks HBEPS using rainfall/grey water



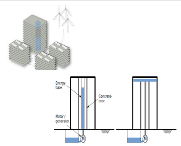
Feasibility & Optimization Software



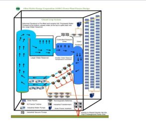
Existed Water Supply System and Three Proposed Multi-tank HBEPS Topo-connection



Two similar proposals by DUT, Holland and AHEC, USA



A concept of "High rise Energy Storage Core (HESC)" with "High rise Construction Tube (HCT)" by an architecture MSc thesis of DUT, Holland



AHEC,USA holds a patent of 70 storey buildings with two 1514 m^3 and 757m^3 water tanks with a 213.29 m long, D10.5 m penstock ,40 Francis turbine generators up to 28,000MW.

Roof Live Loads Standard (USA, China)

US Standard: ASCE-2005 Minimum Design Loads for Buildings and Other Structures

promenade purposes： 2.87 kN/m^2

Roofs used for roof gardens or assembly purposes 4.79 kN/m^2

China Standard: GB 50009-2012 Load code for the design of building structures

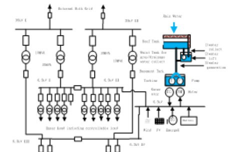
promenade purposes： 2.0 kN/m^2

Roofs used for roof gardens or sport purposes： 3.0 kN/m^2

Parameters of Shanghai Jinmao Building

Blvd Parameters:
Height:420.5m
Section Area:
100m*100m

HBEPS parameters:
Turbine efficiency： 0.9;
Generator efficiency： 0.92
Pump efficiency： 0.8;
Global Efficiency ： 0.6624.



Electrical Parameters (Top Reliability):
Volt: 35kV/6.3kV/380/220V; Incoming: 2*35kV Independent Lines; Main Transformers: 4*10MVA; Static Load:10MVA, so 3 Transf backup; Emer.Standby Gen: 6*1094 kW Oil

TOU based possible charge/discharge decision vector

i	1	2	3	4	5	6	7	8	9
T_i	5	2	3	2	2	3	3	1	3
r_{pi}	r_v	r_a	r_p	r_a	r_p	r_a	r_p	r_a	r_v
u_i	1	X	-1	X	-1	X	-1	X	1

Linear programing for given charge/discharge strategy

Thus, we will have a full linear programing problem where the dimension of decision variables Y are increasing from 9 to 27, or 3 times of number of intervals of TOU tariff structure:

$$\min z = \vartheta^{(k)} Y^T \quad (94)$$

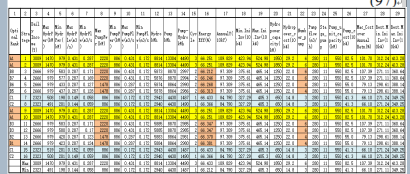
Sub to:

$$GY^T = E \quad (95)$$

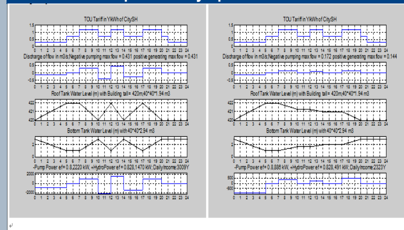
$$Y_{min}^T \le Y^T \le Y_{max}^T \quad (96)$$

Above problem can be solved by many methods to get an absolute optimal solution. Here we use Matlab LP function as follows:

[x,fval,lambda]=linprog(f,A,b,Aeq,beq,vlb,vub,x0,options) (97)



New MILP for optimal daily operation of Jinmao Tower



(a) Maximum return with 3 cycle daily (b) Minimum return with 1 cycle daily

Fig.8 Jinmao Tower HBEPS with Shanghai Tariff

MILP Global Optimum vs 2014 GA Optimization

Tab.10 Final sizing comparison with GA

	Daily Income (¥)	Maximum Hydropower Output (kW)	Maximum Pump Output (kW)	Time of calculation
Paper [2014]	2800	2400	3600	20 minute
This paper	3009	1470	2220	19 second
comparison	+7.46%	-38.75%	-38.33%	

Economic Evaluation for Roof Garden Burden (40*40*2 TopTank)

Hydro capacity: 17000kW； Pump capacity:2200 kW.

Total machine investment: 117.00 (10k ￥)

Daily return: 3900 ￥, Annual 109.9 (10k ￥)

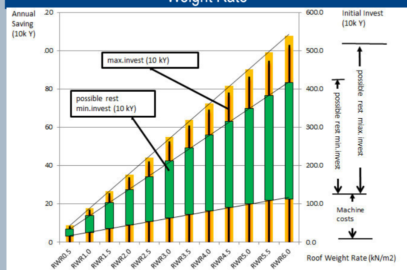
a very good investment.

Comparison Shanghai & Beijing TOU with Jinmao Tower

Cycle	Shanghai TOU					Beijing TOU		
	H=210		H=420			H=420		
	1DySav	+% *1	1DySav	+% *1	+% *2	1DySav	+% *1	+% *3
1	1162		2323		99.91	2370		2.02
2	1333	14.72	2666	14.77	100	2514	6.08	-5.7
3	1505	12.9	3009	12.87	99.93	2657	5.69	-11.7

*1 comparison itself
*2 comparison with H=210
*3 comparison with Shanghai

Study on economic viability of HBEPS in different Roof Weight Rate



Study on economic viability of HBEPS in different RWR