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Optimization of Power Allocation for a Hybrid Wind-Hydro Power System

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Abstract: With deeper research of wind key technologies, concern on optimization of power allocation for a power system with wind farms has been aroused greatly. A typical hybrid power system interconnected with the main grid, including wind power, hydro power, storage devices and local load, is taken as our study case. Its mathematical model used in optimizing power allocation was firstly constructed, PSO (Particle Swarm Optimization) algorithm was applied to slow the optimization problem and the optimal power allocation is gotten. Finally, numerical simulation is discussed which demonstrated that storage battery with larger capacity will decrease the waste of wind resources, and improve operation performances of the hybrid wind-hydro power system. *Copyright © 2013 IFSA.*

Keywords: Hybrid wind-hydro power system, Optimization, Power allocation, Capacity of storage battery, PSO (Particle swarm optimization) algorithm.

1. Introduction

With the commercial application of wind generation technologies, wind energy becomes one of the fastest developed energy among all of renewably energy resources. As we known, wind resource is scatter and its deposit is abundant. One of the best ways to consume plenty of output produced by wind units is to incorporate wind farms into main grids [1]. However, wind speed inputted into wind units is random. Then, to accurately predict wind power of next day is rather difficult [2]. The uncertain wind power would affect the correctness of daily operation scheme and result in making power allocation scheme difficultly for the power system. More over, great unsteady output from wind units would endanger the security and stability of power system potentially [3].

Supposing a hybrid system with wind energy and other kinds of energy were constructed, whose characteristics is complementary to wind resource, then we able to fully utilize wind resource and other energy resources synthetically. Meanwhile, such a system would provide users power supply with high reliability. In fact, such a hybrid system is very common in those isolated wind farms. For example, wind-diesel hybrid system [4], wind-solar hybrid system, wind-hydrogen hybrid system [6] and so on have been reported.

However, for wind-diesel hybrid system, fossil fuel is needed which may produce environment pollution. As for wind-solar hybrid system, wind energy is only complementary to solar energy in seasons, which means that there is plenty of wind and lack of sunshine in winter, and vise verse in summer. Wind-hydrogen storage system is depended on the construction of hydrogen supply and hydrogen consumption system. To accomplish hydrogen project from demonstration to commercial application would need some years awaiting.

Actually, for short term, which is commonly referred to one day, the better complementary characteristic exists between water resource and wind resource, this founding was proposed by some experts in late 90's [7, 8], and some valuable suggestion was put forward. Research of daily optimal power allocation had not researched until 2005 [9]. In that literature, a hybrid wind-pumped storage hydro-power station was discussed [10, 11].

As we known, to construct a pumped-storage hydro-power station needs plenty of investment, and its operation cost is also very expensive. As a result, pump-storage power stations usually account for very low percentage of capacity in a power system. What is even worse, some power systems may have no pumped-storage station. Therefore, for a large power grid, if the capacity of pumped-storage hydro-power plants were as low as not to bear the surplus or deficit of wind power outputted, its ability of power regulation would be very limited. In this case, such a hybrid system incorporated wind farms only with pumped-storage hydro-power plants is difficult to be applied into practice, when main grid is required to accept plenty of wind power injected. A novel proposal [12] was proposed in 2009, which is to construct a hybrid system including wind farms and variable-head hydro power plants. This proposal is wonderful to find a better way to utilize wind energy maximally with help of the regulation characteristic of reservoir. Such a hybrid power system is regarded as an independent sub-system to the main grid and would not only decrease the unnecessary waste of wind energy, but also greatly decrease interrupt to the main grid and improve the steady and security of the main grid.

Whereas, hydro-plant is not likely to consume the excessive wind output. The reason is because a variable-head hydro-power plant is only available to regulate power by stopping hydro turbines when wind turbines generate electricity [13]. Therefore, certain capacity of energy-storage devices is necessary for such a hybrid wind-hydro power system in order to store excessive power from wind units. With such a wind-hydro power system with storage devices will utilize wind energy maximally during one-day period.

Regarding to the discussed hybrid system which has a storage device and interconnect with the main grid, our focus is how to coordinate various sources to get maximal profit is very important. In addition, how much capacity of storage devices is designed for getting better operation performance. Therefore, the first step is to understand fundamental characteristics of power generation resources, then to build the corresponding mathematical model, finally to simulate the operation of the designed hybrid wind-hydro power system and to find the proper capacity the storage devices should be adopted.

2. Composition of the Hybrid Wind-Hydro System

China is abundant of wind resource and water resource in west areas and north areas [16]. Therefore, to configure a hybrid wind-hydro power system is accessible. From view of the daily operation characteristic, output of variable-head hydro power station fluctuate little, its run-off flow is steady in one day, while wind fluctuate greatly [12]. Therefore, combining the adjustable output of variable-head hydro power plants with the uncontrolled output of wind farms would produce a synthetic output characteristic with a less fluctuation and decrease interrupt to main grids connected.

Considering that conventional hydro power station is not available to storage energy like pump-storage hydro-electric power plant. But, when the output of wind power is lager than what the local load need, the excessive output needs some storage devices to store, then wind resource will not be waste. At present, there are many ways to store electricity [17]. Compared to superconducting magnetic energy storage (SMES), pumped storage and so on, storage battery is with many advantages, which are demonstrated in higher efficiency of energy conversion, simple structure, higher reliability, faster speed of discharging power r, longer life cycle, lighter weight and so on. Therefore, storage battery is applied more widely. We use storage battery to store the excessive wind energy and to discharge at the proper intervals.

Micro-grid is gradually formed with the development of distribution generation technology. Micro-grid is an autonomy system. With power electronic technology, power flows in bi-direction between the main-grid and the micro-grid. As of difference in resources among micro-gird, the structure of micro-grid is not the same. The micro-grid interconnected to the main-grid we discussed is consisted of a wind farm, a hydro-plant, a storage battery and local load, see Fig. 1, where the flow relation among these resources is illustrated clearly.

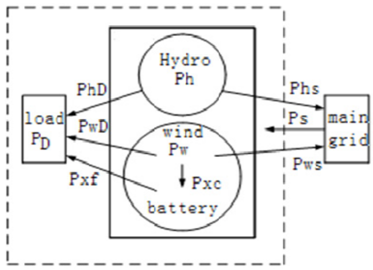

Fig. 1. The structure of micro-grid with hybrid wind-hydro power system.

$$\begin{cases} P_h = P_{hD} + P_{hs} \\ P_w = P_{wD} + P_{xc} + P_{wc} \\ P_D = P_{wD} + P_{hD} + P_s + P_{xf} \end{cases},$$

where P_h, P_{hD} and P_{hs} represent the output from hydro-plant and part of power supplied to local load. Part of power supplied to the main-grid. P_w, P_{wD}, P_{xc}, P_{ws} represent output of wind units part of power supplied to local load, parts of power supplied to storage battery and part of power supplied to the main grid. P_D is local load. P_s is the power supplied from main grid to the micro-grid. P_{xf} is the power supplied from battery to local load.

3. Mathematical Model of Daily Optimal Power Allocation for the Hybrid Wind-hydro Power System

3.1. Objection

One day is divided into 24 hours, then the objection for maximizing profit of the hybrid wind-hydro micro-grid is

$$\max F = \sum_{t=1}^{N} \{C_1(P_{wt} + P_{xt}) + C_2 P_{ht} - C_3 P_t\} \quad (1)$$

In equation (1), the meaning of all variables is explained as follow:

N is the period we discussed (hour), N=24;

C_1 is the price per kW for wind units (Yuan/kW);

C_2 is the price per kW for hydro-plant (Yuan/kW);

C_3 is the price for the main-grid selling to micro-grid (Yuan);

P_{wt} is the output for wind units at t interval (kW);

P_{ht} is the output for hydro-plant at t interval (kW);

P_{xt} is the charging/discharging power for storage battery at t interval (kW) (the positive value is referred to discharge, and the negative is referred to charge);

P_t is the power supplied from main-grid at t interval when the micro-grid is short of supply capacity (kW);

In addition, it is assumption that price of wind units is simply considered as the same as price of hydro-plant.

3.2. Constrains

Referred to the optimization of power allocation, there are a lot of constrains, including:

1) Power equilibrium equation for the micro-grid

$$P_{wt} + P_{ht} + P_{xt} + \Delta P_t = P_{Dt}, \quad (2)$$

where ΔP_t refers to the power that the micro-grid exchange with the main grid, see equation (4).

$$\Delta P_t = \begin{cases} P_t, & P_{wt} + P_{xt} + P_{ht} < P_{Dt} \\ -P_{wst} - P_{hst}, & P_{wt} + P_{xt} + P_{ht} \geq P_{Dt} \end{cases} \quad (3)$$

P_{wst} and P_{hst} refer to the excessive power injected to the main-grid by wind units and hydro-plant at t interval.

2) Water equilibrium equation for the reservoir

$$V_{t+1} = V_t + (q_t - Q_t) \bullet \Delta t \quad (4)$$

3) Capacity limit of the reservoir

$$V_{\min} \leq V_t \leq V_{\max} \quad (5)$$

4) Output limit of the hydro-plant

$$P_{h\min} \leq P_h \leq P_{h\max} \quad (6)$$

5) Water discharge limit of the hydro-plant

$$Q_{\min} \leq Q_t \leq Q_{\max} \quad (7)$$

6) Power equilibrium equation for the storage battery

$$W_{t+1} = W_t + P_{Xt} \bullet \Delta t \quad (8)$$

7) Capacity limit of storage battery

$$W_{\min} \leq W_t \leq W_{\max} \quad (9)$$

The meaning of variables from equation (2) to (9) is explained as following:

ΔP_t is the input or output power to the main-grid at t interval (kW);

P_{Dt} is the local load at t interval (kW);

W_t is the initial capacity of storage battery at t interval (kWh);

W_{t+1} is the final volume of storage battery at t interval (kWh);

V_t is the initial volume of the reservoir at t interval (×108 m^3);

V_{t+1} is the final volume of the reservoir at t interval (×108 m^3);

q_t is the average runoff of the hydro-plant at t interval (m^3/s);

Q_t is the discharging flow used in generating electricity for hydro-plant at t interval (m^3/s);

Δt is the length for every interval, Δt=1 h.

Supposing that charging or discharging for storage battery is accomplished without one second delay.

In equation (2), the output of hydro-plant is calculated as follow:

$$P_{ht} = A \bullet Q_t \bullet H_t \quad (10)$$

where H_t is the net head for hydro-plant at t interval, which is determined as follow. Water level at the upstream is substracted by the sum of water level at the down-stream plus the head loss. Wherein, the water level at the up-stream is depended on the capacity of reservoir, and the water level is depended on the discharging flow, the head loss is neglected.

A - the coefficient of hydro-plant, typically, large-size hydro-plant is given as 8.5, and medium-size hydro-plant is given as 8.0~8.5, and small-size is given as 6.0□8.0.

In equation (2), the output of wind units is described as below.

$$P = \begin{cases} 0 & 0 \le V < V_{ci}, V \ge V_{co} \\ f(V) & V_{ci} \le V \le V_R \\ P_R & V_R \le V \le V_{co} \end{cases} \quad (11)$$

In equation (12), V_{ci} refers to the cut-in speed of wind units. V_{CO} refers to the cut-out speed of wind units. V_R refers to the rated speed of wind units. f(V) is used in expressing the wind power function of wind speed when wind speed is within V_{ci} and V_R. There are three operation conditions for wind units.

1) When $V < V_{ci}$, the output of wind units is set at 0. When $V \ge V_{co}$, wind units will stop running for the sake of protection.

2) When $V_{ci} \le V < V_R$, wind units will convert wind energy into electric power at the maximal efficiency.

The cubic function is usually used in describing output of wind units approximately.

$$f(V) = P_R(V^3 - V_{ci}^3)/(V_R^3 - V_{ci}^3) \quad (12)$$

3) When $V_R \le V < V_{cO}$, for the capacity limit, wind units will operate at the rated condition.

4. Optimization of Power Allocation for Hybrid Wind-hydro Power System based on PSO Algorithm

To solve the complicate problem we discussed above, optimization approach is needed. PSO (Particle Swarm Optimization) [18], as an emerging optimization algorithm, was firstly proposed by Mr. Eberhart and Mr. James Kennedy in 1995. Similar to other evolution algorithms, PSO is also based on colony concept. The remarkable advantage of PSO algorithm is attributed to its simple calculation, fast convergence, few parameters, easy realization and so on. The most excellent advantage of the algorithm demonstrates in overall searching ability subjected to those problems with non-linear, and multiple modality. As of high efficiency, PSO has been applied in many fields.

4.1. Principle of PSO Algorithm

When PSO is used in solving the optimization problem, every solution is taken as the position of a bird within the searching space. And these birds are termed as particles. Every particle has its fitness which is determined by objection function. The velocity and position will determine the direction and distance of these particles.

At first, to generate a random group with m particles acts as initial solution. The position of every particle will be potential solution. The particle group is flying within D-dimension search space, and every particle will find its best solution by a few of iterations. At every iteration, the particle will update its position and velocity by tracing two best values. One is the best solution is so-called its individual solution among the local area, denoted as pBest. the other is the best solution among the global domain, denoted as gBest, see equation (13) and (14).

Supposing there are *m* particles, and the information of the i^th^ particle is *D* dimensions, the position vector is expressed as $X_i=(X_{i1}, X_{i2}, ..., X_{iD})$, the velocity vector is expressed as $V_i=(V_{i1}, V_{i2}, ..., V_{iD})$, $i=(1, 2, \ldots, m)$, others vectors are similar to those indicated above. The updated equation of position and velocity are shown as:

$$\begin{aligned} V_{id}^{k+1} &= \omega V_{id}^k + c_1 rand_1^k (pbest_{id}^k - x_{id}^k) \\ &+ c_2 rand_2^k (gbest_{id}^k - x_{id}^k) \end{aligned} \quad (13)$$

$$x_{id}^{k+1} = x_{id}^k + V_{id}^{k+1} \quad (14)$$

In these formulas, k refers to the current time of evolution; d=(1, 2, …, D).ω refers to weight factor of inertia, which is the coefficient of keeping the former velocity, commonly is set to [0.8, 1.2]. c_1 and c_2 refer to learning factors, used in representing the weight coefficients tracing the best history value itself and the globe best value. These coefficients demonstrate the knowledge degree of the particles, which are set as 2. rand1 and rand2 are the random number within [0, 1]. V_{idk} is the flying velocity for the i^{th} particle within d-dimensions. X_{idk} is the position for the i^{th} particle within d- dimensions.

For ensuring the particle is always within the designated range, the velocity at every dimension is limited at a maximal velocity V_{max}. If the updated velocity at a dimension is greater than V_{max}, then this velocity is set as V_{max}.

4.2. Principle of PSO Algorithm

PSO algorithm is preceded according to the following steps:

1) To give the initial parameters of PSO algorithm.

2) To initialize the velocity and position of m particles.

3) To calculate the objection of m particles, write down the individual best value of every particle and choose the particle with the maximal best value as the globe best value, and denote the corresponding the series number of particle.

4) To update the velocity and position for i^{th} particle according to the equation (13) and (14).

5) To check if the velocity is greater than V_{max}, if it's true, denote the velocity as V_{max}.

6) To calculate the objection for all particles and update the best position and the best globe position based on the current iteration.

7) To check if the ending condition is satisfied, i.e. If the maximal iteration times is reached or the best solution is got, or there is no any change in the velocity or position, then to stop the iteration. Otherwise, go to the step 4) and continue to iterate.

4.3. Optimization of Power Allocation for Hybrid Wind-hydro Power System

In fact, Optimization of power allocation is essentially to dispatch the discharging or charging power P_{xt} of the storage battery and discharging flow Q_t of the hydro-plant within a day. The best P_{xt} and Q_t at every interval will satisfy all constrains and minimize the disturbance to the main-grid and maximize profit of the hybrid wind-hydro power system.

Now the problem is attributed to find the decision variable P_{xt} and Q_t. The final volume of reservoir at t interval is solved by Q_t , then the water level at the up-stream, water level at the down-stream, and output of hydro-plant will be determined. Finally, the exchanging power ΔP_t between the hybrid wind-hydro power system will be gotten.

Supposing the dimension of particle is 24×2□P_{xt} and Q_t are respectively vectors with 24-dimensions. Then the position of the i^{th} particle is expressed below.

$$x = [P_{x1}, P_{x2}, ..., P_{x24}, Q_1, Q_2, ...Q_{24}] \quad (15)$$

Velocity Vector V_i represents the variation of every particle at the i^{th} interval. It should be noted that all value after updating must meet the requirements from all constrains.

Based on above analysis, the program is designed with MATLAB as below.

1) To set all parameters used in PSO, such as iteration times k_{max}, weight of inertia, the maximal velocity of particle V_{max} and so on.

2) To calculate the output of wind units P_{wt} at every interval with known wind speed V_t.

3) To determine the variation range of charging/discharging capacity P_{xt} for storage battery with known the local load P_{Dt} and output of wind units P_{wt}, to produce particles at all intervals randomly.

4) To produce particles of discharging flow Q_t of hydro-plant at all intervals randomly, and to calculate the finial volume of reservoir and the output P_{ht} of hydro-plant with known initial volume of reservoir and average discharging flow. In this case, the volume of reservoir is always restricted within the permitted range.

5) To calculate the exchange power ΔP_t between the main-grid and hybrid wind-hydro power system with known P_{Dt}, P_{wt}, P_{xt} and P_{ht}.

Finally, taking the objection as fitness function of PSO algorithm, the optimal solution will be got after many times of iterations.

5. Simulation and its Analysis

5.1. Parameters of PSO Algorithm

Some parameters used in PSO algorithm are needed to be given in advance, see Table 1.

Table 1. Parameters in the PSO.

C_1	C_2	ω_{max}	ω_{min}	k_{max}	V_{max}
2	2	0.95	0.4	500	100

5.2. Parameters and Curves Used in the Model

Subjected to the example as below, some parameters or curves must be known in advance in order to proceed optimization calculation, including:

1) Price used in objection.

Let C_1=0.56, C_2=0.43, C_3=0.61.

2) Parameters of the reservoir and its characteristic curves.

The capacity of reservoir is 1.0343×10^8 m^3, the storage level of reservoir is normally 1179.6 m, the corresponding volume of reservoir is 2990×10^4 m^3. In flood season, the minimum water level is 1177.1 m. The flood-controlled volume of reservoir is 930×104 m^3, the dead level is 1175.8 m, the dead volume of reservoir is 5730×10^4 m^3. The average runoff is 7244×10^4 m^3 based on many years statistic data and the runoff in one day is approximately considered constant (except flood period). The average runoff in spring season is 2.3 m^3/s.

The water level curve of reservoir with the capacity of reservoir is shown as Table 2. Supposing that down-stream level is kept at 1149.7m and daily water volume available is 7032.143×10^4 m^3.

Table 2. The water level curve with reservoir capacity Unit: m, 10^8 m^3.

Water level	1175.8	1177.1	1177.5	1178.2
Capacity of reservoir	0.573	0.67	0.7032	0.763
Water level	1179.6	1180.8	1181.9	1183.1
Capacity of reservoir	0.89	1.0146	1.0298	1.034

3) Parameters used in calculating output of hydro-plant.

The hydro-plant is consisted of 3 units with capacity of 800 kW and 1 unit with capacity of 400 kW, the total capacity is 2800 kW. Referred to this simulation, one unit with capacity of 800 kW is operating, its maximal discharging flow is 3.56 m^3/s. And no special consideration of flood-controlled is not considered. As the installed capacity of the discussed hydro-plant is small, then hydraulic coefficient is set as A =7.5 (6.0□8.0).

4) Output characteristic of wind unit and daily anticipant wind speed curve.

An anticipant wind speed is shown in Fig. 2, where we see that wind speed varies stochastically in a day. Normally, wind speed is bigger in the afternoon or at night. The maximal wind speed occurred at 21 intervals, and the minimal wind speed occurred at 8 intervals, the average is 5.12 m/s. Putting these wind data into equation (12), the output of wind unit is gotten.

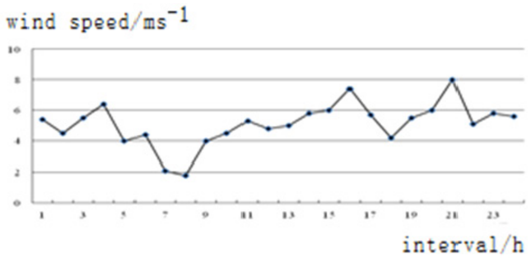

Fig. 2. Predicted wind speed curve for a typical day.

In addition, the installed capacity of wind farm is 3600 kW consisted of 6 wind units with capacity of 600 kW. Output curve of wind units with wind speed is shown as Fig. 3.

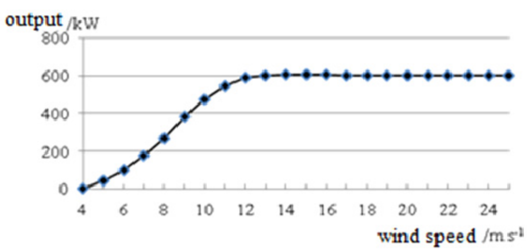

Fig. 3. The wind power curve with speed.

5) Capacity of storage battery.

The capacity of storage battery is determinate by the installed capacity of wind farm and its local load. Whether lager-size battery or small-size battery is not recommended. A capacity with 600 kWh is available for the wind farm which installed capacity is 3600 kW.

6) Local load curve.

Local power demand for users in 24 hours is indicate in the Fig. 4. Then we find that load varied stochastically. The morning peak occurred at 10 interval and the evening peak occurred at 19 interval. Daily average load is 548.2 kW, and daily load rate is 39.79 %, the difference between peak and valley is 1236.6 kW.

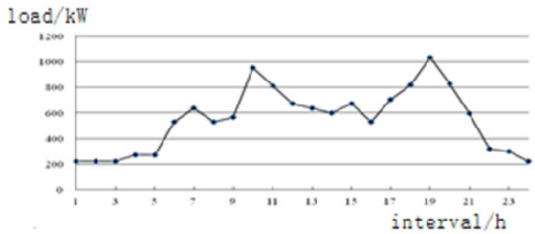

Fig. 4. Daily load curve on a typical day.

7) Limit of exchanging power for the main-grid

Supposing [-500, 500] kW is the available power accepted by the main-grid, the value is used in checking whether the main-grid operates securely and steady.

8) Boundary constrains for inequality equation

All limits used in boundary constrains From equation (3) to (10) is shown as Table 3.

Table 3. Limits for inequality equations.

Variables	P_{hmin}	P_{hmax}	V_{min}	V_{max}
Unit	kW	kW	10^8m^3	10^8m^3
Values	0	2800	0.573	0.89
Variables	Q_{min}	**Qmax**	**Wmin**	**Wmax**
Unit	m3/s	m^3/s	kWh	kWh
Values	0	3.56	0	600

5.3. Optimization Calculation

Putting the above parameters into the designed program with Matlab, all allocated power, including output of wind units which is accepted by wind units, power of storage battery, output of hydro-plant, the excessive output inputting to the main-grid, and supplying power by the main-grid is shown in Fig. 5.

In Fig. 5, the value above the horizontal axis represents the sum of allocated power within wind units, hydro-plant and storage battery at every interval, and value under the horizontal axis represents the excessive output of wind units inputted into the main-grid.

1) As wind speed from 7 interval to 15 interval and from 18 interval to 20 interval is so low that the need from load is not met by wind units. At these intervals, hydro-plant outputs power to supply load. With the complementary characteristic existed between wind units and hydro-plant, the output

characteristic of wind units is to be optimized. 2) During the period from 1 interval to 6 interval, from 16 interval to 17 interval, from 21 interval to 24 interval, the wind speed is greater and demand from load is low, it's better to preferentially consume electricity from wind units, the excessive electricity is used in charging storage battery, then sent to the main grid. While the hydro-turbine is arranged to stop and the runoff is stored at these intervals.

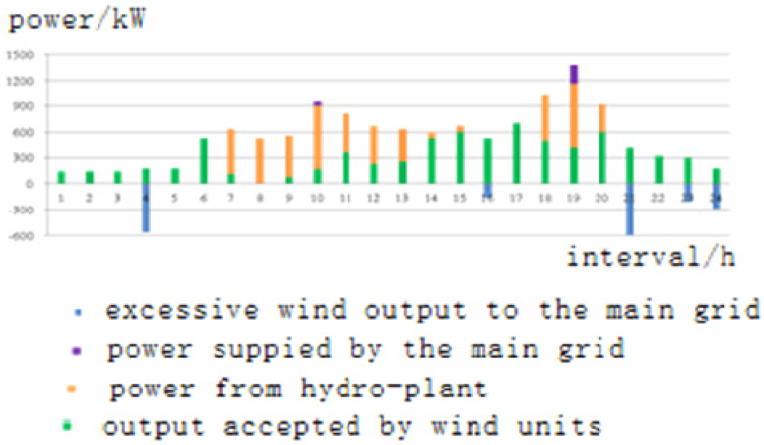

Fig. 5. Power allocation for hybrid wind-hydro power system.

3) No excessive output from hydro-plant is sent to the main-grid, this is because that reservoir is available to store energy from runoff, which is different from wind units. For wind units, when wind speed is greater, the excessive output from wind units either is given to the storage battery or sent to the main-grid.

4) The disturbance from hybrid wind-hydro power system is suggested to be minimum. Unfortunately, the equilibrium between supply from wind-hydro power system and load at some intervals is difficult to reach. For example, at 10 interval and 19 interval, the load is so great that hybrid wind-hydro power system is not available to supply enough power. In this case, to ensure reliable electricity to users, electricity from the main-grid is needed to supply load. While as, at 4 interval, 16 interval, 21 interval, 23 interval and 24 interval, the output from wind-hydro power system is enough to meet the demand for local load and fulfill storage battery, then the excessive electricity is sent to the main-grid. Specially, at 4 interval and 21 interval, the output from hybrid wind-hydro power system excesses the permitted capacity accept by the main-grid, these wind resources have to be wasted.

Obviously, when configuring a larger capacity of storage battery, the less interrupt the main-grid would be realized, which means wind power is more friendly to the main-grid as of better output characteristic and decrease disturbances to the main-grid. Table 4 demonstrates the excessive power to the main-grid when configuring different capacity of storage battery.

It is found that less disturbance to the main-grid when the capacity of storage battery is 800 W compared to the capacity with 600 kW. Meanwhile, no waste of wind power occurred anymore. In addition, when capacity of storage battery is 800 kW, the profit for the hybrid wind-hydro power system is increased from 5941.86 Yuan to 6043.86 Yuan. The simulation tells us the proper capacity of storage battery is important.

Table 3. The excess wind power sent to the main-grid.

Rated capacity	**4**	**16**	**21**	**23**	**24**
600 kW	561.1	147.5	593	203.9	284.3
800 kW	361.1	0	393	203.9	284.3

6. Conclusions

Based on the above research, some conclusions can be summed as below.

1) An example is used to demonstrate the importance of proper configuration for a hybrid power system. The proper capacity of battery is available to store the excessive electricity generated by wind units. The wind farms is arranged to carry base load and hydro power plants is arranged to carry variable load. In this way. the exchanging power between the hybrid wind-hydro power system and the main grid would be minimal, and the utilization of renewable energy is maximal.

2) The mathematical model of hybrid wind-hydro power system used in operation optimization is built, and with PSO algorithm, the power of hydro power plants, wind farms, storage devices and the main grid in every interval is gotten and the benefit of hybrid wind-hydro power system is ensured to be maximal.

3) The simulation for configuring different capacity of storage battery is proceeded, which tells us that the disturbance to the main-grid and profit for hybrid wind-hydro power system is related to the capacity of storage battery.

Furthermore, the characteristic of discharging/charging transient process for storage battery will be our next research. This is because the more accurate model is, the closer the operation condition is to be.

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References

[1]. Thomas Ackermann, Wind Power in Power Systems, *Willy*, 2005.

[2]. Liu Yong Qian, Han Shuang, Hu Yongshen, Review on Short-term Wind Power Prediction, *Modern Electric Power*, 24, 5, 2007, pp. 6-11.

[3]. Chi Yongning, Liu Yanhua, Zhang Weisheng, Study on impact of wind power integration on power system, *Power System Technology*, 31, 3, 2007, pp. 77-81.

[4]. Elhadiddy M. A., Shaahid S. M., Optimal sizing of battery storage for hybrid (wind+diesel) power system, *Renewable Energ*y, 18, 1, 1999, pp. 77-86.

[5]. Lu Huyu, Ma Shenghongm, Solar•wind hybrid generation system used in village, *China Electric Power Press*, 2005.

[6]. Kotak, D. B, Gruver, W. A, System Architecture for Fuel. Cell Based Intelligent And Distributed Energy Applications, in *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, Den Haag, Netherlands, 10-13 Oct. 2004, Vol. 2, pp. 1979 - 1983.

[7]. Bao Xioaqing, Li Zhengang, Bao Jinshan, Study on wind power/hydro power hybrid system, *New Energy*, 19, 3, 1997, pp. 34-37.

[8]. Yu Wuming, Cai Wanwen, Wang Xihong, To build hydro power- wind power hybrid system in Altay region, *Xijiang Electric Power*, 17, 3, 1999, pp. 1-6.

[9]. E. D. Castro Nuowo, etc., The optimization for daily operation of wind park combined with water power system, *Bulletin of Water Conservancy and Hydropower Engineering*, 2620, 2005, pp. 3-8.

[10]. Wenxia Pan, Yongwei Fan, Nanying He, The optimal dispatching research of the wind-hydro hybrid system, in *Proceedings of the International Power Engineering Conference (IPEC'07)*, Singapore, 3-6 December 2007, pp. 977 - 981.

[11]. Pan Wenxia, Fan Yongwei, Yang Wei, The optimization for operation of wind park combined with water power system, *Acta Energiae Solaris Sinica*, 29, 1, 2008, pp. 81-84.

[12]. Sun Chun-Shun, Study on combined operation of Hydro and wind power generation system, *Acta Energiae Solaris Sinica*, 30, 2, 2009, pp. 232-236.

[13]. Chen Shenlin, Reservoir operation and dispatch for power station, *China Electric Power Press*, 2008.

[14]. Liu Lijie, Wu Fubao, Survey of Micro-grid technology application in China and its prospect, *Rural Electrification*, 31, 6, 2010, pp. 38-40.

[15]. Lao Zhirong, Lao Derong, Demand-side management and its application, *China Electric Power Press*, 2008.

[16]. Tong Jiandong, Small-size hydro power station in China, *China Water Power Press*, 2006.

[17]. Fan Shuanshi, Liang Deqing, Yang Xiangyang, etc, Materials used in storage energy and its technology, *Chemical Industry Press*, 2004.

[18]. Li Zhen, Liao Huilian, Wu Qinghua, Algorithm of particle swarm optimization and its application, *Science Press*, 2009.