

A Rapid Active Power Regulating Technique for A Virtual Small-hydro Cluster

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Abstract. A rapid active power regulating technique for a virtual small-hydro cluster is studied in this paper. The virtual small-hydro cluster consists of several decentralized small-hydro power stations, which quickly responds to the active power target instructions of real-time dispatch and AGC. Furthermore, the power fluctuation of the delivery cross-section caused by intermittent power source in short-term scale can be efficiently smoothed. When any tie line transmission power reaches its thermal stability limit, the active power target instructions is allocated according to the sensitivity priority of small-hydro power plants to threshold-crossing lines among the small-hydro cluster. When all the tie lines transmission powers are within their thermal stability limits, the active power target instruction is allocated on the basis of the priority of the summation of product of tie line power variations and sensitivity of small-hydro power stations to tie lines. Under the constraint of fulfilling the active power target instructions, the simulation results show that the adopted control strategy and allocation algorithm can effectively decrease the power fluctuation of each tie line.

1. Introduction

Large-scale intermittent power generation integration increases the active power fluctuation and frequency excursion of power grid, however, we can still employ the adjustment ability of distributed generators to smooth the power fluctuation caused by themselves. In distribution networks, the typical distributed generators involve wind turbine, photovoltaic(PV) power generation and small-hydro power station basically, etc.

At present, the synthetic inertial control technique and primary frequency auxiliary control technique with respect to wind turbine have been raised already, but they are not popularized and utilized in the power grid yet, the MPPT strategy is adopted in most wind farms in the domestic and overseas[1-4]. The coordination control between PV and energy storage device to achieve active power smoothing control normally, however, the investment cost will increase visibly for the large-scale application of this technology[5-7]. In some areas of China, distribution network incorporates small hydro-power with high penetrations, and also the active power fluctuation can be restrained applying small hydro-power stations. As a matter of fact, the small hydro-power station contains run-off-station and non-run-off-station. For run-off-station, the output is stochastic, the storage capacity is deficient normally and the active power control ability is limited. Therefore, the active power adjustment in the region where contains a large number of run-off-stations is difficult[8, 9]. While the



non-run-off-station possesses a certain storage capacity and active power adjustment ability on hours level time scale, thus as mall-hydro cluster that consists of multiple non-run-off-stations will definitely provide with assistance on active power adjustment of power grid.

Therefore, a virtual small-hydro cluster consists of several decentralized non-run-off-stations in this study, which quickly responds to the active power target instructions of real-time dispatch and AGC. Because almost all the non-run-off-stations are not utilized to participate in power grid dispatching, the raised technique is highly valued in popularization.

2. The control strategy and control algorithm of virtual small-hydro cluster

2.1. The control strategy of virtual small-hydro cluster

The proposed control strategy is illustrated in Figure 1. A virtual small-hydro cluster consists of several small-hydro stations possessing a little adjustment ability responds to regional real-time dispatch and Automatic Generation Control (AGC) collectively. The real-time dispatch delivers basic point active power through regional dispatch center and AGC delivers active power regulation instruction to the small-hydro cluster. The virtual small-hydro cluster control center calculates the total active power adjustment target value combining the actual operating status of each small-hydro station and allocates it among the small-hydro stations according to the proposed control algorithm subsequently. Meanwhile, the regulation of small-hydro cluster should be effective in suppressing the active power fluctuation of cross-section tie lines resulting from intermittent power.

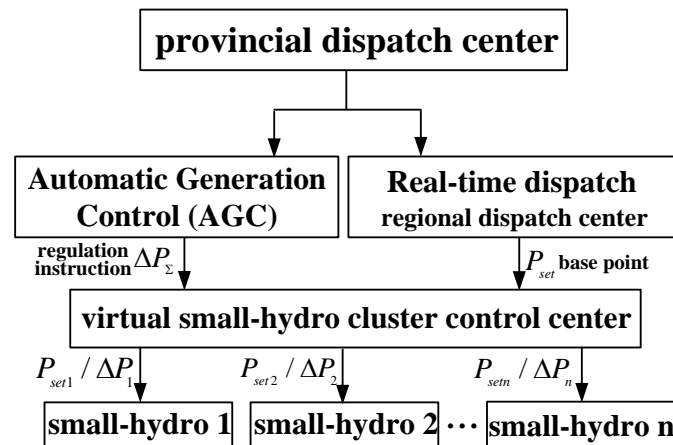


Figure 1. The control strategy of virtual small-hydro cluster.

2.2. The mathematical model of small-hydro station

The output power of hydropower unit is given by[10]:

$$P_G = 9.81\eta_h\eta_G(Q - Q_0)H \quad (1)$$

where η_h is the efficiencycoefficient of hydraulicturbine, η_G is theefficiencycoefficient of generator unit, Q is the flow of hydraulicturbine, Q_0 is the no-loadflow of hydraulic turbine, H is the operating head of hydraulic turbine. Q is given by[10]:

$$Q = k_u G\sqrt{H} \quad (2)$$

where k_u is the proportionalitycoefficient, G is the ideal opening.

According to (1) and (2), the rated output power P_{GN} , the rated flow Q_N and the no load flow Q_0 are described as follows:

$$P_{GN} = 9.81\eta_h\eta_G(Q_N - Q_0)H_N \quad (3)$$

$$Q_N = k_u G_N\sqrt{H_N} \quad (4)$$

$$Q_0 = k_u G_0 \sqrt{H_0} \quad (5)$$

where H_N is the rated head, H_0 is the no load head. The mathematical equations in pu unit corresponding to (1) through dividing (1) by P_{GN} and dividing (2), (5) by Q_N is given by:

$$P_G^* = \left(\frac{G\sqrt{H^*} - Q_0^*}{1 - Q_0^*} \right) H^* \quad (6)$$

According to (6), the total active power in real-time of a small-hydro station i containing m units is given by:

$$P_{hi} = \sum_{j=1}^m \left[\left(\frac{\sqrt{H_{ji}^*} - Q_0^*}{1 - Q_0^*} \right) H_{ji}^* P_{GNji} \right] \quad (7)$$

where Q_0^* equals 0.05.

2.3. The active power allocation algorithm of virtual small-hydro cluster

2.3.1. The calculation of regulation limits. The active power regulation upperlimits and lower limits of the small-hydro stations keep changed alone with operating status. Consequently, virtual small-hydro control center should upload the upper limits and lower limits to dispatching center for real-time, which contributes to assign instructions reasonably for the regional dispatch center and AGC.

Universally, ΔP_i^+ and ΔP_i^- denotes the active power regulation upperlimit and lowerlimit of the small-hydro station i respectively. For the unit j in the small-hydro station i , the active power regulation upperlimit and lower limit should be determined combining the operating head H_{ji} . When $H_{ji} > H_N$, the active power regulation upperlimit of unit j is rated value P_{GNji} . Hence, ΔP_i^+ is given by:

$$\Delta P_i^+ = m P_{GNji} - P_{hi} \quad (8)$$

When $H_{ji} < H_N$, the active power regulation upperlimit of unit is the output power that the guide vane opening attains the maximum value. Hence, ΔP_i^+ is given by:

$$\Delta P_i^+ = \sum_{j=1}^m \left[\left(\frac{\sqrt{H_{ji}^*} - Q_0^*}{1 - Q_0^*} \right) H_{ji}^* P_{GNji} \right] - P_{hi} \quad (9)$$

In any case, ΔP_i^- is given by:

$$\Delta P_i^- = -P_{hi} \quad (10)$$

According to (8) and (9), the total active power regulation upperlimit of the virtual small-hydro cluster containing n units is given by:

$$\Delta P_\Sigma^+ = \sum_{i=1}^n \Delta P_i^+ \quad (11)$$

According to (10), the total active power regulation lowerlimit of the virtual small-hydro cluster is given by:

$$\Delta P_\Sigma^- = \sum_{i=1}^n \Delta P_i^- \quad (12)$$

ΔP_i^+ and ΔP_i^- are uploaded every 5s in the practical application.

2.3.2. The calculation of total active power adjustment instruction. The virtual small-hydro cluster responds to the dispatch control in accordance with 2.1. Regional real-time dispatch sends base active power instruction and AGC system sends regulating instruction to the small-hydro cluster. Thus, the total active power adjustment target value ΔP_Σ must be calculated firstly and then can be allocated

among small-hydro stations. The total active power target value of small-hydro cluster P_{Σ} can be obtained easily when P_{set} and ΔP_{AGC} are received from dispatch control center:

$$P_{\Sigma} = \Delta P_{AGC} + P_{set} \quad (13)$$

The active power (P_{hi}) of each small-hydro station in real time is sampled, then ΔP_{Σ} is given by:

$$\Delta P_{\Sigma} = P_{\Sigma} - \sum_{i=1}^n P_{hi} \quad (14)$$

2.3.3. The allocation algorithm aiming at inhibiting active power fluctuation of cross-section

2.3.3.1. *Calculation of the active power allocation priority p.* The active power should be allocated among the small-hydro cluster when $\Delta P_{\Sigma} \neq 0$.

Sampling the real-time transmission active power $P_k(n)$ and the last value $P_k(n-1)$ for the cross-section tie line k , one obtains the power fluctuation $\Delta P_k = P_k(n) - P_k(n-1)$. Then the ratio of ΔP_k to the total power fluctuation of all the cross-section tie line can be obtained:

$$\Delta P_k \% = |\Delta P_k| / \sum_{k=1}^n |\Delta P_k| \quad (15)$$

Based on that, one can calculate the index:

$$\zeta = \sum_{i=1}^n S_{ki} \Delta P_k \% \quad (16)$$

where S_{ki} is the sensitivity of the output active power of the small-hydro station i relative to the transmission active power of the cross-section tie line k . The priority p for active power allocation among small-hydro stations is determined by ζ , and the p is lower for the greater ζ .

2.3.3.2. *Upward regulations of small-hydro stations.* In general, for the small-hydro station i with priority p , if $\Delta P_{\Sigma} > 0$ and $H_{ji} > H_N$, ΔP_i^+ is given by (8), and if $H_{ji} < H_N$, ΔP_i^+ is given by (9). Considering the primary frequency of the small-hydro station, the actual adjustable active power upper limit for the small-hydro station i is given by:

$$\Delta P_{i\max} = \Delta P_i^+ - \Delta f_i / R_i \quad (17)$$

where R_i is the adjustment coefficient of small hydropower unit, Δf_i is the frequency deviation for the grid-connected point of the small-hydro station i .

If $\Delta P_{i\max} < \Delta P_{\Sigma}$, the active power allocation instruction for the small-hydro station i is $\Delta P_{hi} = \Delta P_{i\max}$, the remaining total active power regulation instruction is updated to $\Delta P_{\Sigma} - \Delta P_{hi}$ and it will be allocated sequentially by the small-hydro station with priority $p=i+1$, the distribution process remains unchanged among subsequent small-hydro stations until the ΔP_{Σ} is allocated altogether or $p=n$. Instead, if $\Delta P_{i\max} > \Delta P_{\Sigma}$, the active power allocation instruction for the small-hydro station i is $\Delta P_{hi} = \Delta P_{\Sigma}$, the total active power regulation instruction is allocated by the small-hydro station i with the highest priority completely.

2.3.3.3. *Downward regulations of small-hydro stations.* For the small-hydro station i with priority p , if $\Delta P_{\Sigma} < 0$, equally, considering the primary frequency of the small-hydro station, the actual adjustable active power lower limit for the small-hydro station i is given by:

$$\Delta P_{i\min} = P_{hi} - \Delta f_i / R_i \quad (18)$$

If $\Delta P_{i\min} < -\Delta P_{\Sigma}$, the active power allocation instruction for the small-hydro station i is $\Delta P_{hi} = -\Delta P_{i\min}$, the remaining total active power regulation instruction is updated to $\Delta P_{\Sigma} - \Delta P_{hi}$ and it will be allocated sequentially by the small-hydro station with priority $p=i+1$, the distribution process remains unchanged among subsequent small-hydro stations until the ΔP_{Σ} is allocated altogether or $p=n$. If $\Delta P_{i\min} > -\Delta P_{\Sigma}$, the active power allocation instruction for the small-hydro station i is $\Delta P_{hi} = \Delta P_{\Sigma}$, the total active power regulation instruction is allocated by the small-hydro station i with the highest priority completely.

2.3.4. The allocation algorithm considering security constraint of cross-section. The active power regulation of small-hydro stations is achieved through changing their active power, as a result, the transmission active power of the cross-section tie lines may exceed the stability constraint. Consequently, the transmission powers of the cross-section tie lines must be restricted within their stability constraint, namely satisfying:

$$P_k \leq (1 - \gamma_k) P_{k_max} \quad (19)$$

where P_{k_max} and γ_k are separately the stability constraint and the stability allowance of the cross-section tie line k .

If $\Delta P_{\Sigma} \neq 0$ and any cross-section tie line hits its stability limit, namely satisfying $P_k \geq (1 - \gamma_k) P_{k_max}$, the active power allocation priority is determined by S_{ki} , the specific allocation algorithm is the same as 2.3.3).

3. Simulation verification

3.1. The simulation system

A regional power grid is utilized to validate the rapid active power regulating technique for a virtual small-hydro cluster, as shown in Figure 2. In this power grid, the generation units contain four thermal power plants (as shown in Figure), a number of small-hydro power stations (five small-hydro station), and wind farms (including a wind power base and a wind farm). The incorporated capacity of wind power is about 800 MW, the power transmission between the regional power grid and the neighbour power grid is achieved via 4 tie lines (tie line 1, 2, 3, 4), 5 disperses small-hydro stations are exploited to build the virtual small-hydro cluster control center, whose target is to receive control instruction from dispatch center and allocate the active power instruction among the 5 small-hydro stations. In this regional power grid, the transmission powers of the cross-section tie lines fluctuate obviously influenced by the intermittent power, consequently, the neighbour power grid is surely impacted by the transmission power fluctuation. In this section, the proposed control strategy and allocation algorithm in section II are adopted to perform the effect on suppressing the active power fluctuation of cross-section tie lines resulting from intermittent power. The simulation model is built using PSD-BPA.

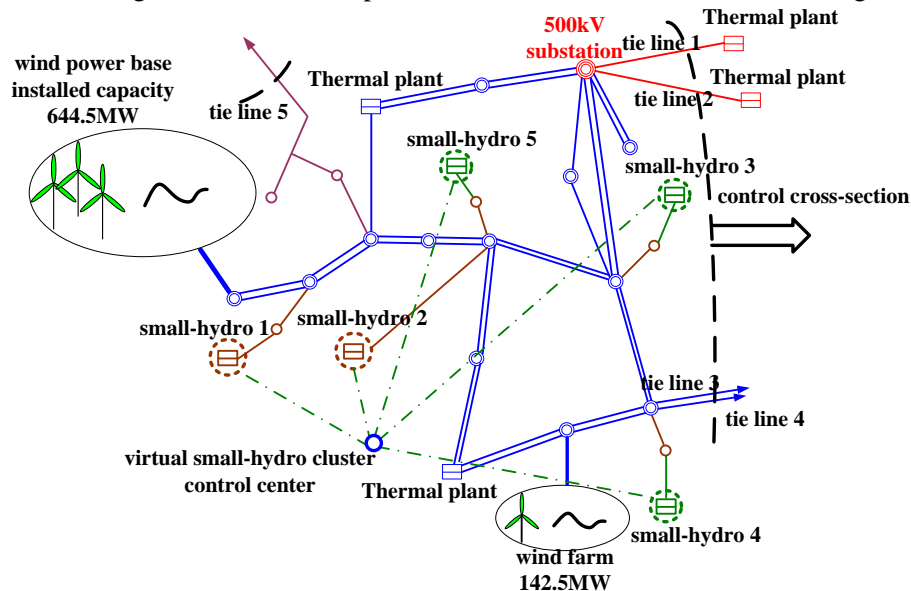


Figure 2. The regional power grid.

3.2. The verification of control strategy and allocation algorithm

At $t=0s$, the wind power decreases 40.5 MW in sixty-fifth seconds in the regional power grid, which leads to the transmission power fluctuation of the 4 tie lines. The black curves display the transmission

power fluctuation without control strategy and allocation algorithm, as illustrated in Figure 3 (a-d). Meanwhile, when the control strategy of virtual small-hydro cluster is employed equally, the 3 allocation algorithms, including average allocation, positive sequence allocation, inverse sequence allocation are compared to show the performance on inhibiting power fluctuation of every tie lines. To be clear: the average allocation algorithm indicates ΔP_{Σ} is assigned averagely among 5 small-hydro stations, the positive sequence allocation algorithm indicates ΔP_{Σ} is assigned according to the priority p determined by ζ , which is used in this study, and the inverse sequence allocation algorithm indicates ΔP_{Σ} is assigned according to the inverse priority p .

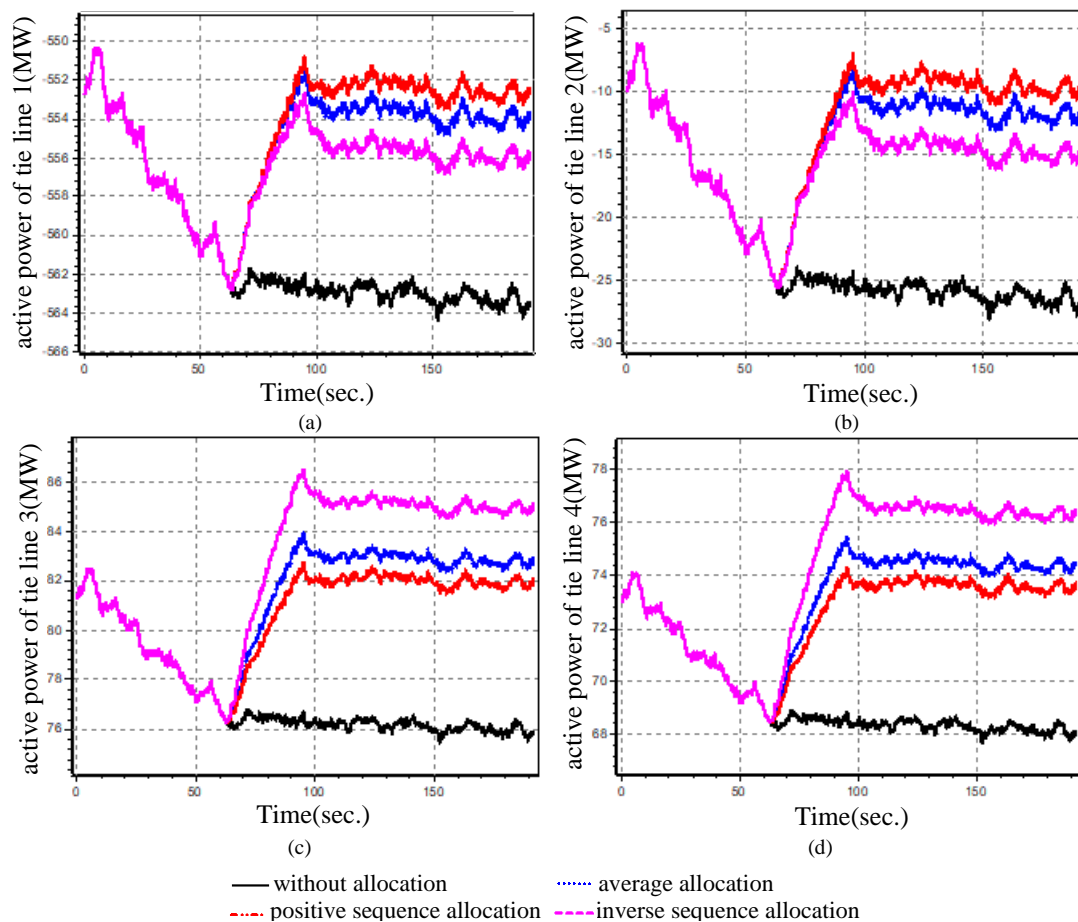


Figure 3. The transmission active power of the cross-section tie line 1-4 for different control algorithm.

When the wind power decreases 40.5MW, the total active power instruction ΔP_{Σ} from the dispatch center is +40.5MW. According to the comparative curves of the 3 different allocation algorithms as illustrated in Figure 3 (a, b, c, d), the transmission power fluctuations of tie lines are inhibited rapidly from sixty-fifth seconds to ninety-fifth seconds, which demonstrates the rapid regulation characteristic of the constructed virtual small-hydro cluster. In addition, it can be found that the power fluctuations are restrained most smoothly when the positive sequence allocation is executed for any a tie line, the smooth effect takes second place adopting the average allocation algorithm, while the worst smooth effect is arisen using the inverse sequence allocation algorithm. Therefore, it can be seen that the positive sequence allocation algorithm is effective on smoothing the transmission power fluctuations of the cross-section tie lines resulting from the intermittent wind power.

4. Conclusion

In this paper, a rapid active power regulating technique for a virtual small-hydro cluster is proposed to reduce the power fluctuation resulting from the intermittent power within regional power grid. The control strategy and allocation algorithm are specially valid to smooth the transmission power fluctuations of all tie lines, which is favourable to weaken the disturbance and influence on neighbour power grid. This regulating technique can be popularized by the regional power grid with massive small-hydro power and intermittent power.

Acknowledgments

This work was supported by the innovation consulting project of state grid ningbo power supply company (FC11), high level introduction of talent research start-up fund of China Three Gorges University(1910103) and Hubei provincial research center on microgrid engineering technology, China Three Gorges University(2016KDW01).

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