An Algorithm of Emergent Power Control among Wind Farms

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Abstract－When emergent active power abscission command is given to wind farm cluster by dispatching center, it is necessary for wind farms to coordinate with each other to optimize power abscission distribution. This paper firstly analyzes active power abscission ways of wind farm, and four kinds of power allocation algorithm models, such as wind power allocation algorithm based on combination of cut wind farms, are proposed based on this. Then, a comprehensive evaluation index is constructed by weighted combination of five indicators, such as distribution deviation and the number of cut wind farms, to evaluate the algorithms. Finally, an actual wind power cluster is employed as an example to verify the validity of proposed algorithms. Distribution results and comprehensive evaluation index values indicate that application scope of different allocation algorithm is different and the algorithm based on the cumulative power abscission of wind farms has smallest comprehensive evaluation index value and widest application scope.

Key words- wind farms; emergent power abscission; wind power distribution; cumulative amount of emergent power abscission; comprehensive evaluation index

I. INTRODUCTION

As the proportion of wind power rapidly increases, abscission of wind farms must be considered in case of an emergency[1-2].Reference points out that system instability after a serious failure is due to the accelerated energy and the sharp drop in the delivery capacity. For mixed wind and thermal power plants, it is difficult to ensure the stability of system by only cutting thermal power generators when failure occurs, and it may lead to excessively high cost to cut off generators. In order to control the system frequency and voltage, ratio of cut thermal power cannot be too high, thus part of wind power must be cut as replacement to keep the system balanced. For a wind farm cluster, method to achieve the emergent active power abscission within a limited time is a problem to be solved.

By learning form the method of emergent active power control in thermal power plant, this paper proposes an algorithm of emergent active power control among wind power cluster. Considering the number of cut wind farms and the distribution deviation, the algorithm provides a way to achieve selective abscission of wind farms. Finally an example is used to verify the validity of proposed algorithm.

II. METHOD OF EMERGENT ACTIVE POWER CONTROL AMONG WIND POWER CLUSTER

Emergent control needs to be rapid and effective. By analyzing the peculiarity of emergent active power control, this paper points out that, due to the response time level, only cutting wind farms can satisfy the rapid requirement of emergent power control.

A. Emergent Active Power Control of Normal Thermal Power Plant

For thermal power plant, abscission should be complete within limited time when emergent command is given.

The operating time is limited not more than 0.3- 0.4s to ensure the stability of system, or it may spent excessively high cost to control. For synchronous generators, turning off the valve and generator tripping are two main measures of emergent power control.

Since the time constant of turbine governor is greater than turbo-generator, valve control is only taken in thermal power plant to improve the system stability when failure occurs[3]. However, generator tripping can be used in both thermal and hydraulic plant. Mechanic output power can be decreased to a new ideal level through valve control[4]. For a certain plant, turning off valves can change the output power to 0 within 0.6-0.7s[5] and steam turbine can turn off all the valves in 0.3s to complete abscission[6]. In conclusion, generator tripping can be finished in 0.3s for thermal plants and 50%-60% of power output can be decreased through rapid valve turning off in 0.3-.04s.

There are 3 ways to distribute emergent power abscission for thermal plant: generator tripping, rapid turning off valves and the combination of both.

B. Specialties of Emergent Active Power Control among Wind Power Cluster

According to the requirement of thermal plant emergent power control and the specialty of wind farm cluster, the emergent power control is much different from the other controls of wind farm cluster, such as automatic threshold control, regulation control, slope control, deviation control and frequency control[7].For example:

In time scale: Emergent control needs to be finished in hundreds micro seconds, when control unit is inaccessible, only generator tripping will satisfy the time limit,

however, other power control is seconds-level or minutes-level[8]. This is similar to active power rescheduling and emergent abscission of thermal power plant.

The need of wind power prediction: The other controls mentioned above all need the prediction of wind power in the next period of time[9], however since emergent control is completed in hundreds micro seconds, wind speed is considered to be constant, thus power prediction is not necessary for emergent active power control of among wind farms cluster.

The purpose of control: Emergent control aims to minimize the amount of cut wind farms and the control deviation, while the other control usually aims to maximize the output power.

III. ALLOCATION ALGORITHM OF EMERGENT ACTIVE POWER ABSCISSION BASED ON COMBINATION OF CUT WIND FARMS

Active power control of large scale wind farms is to ensure the safety and stability of power grid, so that wind energy resource can be made full use[10].

According to the total abscission power which is ΔP, when only generator tripping is accessible and abscission power should be no less than required, the target is to minimize the D_E, thus we get the active power allocation object function:

$$min\, D_E = min\{\sum_{i=1}^{n} \alpha_i P_{Wi} - \Delta P\} \qquad (1)$$

$$S.T\, \Delta P \le \sum_{i=1}^{n} \alpha_i P_{Wi}\, \alpha_i \in \{0,1\}, i = 1,2\dots n \quad (2)$$

In the equation, P_{Wi} is the current output power of number i wind farm, while character n represents the total number of wind farms which is related to the control, α_i decides whether a wind farm is cut, when $\alpha_i = 1$, it means the number i wind farm will be cut, while when $\alpha_i = 0$, it means the number i farm will not be cut off, it will not participate the control.

The active power allocation algorithm based on cut wind farms aims to miniature the amount of cut wind farms[11].

If accumulated active power abscission is not taken into consideration, the imbalance of wind farms abscission may occur, which means some wind farms may get cut many times while the others never be cut once[12]. To avoid this situation, this paper proposes an allocation algorithm based on the accumulated active power abscission[13]. In the equation below, $P_{i \sum QT}$ means in a time cycle T, the accumulate amount of active power abscission:

$$P_{i \sum QT} = \sum_{j=1}^{n} \Delta P_{WFj} \qquad (9)$$

In the equation, character n represents the number of times emergent control is taken in number i wind farm within a time cycle T, ΔP_{WFj} is the allocated active power abscission in number J control process.

The equation below is the index to decide the order of abscission:

$$g(P_{Wi}, P_{i \sum QT}) = \alpha \left(1 + \frac{\Delta P_{mi}}{P_{Base}}\right) + \beta \left(10 + \frac{P_{Base}}{P_{i \sum QT}}\right)(10)$$

In the equation, α and β both are nonnegative integer, object to $\alpha + \beta = 1$. If $P_{i \sum QT}=0$, $\alpha = 1$, or $\alpha = o$.

IV. EXAMPLE AND ANALYSIS

An actual wind farm cluster is employed to verify the validity of proposed algorithm. This wind farm cluster is constituted by DFIG GE1.5WM[14], and is divided into 16 wind farms with 201MW installed capacity each and a single wind farm with 300MW installed capacity, the total capacity reaches to 3516MW[15]. The wiring diagram is shown in Fig .1, and the condition of each wind generator is shown in TABLE I.
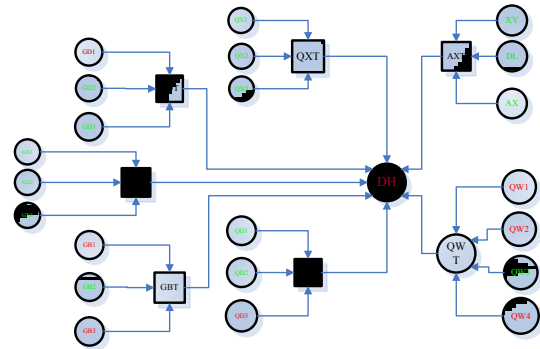

Figure 1. Wiring Diagram of Wind Farms in the Wind Farm Cluster

In the situation, a continuous 7 times emergent control is taken according to the allocation algorithm[16], assuming that the initial accumulated active power abscission is 0[17].

Example No.1：

A three phase short circuit fault occurs at a 750KV line out of the cluster, it is removed after 0.1s[18], the simulation result is shown at Fig .2. An extra more 250WM power needs to be cut off the wind farms cluster, the allocation result is shown in TABLE I.

Example No.2-No.7：

As the same method of example applied above, we get the result of other examples. The abscission required by dispatch center is 100MW, 150MW, 300MW, 400MW, 500MW, 671MW for each example[19]. Considering the accumulated cut power, we get the control order which is shown in TABLE II. In contrast, result of not considering accumulated cut power is shown in TABLE III.
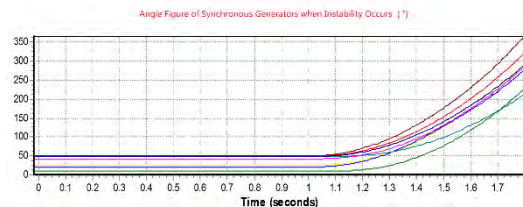

Figure 2. Power-Angle Curves of Synchronous Thermal Generators after Three Phase-Fault Applied at 750KV Line

It shows that without emergent control, the system angel will keep increasing, and finally system angle

stability will be broken[20]. When emergent control is taken, the angle stability of system could maintain.

TABLE I. WIND FARMS' OPERATION SITUATION AND PARTICIPATING WIND FARMS OF EACH DISTRIBUTION METHOD OF CASE 1

Wind farm	Serve signal	active power （MW）	Wind farm condition
GD1	F	-	-
GD2	T	158.5	0
GD3	T	100.5	0
GX1	T	40.5	1
GX2	T	140.5	0
GX3	T	170	0
GB1	F	-	-
GB2	T	180	1
GB3	F	-	-
QX1	T	21	1
QX2	T	163	0
QX3	T	160.5	0
QD1	T	168	0
QD2	T	173	0
QD3	F	-	-
QW1	F	-	-
QW2	F	-	-
QW3	T	176	0
QW4	F	-	-
Cluster	T	1651.5MW	-

note："F" means not in serve,"T" means in serve,"1" means cut off,"0" means not cut off, "-" means nonsense .

TABLE II. WIND FARMS' CONTROL SEQUENCE OF EACH CASE OF METHOD 4

Wind farm Order	Example number					
	C2	C3	C4	C5	C6	C7
GD2	6	5	4	2	9	7
GD3	8	7	6	4	1	3
GX1	9	8	7	5	2	2
GX2	7	6	5	3	5	11
GX3	2	1	11	10	8	6
GB2	12	12	12	12	12	10
QX1	10	9	8	6	3	1
QX2	4	3	2	9	7	5
QX3	5	4	3	1	10	8
QD1	3	2	1	11	11	9
QD2	1	11	10	8	6	4
QW3	11	10	9	7	4	12

Comparing the results, we will find that control order is decided by accumulated cut power, and changes frequently. Without the accumulated cut power algorithm, the order and times of cut wind farm is unbalanced and unfair, when accumulated abscission of wind farms is considered, the allocation solution becomes more reasonable.

TABLE III. WIND FARMS' CUMULATIVE AMOUNT OF EMERGENT POWER ABSCISSION OF FOUR KINDS OF DISTRIBUTION METHOD

	Accumulation not considered	accumulation considered
GD2	634	161.5
GD3	402	201
GX1	0	81
GX2	281	221.5
GX3	0	320
GB2	540	180
QX1	42	42
QX2	163	295
QX3	160.5	160.5
QD1	168	168
QD2	0	294.5
QW3	0	246

According the TABLE III, we find that the allocation algorithm based on combination of cut wind farms is simple and fair while it may lead to over cutting.

V. CONCLUSION

As the proportion of wind power rapidly increases, abscission of wind farms must be considered in case of an emergency. This paper proposes an allocation algorithm based on accumulated cut wind farms to solve the problem. Then an actual wind farm cluster is used as an example to verify the validity of the proposed algorithm. Result shows that the allocation algorithm improves the balance of cutting off wind farms cluster, in the same time the allocation algorithm has a wide application scope.

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