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BRANCH AND BOUND TECHNIQUE FOR FREQUENCY CONTROL IN WIND/THERMAL GENERATION

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Abstract*— Promptly increasing the saturation level of renewable energy has executed new tasks to the operation of power systems. Incompetence or inability of these resources in providing inertial, primary and secondary frequency responses is one of the significant challenges. In this paper, the proposed method of Branch and Bound algorithm controls the problem of frequency deviation within the limit using the IEEE six bus systems. The problem is formulated as a mixed-integer linear programming (MILP) problem which is solved efficiently by available commercial solvers. Then the Branch and Bound technique is applied in the solver. The result indicates of proposed method that the frequency is controlled within the limit in wind/thermal power generation into power systems.

***Keywords*—Six bus system, inertial response, primary frequency control, secondary frequency control, wind power, thermal power.**

I. INTRODUCTION

An unpredicted disturbance causing a bad fit during power supply in a power system, the system frequency starts deviating from the minimal value. In a real system, frequency drop caused by loss of generation or frequency fence caused by loss of load are of essential importance. Solving the time-domain equations describing power system dynamics would lead to different rotational speed for each generator during the transient period. For this reason, using the speed of a specific generator to represent system overall frequency condition is questionable.

There have been many efforts to find the system average frequency path and avoiding the computationally expensive time-domain solutions, e.g., [1] and [2]. In these studies, an important assumption is made, which is to have a unique frequency variation throughout the system. Promptly increasing the penetration of renewable energies into the power systems has made the system operators meet new tasks in terms of maintaining power system security. In particular, wind power, as the leading source of renewables, has introduced many operational issues at high saturation levels [12].

The problem arising from integrating a large amount of wind generation originates from the incapability of widely used variable speed wind-turbine technologies in providing inertial response and participation in frequency regulation in a similar way as the conventional synchronous generators. Newly, the problem of reduced inertia of wind turbines which use the doubly-fed induction generators or permanent magnet synchronous generators technologies have been addressed in some prototypes. Advanced control methods in active power modulation can inject more active power during sudden frequency drops by discharging the kinetic energy stored in the turbine shaft [3]. However, this sudden energy discharge would reduce the rotor speed almost immediately. The resultant extreme mechanical stress forced on the shaft and drive train would lead to higher manufacturing cost of mechanical parts [4]. In addition, the wind generation is almost unable to deliver primary/secondary frequency control during contingencies due to lack of operational reserve. In fact, it would be inefficient to always use a portion of the whole available power from wind farms just to have some operational reserve. In count, the probabilistic nature of wind speed makes the results of deterministic studies less reliable [5].

The problems of ensuring frequency response within an electricity market are studied in [6]. Two constraints are added to the problem of economic dispatch: one for limiting the rate of change of frequency and the other one for limiting the maximum frequency fall. However, the effect of each individual generator governor response cannot be seen in these constraints. Similarly, the offline calculation of the second constraint may need to be performed again if the system parameters change. The power flow and generators constraints are also left behind in [6]. These issues are addressed in the present study.

The system frequency deviance after a contingency can be approximately derived based on static analysis. Governor load flow and inertia are the well-known static analysis of system frequency response [7].

A first order model for system frequency response as the governor droops has also been used in [8]. The differential equation is then discretized using integration rules to derive linear equation. The obtained set of linear equations is then injected in the optimization problem. Depending on the integration step size, the number of new variables and constraints presented to the original problem is very high, which is a binding factor for the application of the proposed method in [8] for large-scale systems.

System spinning and operating reserves also suffer from high saturation level of irregular and unpredictable generation. The reserve requirement for system primary frequency response is studied in [9]. The frequency deviance considered in [9] is based on static analysis, similar to governor load flow, and no information about the system dynamics is retrievable from the simulations. More specifically, the scope of [9] is to find the best reserve for the generation units to ensure sufficient primary and tertiary reserves for the system after a contingency. Optimal reserve requirements for a system with large amount of wind generation are intended in [10]–[11] using stochastic optimization methods.

In this paper, the frequency control using Branch and Bound algorithm is proposed which reports the problem of system-reduced inertia and primary frequency control due to high level of wind generation integration. Simplified system frequency response models are first derived and used to find analytical representation of system minimum frequency. The optimization problem is formulated as a mixed-integer linear programming (MILP) problem and is solved using Branch and Bound algorithm implemented.

The remainder of this paper is organized as follows. In Section II, the basic concept of frequency control in power system and derivation of the simplified system frequency response is revised. Section III describes the formulation of the proposed SCUC framework with inertial response constraints. The result of applying the proposed method to the test system is reported in Section IV. Section V concludes the results obtained in the present study.

II. SYSTEM FREQUENCY RESPONSE MODEL

The stability between the supplied and consumed power should be maintained during the power system operation to maintain synchronism. The smooth change in the load is met within day-ahead unit commitment and generators are scheduled to change their output power according to the load variation. Based on this approach for normal operation of power systems, the frequency is maintained within certain limits. Though, if a sudden disturbance happens, particularly in terms of large generation loss, the system will undergo a transient, as shown in Fig. 1. The main motivation of system frequency control is to help survive this transient period safely and rapidly.

In this paper, two stages in frequency transient phenomena are considered. The time duration of these stages varies from system to system, depending on the governor’s control and system reserve. Right after the loss of generation, the frequency starts decreasing with a certain rate of decay, which can be found by the swing equation (1) of system equivalent single-machine representation.

$$\Delta P_m - \Delta P_e = M \frac{d\Delta\omega}{dt} + D\Delta\omega \tag{1}$$

Assuming that there is no change in the mechanical power of prime movers (2) in the very beginning of the incident $(\Delta P_m = 0)$, load has no contribution in frequency response $(D = 0)$, one will have

$$\frac{d\Delta\omega}{dt} = -\frac{\Delta P_e}{M} \tag{2}$$

Thus, the initial rate of decay of frequency mainly depends on the magnitude of the disturbance and the system equivalent inertia. The first stage in Fig.1 (Δt_1), which is mainly governed by M and ΔP_e, is referred to as system inertial response. The duration of this stage is usually a few seconds.

After the first stage, the governor start to respond to the frequency fall, preventing it from further reduction. This stage, shown in Fig.1 as Δt_2, is referred to as primary frequency control. The third stage in the frequency response begins when the governors cannot bring back the frequency to its original value (Δt_3 in Fig. 1). At this moment, the automatic generation control units participate in the frequency control and use their reserve to bring the frequency back. This stage is referred to as secondary frequency control.

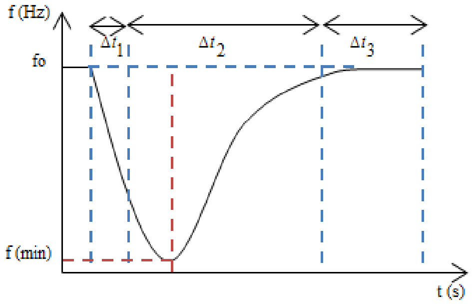

Fig. 1. Frequency Transient after Sudden Loss of Generation.

Δt_1 ***: Inertial response;***

Δt_2 ***: Primary frequency control;***

Δt_3 ***:secondary control***

III. PROPOSED ALGORITHM

3.1 Algorithm of Branch and Bound Method

Branch and Bound algorithm is the best algorithm in MILP to solve the optimization problem. Branch refers to splitting the problem into subsets and bound refers to compute the upper and lower bounds for the minimum value of the subsets. The algorithm of proposed technique is as follows:

Step 1: *Initialize the nodes of units which is given in the test system.*

Step 2: *Generate the branches into sub problems. If violation is not occur then go to next step or else go to step 4.*

Step 3: *Select the node of the sub problems.*

Step 4: *Calculate the upper and lower bound values and choose the best bound for maximum optimization.*

Step 5: *If violation occurs, go back to step 3 or else continue the steps.*

Step 6: *Obtain maximum frequency or else go to step 2.*

Step 7: *Get the optimum solution.*

This proposed algorithm is shown in the flow chart Fig.2. By solving all sub-problems would require a considerable amount of time so a second step known as bounding is applied. The bounds of a sub-problem are defined by its optimal solution and objective (minimization or maximization). A feasible solution exists when the bound value achieve the maximum frequency or else repeat the iteration process to achieve the optimum value.

3.2 Flowchart for B&B Algorithm

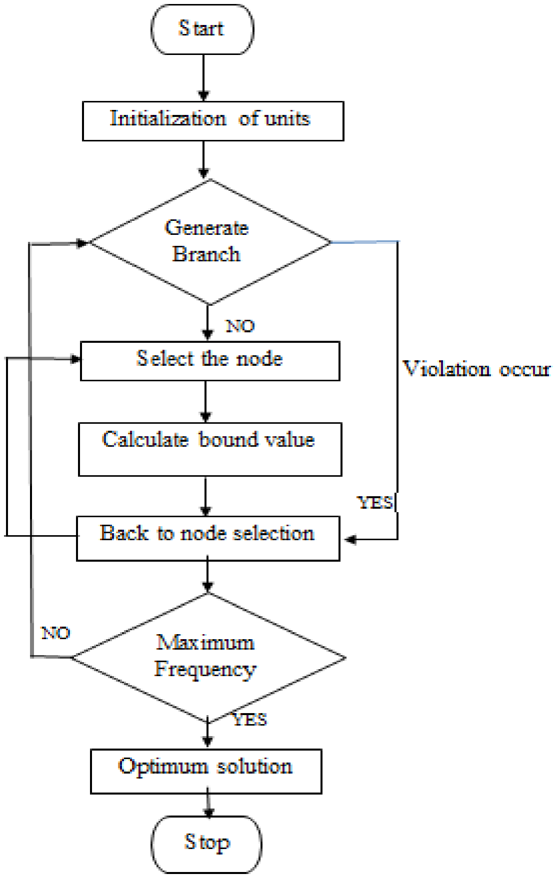

Fig. 2. Flowchart for Branch and Bound Algorithm

IV. SIMULATION RESULTS

4.1 Six-Bus Test System

Here, the standard IEEE test system is used to show the application of the proposed structure. The six-bus test system is shown in Fig. 3. The system data and generators dynamic data are given in Table I and Table II.

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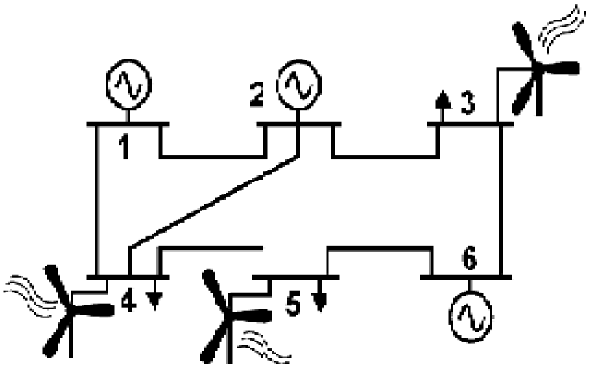

Fig. 3. Six-bus test system

TABLE I SYSTEM DATA FOR THE SIX-BUS SYSTEM

Pmax (MW)	Pmin (MW)	Ini.St. (h)	Min Up (h)	Min Down (h)	Ramp (MW/h)
220	100	4	4	4	55
100	10	2	2	2	50
20	10	2	2	2	20

TABLE II GENERATOR DYNAMIC DATA FOR THE SIX-BUS TEST SYSTEM

Gen.No	K	T_R	H	F_H	R	X'_d
1	0	8	7	0.15	0.04	0.061
2	0.95	7	5.5	0.35	0.03	0.120
3	0.98	9	3.5	0.25	0.05	0.181

4.2 Simulation of Frequency Control

To verify the above design and analysis, a simulation model was developed in MATLAB/Simulink, as shown in Fig.4. The simulation shows the frequency control using six bus test system. The six generating units are connected as a buses as shown in the single line diagram of test system. The variable speed constant frequency is produced using Permanent Magnet Synchronous Generator (PMSG). The frequency is maintained at standard value of 50Hz during continuous flow of wind and rated speed. When the speed of wind is reduced, thermal unit is connected to compensate the power production and frequency is maintained to the limit.

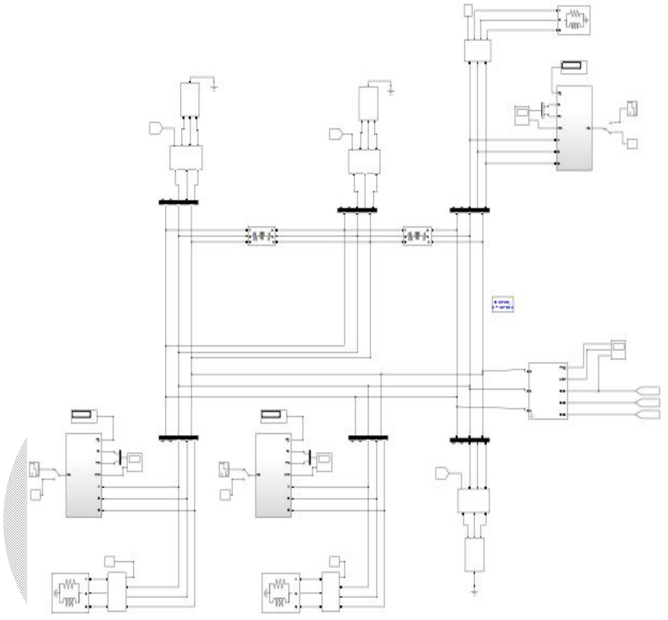

Fig. 4. Simulation Model of IEEE Six Bus Test System for Frequency Control

The output of the simulation model is depicted in the Fig.5 which gives the frequency within the limit. According to the proposed algorithm, the value is computed to upper and lower bounds as a waveform. By adding the generating units, the frequency is varied and controlled to the limit with ± 0.5%. The limit on the maximum frequency fall is assumed to be 49.5 Hz. Here in this output waveform, the frequency maintains the limit from the lower bound. And the operation of circuit breaker is done during generation i.e., the circuit breaker makes or breaks the circuit according to the need of power demand.

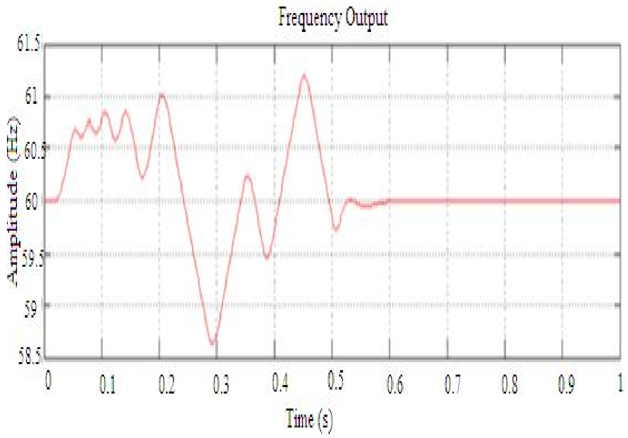

Fig. 5. Output Waveform of Frequency Control

V. CONCLUSION

The problem of reduced system inertial, primary and secondary frequency responses due to high saturation level of renewable resources are addressed by means of system frequency control within the limit. By keeping sufficient synchronous generators, it is possible to respect the frequency limits. The proposed method of Branch and Bound algorithm controls the problem of frequency deviation within the limit using the IEEE standard six bus system. As forthcoming work, for systems with considerable hydro generation, different transfer function has to be derived to applicably model their governor response.

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