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A REVIEW ONA HYBRID DYNAMIC DEMAND CONTROL TECHNIQUE FOR POWER SYSTEM FREQUENCY REGULATION

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Abstract— The fast increment in sustainable power source coordination carries with it a progression of vulnerability to the transmission and conveyance frameworks. All in all, huge scope wind and sun based force reconciliation consistently cause transient jumble among age and burden request due to their discontinuous nature. The customary method of managing this issue is to expand the turning save, which is very expensive. Lately, it has been recommended that aspect of the heap can be controlled progressively for recurrence guideline with little effect on clients' living solace. This paper proposes a cross breed dynamic interest control (DDC) procedure for the essential and optional recurrence guideline. Specifically, the heaps can capture the abrupt recurrence drop, yet additionally carry the recurrence closer to the ostensible worth. With the proposed control system, the interest side can give a quick and smooth recurrence guideline administration, accordingly supplanting some age save to accomplish a lower cost.

Index Terms—Dynamic demand control, frequency regulation, hybrid control, responsive load, turbine governor.

I. INTRODUCTION

FREQUENCY dependability is a basic concern with respect to control framework activity. Recurrence change or deviation is an aftereffect of unbalance among age and burden request. The force unbalance may be brought about by the huge generator unit trip, tie-line trip or unexpected difference in loads, and so forth [1]. In the force business, the recurrence guideline is partitioned into three levels. Essential recurrence guideline (PFR) is a programmed decentralized control that changes the generator units to rapidly capture the recurrence outing inside a couple of moments. Optional recurrence guideline (SFR) is ordinarily a concentrated programmed control that changes the generator yield reference to take the recurrence back to its objective worth. Tertiary recurrence guideline (TFR) alludes to manual alteration in the dedication of generator units or coupon-based interest reaction program [2]–[4]. This control is utilized torestore the PFR and SFR holds and to oversee clogs in transmission organizations. Lately, the improvement of sustainable power source combination and force market has achieved a few difficulties to the recurrence dependability. 1) The discontinuous idea of sustainable power source consistently causes a crisscross between power age and request. Consequently, recurrence variance is probably going to happen [5]. 2) Some coordinated generators are supplanted by converterbased fuel sources, for example, wind inverters and photovoltaic inverters, which cause a reduction in framework complete mechanical inertial [5]–[7]. 3) The hourly-based energy market is likely to cause a mismatch between generation and load in the first few minutes of an hour [8]. Confronted by the above challenges, dynamic demand control (DDC) has been proposed to mitigate the short-term frequency fluctuation [9]. Some residential loads with thermal storage feature can be switched off for a short period when the frequency drops below a threshold and switched back on again when the frequency recovers. These loads are called responsive loads, and can be seen in electric water heaters (EWH) and heating, ventilation, and air-conditioners (HVAC) [8]–[10]. Switching off EWH or HVAC for a few minutes hardly affects customers' living comfort because the water temperature or air temperature almost remains constant. If the control scheme is properly designed, the aggregated responsive loads can act as a frequency reserve and thus help reduce the capacity of generator spinning reserve for frequency regulation.

II. PRINCIPLE OF SYSTEM FREQUENCY RESPONSE

Power system frequency dynamics result from power unbalance. When the system neglects local frequency differences caused by electromechanical transients and oscillations, it is naturally governed by the physics of motion. Expressing this law regarding deviations from the nominal values gives [1]:

$$\Delta P_{\mathrm{g}}(t) - \Delta P_{\mathrm{d}}(t) = 2H\frac{d\Delta f(t)}{dt} + D\Delta f(t)$$

where $\Delta Pg(t)$ is the generator mechanical power deviation from the pre-disturbance value, $\Delta Pd(t)$ is the load demand deviation from the pre-disturbance value, and $\Delta f(t)$ is the system frequency deviation from the nominal value at time t ($\Delta f(t) = f(t) - 60$). Note: power and frequency variables are in per-unit value. H is the system total inertia constant. D is the system total load damping coefficient, which mainly results from generators and frequency-dependent loads such as induction motors. The framework recurrence reaction model is communicated as lumped generator turbine lead representative and lumped frequencydependent load, as is appeared in Fig. 1(a), where $\Delta P = Pg - Pd = \Delta Pg - \Delta Pd$ speaks to the force unbalance that is brought about by age decline or unexpected burden change. ΔP can be both positive and negative. The normal boundaries of the turbine lead representative are appeared in Table I [18], [19]. Since TG and TC are a lot more modest than TR, we can disregard these two sections so as to streamline the investigative examination. At that point the request

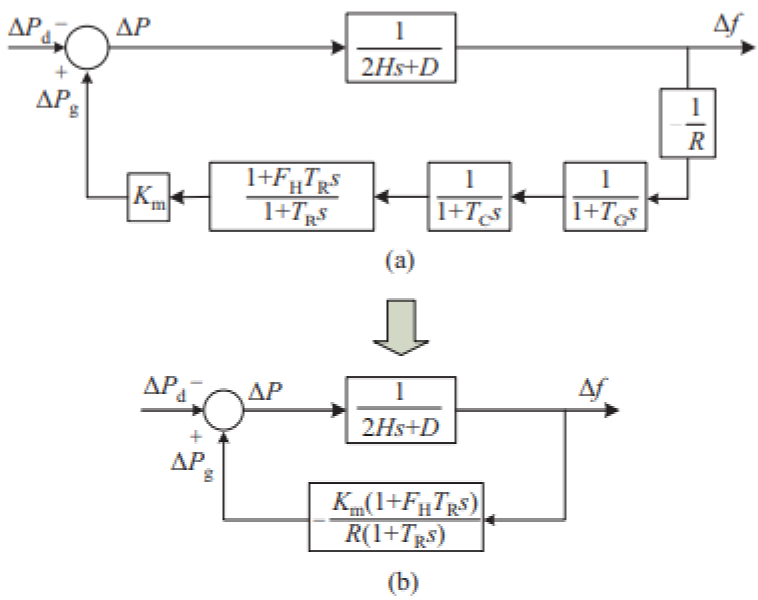

Fig. 1. The system frequency response model. (a) Full model. (b) Reduced order model.

TABLE I
PARAMETERS OF THE TURBINE GOVERNOR

Parameter	Typical Value
Governor time constant T_G	0.2 s
Steam chest time constant T_C	0.3 s
Reheat time constant T_R	10 s
High-pressure turbine fraction F_H	0.3
Mechanical power gain factor K_m	0.95–1
Inertia constant H	3–6 s
Governor speed regulation R	0.05
Load damping coefficient D	1.0

III. DYNAMIC DEMAND CONTROL STRATEGY

The decentralized DDC can take an interest in both the essential recurrence guideline [8], [10] and auxiliary recurrence guideline [9]. An inherent worry with decentralized DDC is that an individual burden regulator doesn't "know" the activity of different regulators. Therefore, the amassed responsive burdens may give exorbitant or lacking force pay and neglect to take the recurrence back to the ostensible worth. Accordingly, the DDC calculation should have versatile attributes and facilitate with the turbine lead representative control. In this paper, a crossover DDC strategy is proposed. At the point when the framework recurrence falls beneath the recurrence dead-band, we can conjecture the recurrence nadir (fnadir) through various recurrence estimation information. In the event that the gauge fnadir isn't sufficiently low, at that point the

DDC just needs to take an interest in the SFR; it will stand by until the new recurrence consistent state is reached and then bring the frequency back to the frequency dead-band. If fnadir is low enough, then the DDC needs to participate in the PFR at first; some responsive load will be switched off immediately. The next two subsections will explain the algorithms of the frequency nadir forecast and demand control, respectively

A. Frequency Nadir Forecast -
   Based on the three items of the conclusion made in Section II, the LS-based method is proposed for forecasting fnadir. As is shown in Fig. 2, the t0 − tnadir segment of nonlinear curve f(t) can be fitted by a quadratic curve. For the next frequency disturbance, it is possible to roughly forecast fnadir before it actually happens. By assuming the system total inertia to be constant,
A. Dynamic Demand Control -
   The frequency nadir indicates how serious this frequency disturbance is. First, if at the time step t0 the measured frequency falls below the dead-band (59.95 Hz), this indicates a “suspicious” under-frequency disturbance. Then the controller starts to sample the frequency with a time interval of 0.1 s for a 1.5 s duration (Tsamp). When Tsamp is expired, the controller immediately forecasts the frequency nadir using the latest frequency data between t0 and t0 + Tsamp to decide whether to perform PFR. Furthermore, when the frequency reaches the steady state fss, the controller will also decide whether to perform SFR.
B. Summary -
   The whole DDC algorithm is summarized in Fig. 6. In the steady-state, the time step for frequency measurement is 1 second. First, a low-frequency snapshot (< 59.95 Hz) is detected, which indicates a suspicious under-frequency event. The time step for frequency measurement is switched to 0.1 second. After a sampling time of 1.5 s, the controller forecasts fnadir. Second, if ˆfnadir < 59.75 Hz, the controller performs PFR immediately. Third, when the steady-state frequency is reached, the controller determines whether to perform SFR according to the measured frequency f(t). Note: The “steadystate” is identified by the formula |fmav(t)−fmav(t−Δt)| < ε, where fmav is the moving average frequency of the latest few samples and Δt = 1 s. Besides, in a large-scale system, the possibility of large frequency deviation is quite low. In most cases, the DDC perhaps only needs to perform the SFR. By defining appropriate load-frequency sensitivity factor and time delay, the aggregated responsive loads can achieve similar results to generators with AGC control

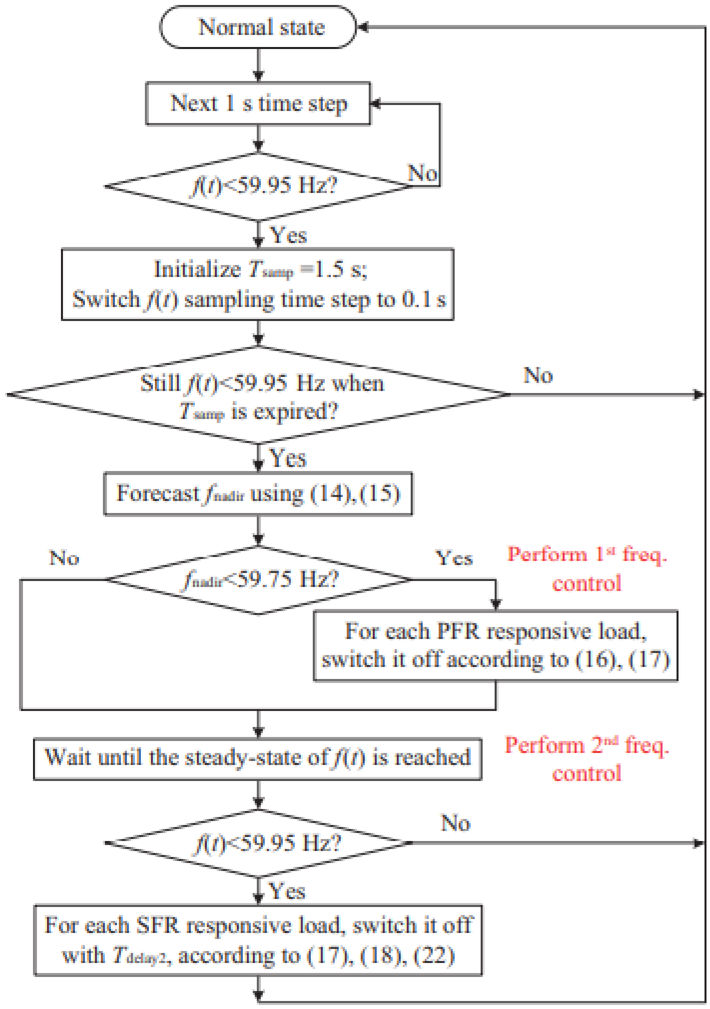

Fig. 6. Overall flowchart of bi-level DDC algorithm.

Two practical issues are critical for the control scheme. First, an individual load can either participate in PFR or SFR during one under-frequency event. A possible implementation is that customers sign contracts with the load aggregator company to choose whether to participate in PFR or SFR. The second issue is the responsive load uncertainty because the responsive loads are not always in operation. Generally, the ideal candidates for responsive loads should meet the following requirements:

1) Continuously or regularly in operation, since frequency regulation is needed at any time;

2) Big power rating in order to obtain a considerable total power compensation with a limited number of loads;

3) Little impact on customers' living comfort if turned off for a short period [24]. Therefore, the thermostat-controlled loads, especially EWH and HVAC, are perfect choices for frequency control due to their thermal inertia and high power rating [12].

IV. SIMULATION STUDY

This section verifies the proposed method through a detailed system simulation using the Matlab PSAT toolbox (V. 2.1.9) [25]. A. Description of the Testing System The IEEE 14-bus dynamic testing system is shown in Fig. 7. Buses 1–5 are 69 kV level, buses 7 and 9–14 are 13.8 kV level, and bus 8 is 18 kV. G1 is a slack generator, G2 is a constant-PV generator, and C3, C6, and C8 are three synchronous phasor compensators. Several PQ constant loads are connected to the buses. The parameters are shown in Table II. The system base power is Sbase = 100 MVA. The testing system includes the turbine governor model and exciter model along with the synchronous generator. The turbine governor parameters are listed in Table III [25].

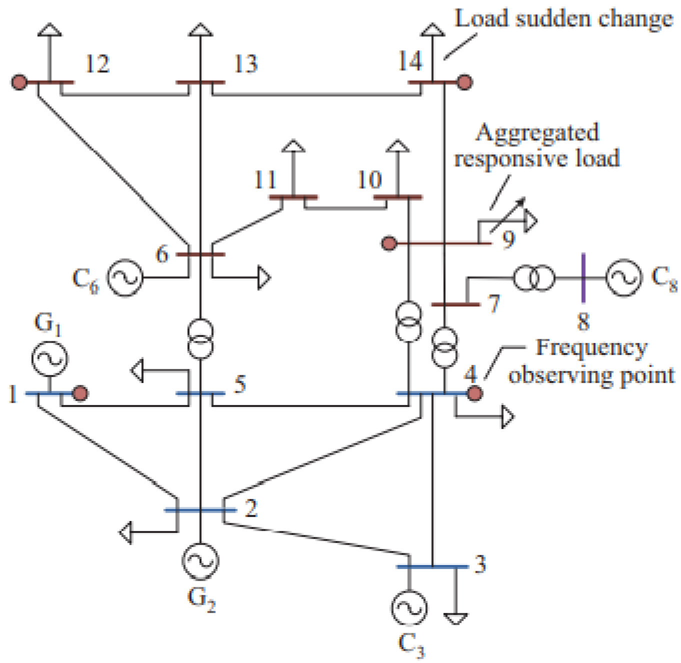

Fig. 7. IEEE 14-bus testing system

TABLE II
PQ LOAD PARAMETERS

Node Order	P (p.u.)	Q (p.u.)
2	0.217	0.127
3	0.942	0.19
4	0.478	0.04
5	0.076	0.016
6	0.112	0.075
9	0.295	0.166
10	0.09	0.058
11	0.035	0.018
12	0.061	0.016
13	0.135	0.058
14	0.149	0.05
Total power loss	**0.122**	**0.093**
Total loading level	**2.71**	**0.907**

B. Simulation Results

Decentralized control has the benefit of minimal effort and quick reaction in recurrence guideline. In any case, its detriment is the trouble in giving exact force pay in light of the deliberate recurrence deviation. The fundamental commitment of this paper is to propose a novel cross breed DDC methodology that joins the brought together boundary setting and the decentralized control activity. As per the strategy, each heap regulator initially concludes whether to take an interest in PFR as indicated by the conjecture recurrence nadir. At that point at the consistent express, the heap regulator likewise takes an interest in SFR if the recurrence is past the dead-band. Specifically, when the measure of intensity pay is determined, the regulator haphazardly decides if and when to act as indicated by SDM. The SDM guarantees that the non-conveyed accumulated burdens have an approximated recurrence hang trademark that is like generators. Moreover, the control boundaries can be refreshed by the control place, which has a low correspondence necessity. Besides, the reproduction concentrate completely copies the genuine force framework since the generator exciter and simultaneous model are thought of. Despite the fact that the exciter doesn't straightforwardly control the force yield of the main player, it influences the between machine power swaying during the recurrence dynamic cycle. Along these lines, to completely test the DDC execution, a point by point dynamic reenactment case is suggested.

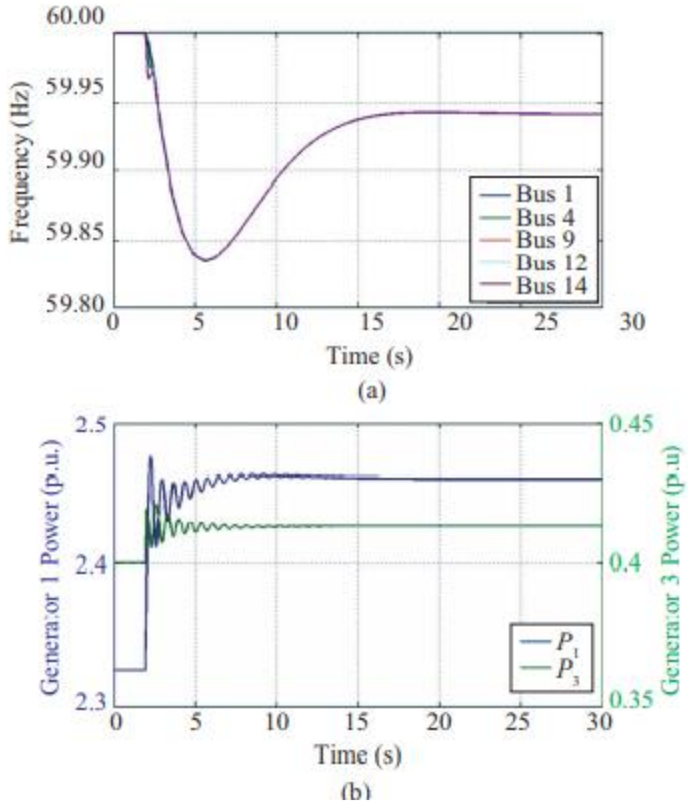

Fig. 8. Frequency and power output response with 5% power unbalance. (a) Frequency response of 5 buses. (b) Power output of 2 generators.

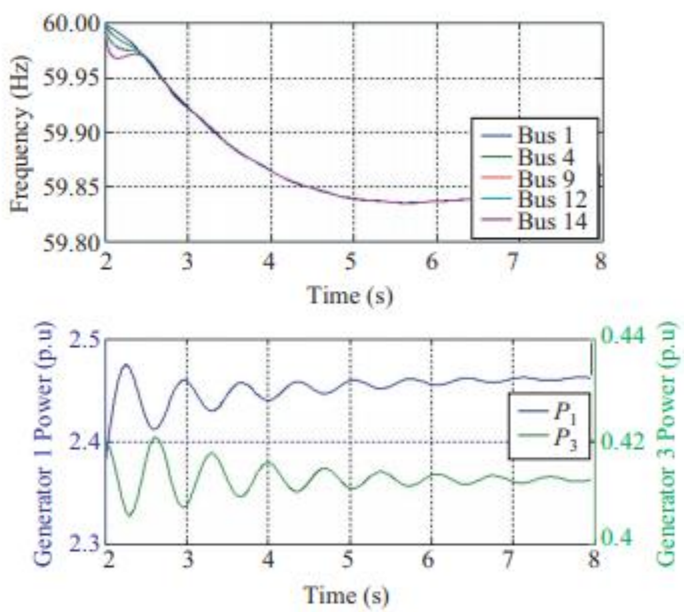

Fig. 9. Partial amplitude of frequency and power dynamic response.

V. CONCLUSION

Decentralized control has the benefit of minimal effort and quick reaction in recurrence guideline. In any case, its detriment is the trouble in giving exact force pay in light of the deliberate recurrence deviation. The fundamental commitment of this paper is to propose a novel cross breed DDC methodology that joins the brought together boundary setting and the decentralized control activity. As per the strategy, each heap regulator initially concludes whether to take an interest in PFR as indicated by the conjecture recurrence nadir. At that point at the consistent express, the heap regulator likewise takes an interest in SFR if the recurrence is past the dead-band. Specifically, when the measure of intensity pay is determined, the regulator haphazardly decides if and when to act as indicated by SDM. The SDM guarantees that the non-conveyed accumulated burdens have an approximated recurrence hang trademark that is like generators. Moreover, the control boundaries can be refreshed by the control place, which has a low correspondence necessity. Besides, the reproduction concentrate completely copies the genuine force framework since the generator exciter and simultaneous model are thought of. Despite the fact that the exciter doesn't straightforwardly control the force yield of the main player, it influences the between machine power swaying during the recurrence dynamic cycle. Along these lines, to completely test the DDC execution, a point by point dynamic reenactment case is suggested.

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