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.

A New Automatic Generation Control with Heterogeneous Assets for Integration of Renewables

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***Abstract*—**High penetration of intermittent, non-dispatchable distributed energy sources (DER) necessitates new tools for Automatic Generation Control. The intermittency in turn introduces an increasing need to install expensive spinning-reserves. This paper presents a new control strategy that avoids this expensive solution. This strategy consists of three components, the first of which is a combined use of different assets including storage, demand-response and thermal units to meet load fluctuations at high and low frequencies. The second is the use of a one step-ahead stochastic load model that helps provides accurate set-points for the assets to follow. The third is the use of a cyber-communication infrastructure that monitors, computes, and communicates the necessary information to various nodes. Together the resulting Decision and Control strategy provides a necessary blueprint for the design of a Smart Grid.

I. Introduction

The report on annual energy outlook in [11] points out that by 2035, the combined intermittent, non-dispatchable generation sources are expected to deliver 4% of total generation in energy. Impediments to increasing this percentage further stem from (i) the need to install expensive spinning-reserves, (ii) the resulting wear and tear of thermal units, and (iii) the inability to achieve adequate voltage. We submit that by the use of a grid-pervasive installation of DCS both in utility substations and microgrids, monitored and controlled through a cyber-communication infrastructure by a hierarchical decision and control paradigm, and including use of VPS units for low frequency load changes, and DCS and DR-compatible loads for high frequency load fluctuations will enable a high penetration of renewables.

This paper addresses the following:

1. Current automatic generation control (AGC).
2. Distributed cyber architecture for monitoring of power grid assets.
3. Management of heterogeneous assets in Automatic generation control (AGC) to accommodate high and low frequency load fluctuations.

II. Automatic Generation Control

The function of automatic generation control (AGC) is as follows: i) to match the tie-line interchanged with the schedules and to control the system frequency. ii) To distribute the changing loads among of power grid assets so as to minimize the operating costs subject to various constraints and security considerations. Current industry AGC can be briefly described as follows [3, 4]. The primary governor speed control ensures that the unit runs at synchronous speed, and is a part of the governor at steam and hydro units at the generating station. When there is a load change, Area Control Error (ACE), a weighted combination of frequency and tie-line error, provides each area with approximate knowledge of the load change. The AGC in turn manipulates the turbine valves of steam and/or gate of hydro units through its supplementary controller, every few seconds, to reduce ACE. The AGC also samples the load demand every few minutes and allocates the changing load among different steam/hydro units so as to minimize the operation costs. This presumes that the load demand remains constant during each period of economic dispatch. The latter, with its low sampling rate, attempts to economize without concern for the direction of the changing load.

It is possible that under a rapid load rise, the signals from economic dispatch and tie-line loads could conflict with each other. In such a case, the "permissive" and "countdown" computer logic of the AGC attempts to cancel control action on the assets. In general, the stable operation of power grids requires disabling economic dispatch for the sake of regulation using all grid assets for generation control [7].

III. A CYBER ARCHITECTURE FOR SMART GRIDS WITH HIGH PENETRATION OF DERS

We envision a mega-scale smart grid that consists of millions of nodes, with sensors for measuring the grid states (e.g., bus voltages) and phasor measurement units (MU). Optimal resource allocation decisions are to be made based on market signals and inputs from these sensor nodes. Thus, the power grid decision making strongly depends on the availability of a reliable communication infrastructure for gathering sensor information and disseminating control information.

Figure 1 depicts our proposed cyber-architecture to facilitate the goals of a Smart Grid with a large number of DER assets. In this figure, Server Fusion Node represents monitoring and control centers at various locations in the grid for data collection, data aggregation, pre-filtering and post-filtering. Smart meters are the points of communication with end energy user/provider (E/P) where residential, industrial and commercial customers are located. At the subtransmission level, larger energy providers such independent power producers (E/P) and large critical power sites are located.

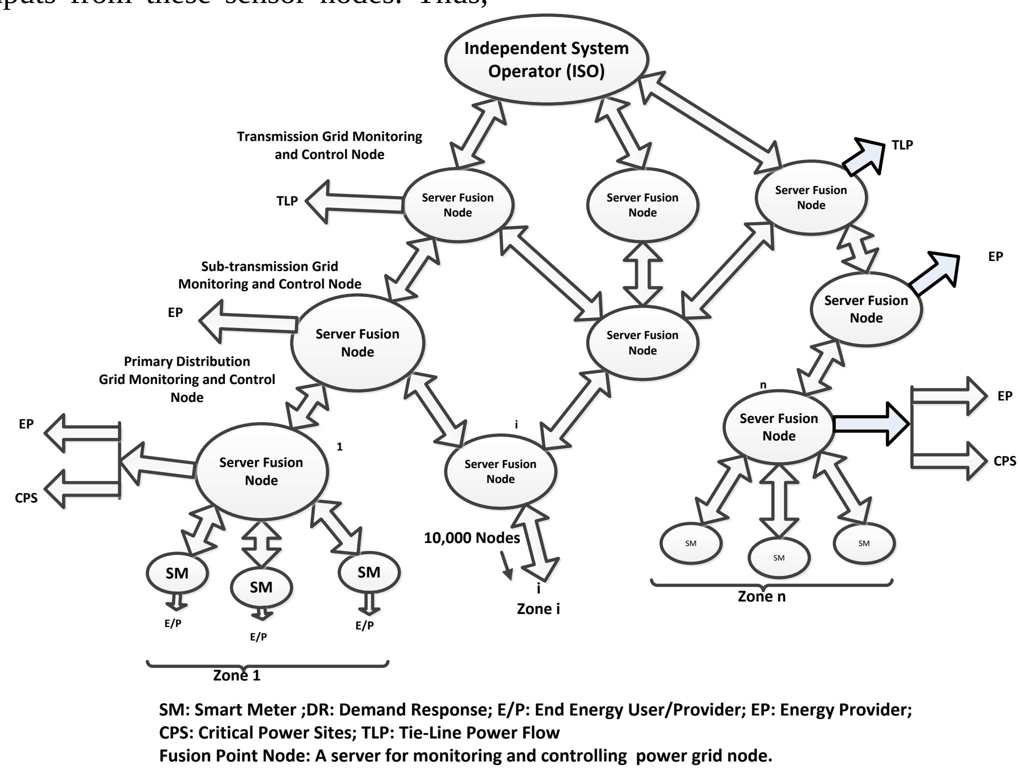

Fig. 1. Proposed Cyber Architecture for power grid with heterogeneous assets [6].

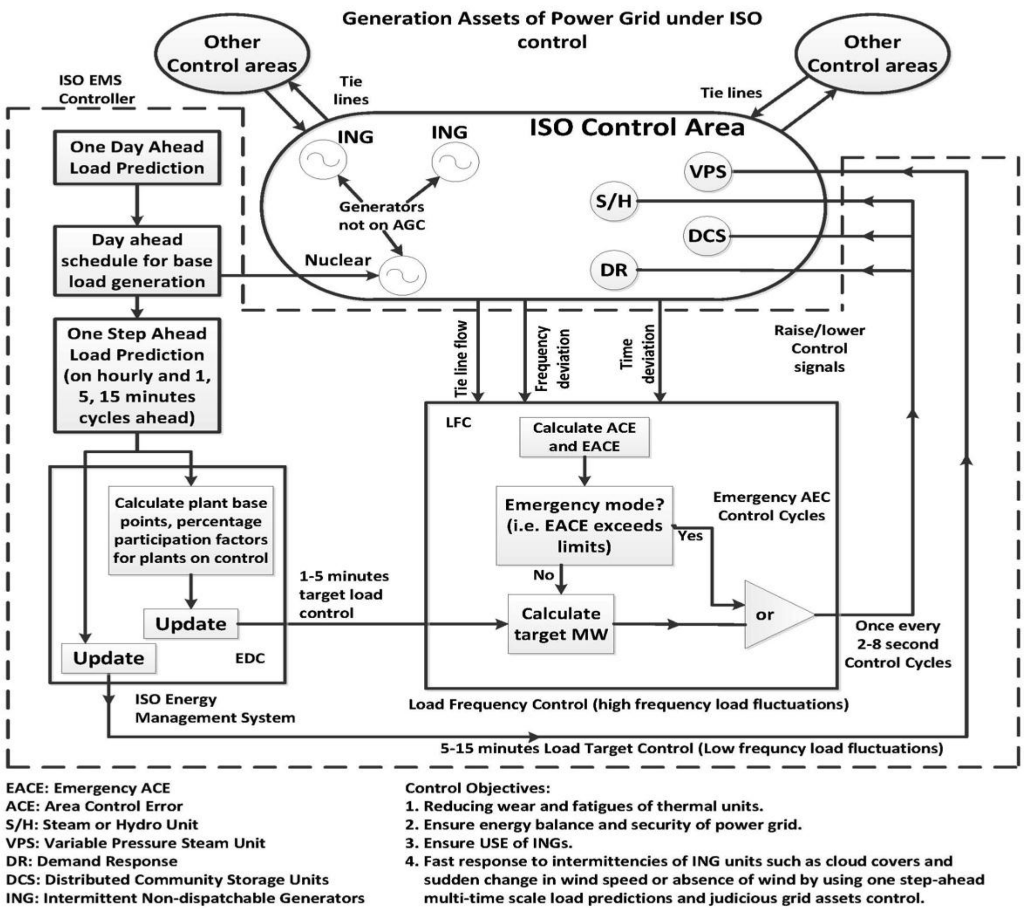

Fig. 2. Proposed AGC control structure with heterogeneous assets [4]

At the transmission level, tie-line power (TPL) to other connected power grids is metered and data are sent to ISO. For example, in zone 1, the DR of 1000 smart meters are aggregated to a sum load in range of a few MW demand under the control of one command. End energy users/providers (E/Ps) can be a residential microgrid of PV roof tops with its local storage or commercial/industrial microgrids with PV, wind and Combined Heat and Power (CHP). Based on differential pricing, some E/P providers may be DR-compatible [12]. Other E/P providers may be energy producers and sell power to the grid. The DR-compatible loads can then be controlled by the ISO when ACE exceeds its emergency value.

The design of such a cyber-architecture faces a number of challenges including the possibility of incomplete information flow due to communication losses and constrained computation resources. If wireless networks, a highly popular choice of communication, were to be used, often messages are transmitted in a multi-hop fashion from the source to the destination via a number of fusion nodes where resource allocation decisions are made. While there has been a great deal of work on the design of control algorithms for wireless networks, the smart grid applications require several special considerations such as the following:

1. The need to gather information from a large number of sensor nodes simultaneously and in real-time.
2. The need to distribute (possibly broadcast) control information to the fusion points on the grid in real-time.
3. Relatively low throughput requirements (as opposed to traditional networks where high throughput is paramount).
4. Stringent delay requirements for real-time control messaging and data gathering.
5. High reliability requirement for certain control messages.
6. Differentiated service requirements for different messages (e.g., certain messages may have stringent delay constraints, while others may be able to tolerate some delays; similarly, some messages may require

assured delivery while others may be less critical).

7. Accommodation of the tree-like structure of a power grid, with high density in some places such as the distribution systems, and sparse structures in others (such as transmission and sub transmission systems)

While the backbone of such a network is likely to be comprised of fiber-optic transmission line, access to sensory nodes at dispersed locations will require a more flexible architecture that can be deployed rapidly and at a minimal investment in additional infrastructure.

One of the main challenges that have to be faced here are geographically distributed sensors sampling data at different rates. The grid data are sampled over a range of time-scales from millisecond (ms) to hours (hr), including at 10 ms to protect and mitigate impending energy imbalance problem for control actions on load shedding, generation rejection, and system separation; 100 (ms) sampled data for control of imminent system instabilities including execution of protection actions based on-line models or criteria identified by slower sampled cycles 1second (s) for maintaining the bus voltages ; 2 (s) sampled data for on-line data validation for use by control area or interconnection including the data acquired in the 10 (ms) cycle from PMUs for area Generation Control: 5-20 (min) cycles for one-step ahead load modeling as well as spinning reserves calculation. Another challenge is the presence of communication constraints that preclude the availability of all data at all locations.

IV. Use of heterogeneous Assets for load Following

Figure 2 depicts the proposed AGC control structure with heterogeneous assets. To ensure the control of grid with high DER, a wide range of heterogeneous assets dispersed over the grid is needed. These assets are demand response (DR) clusters, distributed community storage (DCS) units, and variable pressure steam (VPS) units including the current assets of constant pressure steam units, hydro units and nuclear units. The control objectives are two-fold: i) to reduce costly reliance on gas-fired units as spinning reserves in response to intermittent non-dispatchable DER; ii) to reduce rapid pulsating of steam units and thereby reduce wear and tear of governing valve systems in response to high frequency load fluctuations.

Given these assets, the key questions that need to be addressed in operation planning are as follows: What mix of committed DCS, DR and VPS assets in day-ahead energy and ancillary markets must be used to ensure minimum cost of operation? How can the dynamic generation cost of VPS units be minimized? How does one combine the firm assets of DCS, DR, and VPS with the non-firm assets of DER sources?

Figure 3 depicts one possible set of answers to the above questions. Since DER sources are not under AGC control, they are to be used as base-load for minimum carbon footprint. Since the nuclear units cannot participate in regulation due to safety considerations, they are base loaded as well. The remaining assets, distributed storage system (DCS), demand response (DR) and variable pressure steam (VPS) units are used as regulating units based on power grid operating states. When the change in the system generation is significant, that is precisely the time when the economic reallocation is needed. The base point reallocations will cause additional disturbances in the MW output when the system is at its most active state (i.e., fast-changing load). This control action works against the regulating task.

From the above discussions, it may be apparent that from the outset one should separate load changes that are due to high frequency variations from low frequency variations. In order to carry out the separation, the dynamic, low-frequency trend in the load needs to be modeled using a one step-ahead, stochastic approach and is discussed in the next section. If these load trends are followed by an asset such as the VPS, it can lead to a reduction in ACE over the sampling periods of economic dispatch. This reduction of ACE will reduce the control actions by the AGC controller which in turn eliminates excessive pulsing of steam regulating units. In addition to the above if fast responding distributed community storage (DCS) units are used as well, the ACE can be further reduced. The three modes of power grid operation are normal, alert, and emergency states.

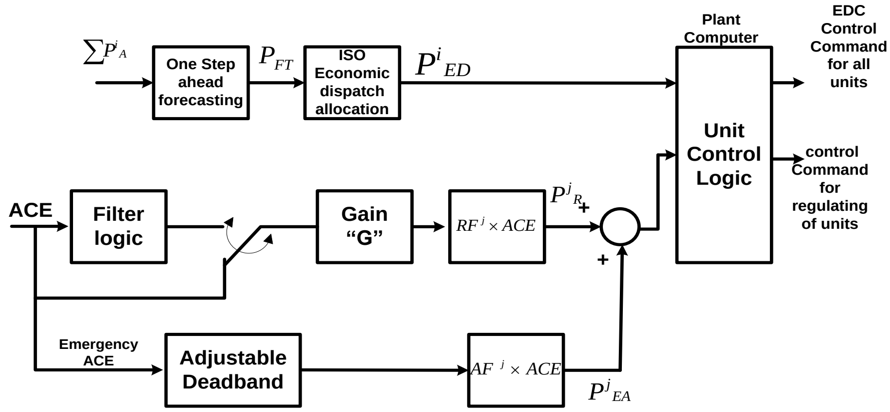

Fig. 3: AGC with asset allocation (RF: regulating factor; AF: Emergency assistance factor; Gain: Controller gain) with steam/hydro and variable pressure units reallocated using load forecast and other units performing load-frequency control.

In normal state, the load is changing very slowly and the grid has adequate on-line spinning reserves. In alert state, the load is changing rapidly and the level of spinning reserves has been reduced. In this state, the grid DCS assets are used to ensure stability. In emergency state, the grid DR assets are used to ensure stability.

V. CONCLUSIONS

This paper presents a new control method to address the intermittency of non-dispatchable units that avoids costly installation of gas fired units. This strategy consists of using DCS and DR and VPS together with load-forecast to meet load fluctuations at high and low frequencies. The proposed cyber-communication infrastructure and monitoring together with a hierarchical, distributed Decision and Control strategy provides a necessary blueprint for the design of a Smart Grid.

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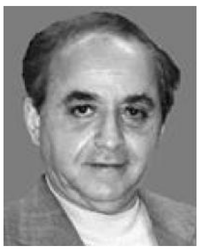

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