METHODS, SYSTEMS AND APPARATUS FOR REGULATING FREQUENCY OF GENERATED POWER USING FLYWHEEL ENERGY STORAGE SYSTEMS WITH VARYING LOAD AND/OR POWER GENERATION

FIELD OF INVENTION

[**0001**] The present invention relates to methods, systems and apparatuses for regulating the frequency of the generated power when the load and/or generated power is subject to variation as a function of time, in particular methods, systems and apparatuses for regulating frequency of generated electrical power when the load and/or power being generated varies as a function of time and more particularly, methods, systems and apparatuses for regulating frequency of generated electrical power when the load and/or power being generated varies as a function of time using one or more flywheel energy storage systems.

BACKGROUND OF THE INVENTION

[**0002**] In the United States, electric power is generated so as to provide an AC voltage in a desired voltage range and at a desired frequency, 60 Hz. Such power is generated by anyone of a number of power generation plants or power generation methods including for example large fixed electrical power generation facilities using fossil fuel (e.g., natural gas, coal, or fuel oil) or nuclear energy to generate electricity, hydroelectric power generation facilities, and pumped hydroelectric power generation facilities. The particular mixture of electrical power generation facilities that are to be operated at any given time are selected based on cost and other factors including regulating the grid voltage as to be within a desired range and regulating the frequency of the AC voltage so as to be at or about the desired frequency.

[**0003**] There is shown in **FIG. 1A**, an exemplary daily load curve that illustrates the variation as a function of time of the electrical load that is created by users and imposed on the electrical grid or electrical generation and distribution system that interconnects the power generation facilities and the various electrical load sources. Such electrical load sources include households, businesses, manufacturing facilities, computer facilities, and transportation services (e.g., mass transit systems powered by electricity). Although the curve illustrated in **FIG. 1A** suggests that the load changes occur over a large time period, in actuality load changes are extremely rapid (e.g., sub-second) as the various electrical power users or consumers adjust their individual electrical power requirements. There is shown in **FIG. 1B** an exemplary load curve that illustrates the short-term variation in the daily load illustrated in **FIG. 1A** between the hours of midnight and 3 AM.

[**0004**] Because of such short-term variations that occur in the electrical load imposed on the electrical generation and distribution system and because the ability of a generator to follow such load variations is typically much slower than the time period of the load variation, the electrical generation and distribution system is constantly challenged with a mismatch between the load and the power being generated. As is known in the art, when the electrical load exceeds the total power being generated, the system the AC frequency drops. Alternatively, when the total power being generated exceeds the electrical load requirement, the frequency rises.

[**0005**] There is shown in **FIG. 2**, an exemplary curve that illustrates the variation in AC frequency as a function of time over a 24 hour time period. As illustrated, the mean AC frequency is 60.002 Hz, the maximum AC frequency is 60.063 Hz, and the minimum AC frequency is 59.944 Hz. In a number of applications, such changes in AC frequency cannot be tolerated and so the power producer or consumer must install a system that is interconnected to the input from the electrical output generation and distribution system and that locally regulates the AC frequency so as to be within a desired range or at a desired value.

[**0006**] Consequently, the power output of the electrical generation equipment is being constantly adjusted so as to match the total power being consumed by or lost to the transmission and distribution and consumed by the customer load(s). In order to keep both the voltage and AC frequency within desired limits and/or ranges, the difference between the load and the power being generated is determined periodically and this difference is used to increase or decrease the output of the generators/power generation facilities. In this regard, and as known to those skilled in the art, real power generation/absorption is associated with frequency regulation and reactive power generation/absorption is associated with voltage regulation.

[**0007**] More particularly, a regional dispatching location or center is tasked with monitoring load and power generation as well as other factors (e.g., correction for frequency shift or time error) and outputs a control/dispatch signal (e.g., sometimes referred to as an energy management system (EMS) signal) to one or more generators/power generation facilities to increase or decrease the power output of such generators/power generation facilities. According to one technique, a large number of monitoring points or nodes are defined for a given area and the dispatching location or center monitors each of the monitoring points as to the foregoing factors. In addition and as described further herein, such a determination also can result in additional generating capacity being brought on-line so as to increase the total generating capacity of the power generation and distribution system or to take on-line generating capacity off-line, or put it in a standby on-line condition, so as to decrease the total generating capacity of the power generation and distribution system.

[**0008**] For example, a determination is made of the difference between the load and power generation, and a control/correction signal is outputted periodically (e.g., every 2-4 seconds) to the power generator/power generation facility(s). Because of the time lag associated with increasing or decreasing power by a given power generator, however, the effect on power generation by the signal being in outputted is delayed in time. There is shown in FIGS. **3A**,B, generation and load curves that illustrate the responsiveness of a fossil-fuel power generator **(FIG. 3A)** and a pumped Hydro power generator **(FIG. 3B)** to a varying load.

[**0009**] As implemented in most electric power grids, regulation is a function or parameter that involves the use of on-line generation that is equipped with automatic generation control (AGC) and that can change output quickly (MW/minute) to track the moment-to-moment fluctuations in customer loads and to correct for the unintended fluctuations in generation. In so doing, regulation helps to maintain interconnection frequency, manage differences between