IMMC 2020 Greater China Problem C (Winter) (English 简体 繁體)

Grid Frequency Response

"Earth Hour" is expressing concerns for the planetary sustainability and climate change, but it has worried the professional organizations of power and electricity transmission. The European Network of Transmission System Operators for Electricity (ENTSO-E), which represents Transmission System Operators (TSOs) across 34 European countries, once called for "Earth Hour" organizers and participants not to switch off and on the lights at exactly the same moment; instead, switching off/on progressively at stages to reduce the threats to the power grid security caused by large fluctuations of electricity consumption, avoiding to plump the entire Europe into blackout for good that may even be triggered (ENTSO-E, 2010; 2011). However, some people think that the fluctuation of electricity consumption caused by “Earth Hour” is trivial and not worthy of a concern (Chai Zhidao, 2019).

The above example is relevant to an important prerequisite for the safe operation of power systems, maintaining stability of grid frequency. When the total power used by the grid-connected electric equipment exceeds the output power of the generators, such as at the moment when a city's street lights are turned on, the frequency will decrease; otherwise, the frequency will increase. Therefore, the frequency of the power system always fluctuates around the rated frequency. Synchronous generators such as coal-fired generators and gas-fired generators have inertia and are an important pillar to stabilize the grid frequency against large-scale fluctuations. When the power grid frequency fluctuates widely, it is likely that some generator units will automatically withdraw from operation, and some electric equipment will also be operating abnormally. Wind power, photovoltaic and other non-synchronous power sources do not have inertia; when the proportion of such power sources increases, the frequency inertia and stability of the power system will decrease, the risk of large-scale frequency fluctuations increases, and the possible large-scale power failure may result. Such kind of a large blackout occurred in the UK on August 9, 2019 (PSD, 2019).

Against the background of a substantial increase in the proportion of wind power and photovoltaic power generation, the use of electric loads to respond to the frequency fluctuation of the power grid has become an effective and economical means for maintaining the stability of the grid frequency. For example, when the frequency of the power grid drops to a certain level, some non-critical loads actively reduce the power consumption, which has the same effect as the power system increases the power generation. The main equipment participating in the frequency response can be selected from air conditioners, water heaters, and electric vehicle charging facilities among other loads. In the load-involved response to frequency change, the distributed control method is that each electric equipment actively monitors the frequency of the power grid and responds proactively when the frequency deviation reaches a certain level.

This challenge considers only the case of grid frequency lower than the rated value. We can see that in the means of distributed control, the parameters that need to be decided are: the threshold value of frequency deviation, and the period of monitoring cycle of the grid frequency by the electric equipment. The objectives concerned in the frequency response are: user experience (e.g. too frequently involved into the response may reduce the satisfaction of electricity consumption.), and the frequency adjustment effect. Try to build mathematical models and make preliminary computation and test.

1) Assuming that the frequency deviation of the power system is normally distributed within ± 0.1 Hz, try to establish a function correlating the user experience, the threshold of the frequency deviation, and the period of monitoring the grid frequency by the electric equipment.
2) Assuming that each time the electric equipment participates in the response, it automatically closes a period of operational cycle. In the next cycle it continues to monitor the frequency of the grid. If the deviation continues to exceed the threshold value, it continues to shut down for another cycle, and it resumes operation until the frequency fluctuation is below the threshold value. Try to establish a function relationship between the frequency adjustment effect, the threshold value, and the cycle period of the electric equipment's monitoring grid frequency.
3) Based on the above mathematical models and your computation, give your suggested parameter settings.
4) Based on your modeling solution, what policy implications would you like to propose for engaging consumers' electric loads into the grid frequency response?

Submission

Your solution paper should include a 1-page Summary Sheet. The body cannot exceed 20 pages for a maximum of 21 pages with the Summary Sheet inclusive. The appendices and references should appear at the end of the paper and do not count towards the 21 pages limit.

Glossary

Grid frequency: As physics tells, the power system uses alternating current, and the voltage and current are described by a sine function. Grid frequency is the number of cycles of voltage and current per second, which is determined by the rotation speed of the synchronous generator. Under steady-state conditions, the generators run synchronously, and the frequency of the entire power grid is the same. The frequency is an operating parameter that is consistent within the entire system. The frequency of power grids around the world is mostly 50Hz, and in some countries or regions, 60Hz, that is, the alternating current changes 50 times or 60 times per second.

Load: The sum of the electric power consumed by the consumer's electric equipment from the power system at a certain moment is called the load.

Frequency response: Once the frequency of the power grid deviates from the rated value, the power grid unit will make corresponding changes to limit the frequency change of the power grid and maintain a stable frequency for the power grid through a process of automatic control.

Frequency deviation threshold: The minimum frequency deviation of the electric load to be engaged in the frequency response. Only when the frequency deviation exceeds the threshold value, the electric load starts to participate in the frequency response.

Period of monitoring grid frequency: The period of monitoring the grid frequency with the electric equipment, that is, how often the grid frequency is monitored.

User experience: The impact of electric load engaging in the frequency response upon the user's feeling and comfort. For example, the engagement of the thermal load such as air conditioning into frequency response may result in temperature changes.

Frequency adjustment effect: In frequency response, two indicators, the maximum frequency deviation and the cumulative time of the frequency deviation exceeding the threshold, are the most important.

References:

ENTSO-E, 2010. “WWF Earth Hour bears risks for European electricity transmission system”, https://www.entsoe.eu/2010/03/25/wwf-earth-hour-bears-risks-for-european-electricity-transmission-system/

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IMMC 2020 中华赛 C 题（冬季赛） （English 简体 繁体）

电网频率响应

“地球一小时”是为了表达对可持续发展和气候变化的关注，却引起电力专业组织的担忧。包括 34 个国家的欧洲电力传输运营商联盟（ENTSO-E）曾呼吁“地球一小时”组织者和参加者不要在统一时间集中关灯和开灯，而可以采取分阶段渐进式开关灯，以减小用电大起大落对电网安全的威胁，避免出于好意却可能触发的大面积停电 (ENTSO-E, 2010; 2011)。但也有人认为地球一小时引起的用电量波动不足为虑(柴知道，2019)。

上述例子关乎电力系统安全运行的一个重要前提，即维持电网频率稳定。当并网用电设备希望使用的功率超过发电机输出功率时，比如一个城市的路灯开启瞬间，频率会下降；反之，频率会上升。因此，电力系统的频率总是在额定频率附近波动。燃煤发电机、燃气发电机等同步发电机具有惯性，是支撑电网频率不发生大范围波动的重要支柱。当电网频率发生大范围波动时，很可能导致一些发电机机组自动退出运行，部分用电设备也将发生异常。风力发电、光伏等非同步机的电源，本身不具有惯性；而当这类电力来源比重增加时，电力系统频率惯性将降低，发生频率大范围波动的风险增加，并可能导致大范围停电。2019 年 8 月 9 日英国就发生了这类大停电事故(PSD，2019)。

在风力、光伏发电比例大幅增长的背景下，用电负荷参与电网的频率响应，成为维持电网频率稳定的有效、经济的手段。比如，电网频率下降到一定程度时，一些非关键负荷主动降低用电功率，效果形同有电源增加了发电功率。参与频率响应的主要设备可以选择空调、热水器、电动汽车充电负荷等。负荷参与频率响应中，分布式的控制方式是，各个用电设备主动监测电网频率，频率偏差达到一定程度时主动响应。

本题目只考虑电网频率偏低的情况。我们可以看到，在分布式控制中，需要决策的参数有：频率偏差的门槛值，以及用电设备监测电网频率的周期。频率响应中需要关注的目标有：用户体验（过于频繁的参与响应可能降低用电满意度），以及调频效果。试就此建立数学模型，并进行初步的测算。

1）假定电力系统频率偏差在正负 0.1Hz 内按正态分布，试建立用户体验与频率偏差的门槛值、用电设备监测电网频率的周期的函数关系。

2）假定用电设备每次参与响应，是自动关闭一个周期；下一个周期继续监测电网频率，若偏差继续超过门槛值，则继续关闭；不超过门槛值则恢复。试建立调频效果与门槛值、用电设备监测电网频率的周期的函数关系。

3）根据以上数学模型以及您的测算，给出您建议的参数设置。

4）基于您的建模方案，对于用电负荷参与电网频率响应，您有何政策建议？

提交

您的解决方案论文应包括 1 页的摘要，正文不能超过 20 页，含摘要最多 21 页。附录和参考资料应出现在正文之后，不算在 21 页的限制之内。

词汇表

电网频率：物理课告诉我们，电力系统使用交流电，电压电流用正弦函数描述。电网频率是电压和电流每秒的周波数，由同步发电机的旋转速度决定。在稳态条件下，各发电机同步运行，整个电网的频率相等，是一个全系统一致的运行参数。世界各地的电网频率多为 50Hz，部分国家或地区为 60Hz，即交流电每秒钟变化 50 次，或 60 次。

负荷：电能用户的用电设备在某一时刻向电力系统取用的电功率的总和，称为负荷。

频率响应：指电网的频率一旦偏离额定频率值时，电网机组做出相应的变化，限制电网频率变化，使电网频率维持稳定的自动控制过程。

频率偏差门槛：用电负荷参与频率响应的频率偏差最小值。频率偏差超过门槛值，用电负荷才开始参与频率响应。

监测电网频率周期：用电设备监测电网频率的周期，即多久监测一次电网频率。

用户体验：用电负荷参与频率响应给用户带来的感受和舒适度的影响，如热负荷参与，可能带来温度的改变。

调频效果：频率响应时，以最大频率偏差和超过门槛值的频率偏差的累积时间两个指标最为重要。

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IMMC 2020 中華賽 C 题（冬季賽） （English 简体 繁體）

電網頻率響應

“地球一小時”是為了表達對可持續發展和氣候變化的關註，卻引起電力專業組織的擔憂。包括 34 個國家的歐洲電力傳輸運營商聯盟（ENTSO-E）曾呼籲“地球一小時”組織者和參加者不要在統一時間集中關燈和開燈，而可以采取分階段漸進式開關燈，以減小用電大起大落對電網安全的威脅，避免出於好意卻可能觸發的大面積停電 (ENTSO-E, 2010; 2011)。但也有人認為地球一小時引起的用電量波動不足為慮(柴知道，2019)。

上述例子關乎電力系統安全運行的一個重要前提，即維持電網頻率穩定。當並網用電設備希望使用的功率超過發電機輸出功率時，比如一個城市的路燈開啟瞬間，頻率會下降；反之，頻率會上升。因此，電力系統的頻率總是在額定頻率附近波動。燃煤發電機、燃氣發電機等同步發電機具有慣性，是支撐電網頻率不發生大範圍波動的重要支柱。當電網頻率發生大範圍波動時，很可能導致一些發電機機組自動退出運行，部分用電設備也將發生異常。風力發電、光伏等非同步機的電源，本身不具有慣性；而當這類電力來源比重增加時，電力系統頻率慣性將降低，發生頻率大範圍波動的風險增加，並可能導致大範圍停電。2019 年 8 月 9 日英國就發生了這類大停電事故(PSD，2019)。

在風力、光伏發電比例大幅增長的背景下，用電負荷參與電網的頻率響應，成為維持電網頻率穩定的有效、經濟的手段。比如，電網頻率下降到一定程度時，一些非關鍵負荷主動降低用電功率，效果形同有電源增加了發電功率。參與頻率響應的主要設備可以選擇冷氣機、熱水器、電動汽車充電負荷等。負荷參與頻率響應中，分布式的控制方式是，各個用電設備主動監測電網頻率，頻率偏差達到一定程度時主動響應。

本題目只考慮電網頻率偏低的情況。我們可以看到，在分布式控制中，需要決策的參數有：頻率偏差的門檻值，以及用電設備監測電網頻率的周期。頻率響應中需要關注的目標有：用戶體驗(過於頻繁的參與響應可能降低用電滿意度)，以及調頻效果。試就此建立數學模型，並進行初步的測算。

1）假定電力系統頻率偏差在正負 0.1Hz 內按正態分布，試建立用戶體驗與頻率偏差的門檻值、用電設備監測電網頻率的周期的函數關係。

2）假定用電設備每次參與響應，是自動關閉一個周期；下一個周期繼續監測電網頻率，若偏差繼續超過門檻值，則繼續關閉；不超過門檻值則恢復。試建立調頻效果與門檻值、用電設備監測電網頻率的周期的函數關係。

3）根據以上數學模型以及您的測算，給出您建議的參數設置。

4）基於您的建模方案，對於用電負荷參與電網頻率響應，您有何政策建議?

提交

您的解決方案論文應包括 1 頁的摘要，正文不能超過 20 頁，含摘要最多 21 頁。附錄和參考資料應出現在正文之後，不算在 21 頁的限制之內。

詞匯表

電網頻率：物理課告訴我們，電力系統使用交流電，電壓電流用正弦函數描述。電網頻率是電壓和電流每秒的周波數，由同步發電機的旋轉速度決定。在穩態條件下，各發電機同步運行，整個電網的頻率相等，是一個全系統一致的運行參數。世界各地的電網頻率多為 50Hz，部分國家或地區為 60Hz，即交流電每秒鐘變化 50 次，或 60 次。

負荷： 電能用戶的用電設備在某一時刻向電力系統取用的電功率的總和，稱為負荷。

頻率響應：指電網的頻率一旦偏離額定頻率值時，電網機組做出相應的變化，限制電網頻率變化，使電網頻率維持穩定的自動控制過程。

頻率偏差門檻：用電負荷參與頻率響應的頻率偏差最小值。頻率偏差超過門檻值，用電負荷才開始參與頻率響應。

監測電網頻率周期：用電設備監測電網頻率的周期，即多久監測一次電網頻率。

用戶體驗：用電負荷參與頻率響應給用戶帶來的感受和舒適度的影響，如熱負荷參與，可能帶來溫度的改變。

調頻效果：頻率響應時，以最大頻率偏差和超過門檻值的頻率偏差的累積時間兩個指標最為重要。

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