WEP Warwick Evans Publishing

International Journal of Mechanical and Electrical Engineering

ISSN: 3005-9615 (Print), ISSN: 3005-7132 (Online) | Volume 5, Number 1, Year 2025
DOI: https://doi.org/10.62051/ijmee.v5n1.03
Journal homepage: https://wepub.org/index.php/IJMEE/index

The Relative Bandwidth Occupation Ratio Event Triggered Control on Power System With LFC-VSG Scheme under Unreliable Network

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ABSTRACT

This study proposes a load frequency control (LFC) scheme that leverages virtual synchronous generator technology (VSG) to address the challenge of reduced power system inertia resulting from the integration of energy resources into the power grid. Firstly, a multi-area VSG-LFC model considering delay under the context of unreliable network transmission is developed. Secondly, this paper proposes an adaptive event-triggered mechanism (BAETM) based on the relative bandwidth occupation ratio, which dynamically regulates thresholds by considering the bandwidth state occupation ratio and system output state. The introduced mechanism effectively reduces data transmission and optimizes the utilization of limited network resources.

KEYWORDS

Load Frequency Control (LFC); Virtual Synchronous Generator (VSG); The Relative Bandwidth Occupation Ratio State Adaptive Event Triggered Mechanism (BAETM).

1. INTRODUCTION

Frequency stability is the premise of the power system to do stable work, and LFC is an important method to keep the frequency stability of the power system, which mainly aims to ensure the frequency stability in the predetermined value by maintaining the balance between the power generation power and the load consumption of the power system [1]. For the purpose of improving the power quality of the power grid, the LFC method has been increasingly attracted the attention of more and more scholars and achieved great progress in recent years[2]. Because of the global resource shortages, the percentage of traditional synchronous generators is gradually decreasing as the proportion of new energy sources penetrating the power grid has been increasing[3,4]. To address the above issues, the integration of VSG technology and LFC is utilized to compensate for the inertia and damping characteristics of the power system, thereby enhancing the penetration rate of new energy into the grid[5]. By employing VSG technology, the capacity of the system to absorb and respond to fluctuations in renewable energy sources can be increased, further improving the stability and reliability of the power grid in general[6].

The use of new energy sources to participate in grid-connected power generation, which can solve the problem of energy structure crisis, has attracted widespread attention in many countries[7]. This unique attribute empowers EVs to play a crucial role in stabilizing both load and frequency fluctuations within power systems due to the characteristics of their batteries which have a fast response capability[8]. Evs as a representative of clean energy, which can function as both a load and an energy storage device, providing the advantage of bidirectional regulation once integrated into the power grid. This means that they can not only consume electricity from the power grid as a traditional load, but also feed electricity back into the grid to compensate for the disadvantages of the unpredictability which sustainable energy sources such as wind energy and solar energy have[9,10]. This bidirectional regulation capability can help balance the supply and demand of electricity within the grid, thereby improving stability of power system and energy utilisation.

There are a variety of triggering mechanisms have been created in order to reduce the waste of network resources and simplify the computational complexity. Originally, it was significant to ensure that the system operated properly in non-ideal situations, which was solved by using the periodic triggering mechanism. Since the sampling interval of this triggering mechanism is usually constant and remains unchanged, it would lead to a large amount of redundant data being released and affect the control performance[11]. An event triggering mechanisms (ETM) have been proposed in order to solve the problem of transferring unnecessary data in the reference[12]. ETM requires the design of event generation conditions and only signals that satisfy the conditions can be transmitted to the controller otherwise they cannot be transmitted. For ETM, there is a limitation to the system control performance caused by its unchanged trigger threshold[13]. Adaptive triggering mechanism(ATM) has been more popular due to the advantage that it can spontaneously adjust the threshold parameter and change its transmission rate [14,15,16]. In reference[14], it is provided an $H\infty$ LFC scheme with an adaptive event-triggering communication scheme to adjust threshold. A dynamic memory event triggering mechanism to regulate the number of historical packets utilised according to the system error is established which reduced the occupancy of the communication network in[15]. However, it is bound to be limited by the relative bandwidth occupation ratio for data transmission under the limited transmission capacity of communication channels. It is of major importance to ensure good control performance in the presence of unstable bandwidth occupation ratio. In previous studies there has been minimal consideration of whether the relative bandwidth occupation ratio supports a lot of signal transmission, which is the motivation for this paper.

Based on the above discussion, the main purpose of this work is to study the VSG-LFC scheme for power system based on bandwidth state adaptive triggering mechanism. The main contributions below can be summarised in three aspects:

An LFC-VSG scheme of power system is designed to address the problem of the frequency fluctuations caused by the decrease in damping and inertia during the renewable energy penetration the power system.

Considering the limit caused by bandwidth in the progress data transmission, an adaptive event triggering mechanism based on the relative bandwidth occupation ratio is designed to regulate the threshold by employing the bandwidth state and the system output state, aiming to reduce data transmission while ensuring system control performance.

2. PROBLEM FORMULATION

From **Figure 1**, the transfer function of the system and the logical relationships between various variables is obtained. Evs can view as both a load and an energy storage unit after being connected into the power grid, with the advantage of bidirectional regulation.

The use of electric vehicles as energy storage units can be a good solution to the problem of excessive load pressure on the grid. Compared with the traditional multi-area power system model, **Figure 1** established an equivalent model of the power system, in which electric vehicles serve as energy storage systems as well as wind and solar generators participating in concert.

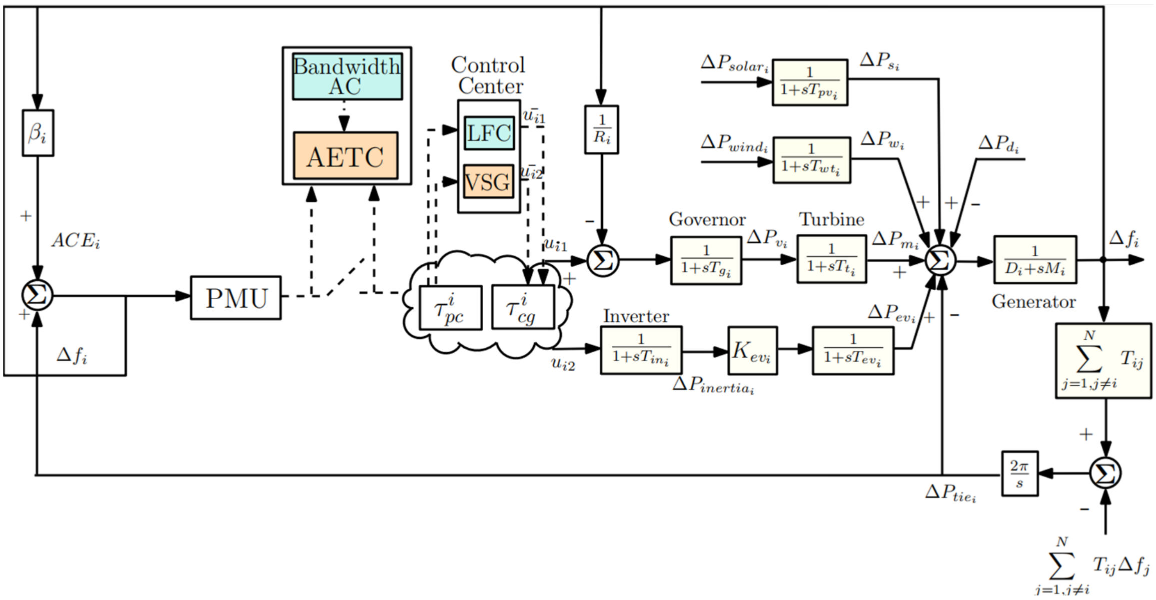

Figure 1. The framework of the ith area with VSG-LFC scheme under the BAETM.

At the same time, VSG technology and LFC are combined as shown in **Figure 2** to compensate for the inertia and damping characteristics of the system, and to improve the penetration of new energy into the grid. In addition, the system incorporates an adaptive triggering mechanism that is related to the bandwidth status because data transmission can be affected by network bandwidth. This threshold parameters are adjusted by using both the system output and current bandwidth status. Also, considering the complexity of the system behavior, a time delay in data transmission to the controller is included in the model.

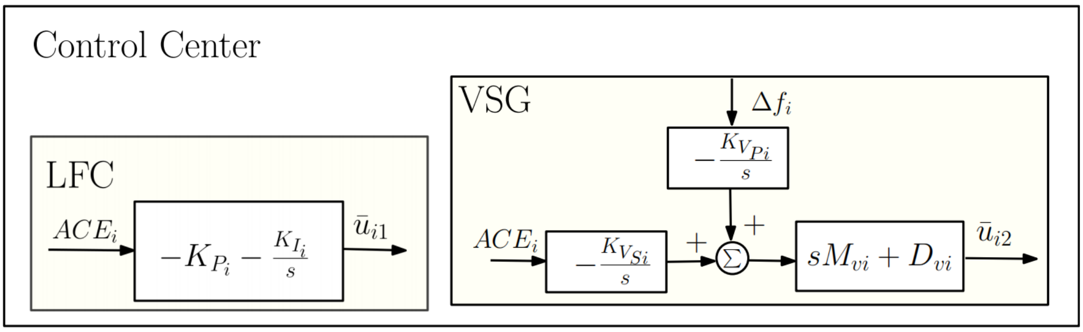

Figure 2. The VSG-LFC scheme of ith area.

And the abbreviations and system parameters are listed in **Table 1**.

3. SIMULATION EVALUATION

3.1. Literature References

In this section, a network-interconnected two-area power system model is established to validate the feasibility of the proposed VSG-LFC scheme based on based on the relative bandwidth allocation ratio adaptive event triggered mechanism in the power system. Moreover, the effectiveness of the controller in the power system was verified under uncertain conditions of data loss and disturbances, while also validating the superiority of the triggering mechanism based on the relative bandwidth occupation ratio.

Table 1. List of system variables and parameters

Variable	Practical meaning
Δf_i	the frequency deviation
ΔPs_i	solar farm power change
ΔPw_i	wind farm power change
ΔPd_i	load disturbance deviation
ΔPm_i	turbine output power deviation
$\Delta Ptie_i$	the tie line power deviation
ΔPv_i	governor output power deviation
$\Delta Pinertia_i$	virtual inertia power change
T_{ij}	tie-line synchronizing coefficient
ACE_i	area control error
ΔPev_i	Electric vehicle output power deviation
R_i	droop constant
Tg_i	The time constant of the governor
Tin_i	inverter time constant
Tpv_i	solar system time constant
Twt_i	wind turbine time constant
Tt_i	turbine time constant
M_i	generator inertia constant
D_i	generator damping coefficient
Dv_i	virtual generator damping coefficient
β_i	frequency bias factor

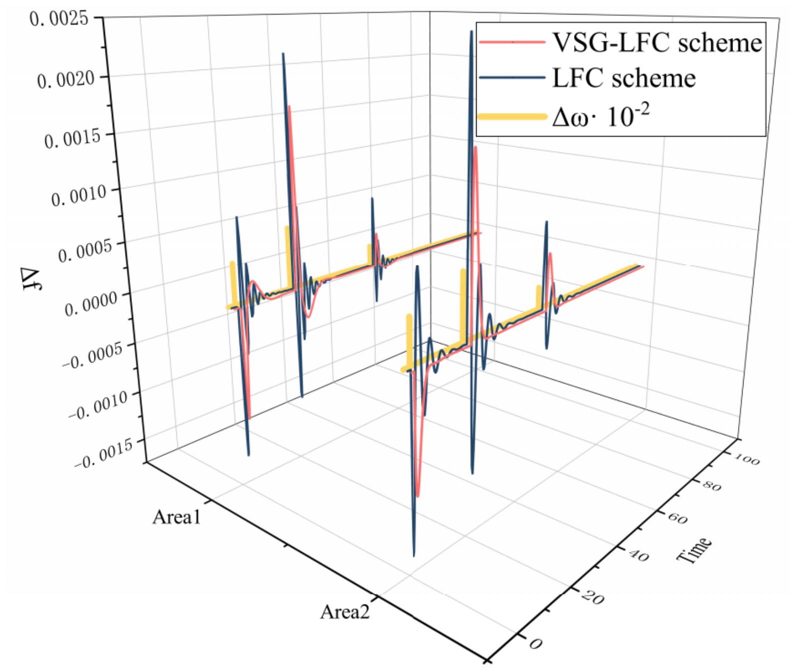

Figure 3. The VSG-LFC scheme of ith area.

The frequency response of the two-area network interconnected power system based on both the VSG-LFC scheme and the LFC scheme is shown in Fig **Figure 3**. Load, wind, and solar power fluctuations are introduced into the power system at specific time intervals (t=0s, t=20s and t=50s) as depicted in Fig **Figure 3**. And the performance of VSG-LFC scheme is analysed in comparison with the performance of conventional LFC scheme to regulate the power system frequency response under load, wind power and solar power fluctuations. The frequency response of the power system under both schemes is subject to local oscillations in a small range. The frequency exhibits slight fluctuations after a period of control with LFC scheme. However, the frequency fluctuations in the power system are reduced, and it can recover to a stable state more quickly with the VSG-LFC scheme. This illustrates that the proposed VSG-LFC scheme can regulate the system more effectively.

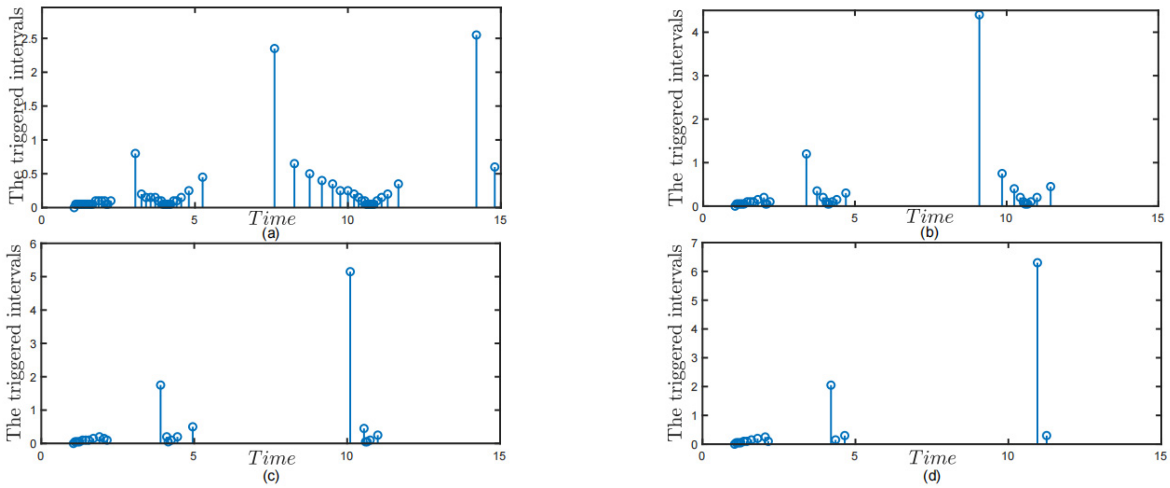

Figure 4. The triggered intervals under different relative bandwidth occupation ratio.

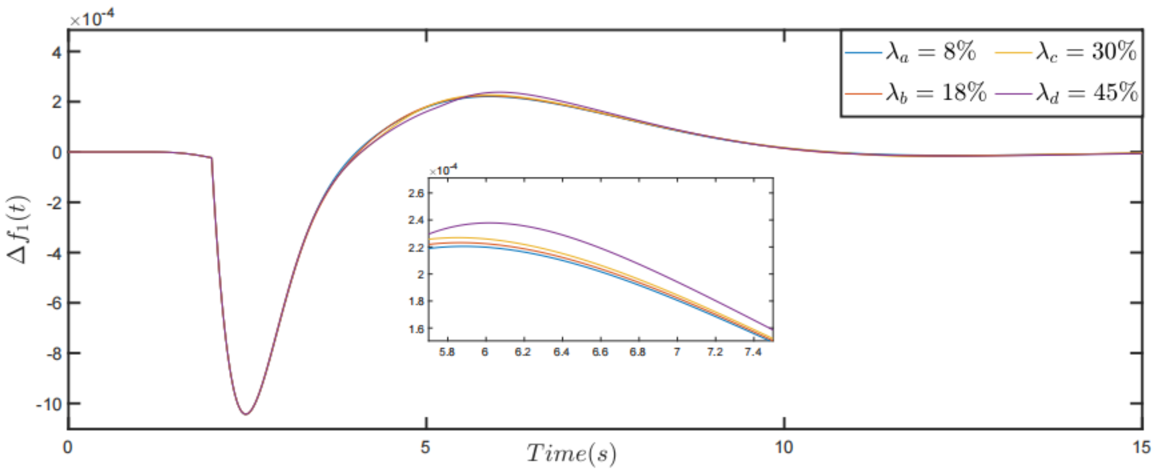

Figure 5. Frequency responses of the first area under different relative bandwidth occupation ratio.

The adaptive triggering mechanism based on relative bandwidth occupancy ratio proposed in this paper gives important advantages in bandwidth saving. For ease of observation, only the trigger intervals were selected for reference as shown in **Figure 4** from 0s to 15s. In the previous section, it was mentioned that when a tends to be 1, the system operates in a busy state with a high the relative bandwidth occupancy ratio. During this time, the system cannot accommodate a large amount of data for transmission. In **Figure 4**, the relative bandwidth allocation ratio is varied to different values(λ_a=8 %, λ_b=18 %, λ_c=30,%,λ_d=45 %). It can be observed that as the relative bandwidth allocation ratio increases, the triggering interval becomes larger, indicating that the number of triggers is less. This illustrates that the trigger mechanism can utilise the available communication resources to adjust the trigger frequency. The frequency responses of area 1 under different relative bandwidth occupation ratio is shown in **Figure 5**. Combining the information from **Figure 6**, it is evident that different relative bandwidth ratios have an impact on frequency responses. As the relative bandwidth occupation ratio increases, the frequency experiences more noticeable fluctuations.

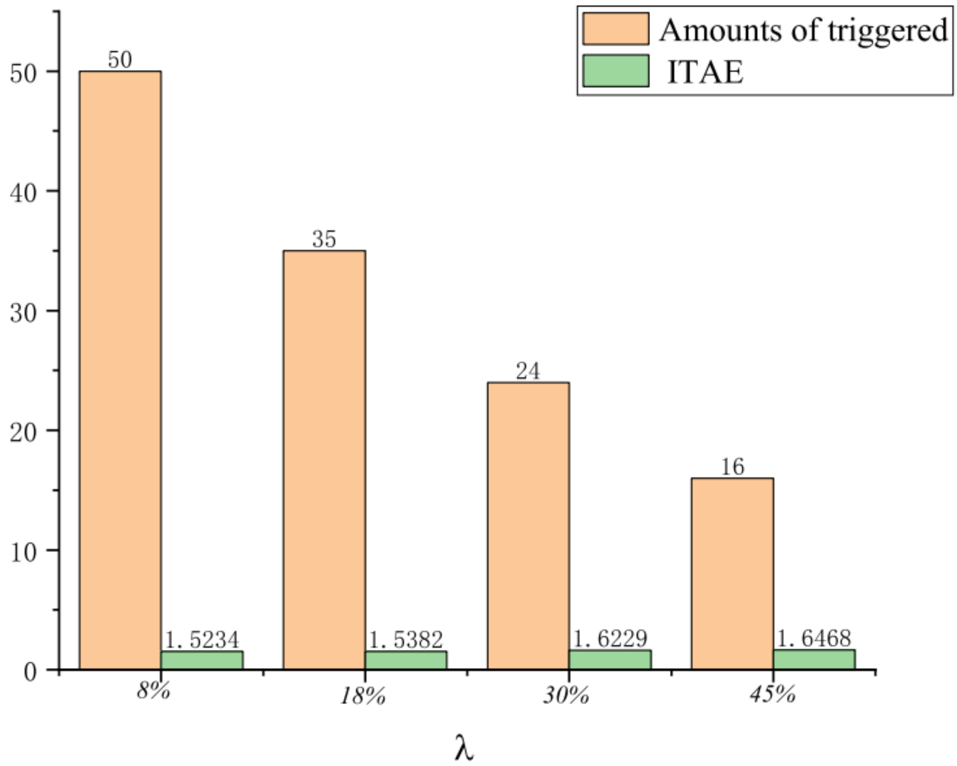

Figure 6. The influence of different relative bandwidth occupation ratio.

4. SUMMARY

In this paper, the adaptive event triggered mechanism based on the relative bandwidth allocation ratio VSG-LFC scheme has been designed for the multi-area power system. The proposed event triggered mechanism adjusts the threshold parameters based on the system response fluctuations and the relative bandwidth allocation ratio to ensure control performance while alleviating the communication burden. This control scheme successfully overcomes the challenges of time delays and unreliable transmission that may arise within the closed-loop system. Moreover, the VSG-LFC scheme has significant advantages in controlling frequency fluctuations resulting from changes in renewable energy generation or fluctuations in load demand.

REFERENCES

[1] Z. Hu, S. Liu, W. Luo, and L. Wu, "Resilient distributed fuzzy load frequency regulation for power systems under cross-layer random denial-of-service attacks," IEEE Transactions on Cybernetics, vol. 52, no. 4, pp. 2396–2406, 2022.

[2] H. Bevrani, T. Ise, and Y. Miura, "Virtual synchronous generators: A survey and new perspectives," International Journal of Electrical Power & Energy Systems, vol. 54, pp. 244–254, 2014.

[3] V. P. Singh, N. Kishor, and P. Samuel, "Load frequency control with communication topology change in smart grid," IEEE Transactions on Industrial Informatics, vol. 12, no. 5, pp. 1943–1952, 2016.

[4] I. Gandhi, L. Ravi, V. Vijayakumar, V. Subramaniyaswamy et al., "Improving security for wind energy systems in smart grid applications using digital protection technique," Sustainable Cities and Society,vol. 60, p. 102265, 2020.

[5] J. Alipoor, Y. Miura, and T. Ise, "Power system stabilization using virtual synchronous generator with alternating moment of inertia," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 3, no. 2, pp. 451–458, 2015.

[6] H. Wu and X. Wang, "A mode-adaptive power-angle control method for transient stability enhancement of virtual synchronous generators," IEEE Journal of Emerging and Selected Topics in Power Electronics,vol. 8, no. 2, pp. 1034–1049, 2020.

[7] C. H. Lee, K.-T. Chau, and W. Zhao, "Guest editorial: Modern electric machines and drives for wind power generation," pp. 1861–1863, 2021.

[8] J. Zhong, L. He, C. Li, Y. Cao, J. Wang, B. Fang, L. Zeng, and G. Xiao, "Coordinated control for largescale EV charging facilities and energy storage devices participating in frequency regulation," Applied Energy, vol. 123, pp. 253–262, 2014.

[9] S. Kfeolu and D. Melchiorre, "Electric vehicles and batteries as domestic storage units in the united kingdom" in 2020 2nd International Conference on Smart Power & Internet Energy Systems (SPIES), 2020, pp. 199–204.

[10] K. S. Ko and D. K. Sung, "The effect of ev aggregators with time-varying delays on the stability of a load frequency control system," IEEE Transactions on Power Systems, vol. 33, no. 1, pp. 669–680, 2017.

[11] M. Donkers and W. Heemels, "Output-based event-triggered control with guaranteed gain and improved event-triggering," in 49th IEEE Conference on Decision and Control (CDC). IEEE, 2010, pp. 3246–3251.

[12] I. Ahmad, X. Ge, and Q.-L. Han, "Decentralized dynamic event-triggered communication and active suspension control of in-wheel motor driven electric vehicles with dynamic damping," IEEE/CAA Journal of Automatica Sinica, vol. 8, no. 5, pp. 971–986, 2021.

[13] X. Chu and M. Li, "Observer-based model following sliding mode tracking control of discretetime linear networked systems with two-channel event-triggered schemes and quantizations" Applied Mathematics and Computation, vol. 355, pp. 428–448, 2019.

[14] Z. Gu, Z. Huan, D. Yue, and F. Yang, "Event-triggered dynamic output feedback control for networked control systems with probabilistic nonlinearities," Information Sciences, vol. 457-458, pp. 99–112,2018.

[15] J. Yang, Q. Zhong, K. Shi, and S. Zhong, "Dynamic-memory event-triggered h load frequency control for reconstructed switched model of power systems under hybrid attacks," IEEE Transactions on Cybernetics, vol. 53, no. 6, pp. 3913–3925, 2023.

[16] S. Long, Z. Zhang, H. Chen, P. Zhang, H. Wang, and S. Zhong, "An esetm based robust synchronizing control on master-slave neural network with multiple time-varying delays," Journal of the Franklin Institute, vol. 359, no. 13, pp. 6632–6658, 2022.