Flicker in the Networks with Distributed Generation Plants and Its Removal Using Group Prognostic Controller

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Abstract. The use of distributed generation (DG) plants in electrical energy system (EES) produces unambiguous effect on power quality. The presence of DG plants allows to reduce losses associated with power transmission and maintain the required voltage levels. In this case, the presence of DG can cause voltage fluctuation, leading to the appearance of flicker, which is understood as a feeling of instability of visual perception. Similar processes can occur at sharp disturbances close proximity to the DG. The situation can be aggravated by improperly configured DG generators controllers. Therefore, it is necessary to conduct an accurate assessment of the DG plants impact on the power grid, which is a rather time consuming task. The article presents results of the EES working modes simulation with a DG plant implemented on the basis of synchronous turbine generators. The results obtained indicated that during temporary connection of heavy load in the connection unit of DG plant and the use of non-concordantly tuned controllers, there are fluctuations in rotor speed and voltage of generators, the analysis of which indicates the presence of flicker. The same effect can obtained a sudden change in the forecast time for individual controllers of turbine generators speed. Flicker can be removed by applying group control of generators speed controllers.

1. Introduction

In order to reduce power transmission losses, increase the efficiency, survivability and reliability of power supply in electrical energy systems (EES), distributed generation (DG) plants can be used [1-6], which are usually connected as close as possible to power consumers.

DG plants parallel operation with EES complicates modes control and requires application of more perfect relay protection and automated systems. At the same time distributed generation produces an unambiguous effect on power quality:

- allows to control and maintain the required voltage level in the network junction points, reduce unsymmetry and harmonic distortions [6-8];
- can cause voltage and frequency fluctuations, leading to the flicker occurrence, which is understood as a feeling of instability of visual perception [9-12].

Flicker occurrence is associated with interaction of DG plant's equipment and dynamic behavior of electric machines in EES, which can occur at a sharp voltage drop in DG plant connection unit. It should also be noted that improperly tuned voltage and frequency controllers of DG plants can increase the likelihood of flicker occurrence. Identifying and solving the flicker problem is a complex
task, because this phenomenon can occur in different modes of DG plants operation and EES. Computer simulation can be used for flicker analysis, but this has the burden of accurate determining the interactions between the DG plants and the electrical energy system.

Thus, before using DG plants in EES, one shall carry out an accurate assessment of their impact on the power grid, determine the connection points and optimize the controllers algorithm and tuning. The solution of these problems will help to avoid possible deterioration of power quality in different operating modes of EES and DG plants. Previous studies [12, 13] indicate that the use of the concordant tuning of automatic voltage controllers (AVC) and automatic speed controllers (ASC) of synchronous generator, as well as prognostic algorithms [14, 15] can improve the quality of voltage and frequency control, and remove the flicker that occurs during abrupt disturbances caused by connection and disconnection of an additional load in DG plant's connection unit. The aim of the study was to determine the efficiency of control and the possibility of removing the flicker in the EES equipped with DG plants group prognostic speed controller. The paper presents a description of the computer model of the EES equipped with a DG plant, AVC, ASC and a group prognostic controller. The results of simulation under the disturbance caused by the flicker occurrence are also presented. The flicker was analyzed using spectral analysis methods and wavelet transform.

2. Description of the study model

Studies were conducted for the scheme of the power supply system (PSS), shown in figure 1 a, the model of which was built in MATLAB using Simulink and SimPowerSystems simulation packages. The PSS included a DG plant, implemented on the basis of three turbine generators with a rated power of 2.5 MW·A each and a voltage of 6 kV. The load of consumers in the PSS is shown in figure 1 a.

Synchronous generators of the CGP were simulated with standard packet data units of SimPowerSystems package of MATLAB system. The structural diagram of the steam turbine model with intermediate steam bleeding is shown in figure 1 b.

![Diagram of the PSS under study](image)

Figure 1. Diagram of the PSS under study (a) and the Simulink diagram of the steam turbine model (b): VT – voltage transformer; EW – excitation winding; CGP – co-generation plant.

The control of the generators rotor speed and voltage was carried out using AVC and ASC models. A detailed description of AVC and ASC models used, including those with prognostic links, is provided in [15]. The schematic of the Simulink model of the proposed group prognostic automatic speed controller (GPASC) is shown in figure 2, in which the forecast time constant was calculated by the frequency of natural oscillations of the master generator rotor [15, 16] and changed depending on the load angle δ.
The model used a standard unit of SimPowerSystems package of MATLAB system – Flickermet, in which the model of a digital flickermeter was implemented in accordance with the international standard IEC 61000-4-15.

3. Simulation results
Flickermeter was created by temporary switching on in the assembly of additional load with power of $5+2$ MV·A, which was 2 times higher than the power of an individual DG plant generator. The study was conducted for the model with non-concordantly tuned AVC and ASC of turbine generators, as well as when using the GPASC with non-concordantly and concordantly tuned controllers. The technique of AVC and ASC coordinated tuning is provided in [17].

Simulation results indicate that at temporary switching on of heavy load in DG plant connection unit and the use of non-concordantly tuned AVC and ASC (controllers tuning was chosen based on practical considerations) there are fluctuations of rotor speed and turbine generators voltage. The corresponding time dependences of turbine generator parameters are shown in figure 3, where the readings of the flickermeter are also provided (figure 3, c).
Figure 3. Time dependences of the generator rotor speed (a), the assembly voltage (b) and flickermeter readings (c) when a heavy load is temporarily switched on.

A wavelet transform was used to analyze the obtained voltage fluctuations and to isolate the resulting noise. When plotting the dependence of spectral power density (SPD) on frequency (figure 4) in accordance with the Berg method [18], it was found that the SPD of the isolated noise is inversely proportional to frequency. This indicates that the selected noise can be attributed to flicker-noise [19, 20].

Figure 4. SPD dependence of frequency.

In [12] it is shown that the application of prognostic control algorithms in AVC and ASC of turbine generators allows to remove the flicker. However, at different values of the forecast time constant for individual turbine generators and at non-concordant tuning of AVC and ASC the processes were also observed, that led to the emergence of flicker even without connection of an additional load. The corresponding voltage dependences in the DG connection unit and flickermeter readings at a sudden change in the time constant of the ASC prognostic link are shown in figure 5. The analysis of the obtained voltage fluctuations, as well as the flickermeter readings indicates the presence of the flicker.
Figure 5. Time dependences of the voltage (a) and the flickermeter readings (b) at ASC different forecast times: prognostic non-concordantly adjusted AVC and ASC were used.

To eliminate the flicker it is proposed to use the group control of prognostic ASC (the GPASC scheme, figure 2), as well as the coordination of AVC and ASC turbine generator settings. The computer simulation results show that even with non-concordant tuning of controllers, but with the use of GPASC it is possible to solve the problem of flicker occurrence. In this case, the coordination of AVC and ASC allows to slightly reduce the arising overregulation of speed and voltage after disconnecting a powerful load. Corresponding temporal dependences of rotor speed, turbogenerator voltage, as well as flickermeter readings are provided in figure 6. Thus, the application of the group prognostic controller of turbine generators speed of one DG plant allows to avoid flicker emergence even at non-optimal or incorrect setting of AVC and ASC. In addition, it should be noted, that the used schematic of the master alternator in the GPASC does not allow to set different time constants of the prognostic links in the ASC, which also hinders the flicker emergence.

Figure 6. The generator rotor speed (a), the assembly voltage (b) and flickermeter readings (c) when a heavy load is temporarily switched on: 1 – GPASC was used with non-concordantly adjusted AVC and ASC; 2 – GPASC was used with concordantly set AVC and ASC.
4. Conclusion
Based on computer simulation results, the following conclusions can be made:

- At temporary switching on of powerful load in the DG plant connection unit and the use of non-concordantly tuned controllers the fluctuations of rotor speed and turbine generator voltage emerge, the analysis of which indicates the presence of flicker;
- As a result of a sudden change in the forecast time constant for individual ASC of turbine generators and at non-concordant tuning of voltage and speed controllers, the processes leading to the emergence of flicker, even without connection of an additional load are also observed;
- The application of the group prognostic controller of turbine generators speed of one DG plant allows to avoid flicker emergence even at non-optimal or incorrect setting of AVC and ASC. In addition, the used schematic of the master alternator in the GPASC does not allow to set different time constants of the prognostic links in the ASC, which also hinders the flicker emergence;
- Harmonization of AVC and ASC settings allows to remove the flicker and reduce to a certain extent the emerging overshoot of speed and voltage in the DG plant connection assembly a heavy load is disconnected.

5. References
[1] Voropai N I, Stychinsky Z A 2010 Renewable energy sources: theoretical foundations, technologies, technical characteristics, economics (Magdeburg: Otto-von-Guericke-Universität) 223
[2] Magdi S M, Fouad M AL-Sunni 2015 Control and Optimization of Distributed Generation Systems (Cham: Springer International Publishing: Imprint: Springer) 578
[3] Martínez Cesena E A, Capuder T, Mancarella P 2016 Flexible distributed multienergy generation system expansion planning under uncertainty IEEE Transaction on Smart Grid 7 348-357
[4] Wang J, Huang A Q, Sung W, Liu Y and Baliga B J 2009 Smart Grid Technologies IEEE Industrial Electronics Magazine 2 16-23
[5] Ackermann T, Anderson G, Söder L 2001 Distributed generation: a definition Electric Power Systems Research 57 195-204
[6] Buchholz B M, Styczynski Z A 2014 Smart Grids – Fundamentals and Technologies in Electricity Networks (Springer-Verlag Berlin Heidelberg) 396
[7] Rugthaicharoencheep N, Auchariyamet S 2012 Technical and Economic Impacts of Distributed Generation on Distribution System International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering 6(4) 385-389
[8] Bulatov Yu N, Kryukov A V, Nguen V H 2019 Effect of distributed generation plants' automatic controllers on power quality factors E3S Web of Conferences 114 1-5
[9] Jenkins N, Allan R, Grossley P, Kirshen D, Strbac G 2000 Embedded Generation (London; IEEE) 273
[10] Barker Ph P, De Mello R W 2000 Determining the Impact of Distributed Generation on Power Systems: Part 1 - Radial Distribution Systems. IEEE PES Summer Meeting, Seattle, WA, USA 222-233
[11] Sikorski T, Rezmer J 2015 Distributed Generation and Its Impact on Power Quality in Low-Voltage Distribution Networks, Power Quality Issues in Distributed Generation (Dr. Jaroslaw Luszcz (Ed.), InTech) DOI: 10.5772/61172
[12] Bulatov Y N, Kryukov A V, Suslov K V 2018 Solving the flicker noise origin problem by optimally controlled units of distributed generation Proceedings of International Conference on Harmonics and Quality of Power, ICHQP 1-4
[13] Bulatov Y, Kryukov A, Nguyen Van Huan 2020 Flicker control in mains with distributed generation plants. E3S Web of Conferences 209 1-7
[14] Camacho E F, Bordons C 2007 Model Predictive Control (Springer, 2nd edition) 405
[15] Bulatov Yu N, Kryukov A V, Nguyen Van Huan 2018 Automatic prognostic regulators of
distributed generators. *International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon)* 1-4

[16] Anderson P M, Fouad A A 2003 *Power System Control and Stability* (Second Edition. IEEE Press) 688

[17] Bulatov Yu N, Kryukov A V 2016 Optimization of automatic regulator settings of the distributed generation plants on the basis of genetic algorithm. *2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)* 1-6

[18] Francis Castanié 2011 Digital spectral analysis: parametric, non-parametric, and advanced methods *ISTE Ltd, John Wiley & Sons, Inc* 400

[19] Voss R F 1979 1/f (Flicker) Noise: A Brief Review *33rd Annual Symposium on Frequency Control, IEEE* 40-46

[20] Gorban I I 2012 Statistically unstable processes: connection with flicker, nonequilibrium, fractal and color noise *Proceedings of universities. Radio electronics 3*(55)* 3

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