Solving the Flicker Noise Origin Problem by Optimally Controlled Units of Distributed Generation

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***Abstract*—Modern power systems shall meet the requirements of efficiency, survivability, reliability of power supply for consumers. The requirements, which become more rigid under conditions of the competitive power supply market, shall be solved by introduction of Smart Grid technologies. Smart Grid technologies stipulate wide use of distributed generation units. Distributed generation can cause fluctuation of voltage and frequency leading to the flicker noise, which is the visual perception instability.**

The article presents results of mode modeling of distributed generation units implemented on the basis of synchronous generators. Obtained results show that, when a load in grids with uncontrolled regulators is switched off/on, flicker noise caused by voltage/ frequency fluctuations occurs. Unmatched tuning of excitation/ frequency regulators of distributed generation unit synchronous generators can cause the same effect. Modeling results show that elimination of flicker noise is possible through using matched tuning of these regulators.

***Index Terms*-- distributed generation units; synchronous generators; fluctuation of voltage and frequency; flicker noise.**

I. Introduction

Modern power systems shall meet the requirements of efficiency, survivability, reliability of power supply for consumers. The requirements, which become more rigid under conditions of the competitive power supply market, shall be solved by introduction of Smart Grid technologies that allow to more efficiently use power sources. Smart Grid technologies stipulate wide use of distributed generation units that are a set of power units operating in immediate proximity to consumers.

The paralleled operation mode of distributed generation units with a centralized modern power system is a reasonable solution from economic and technological points of view, especially in areas with unstable and undergrade power supply. In this case distributed generation units can be used for "peak shaving", stabilization of voltage and frequency, power loss decrease. However, paralleled operation of distributed generation units with modern power systems complicates the mode control tasks and requires using more perfect algorithms of relay protection / automation operation, for example [1]. Besides, influence of distributed generation on power is complex. On one side, distributed generation units allow to maintain the required voltage levels in grid nodes, decrease asymmetry and harmonic distortions [2]-[4]. On the other side, distributed generation can cause fluctuations of voltage and frequency leading to flicker noise, which is the visual perception instability [5]-[7]. Flicker noise is caused by equipment interaction and machine dynamic behavior. In paper [6] it is noted, that flicker noise occurs, when voltage at a distributed generation unit connection point decreases abruptly; in this case using regulators of voltage and frequency in distributed generation unit generators can drastically worsen the situation, especially, if the regulators are not correctly tuned (matched).

Therefore, wide use of distributed generation units implies precise evaluation of their influence on an electric grid, since it would allow to avoid power supply quality worsening. Thus, studying issues of flicker noise origin/ elimination in electric grids with distributed generation units is very important.

The article presents results of modeling flicker noise in grids with a distributed generation unit implemented on the basis of synchronous turbine generators with automatic excitation regulators and automatic speed regulators. Methods of spectral analysis and wavelet transform were used to analyze the modeling results

II. Description of the Model and Research Results

Researches were carried out in MATLAB system for a power supply system model with distributed generation units as per diagram of fig. 1. The power supply system was modeled with consumers' load of 5 + j2.4 MVA; the load was connected to a feeding modern power system through a transformer of 110/35/6 kV. A distributed generation unit implemented on three turbine generators of nominal power 3.125 MVA and voltage of 6 kV (each) was included into the power supply system.

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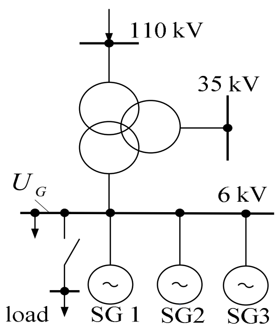

Figure 1. A diagram of an electric supply system with a distributed generation unit: SG – synchronous generator

Standard units of MATLAB system were used as synchronous generator models: synchronous machine models with metrics in relative units. The used model of a steam turbine with respect of intermediate steam bleeding is represented by the following transfer factor:

$$W_T = \frac{3{,}6\, j\,\omega + 1{,}1}{0{,}8(j\,\omega)^2 + 4{,}2\, j\,\omega + 1}, \tag{1}$$

where $j = \sqrt{-1}$; ω – frequency, Hz

Models of thyristor excitation systems of synchronous generators used in modeling are implemented according to equations given in [8]. Pre-amplifiers were modeled as aperiodic links of first order with the amplification coefficient k_a and time constant T_a; in the same time the assumption on linear response of the element was made. In the same way modeling of a thyristor exciter with the coefficient k_e, time constant T_e and a voltage limit unit was done. The following values of the excitation system parameters were used: $k_a = 1$; $T_a = 0.001$ sec; $k_e = 1$; $T_e = 0.025$ sec.

To adjust rotor speed and generator voltage, we used models of an automatic excitation regulator and automatic speed regulator that are proportional-integral-differential regulators described by the following complex transfer factors:

1) automatic excitation regulator unit:

$$W_{ARE} = \frac{1 + 0{,}5\, j\,\omega}{0{,}5\, j\,\omega} \cdot \left(W_{ARE}^{U} + W_{ARE}^{\omega} \right), \tag{2}$$

where $W_{ARE}^{U} = k_{0u} - \frac{0{,}02\, k_{1u}\, j\,\omega}{0{,}06\, j\,\omega + 1}$ – a complex transfer factor of an automatic excitation regulator by voltage;

$W_{ARE}^{\omega} = \frac{2\, k_{0\omega}\, j\,\omega}{(2\, j\,\omega + 1)(0{,}02\, j\,\omega + 1)} + \frac{0{,}05\, k_{1\omega}\, j\,\omega}{0{,}05\, j\,\omega + 1}$ – a complex transfer factor of automatic excitation regulator by frequency; k_{0u}, k_{1u}, $k_{0\omega}$ and $k_{1\omega}$ – coefficients of tuning channels of an automatic excitation regulator;

2) automatic speed regulator unit:

$$W_{ARF} = \left(k_p + \frac{k_i}{0{,}1\, j\,\omega} + \frac{k_d\, j\,\omega}{j\,\omega + 1} \right) \cdot \frac{1}{0{,}01\, j\,\omega + 1}, \tag{3}$$

where k_p, k_i, k_d – required coefficients of tuning an automatic speed regulator; W_{ARF} – frequency transfer function of an automatic speed regulator.

Look-ahead control algorithms were also used in models of an automatic excitation regulator and automatic speed regulator. Their description is given in [9], [10].

A standard unit of MATLAB system, i.e. Flickermeter, a digital flicker meter as per international standard IEC 61000-4-15 was used to fix flicker noise during modeling.

Modes leading to flicker noise origin were created through connecting an additional load to a node with a distributed generation unit and load disconnecting in 0.1 sec. The following distributed generation unit operation modes were studied:

1) operation without regulators of voltage and frequency;

2) operation with matched and unmatched tuning of an automatic excitation regulator and automatic speed regulator;

3) operation with using look-ahead algorithms in an automatic excitation regulator and automatic speed regulator.

Carried out calculation experiments show that, if an automatic excitation regulator and automatic speed regulator are switched off and an additional load is connected to a distributed generation unit connection point, there is high probability that stability is lost and asynchronous run occurs. Such processes occur, when an additional load of 9.43 MVA (the load is equal to capacity of three turbine generators connected to a node) is connected in 5 sec time period. In this case, generator rotor speed fluctuation occurred, and it led to 6 kV voltage fluctuation on consumer's busbars (fig. 2). Such fluctuation can propagate over the entire grid.

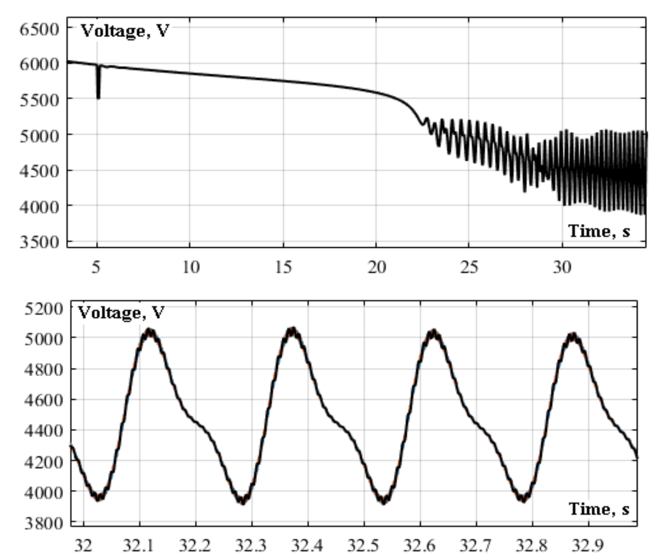

Figure 2. Oscillograms of turbine generator active voltage, when an additional load is connected to the node

In Fig. 3a there is dependency of instantaneous flicker sensation on time, which grows with the voltage excursion increase (fig. 2). The dependence of flicker instantaneous sensation on weighted voltage fluctuation standard flicker meter model in MATLAB) is given in Fig. 3b. This graph shows that weighted voltage fluctuation grows with instantaneous flicker sensation.

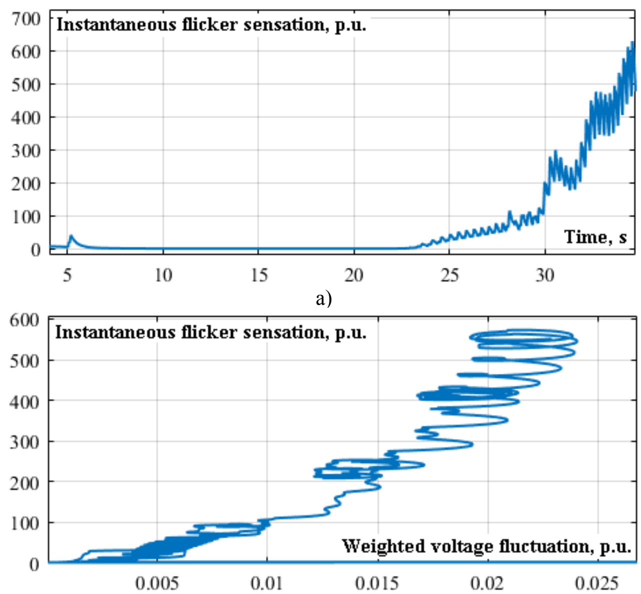

Figure 3. Readings of a flicker meter (a) and the dependency of the flicker noise on voltage (b)

To analyze the voltage noise occurred, we used only constituents having practical importance. Noise was extracted from a signal fragment of active voltage in a node with using wavelet transform. The extracted noise is shown in Fig. 4.

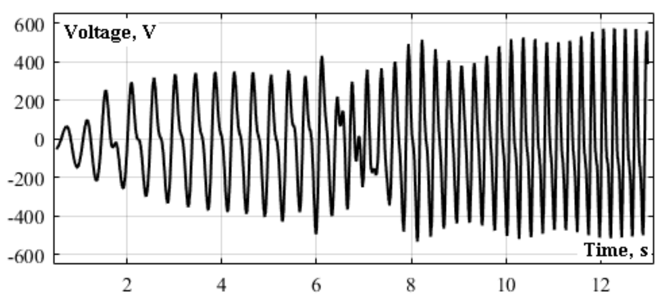

Figure 4. Extracted noise

According to analysis results, spectral power density of the extracted noise is inversely proportional to frequency. The dependence of spectral power density (SPD) on frequency obtained through using the Berg method [11], is shown in fig. 5. Therefore, the extracted noise may be related to the flicker noise [12].

Similar effects are seen in case of imperfect tuning of distributed generation unit regulators.

To eliminate flicker it is proposed to use the method of matched tuning of an automatic excitation regulator and automatic speed regulator of synchronous generators through using genetic algorithms [13] and look-ahead algorithms [9], [10].

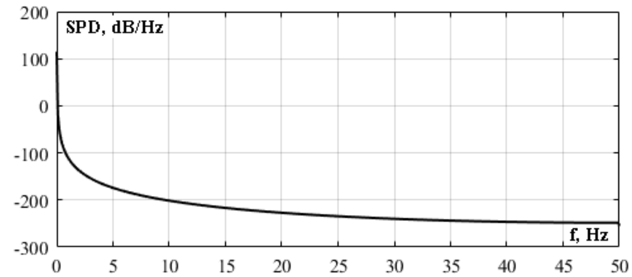

Figure 5. The dependence of spectral power density on frequency

The researches show that using the regulators with matched tuning and look-ahead control algorithms allows to solve the problem of flicker noise, which can be measured in this case with a flicker meter. Corresponding oscillograms of voltage and speed of a generator rotor in case of consumer's abrupt load change are given in Fig. 6. The oscillograms show that using matched tuning of an automatic excitation regulator and automatic speed regulator allows to eliminate flicker noise, which occurs, when a high load is connected to a distributed generation unit node, whereas look-ahead algorithms, which control voltage and frequency, allow to completely eliminate flicker noise and enhance quality of controlling voltage and frequency. A positive effect of eliminating flicker noise is seen in Table 1 below: average and maximal values of instantaneous flicker sensation are determined in the 10...35 sec modeling interval, which takes account of a flicker sensation jump in the moment of excitation.

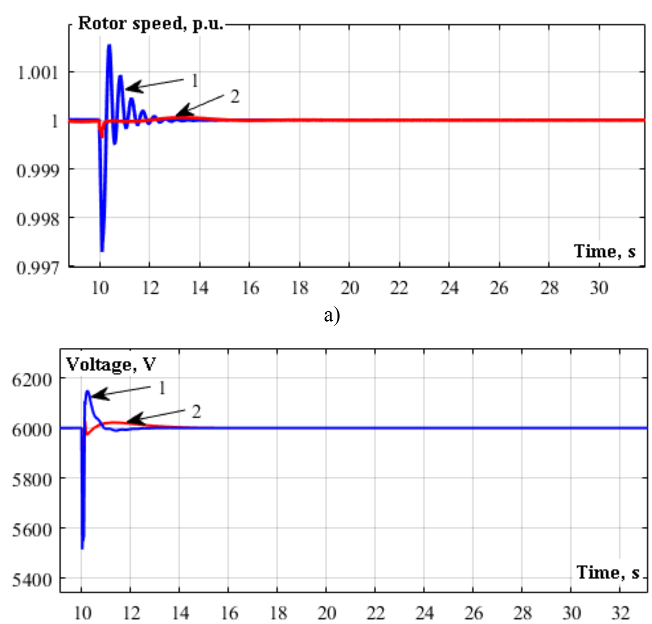

Figure 7. Oscillograms of generator rotor speed (a) and voltage in a node of distributed generation unit connection (b):

1 – generators operated with matched an automatic excitation regulator and automatic speed regulator; 2 – generators operated with using look-ahead algorithms and matched an automatic excitation regulator and automatic speed regulator

TABLE I. FLICKER METER DATA WITH VARIOUS OPERATION MODES OF DISTRIBUTED GENERATION UNITS

Distributed generation unit operation modes	**Average value of flicker sensation, p.u. (per-units)**	**Maximal value of flicker sensation, p.u.**
1. Without regulators	86.7	631.2
2. Operation with unmatched tuning of an automatic excitation regulator and automatic speed regulator	67.4	297.5
3. Operation with matched tuning of an automatic excitation regulator and automatic speed regulator	0.9	55.6
4. Operation with using look-ahead algorithms and matched tuning of an automatic excitation regulator and automatic speed regulator	0.7	43.2

III. CONCLUSION

Based on computer modeling of a power system with distributed generation units one can make the following conclusions:

1. In case of abrupt disturbances caused by switching on/off an additional load in nodes with unregulated distributed generation units implemented on synchronous generators, flicker noise accompanied by fluctuation of voltage and frequency occurs. It was found out that unmatched tuning of distributed generation unit regulators can cause flicker noise as well.

2. Using the look-ahead control algorithms in a perfectly tuned automatic excitation regulator and automatic speed regulator of a distributed generation unit turbine generator completely eliminates flicker noise and enhances quality of controlling voltage and frequency.

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