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Synchronous Generator Active and Reactive Power Oscillations Reduction by BESS

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***Abstract*—In the presented paper, we address the threats arising from the negative transient effects in the electrical grid and we propose ways how to decrease their negative effect on the synchronous generator. The proposed solution uses BESS installed in the common electrical node with the synchronous generator. The main thread arising from these transients is a continuous decrease of the turbomachinery service life, by decreasing the health of the winding insulation or by the mechanical oscillations excited by the transients, which damage the turbine. The analysis and the proposed control algorithm for the BESS have been verified by the simulation model in Simulink (MATLAB) environment. In the Simulink model, we assumed that the turbomachinery is connected to a steam turbine. As a case study, a real measured grid voltage transient has been chosen. This transient consists of a sudden drop in grid voltage magnitude. The model includes proposed control loops for the battery energy storage system and the generator itself. These are key parts affecting the stability and performance of the proposed control and it is discussed in the conclusion.**

Keywords—Battery Energy Storage System, Thermal Powerplant, Service Life Improvement

I. Introduction

Current development of power engineering and energy grids suggests increasing integration of the fluctuating renewable energy sources. This will cause higher demands on grid stability and control which will most probably cause higher integration of energy storages. The advantage is to integrate battery energy storages (BESS) in the grid due to high charge/discharge cycle efficiency as well as short response time and flexible control.

However, in addition, to using the BESS for ensuring the energy balance, there are other possible uses of BESS in the electrical grid. The focus of our current work is paid on the cooperation of BESS and steam turbine (coal-fired, nuclear power plants, or combined cycles in gas power plants). In our previous works, we described suitable battery technology selection [1], accuracy evaluation of synchronous generator models [2], and control of the proposed multilevel CHB converter [3]. These partial works resulted in the full model of turbomachinery and energy storage compilation in Simulink (MATLAB).

The first use of the proposed cooperation of energy storage and the steam turbine was the increase of flexibility and control range of primary frequency control in the thermal power plant. This case is described in [4] along with the detailed turbomachinery model. The same model is used for simulations shown in this paper. This paper focuses on another possible use of the BESS in the power plant - the protection of the generator. Specifically, if the active and reactive power oscillations can be reduced by the active intervention of the BESS, and if it will result in the rotor speed and torque deviation reduction as well. There are papers which are dealing with BESS protection [5], grid frequency oscillations compensation [6], the overall impact of the BESS use on the power grid in Portugal [7] and central Europe [8]. Nevertheless, we have found no publicly available paper devoted to the active protection of the synchronous generator by BESS.

The first part of the paper consists of a brief description of the models used in simulations. It includes changes that were made compared to the turbomachinery model described in [4] including the convertor and its control. In the next part, there are presented simulations of active and reactive power (rotor speed deviation) and oscillations reduction by BESS which are caused by grid voltage fluctuations. The results are discussed in the conclusion.

The main point of this paper is to determine the capability of the proposed BESS to protect a generator and turbine against negative transients of the grid voltage. The principle lays in the stabilization of the voltage at the point of common coupling between the generator, BESS, and grid (before the power transformer). The simple transient based on the real measured data is examined, then the control algorithm is proposed and evaluated. The examined voltage transient is a symmetrical drop and rise of the three-phase voltage. The proposed algorithm is then based on the stabilization of the generator output power.

II. Model Description

Regarding the model, some changes have been made compared to the model used in [4]. The main change is the addition of the grid model including line impedances and a controlled voltage source. This led to a stronger coupling between the generator and BESS model. The consequences were the stability issues of the simulation. As a solution, it was proposed the use of the more robust voltage synchronization algorithm for the BESS and conversion of the electrical BESS model from the Plecs environment into the SimPowerSystems. A detailed description of the modeled components is in the next sections.

A. Turbomachinery Model

A whole turbomachinery model was in detail described in [4]. Brief model topology is shown in the Fig. 1.

However, for the purposes of the following simulations, the model of the lines, power transformer, and power grid

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were added as was noticed before. The SimPowerSystems toolbox was used for that purpose. As a model of the lines, the Three-Phase PI Section Line model was selected. It represents the 0.1 km long line to the power transformer and 10 km to the substation. The power grid is represented by the serial connection of resistor and inductor in each phase with hard voltage sources on the grid side. As a power transformer was selected Three-Phase Transformer (Two Windings) model with D connection on the side of the generator and Y connection on the side of the grid.

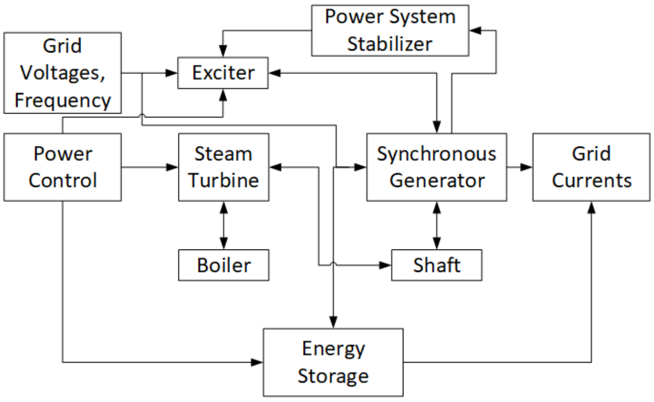

Fig. 1. Model topology

Outputs of the generator and energy storage are connected to the same electrical node.

SimPowerSystems model topology is shown in the Fig. 2.

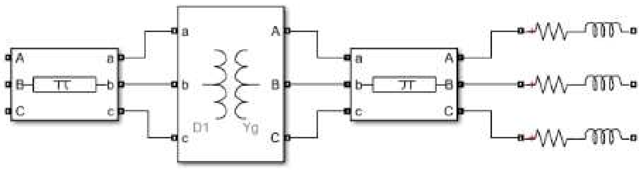

Fig. 2. SimPowerSystems model topology

B. Energy Storage Model

The model of the BESS has been updated compared to the model presented in [4]. The electrical part of the model has been converted from the Plecs environment into the SimPowerSystems for better cooperation with the rest of the model.

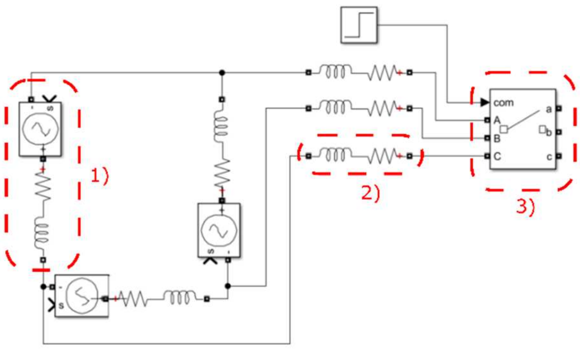

Fig. 3. SimPowerSystems model topology

In the Fig. 3, it is shown the electrical part of the BESS model. In part 1), it is one leg of the converter. The controlled voltage source represents serially connected H-bridges of the inverter and passive components represent output L filter. Passive components in the part 2) represent the impedance of the output transformer of the BESS. Lastly, in the part 3) is the switch connecting BESS to the rest of the system when the generator and grid reach a steady state.

Another change to the BESS model regarding new simulations was the change of the control algorithm, specifically the change of voltage synchronization technique. The previous version used simple SRF-PLL, which has been modified into the DSOGI-PLL algorithm, which provides a more robust operation [9].

The rest of the control algorithm remains the same. Its main part consists of PI control in a rotational reference frame, which controls the output active and reactive power of the BESS. The control algorithm is discussed in [3], where the control algorithm for the small-scale laboratory model is described.

C. Control

The control goal is the protection of the turbomachinery from the transients caused by the sudden changes in the grid voltage. The idea lays in the power smoothing supplied by the generator to the grid using BESS. Required active and reactive BESS power is controlled by the PI controller. Two approaches have been designed and tested. The first approach was simple, it relied on the fast response of BESS compared to the response of the generator. The control algorithm used PI controller, shown in the Fig. 4, utilizes a standard structure extended by a negative feedback loop for the integration part. Gain K_c ensures, that in steady-state when control error reaches zero, the BESS output also returns to zero. This is necessary because of the non-standard use of the controller, which is not directly controlling its input signal. The impact of the BESS action is not compensation of the generator output power, but rather causes voltage drop on the grid line impedance, which compensates for grid voltage fluctuation using the available power range.

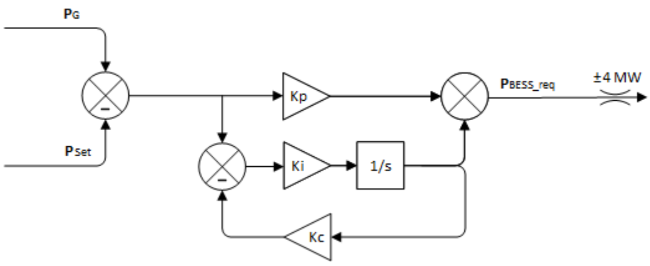

Fig. 4. 1st version of the controller for generator protection

In the second tested approach, the control error is calculated as the difference between the actual output power of the generator and the actual output power passed through the lowpass filter Fig. 5. This control intervenes against a change of the generator output power in a short time horizon, but in steady-state is the control error equal to zero. To simplify the control, the integrational part of the following controller was removed, because it does not contribute to the fast response of the BESS and it presents another parameter, that needs to be tuned.

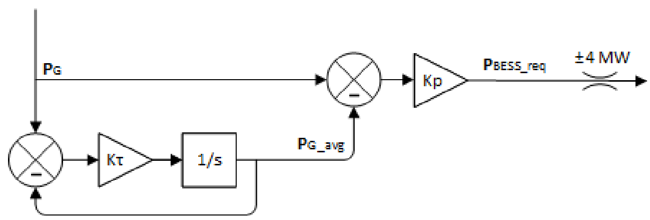

Fig. 5. 2nd version of the controler for generator protection

III. SIMULATIONS

The idea is to reduce the output power (rotor) oscillations of the synchronous generator connected with the steam turbine. The presented simulations are parametrized on a case study of a 200 MW unit of a coal-fired power plant. There is used per unit system defined in [4].

The power oscillations are caused by grid voltage fluctuations based on a real measured transient. Assumed grid voltage RMS is shown in Fig. 6. The whole simulation runs for 200 s and includes voltage fall as well as voltage rise.

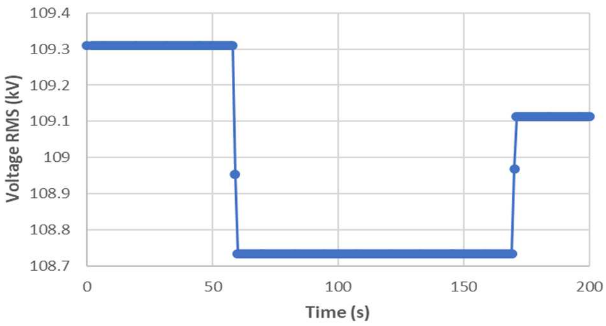

Fig. 6. Grid voltage fluctuations

A. Generator

In this part, the influence of grid voltage distortion on the generator is discussed. It has been stated, that in an effort to protect the generator and turbine, the output power of the generator is stabilized by the BESS. In the Fig. 7 and Fig. 8 the waveforms of the generator output power in response to the voltage fall and rise are presented. The blue waveform corresponds to the system without BESS.

Step change in the grid voltage causes transient in active and reactive power and consequent transient in generator rotor speed. In the figures, the derivation of the rotational speed is shown for a clearer view of the transient. This transient can cause mechanical oscillations and shorten the service life of the generator, turbine, or their coupling.

B. Generator with Energy Storage

In the Fig. 7 and Fig. 8 the orange waveform corresponds to the generator output active and reactive power with the active BESS controlled by the first proposed control algorithm. The yellow waveform corresponds the generator outputs with active BESS controlled by the second proposed control algorithm. In the results, it can be seen that employment of the BESS leads to the damping of transient of the common (generator and BESS) output power and consequently transient in rotational speed.

C. Comparison

For better evaluation of proposed control algorithms, the integral criterion is used (1). The value is an integral of generator rotor angular acceleration, which is calculated as speed differential, this value is squared and integration is started at the initial voltage drop. That means time from 58s to 59s. Results are summarized in the table TABLE I.

$$e = \int_{58}^{59} (d\omega)^2 \, dt \tag{1}$$

TABLE I.

Version	*e (-)*
With out BESS	$4.88 \cdot 10^{-7}$
1st control algorithm	$3.54 \cdot 10^{-7}$
2nd control algorithm	$2.91 \cdot 10^{-7}$

From the table and waveforms, it can be seen, that both methods lead to the lowering of mechanical oscillations. The second control algorithm achieves better results mainly because it reaches a new steady-state faster. Other trials, which are not shown in this paper showed the complexity of the problem. The whole system contains multiple controllers, which interact with each other. This makes it very complicated for tuning.

From the tested approaches, there is another one worth mentioning. It was based on slowing down the reaction of the BESS to the grid voltage change. Normally, BESS reacts to the change of the grid voltage by matching its output voltage to the new parameters of the grid and ensuring the required output power. The slower reaction of the BESS to the grid voltage change leads to the stabilization of the voltage at the point of common coupling, but this effect is negligible, due to the high output impedance of the BESS compared to the line impedance of the grid and stator inductance of the generator. This proved necessary for the active intervention of the BESS to stabilize generator output power.

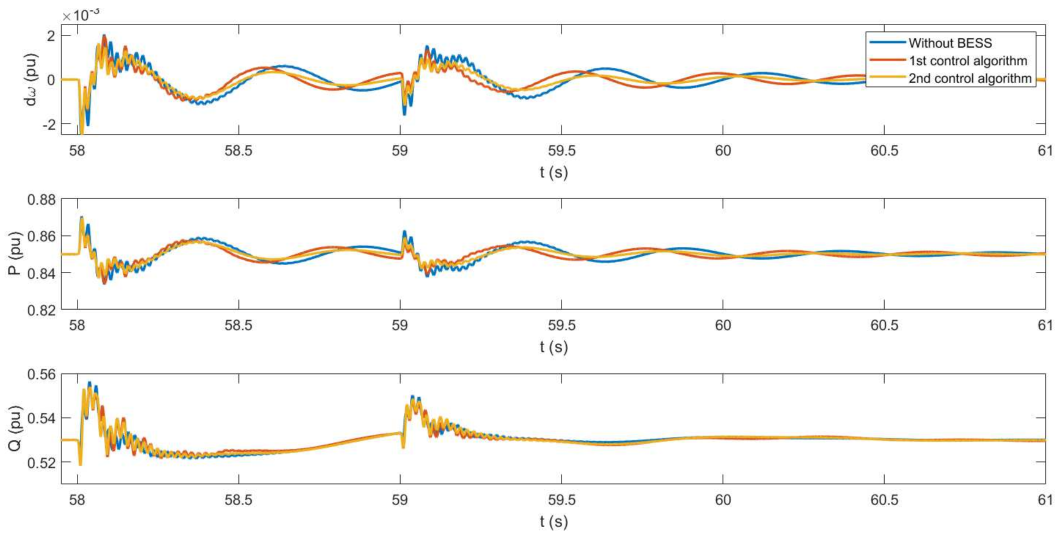

Fig. 7. Grid voltage drop outputs

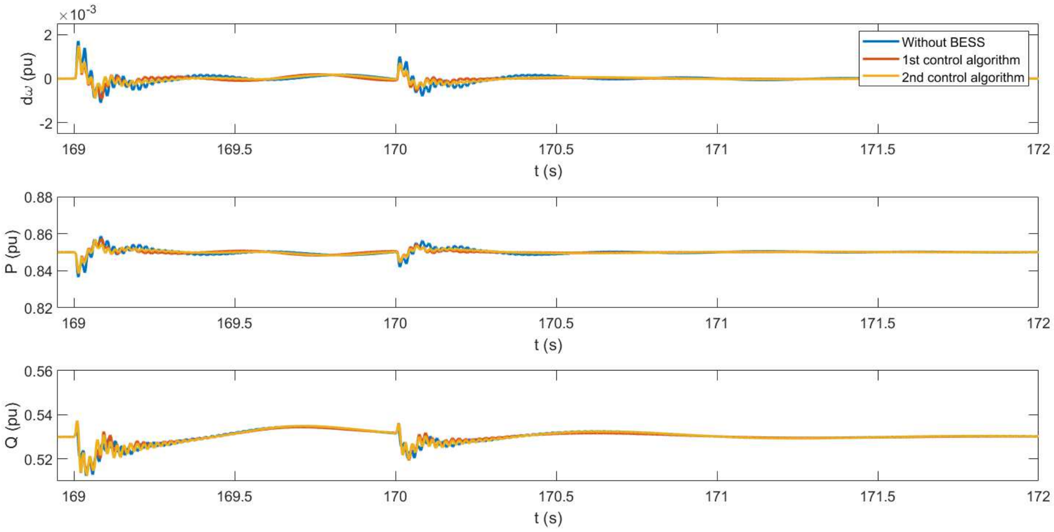

Fig. 8. Grid voltage rise outputs

IV. Conclusion

This paper describes the initial idea of the use of the BESS for decreasing the effects of the selected transient in the grid, which negatively influences the service life of the generator and turbine by mechanical oscillations. Simulation results show that the proposed control algorithm of the BESS leads to a significant reduction of the mechanical oscillations by the stabilization of the generator output power. This reduction will result in prolonged service life for the generator and turbine.

This simulation serves as proof of the concept of the initial idea. Future research will improve the cooperation of generator and BESS control. The focus will be also given to the other imperfection of the grid voltage, such as non-symmetries and higher harmonic components causing for example torsion oscillations.

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