Improvement of power grid stability and load distribution using diesel excitation controller

Ehsan Ganji a, *, Mehdi Mahdavian a

a Department of Computer Engineering, King Mongkut's University of Technology Thonburi
126 Pracha Uthit Rd, Bang Mot, Thung Khru, Bangkok 10140, Thailand

Received 14 March 2022; 1st revision 30 April 2022; 2nd revision 12 May 2022; Accepted 20 May 2022; Published online 29 July 2022

Abstract

One of the requirements for controlling hybrid power systems is designing an appropriate excitation system, flexibility, protection, and coordination of all components to improve system stability. In this paper, various types of equipment simulated in the linear form and non-linear models are connected to the power supply. In the same direction, while presenting a new controller for the diesel generator excitation system and a filter used to purify and attenuate current harmonics is reported on the stability of a grid-independent system. Finally, the variation of the mode for the voltage and power of the system has been confirmed at the time of error and complete system stability. Also, the important indicators in the analysis are obtained in the lowest values, which can be seen from the controlled harmonics of the system of this data. In addition, the variation of the mode for the voltage and power of the system has been confirmed and the important indicators in the analysis are obtained in the lowest values.

Copyright ©2022 National Research and Innovation Agency. This is an open access article under the CC BY-NC-SA license (https://creativecommons.org/licenses/by-nc-sa/4.0/).

Keywords: hybrid power systems; improve system stability; non-linear control models; excitation system; load distribution.

I. Introduction

Electricity consumption has increased dramatically over the past few decades. One way to provide this energy is to increase the use of small independent grids that can be powered by renewable energy. Basically, in independent systems, there are many problems in the field of stability of the power generation system in the event of imbalances and the effects of transmission lines, and several studies have been conducted to stabilize the output voltage. In [1], to solve the synchronous machine fluctuations in different operating conditions, three methods of an automatic voltage regulator, automatic voltage regulator with power system stabilization, and active disturbance rejection control (ADRC) methods have been used for the parallel excitation system of two generators. In [2], diesel technologies have been investigated as an accurate solution for renewable energy penetration focusing on engine time delay and generator inertia constant which is considered in the design of an isolated hybrid power system. In [3], an MG system is modeled to analyze interactions in which a grid-fed voltage converter and a grid-forming system are investigated in their constituent structure.

The major purpose of [4] is to present the status of variable speed diesel generators (VSDG) technologies and evaluate their performance in fuel, increase engine performance and reduce greenhouse gas (GHG) emissions based on performance evaluation and degree of innovation. In [5], information and stabilization of microgrid stability are presented and investigated by considering the characteristics related to small networks along with voltage dependence on frequency, perturbation, and low inertia. In [6], the effectiveness of the genetic algorithm (GA) algorithm in an independent system is presented and validated for comparison with proportional integral derivative (PID) control in the excitation control of a diesel generator used on the coast. In [7], the presentation of the PID controller is shown for two modes of constant excitation value and feedback loop value and selected as an efficient and convenient method along with an Alif and Vegard’s RISC (AVR) processor system for the excitation controller system of an asynchronous machine. The authors in [8] have modeled a hybrid power system the size of an electronic assembly in

* Corresponding Author. Tel: +98-918-5549181
E-mail address: Mr.Ehsanganji@gmail.com

doi: https://dx.doi.org/10.14203/j.mev.2022.v13.36-47
2088-6985 / 2087-3379 ©2022 National Research and Innovation Agency
This is an open access article under the CC BY-NC-SA license (https://creativecommons.org/licenses/by-nc-sa/4.0/)
MEV is Scopus indexed Journal and accredited as Sinta 1 Journal (https://sinta.kemdikbud.go.id/journals/detail?id=814)
which a logical and digital excitation controller is used as the output regulator of a diesel generator. Also, Reliability is considered for advanced performance practices in dealing with island conditions. In [9], a synchronous diesel machine system using a power supply equipped with system voltage control (SVC) with a fuzzy controller is proposed to regulate the reactive power of the injection. The authors also used capacitive banks to set up and stabilize the generator in the shortest possible start-up time. In [10], a reason for using independent scalable and reproducible grids has mentioned intelligence and intricate analysis. They also outline methods for increasing and grid small replicating. In [11], series switches have been used to reduce the interrupt frequency in small and independent grids. Reliability is also included for fast performance in the face of island mode. In [12], stabilization systems and flexible power devices for transient stabilization mode have also received special attention. In [13], the excitation system model has considered evaluating the stability of the system. The use of fuzzy methods and ant colony optimization to reduce losses, improve voltage, and increase the load balance of feeders in the reference [14] has suggested that this algorithm is more accurate than other optimization methods such as genetics and particle swarming. In [15], a detailed model has been presented for power source dynamics and load for frequency effects. To prevent voltage and frequency deviations in a power system, inverter dynamic control strategies have been proposed in the event of an error and the presence of inductive motor loads [16][17]. In [18], a comparison of microgrid systems has confirmed which energy management strategies have been considered for feasibility and control. In [19], an inverter-based distributed controller and mechanical loads were investigated in interrupt conditions, which indicates that this system may lose its stable performance in different loads presence, but the use of reverse strategy improves the situation. In [20], a meta-heuristic control scheme is developed to reduce low-frequency fluctuations and voltage disturbances of a multi-machine system in coordination with an optimized static synchronous compensator. In [21], a control strategy using virtual synchronous generators is used to synchronize output voltages without feedback. Designing and synchronizing an advanced frequency response system using a virtual technique can have significant results in tracking the point force of a permanent magnet generator to store active power. In diesel-wind hybrid systems, the desired system does not remain stable without a storage system with a diesel generators (DG) and clutch.

In this paper, the design of a new controller has been suggested for the excitation system of an emergency diesel generator in a small independent grid. Here, the use of nonlinear systems and feedback control for system controllers in a small autonomous network is an innovation in this paper. To confirm the performance of this system and its use in power grids, two modes of non-oscillation and oscillation of power machines has proposed with the occurrence of transmission line error.

II. Materials and Methods

In Figure 1, the system under study is presented. The study platform is an independent system that is initially ideal for use in a small network, then the information and data are expanded and completed in the form of an analytical project. This system independently consists of two basses, in bus 1 of 25 kV network with equivalent resistance-selfie, and a load with a power of 5 MW. Taking into account the error, the short circuit level 1000 MWA is modeled for quality factor X/R = 10. Bus 2 is powered by a resistive load and an asynchronous machine. This is done with the help of a 25 kV distribution line and a 6 MW transformer. In case of necessity, a synchronous machine is used as the capacitor bank of 500 KVAR to correct the power factor in bus 2. The 25 kV grid is modeled with a resistive-inductive equivalent source and a load with a power output of

![Figure 1. Diagram of the studied system](image-url)
5 MW. Also, an asynchronous machine with a power of 2250 HP is considered, 2.4 kV, and an asynchronous machine with a power of 3.125 MVA. Initially, the motor generates a mechanical power of 2000 HP and the diesel generator generates 500 kW of active power. The synchronous machine controls the voltage of 2400 volts of bus 2 equals to 1 pu and provides the active power of 500 kW in the hands of the consumer [12].

A. Synchronous machine block

The outputs of the voltage and speed of the synchronous machine are used as input feedback in a control system that includes the engine, diesel, steering blocks, and the excitation block. The components of the synchronous machine are shown in Figure 2.

In this block diagram, the design and control are done for the machine completely. First, the values of the machine speed, rotor speed, and angle are entered into the reference frame of (1) and (2).

\[ V = [R] + \frac{d\phi}{dt} + [\omega] \times \phi i \]  
\[ \phi i = [L] \times I \]  
where [R] is the machine resistance matrix in the DQ axis, [L] is the machine inductance matrix in the DQ axis, [\omega] is the speed matrix of the rotor, V is voltage measured from output feedback, \( \frac{d\phi}{dt} \) is Flux derivative obtained from matrix reactance, and I is inside the machine model block. Certain data and parameters must be modeled for function and design in harmony with other dynamic parts of the system. Linear and nonlinear relationships are the most important parametric changes in the machine model. In the following, the dynamic models for synchronous machine modeling are designed as follows:

\[ \delta = w - w_{ref}, w = -\frac{D}{2\pi}(w - w_{ref}) + \frac{w_{ref}}{2\pi}(P_m - P_e) \]  
\[ E = \frac{1}{\tau_e}[E_d' + \frac{(x_a - x_d)}{\tau_e}]_q \]  
\[ I_q = \frac{1}{P_1 + P_2}(P_1E_{q'} - Vx) + P_3(E_d + V_q) \]  
\[ I_d = \frac{1}{P_1 + P_2}[-P_2(E_{q'} - Vx) + P_1(E_d + V_q)] \]  
\[ V_d = E_d - R_dI_d - x_d'q_d V_q = E_q' - R_dI_q - x_d'q_d \]  
\[ V_e = \sqrt{V_d^2 - V_q^2}, P_e = E_{q'}I_q + E_dI_d, Q_e = E_{q'}I_q + E_dI_d \]  
\[ \frac{CS}{C_d} = 0.2\frac{es+1}{0.0002s^2+0.01s+1} \]  
\[ TF = 0.25s+1 \]  
where \( \delta \) is derivative of machine speed difference, \( w \) is machine speed, \( w_{ref} \) is machine reference speed, \( ir \) is derivative of the main speed of the machine, \( D \) is damping coefficient, \( H \) is inertia constant, \( P_m \) is mechanical power, \( P_e, Q_e \) are electrical and reactive electrical power, \( P_1, P_2, P_3 \) are Power values in ephemeral states, \( E_{q'}, E_d \) are internal dq-axis stator voltages, \( x_a, x_d \) are dq-axis reactance, \( T_d, T_q \) are dq-axis torque, \( I_d, I_q \) are dq-axis current, \( V_d, V_q \) are dq-axis voltage, and \( V_e, V_y \) are xy-axis voltage.

B. Diesel block and its controller

In Figure 3, the diesel model diagram is designed with the system under study. Here, the system is designed to create the necessary mechanical power for the synchronous machine to rotate in a nonlinear manner. The feedback speed enters the nonlinear controller section in line with the reference speed, then is applied to the motor section. The mechanical power output appears in a controlled manner in the synchronous machine.
In the design of the controller of this system, non-linear relations have been used for the flexibility of the system by considering the natural modes for the diesel generator at different times. In Fig. 3, CS is the system controller, whose function is as a regulator, and TF1, TF2 are related to the diesel actuator for non-linear control. The excitation controller diagram is designed as follows and the required data are given in Table 1.

Mode variables for diesel excitation will follow the following designed process and in the following equations, $x_1, x_2, x_3, x_4, x_5$ and $A_0, A_1, A_2, A_3, A_4, A_5, A_6, A_7$ are variable coefficients to obtain non-linear relationships in control feedbacks.

\[
\begin{align*}
    \dot{x}_1 &= x_1 \\
    \dot{x}_2 &= -A_0x_2 + A_1P_{mec} - A_1I_qx_3 - A_4x_4 \\
    \dot{x}_3 &= -A_2x_3 - A_3x_4 - A_2x_5 \\
    \dot{x}_4 &= -A_4x_4 + A_5x_5 \\
    \dot{x}_5 &= -A_6x_5 + A_1(W_{ref} + U - W_T)
\end{align*}
\]  

For the overall stability of the excitation system, also a filtered reversing controller is designed with a gradual strategy and feedback for the diesel controller. The diagram and operation process of which is shown in Figure 5.

![Figure 3. Diesel block diagram](image)

![Figure 4. Presentation of diesel controller design](image)

![Figure 4 shows a nonlinear section for the diesel controller, where $W_t$ is Unit speed in time, where $x_1, x_2 = (\omega - \omega_r), x_3 = E_q', x_4 = E_d', x_5 = E_r, U = T. A_1, A_2 = 0, 1, ..., 7$ which are given by](image)

![Table 1. Diesel control parameters](image)
Where $\zeta$ is damping coefficient, $\omega_n$ is synchronous speed, $S_K$ is saturation data, and $S_M$ is saturation mutual data.

In this proposed system, voltage harmonics are created by current harmonics. Voltage harmonic is created by the uneven voltage generated by the harmonic effect of the current with the source impedance. Current and voltage harmonics are directly proportional to the transmission of noise (energy interference) to the load, so the filter in Figure 5 is used to purify and attenuate current harmonics.

C. Diesel engine model

The diesel engine model is shown in Figure 6, which includes the governor, actuator and engine delay. The dynamic modeling relationships are also presented. In Figure 6, the mechanical power is generated in the engine system and is controlled by a diesel injection sensor. The elements in the figure, such as governor function $H_g$, actuator function $H_a$, and $T(1, 2, ..., 6)$ different values of torque in feedback, are expressed as [9]:

\[
\begin{align*}
\dot{p}_1 &= p_2 \\
\dot{p}_2 &= -2\zeta\omega_n \left[ S_K \left( \frac{\omega_n}{2\zeta} \right) p_1 + p_2 + S_K \left( \frac{\omega_n}{2\zeta} \right) S_M (x_r) \right] \\
S_M (x') &= \begin{cases} 
M & x' \geq M \\
-x' & x' \leq M
\end{cases}
\end{align*}
\]

(16)

(17)

Where $\zeta$ is damping coefficient, $\omega_n$ is synchronous speed, $S_K$ is saturation data, and $S_M$ is saturation mutual data.

In this proposed system, voltage harmonics are created by current harmonics. Voltage harmonic is created by the uneven voltage generated by the harmonic effect of the current with the source impedance. Current and voltage harmonics are directly proportional to the transmission of noise (energy interference) to the load, so the filter in Figure 5 is used to purify and attenuate current harmonics.

D. Asynchronous machine parameters

The asynchronous machine parameters are based on the SI system. The rotor reference frame and other parameters considered are tabulated in Table 2.

III. Results and Discussions

Typically, the initial conditions of the synchronous and asynchronous machines in a steady state are not clear; these conditions are:

• In synchronous machine block: The initial value of speed deviation, the rotor angle, the phase and amplitude of the current in the stator windings, and the initial field voltage required to reach the desired output voltage under specified load distribution.

• In asynchronous machine block: The initial amount of slip, phase, and amplitude of the motor windings current

In Figure 7, at the beginning of simulation in the asynchronous machine, the stator current values start at zero and the initial DC values gradually disappear. In Figure 8, the machine speed due to unbalanced conditions and variable load to achieve a steady-state takes time. We review here the two systems of non-oscillating and oscillating systems for checking the load distribution of the machines.
A. Load distribution in non-oscillating machine mode

Figure 9, Figure 10, Figure 11, and Figure 12 show the mechanical reaction, speed, and output voltage of the synchronous machine and the control signal for the diesel and generator system. Voltages and currents parameters of non-linear blocks are provided in Table 3.
In addition, it can be seen that at the time of the error, the output voltage dropped to about 0.2 pu and the excitation voltage was limited to 6 pu. After eliminating the error, the mechanical power is
rapidly increases to 1 pu and stays stable at 0.8. After 3 seconds, the terminal voltage becomes stable close to the reference voltage.

B. Load distribution in oscillating machine mode

In this section, the load distribution has been done with two machines that use the asynchronous machine as a reference instead of the induction source that leads to the required absorbed power or leads to generate to estimate the active generated power by other components and the power consumed.

In this case, but without the proposed controller, load distribution is not done in a sustainable state. So system outputs lose their lasting status and load distribution appears at the low-quality output. In this case, the output of the system is shown in Figure 13. After entering the diesel controller, the voltage terminal is set to 24985 Volts, which is the amount of earlier load distribution of the bus 1. After modeling the new mode, the machines parameters obtained are tabulated in Table 4.

As expected, in Figure 14, the results are similar to the previous state and the active power delivered by the oscillating bus is 7.04 MW. The difference of 0.03 MW is equivalent to transformer losses. Figure 15 and Figure 16 demonstrate the control signal of the proposed controller and the output voltage of the system.

The same is true for the frequency output in Figure 17, and it can be seen that the frequency does not cause severe system malfunction at the time of the error and continues steadily up to the 60 Hz frequency range. In Figure 18, according to the IEEE standard, the harmonic percentage value for our desired output is tolerable up to 5 %.

Table 3. Voltages and currents parameters of non-linear blocks

<table>
<thead>
<tr>
<th>Nonlinear elements</th>
<th>System outputs</th>
<th>System inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>'U_Circuit Breaker/Breaker A' = 0.67 V 3.20°</td>
<td>'U_Circuit Breaker/Breaker A' = 67.02 A 3.20°</td>
<td></td>
</tr>
<tr>
<td>'U_Circuit Breaker/Breaker B' = 0.67 V 116.80°</td>
<td>'U_Circuit Breaker/Breaker B' = 67.02 A 116.80°</td>
<td></td>
</tr>
<tr>
<td>'U_Circuit Breaker/Breaker C' = 0.67 V 123.20°</td>
<td>'U_Circuit Breaker/Breaker C' = 67.02 A 123.20°</td>
<td></td>
</tr>
<tr>
<td>'U_Three-phase to ground Fault/Fault A' = 20400.16 V -0.40°</td>
<td>'U_Three-phase to ground Fault/Fault A' = 0.00 A 0.00°</td>
<td></td>
</tr>
<tr>
<td>'U_Three-phase to ground Fault/Fault B' = 20400.16 V -120.40°</td>
<td>'U_Three-phase to ground Fault/Fault B' = 0.00 A 0.00°</td>
<td></td>
</tr>
<tr>
<td>'U_Three-phase to ground Fault/Fault C' = 20400.16 V 119.60°</td>
<td>'U_Three-phase to ground Fault/Fault C' = 0.00 A 0.00°</td>
<td></td>
</tr>
<tr>
<td>'U_AB: Synchronous Machine 3.125 MVA' = 3394.11 V -1.57°</td>
<td>'U_AB: Synchronous Machine 3.125 MVA' = 325.34 A -90.05°</td>
<td></td>
</tr>
<tr>
<td>'U_BC: Synchronous Machine 3.125 MVA' = 3394.11 V-121.57°</td>
<td>'U_BC: Synchronous Machine 3.125 MVA' = 325.34 A 149.95°</td>
<td></td>
</tr>
<tr>
<td>'U_AB: Asynchronous Machine 2250 HP' = 3394.11 V -1.57°</td>
<td>'U_AB: Asynchronous Machine 2250 HP' = 556.11 A -53.66°</td>
<td></td>
</tr>
<tr>
<td>'U_BC: Asynchronous Machine 2250 HP' = 3394.11 V -121.57°</td>
<td>'U_BC: Asynchronous Machine 2250 HP' = 556.11 A -173.66°</td>
<td></td>
</tr>
</tbody>
</table>
Figure 14. Shapes of mechanical power, controller output signal, output voltage and synchronization machine speed (oscillation mode with the proposed controller for diesel).

Here, the amount of mechanical power stabilizes in 0.8.

Balancing the system output voltage

Balancing the SM machine speed

Figure 15. Control signal of the proposed controller

The reaction is faster, more precise and also the controller signal is balancing.

Figure 16. Output voltage of system
Figure 17. Output Frequent

Figure 18. The harmonic diagram: (a) The harmonic diagram of the system currents; (b) The harmonic diagram of the active, reactive, and mechanical power
IV. Conclusion

In Independent systems, load distribution is generally one of the most important things that must be done seriously. In this small independent system, electric machines and other elements which have been mentioned in the earlier sections, transient time error, engine and generator isolation, synchronous machine drive system and the speed controller for keeping voltage and speed at a certain amount, synchronous machine controllers and emergency diesel controllers and simulation results verify the stability of the independent system. At the time of system error, unbalanced in different parts appeared in charts, but with the arrival of the proposed controller, load distribution was done very accurately. Also, we saw that the diesel had timely compensated for the deficiencies and that stability and output setting was done accurately by the proposed controller. The harmonic values are hardly possible to reach the lowest values that we were able to obtain these amounts to less than acceptable amount. This system is intended as an independent system and can be applied in practice to the industry.

Declarations

Author contribution

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Additional information

Reprints and permission: information is available at https://mev.lipi.go.id/.

References


