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

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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.

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 Alf 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

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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

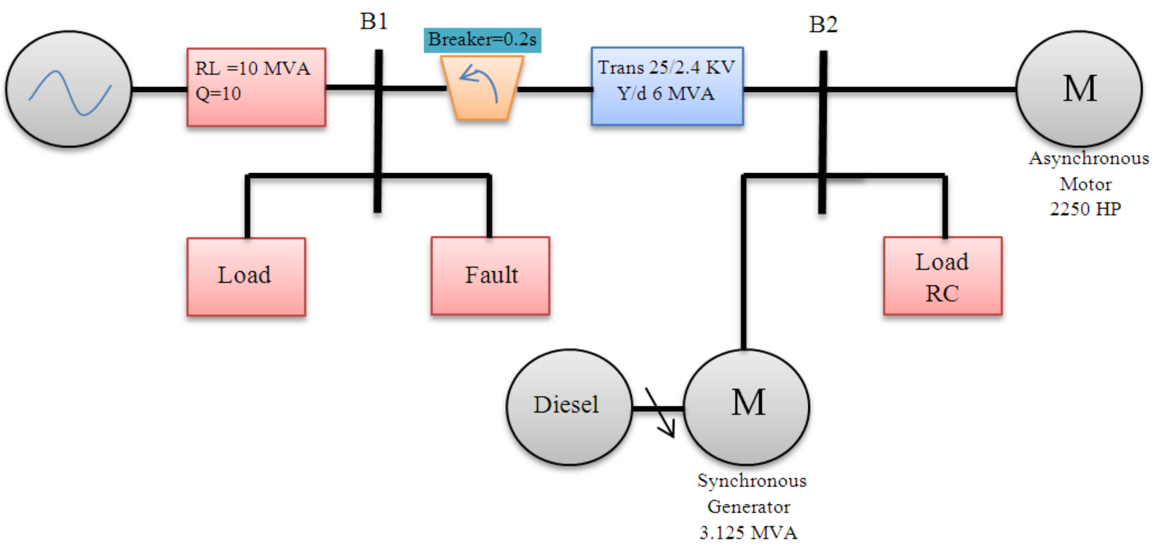


Figure 1. Diagram of the studied system

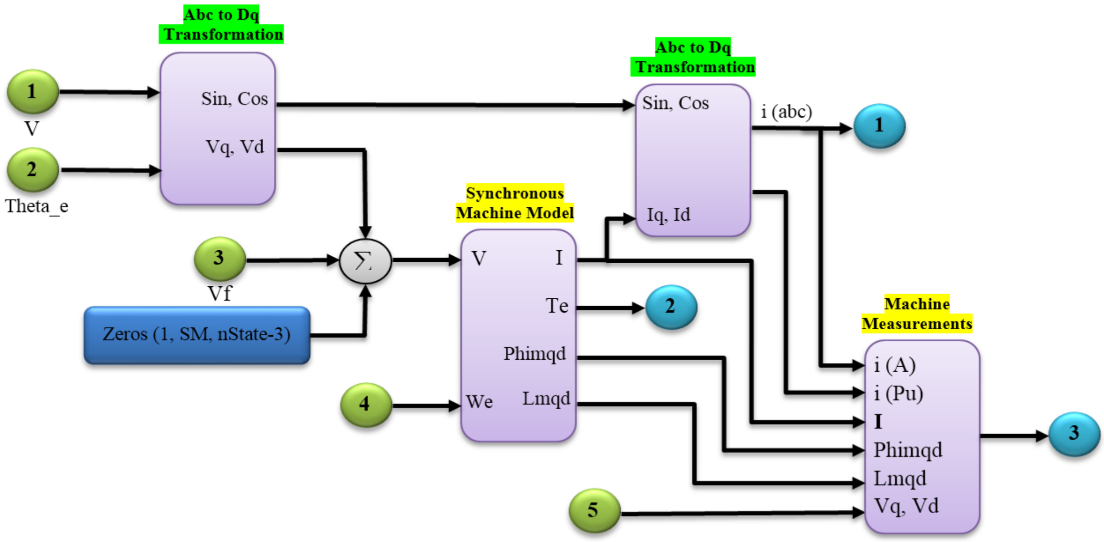


Figure 2. Block diagram of the designed synchronous machine

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 rotor speed and angle are entered into the reference conversion block from the left, and then the obtained information enters the synchronous model block. At its output, we have the torque and other parameters, and in the last block to the right of the measurement block, we have the necessary parameters. The modeling of this diagram is done in the reference frame of (1) and (2).

$$V = [R] + \frac{dphi}{dt} + [\omega] \times phi \tag{1}$$

$$phi = [L] \times I \tag{2}$$

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, $dphi$ 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:

$$\dot{\delta} = w - w_{ref}, \dot{w} = -\frac{D}{2H}(w - w_{ref}) + \frac{w_{ref}}{2H}(P_m - P_e) \tag{3}$$

$$E = {}^{\dot{'}}{}_{q}\frac{1}{T_{d_q}}{}'\frac{(x_d - x_d')}{T_d}\,{}_{d}\frac{1}{T_{d_f}} \tag{4}$$

$$\dot{E}_d' = \frac{1}{T_q}E_d' + \frac{(x_q - x_q')}{T_q}I_q \tag{5}$$

$$I_q = \frac{1}{P_1^2 + P_2P_3}[P_1(E_q' - Vx) + P_3(E_d' + V_y)] \tag{6}$$

$$I_d = \frac{1}{P_1^2 + P_2P_3}[-P_2(E_q' - Vx) + P_1(E_d' + V_y)] \tag{7}$$

$$V_d = E_d' - R_aI_d - x_q'I_q, V_q = E_q' - R_aI_q - x_d'I_d \tag{8}$$

$$V_t = \sqrt{V_d^2 - V_q^2}, P_e = E_q'I_q + E_d'I_d, Q_e = E_q'I_d + E_q'I_d \tag{9}$$

where δ is derivative of machine speed difference, w is machine speed, w_{ref} is machine reference speed, $\dot{w}$ 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_d, x_q 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_x, 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 non-linear manner. The feedback speed enters the non-linear 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.

$$CS = \frac{0.2s+1}{0.0002s^2+0.01s+1} \tag{10}$$

$$TF1 = \frac{0.25s+1}{0.009s+1} \tag{11}$$

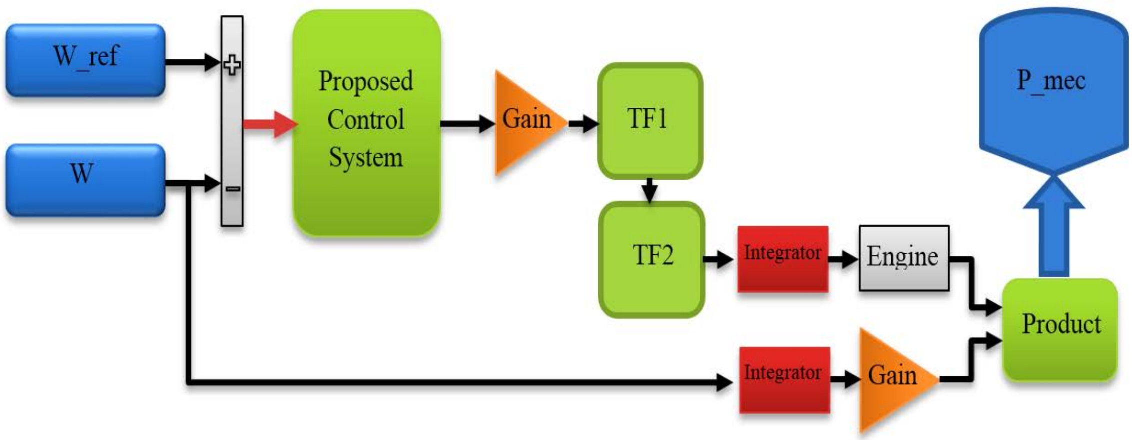


Figure 3. Diesel block diagram

$$TF2 = \frac{1}{0.384s+1} \quad (12)$$

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, 2, 3, 4, 5) and A (0, 1, 2, 3, 4, 5, 6, 7) are variable coefficients to obtain non-linear relationships in control feedbacks.

$$\begin{aligned} \dot{x}_1 &= x_1 \\ \dot{x}_2 &= -A_0 x_2 + A_1 P_{mec} - A_1 I_q x_3 - A_1 I_d x_4 \\ \dot{x}_3 &= -A_2 x_3 - A_3 I_d - A_2 x_5 \\ \dot{x}_4 &= -A_4 x_4 + A_5 I_q \\ \dot{x}_5 &= -A_6 x_5 + A_1 (W_{ref} + U - W_t) \end{aligned} \quad (13)$$

Table 1.
Diesel control parameters

Inductancees (pu)	Machine constant (sec)	Saturation data
Ld=1.56; Lq=1.06	Tdo' = 3.7	S(1,0)=0.1724
Ld'=0.296; Lq"=0.177	Tdo'' = 0.05	S(1,2)=0.6034
Ld"=0.177	Tdo' = 0.05	
L1=0.088	H=1.0716	

Figure 4 shows a nonlinear section for the diesel controller, where W_t is Unit speed in time, where $x_1, x_2 = (\omega - \omega_r), x_3 = E'_q, x_4 = E'_d, x_5 = E_f, U = T.A_i$, A_i=0,1,...,7 which are given by

$$A_0 = \frac{D}{2H}, A_1 = \frac{\omega_r}{2H}, A_2 = \frac{1}{T_d}, A_3 = \frac{L_d\text{-}L'_d}{T_d} \quad (14)$$

$$A_4 = \frac{1}{T''_{do}}, A_5 = \frac{\phi d\text{-}\phi q}{T_d}, A_6 = \frac{1}{Td'}, A7 = \frac{1}{Td''} \quad (15)$$

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.

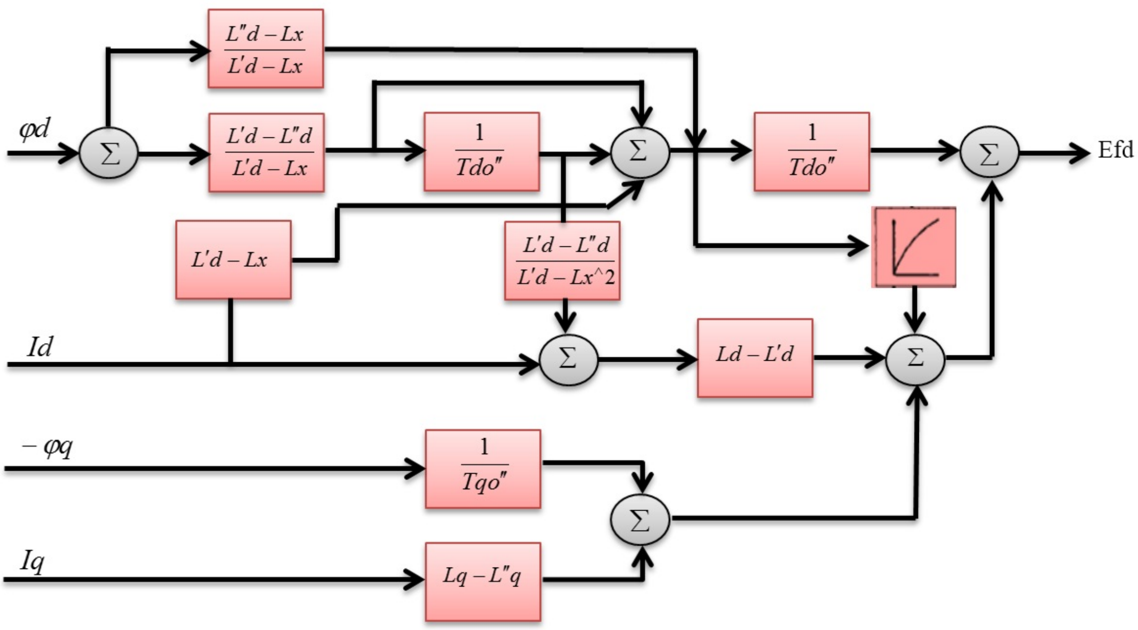


Figure 4. Presentation of diesel controller design

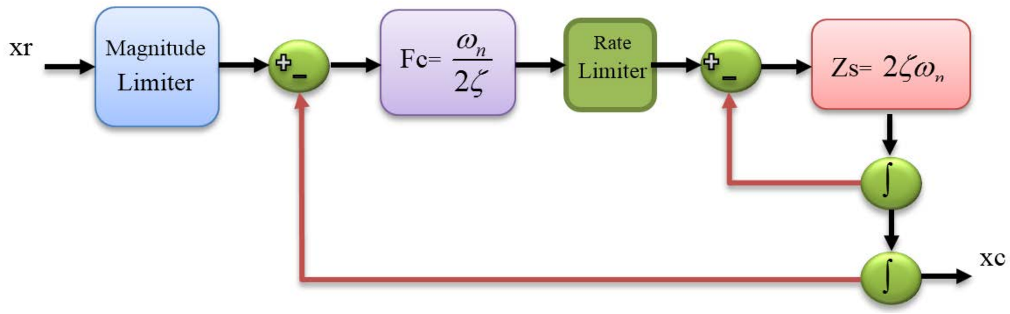


Figure 5. Reverse backup filter model

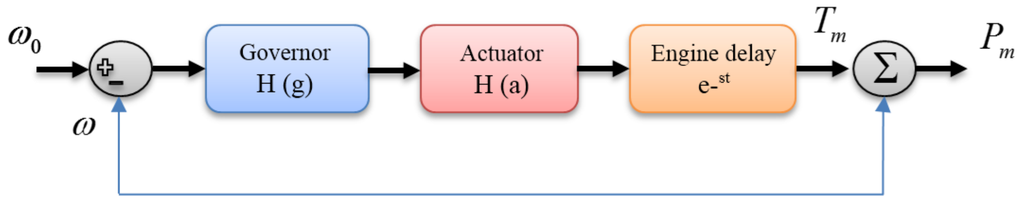


Figure 6. Schematic of a diesel engine

$$\dot{p}_1 = p_2$$

$$\dot{p}_2 = -2\zeta\omega_n \left[S_R \left(\frac{\omega_n}{2\zeta} \right) p1 + p2 + S_R \left(\frac{\omega_n}{2\zeta} \right) S_M(xr) \right] \quad (16)$$

$$S_M(x^r) = \begin{cases} M \xrightarrow{if} x^r \geq M \\ x^r \xrightarrow{if} |x^r| \langle M \\ -M \xrightarrow{if} x^r \leq M \end{cases} \quad (17)$$

Where ζ is damping coefficient, ω_n is synchronous speed, S_R 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]:

$$H_g = \frac{K(1+T_3 s)}{1+(1+T_1 s + T_1 T_2 s^2)},$$
$$H_a = \frac{(1+T_4 s)}{s(1+T_5 s)+(1+T_6 s)} \quad (18)$$

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.

Table 2.
Asynchronous machine parameters

Parameters	Values
Nominal power, voltage(line to line), frequency	[1678500 VA, 2400 Vrms, 60 Hz]
Stator resistance and inductance	[0.029 ohm, 0.0226/377 H]
Rotor resistance and inductance	[0.022 ohm, 0.0226/377 H]
Mutual inductance Lm	13.04/377 H
Inertia, friction factor, pole pairs	[63.87 J, 0 F, 2 P]

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.

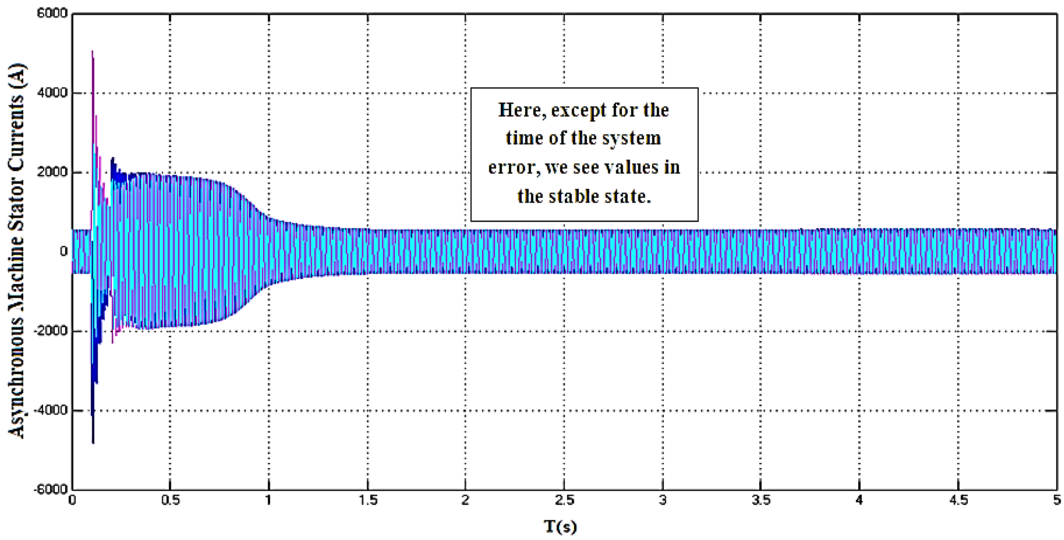


Figure 7. Stator currents asynchronous machine

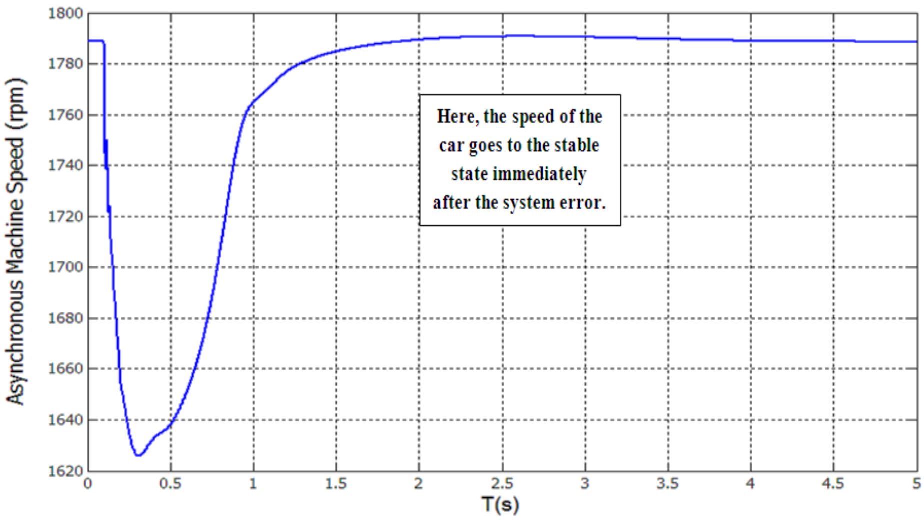


Figure 8. Asynchronous machine speed

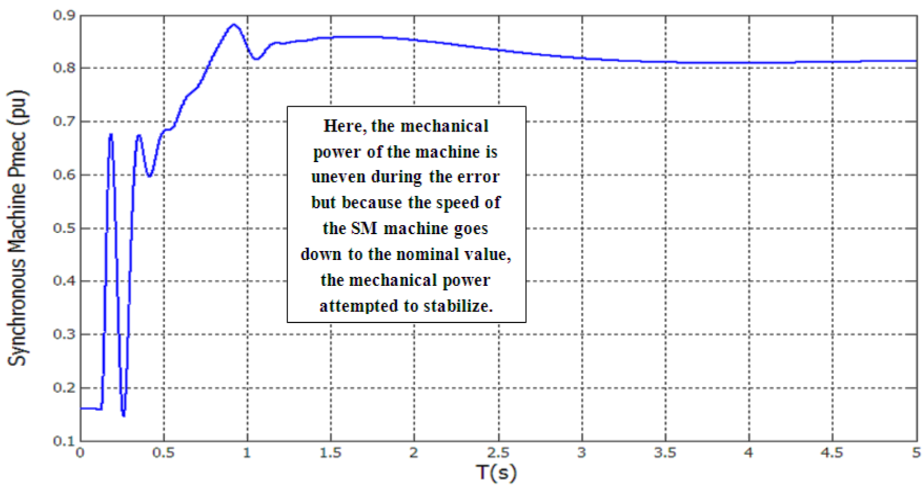


Figure 9. Mechanical power of synchronous machine

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

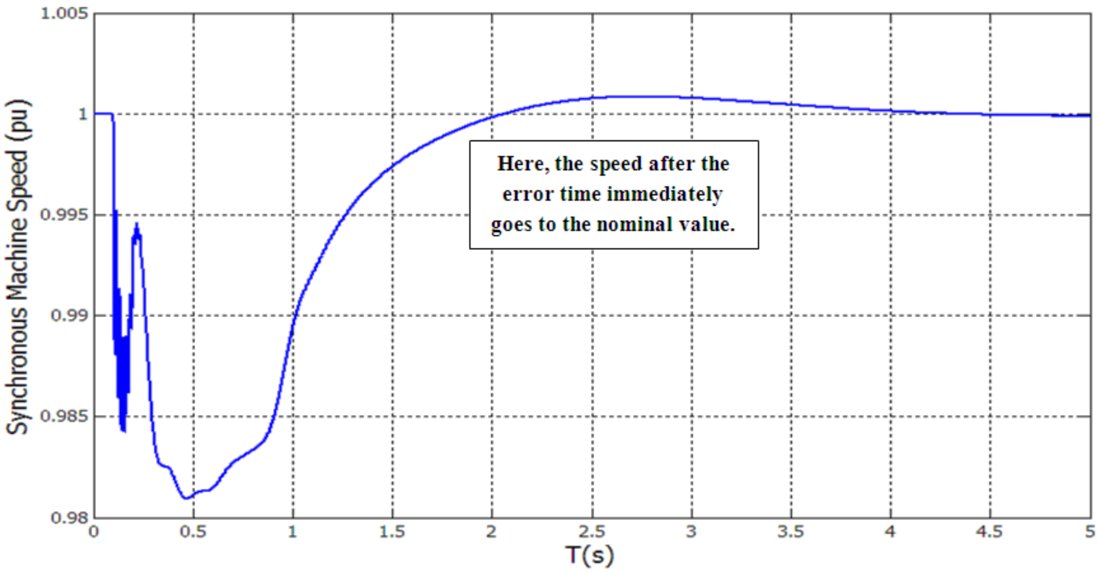


Figure 10. Synchronous machine speed

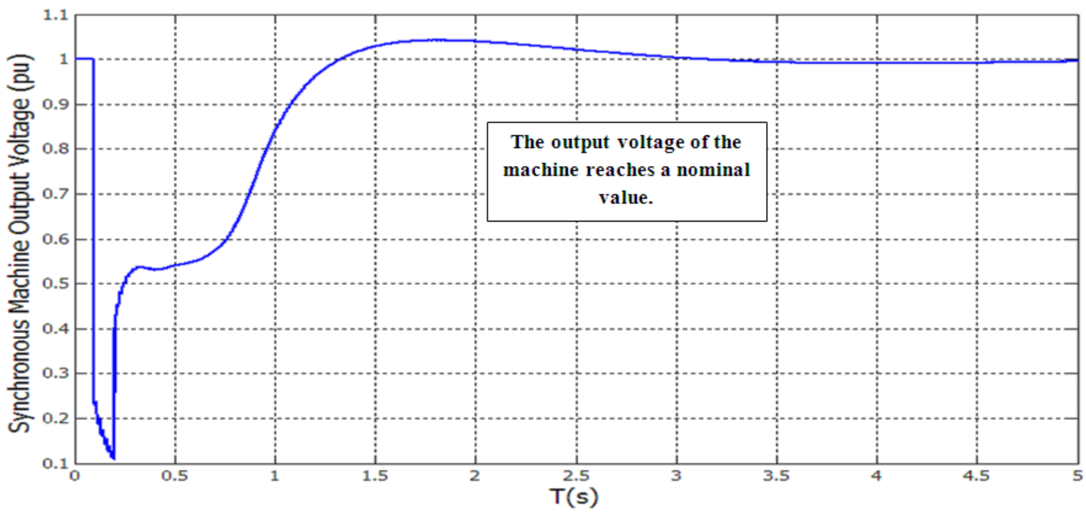


Figure 11. Synchronous machine output voltage

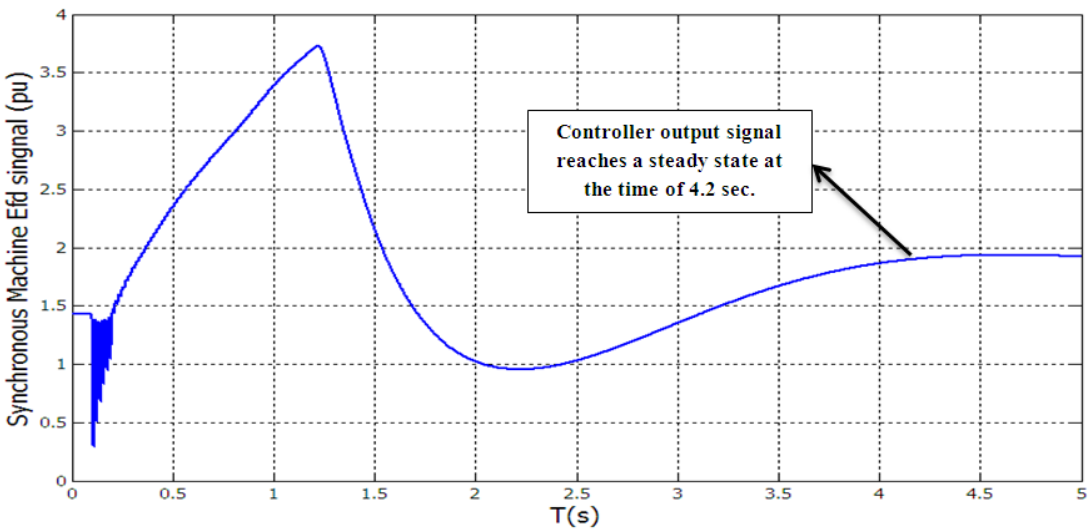


Figure 12. Synchronous and diesel machine control signal

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

Nonlinear elements	
System outputs	System inputs
'U_Circuit Breaker/Breaker A ' = 0.67 V 3.20°	'I_Circuit Breaker/Breaker A ' = 67.02 A 3.20°
'U_Circuit Breaker/Breaker B ' = 0.67 V -116.80°	'I_Circuit Breaker/Breaker B ' = 67.02 A -116.80°
'U_Circuit Breaker/Breaker C ' = 0.67 V 123.20°	'I_Circuit Breaker/Breaker C ' = 67.02 A 123.20°
'U_Three-phase to ground Fault/Fault A' = 20400.16 V -0.40°	'I_Three-phase to ground Fault/Fault A ' = 0.00 A 0.00°
'U_Three-phase to ground Fault/Fault B' = 20400.16 V -120.40°	'I_Three-phase to ground Fault/Fault B ' = 0.00 A 0.00°
'U_Three-phase to ground Fault/Fault C' = 20400.16 V 119.60°	'I_Three-phase to ground Fault/Fault C ' = 0.00 A 0.00°
'U_AB: Synchronous Machine 3.125 MVA ' = 3394.11 V -1.57°	'I_A: Synchronous Machine 3.125 MVA ' = 325.34 A -90.05°
'U_BC: Synchronous Machine 3.125 MVA ' = 3394.11V-121.57°	'I_B: Synchronous Machine 3.125 MVA ' = 325.34 A 149.95°
'U_AB: Asynchronous Machine 2250 HP ' = 3394.11V-1.57°	'I_A_stator: Asynchronous Machine 2250 HP' = 556.11 A -53.66°
'U_BC: Asynchronous Machine 2250 HP ' = 3394.11V -121.57°	'I_B_stator: Asynchronous Machine 2250 HP' = 556.11 A -173.66°

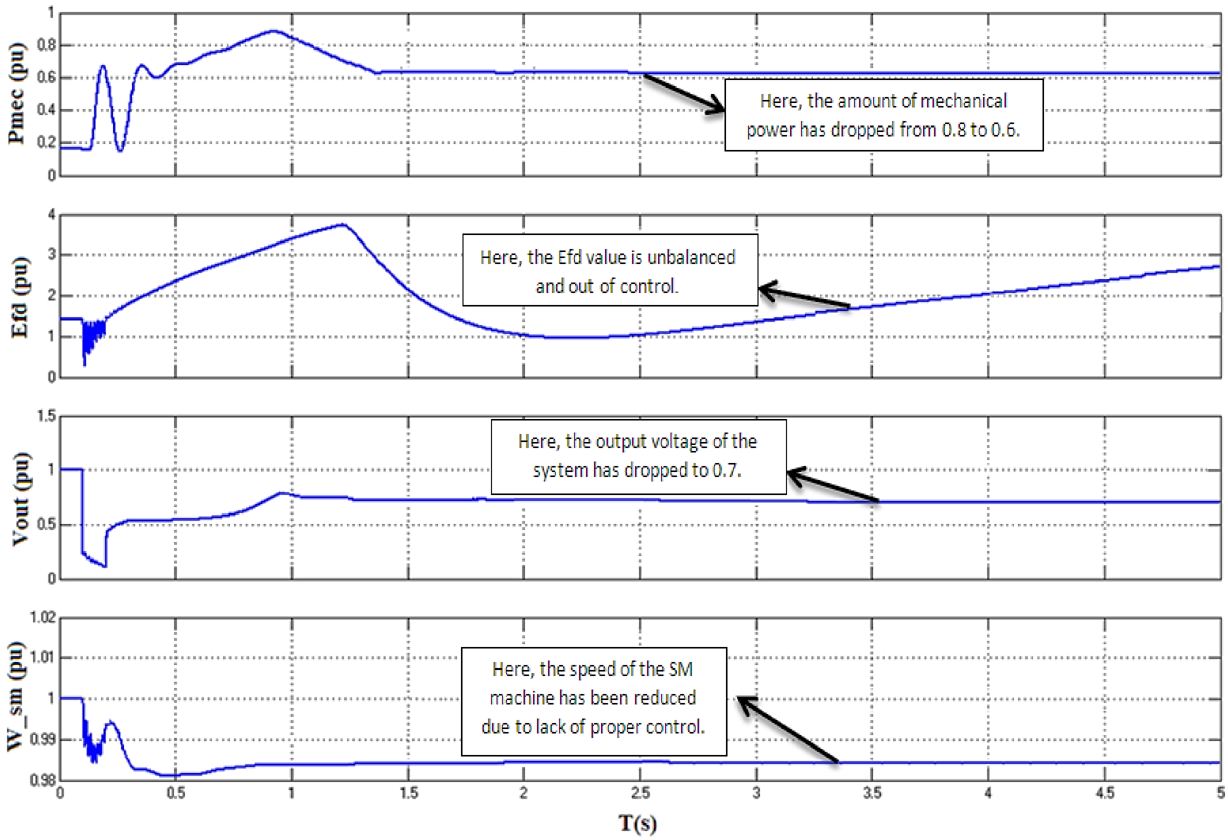


Figure 13. Synchronous and diesel machine control signal (Oscillation mode in the absence of the proposed controller for diesel)

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 %.

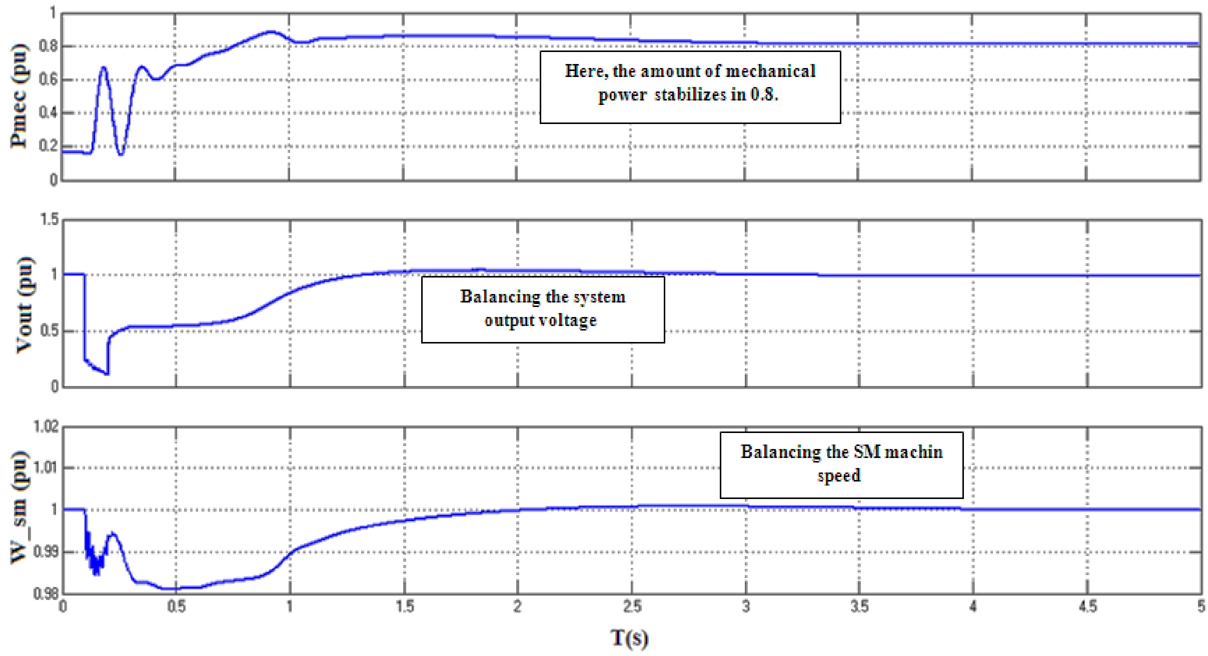


Figure 14. Shapes of mechanical power, controller output signal, output voltage and synchronization machine speed (oscillation mode with the proposed controller for diesel)

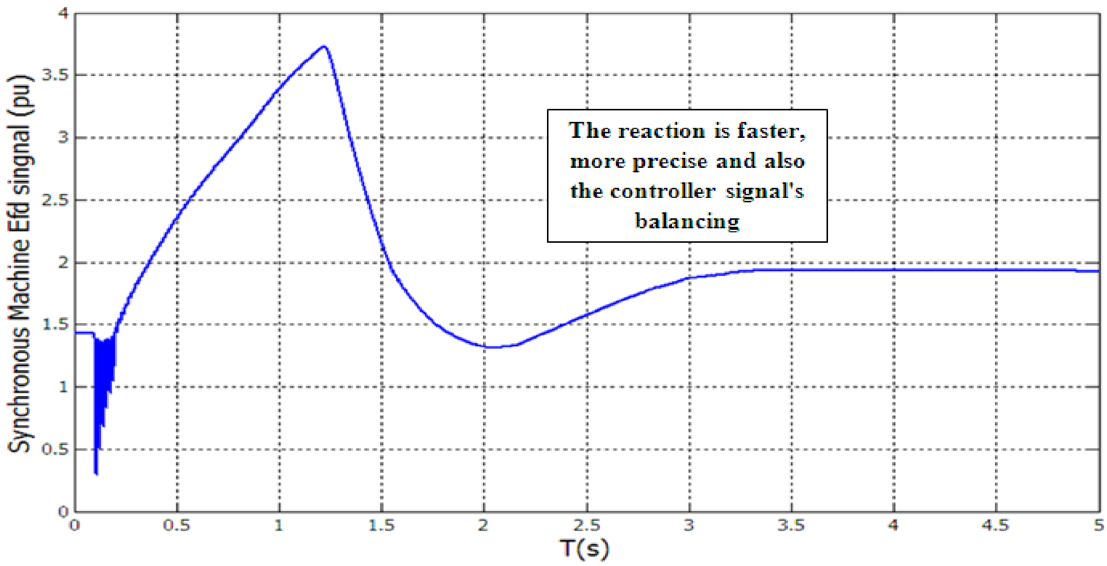


Figure 15. Control signal of the proposed controller

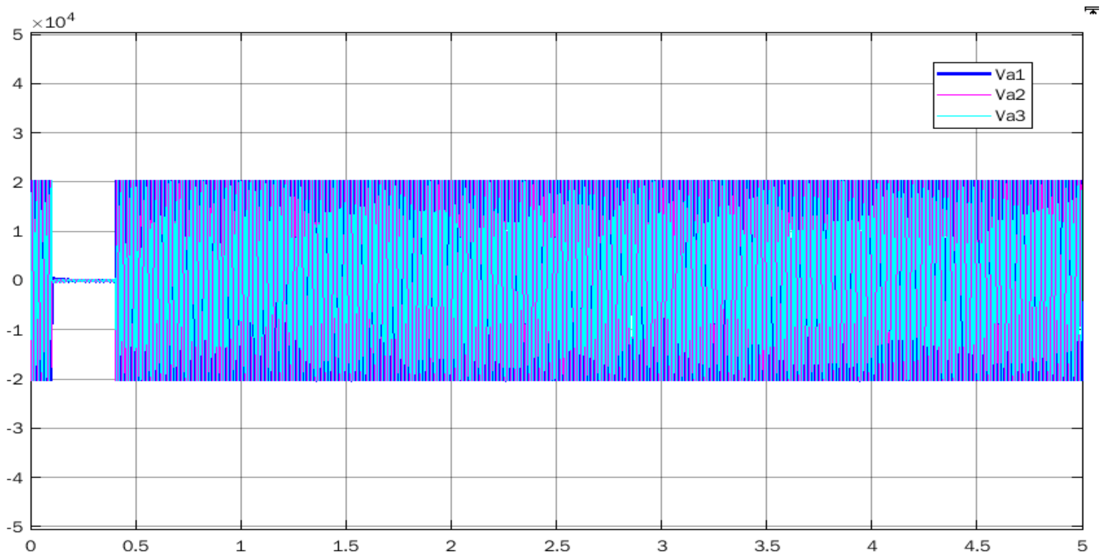


Figure 16. Output voltage of system

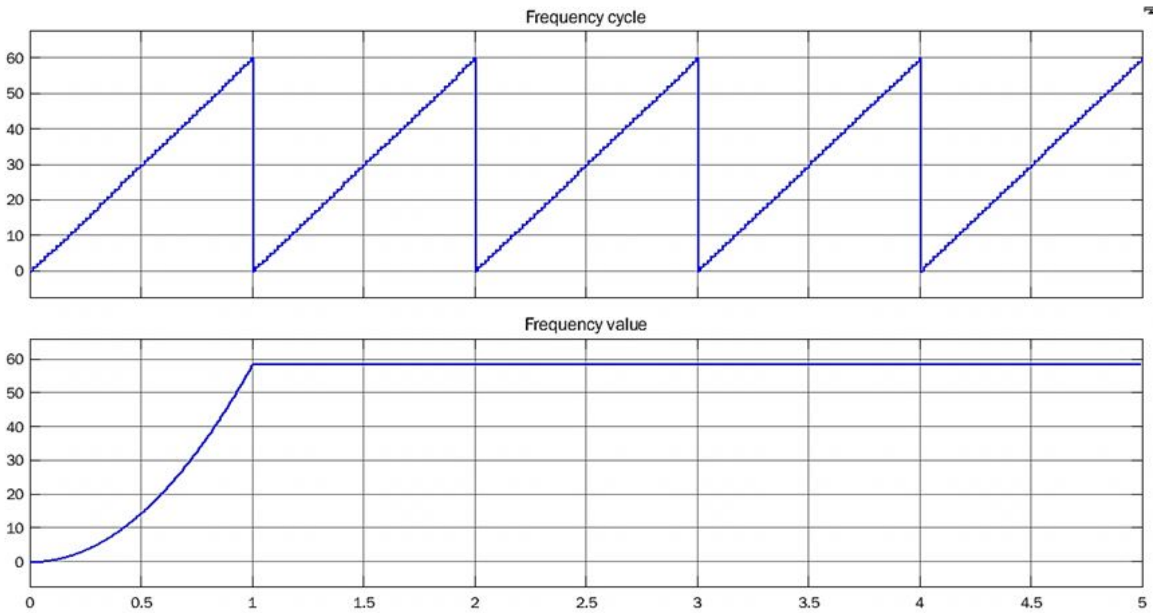
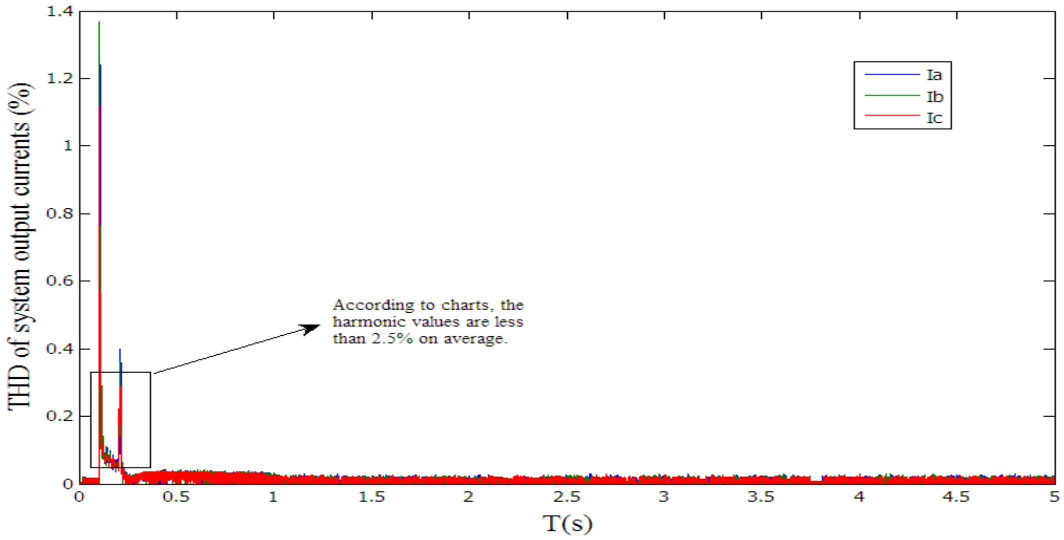
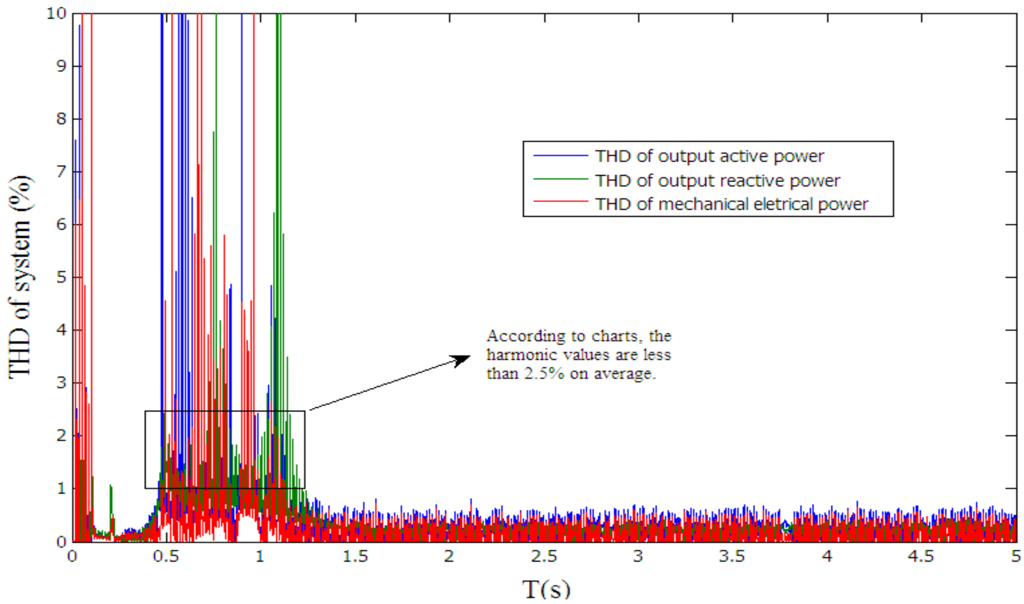


Figure 17. Output Frequent



(a)



(b)

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

Table 4.
Machines parameters

Synchronous machine	Asynchronous machine
Power: 3.125 MVA	Power: 2250 HP
Nominal: 3.125 MVA 2400 V rms	Nominal: 1.6785 MVA 2400 V rms
Bus type: P & V generator	Bus type: Asynchronous Machine
Uan phase: -31.57°	Uan phase: -31.57°
Uab: 2400 Vrms [1 pu] -1.57°	Uab: 2400 Vrms [1 pu] -1.57°
Ubc: 2400 Vrms [1 pu] -121.57°	Ubc: 2400 Vrms [1 pu] -121.57°
Uca: 2400 Vrms [1 pu] 118.43°	Uca: 2400 Vrms [1 pu] 118.43°
Ia: 230.05 Arms [0.306 pu] -90.05°	Ia: 393.23 Arms [0.9739 pu] -53.66°
Ib: 230.05 Arms [0.306 pu] 149.95°	Ib: 393.23 Arms [0.9739 pu] -173.66°
Ic: 230.05 Arms [0.306 pu] 29.95°	Ic: 393.23 Arms [0.9739 pu] 66.34°
P: 5e+05 W [0.16 pu]	P: 1.5146e+06 W [0.9024 pu]
Q: 8.1518e+05 Vars [0.2609 pu]	Q: 6.1473e+05 Vars [0.3662 pu]
Pmec: 5.0105e+05 W [0.1603 pu]	Pmec: 1.492e+06 W [0.8889 pu]
Torque: 2658.2 N.m [0.1603 pu]	Torque: 7964 N.m [0.8944 pu]
Vf: 1.428 pu	slip: 0.006119

IV. Conclusion

In Independent systems, load distribution is generally one of the most important things that must do 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.

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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.

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References

[1] Wang, Rongjie, Xiangyu Liu, and Yuyuan Huang. "Synchronous generator excitation system for a ship based on active disturbance rejection control," *mathematical problems in Engineering*, 2021.

[2] Semshchikov, E., Hamilton, J., Wu, L., Negnevitsky, M., Wang, X., & Lyden, "S. Frequency control within high renewable penetration hybrid systems adopting low load diesel methodologies," *Energy Procedia*, 160, 483-490, 2019.

[3] Moran-Rio, Diana Patricia, *et al*, "Influence of the phase-locked loop on the design of microgrids formed by diesel generators and grid-forming converters," *IEEE Transactions on Power Electronics*, 2021.

[4] M. Mobarra, M. Rezkallah, & A. Ilinca, "Variable speed diesel generators: performance and characteristic comparison," *Energies*, 15(2), 592, 2022.

[5] M. Farrokhabadi, C. A. Cañizares, J. W. Simpson-Porco, E. Nasr, L. Fan, P. A. Mendoza-Araya, ... & J. Reilly, "Microgrid stability definitions, analysis, and examples," *IEEE Transactions on Power Systems*, 35(1), 13-29, 2019.

[6] Rodriqeze-Calvo, Andrea, *et al.*, "Evaluating the determinants of the scalability and reliability of islanded operation in medium voltage networks with cogeneration," In *2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST)*, pp. 80-87, Sept. 2015.

[7] K. May, *et al.*, "Improving scalability and replicability of smart grid projects," *23rd International Conference on Electricity Distribution*, June, 2015.

[8] Conti S, Rizzo SA, El-Saadany EF, Essam M, Atwa YM, "Reliability assessment of distribution systems considering telecontrolled switches and micro-grids," *IEEE Transactions on Power Systems*. Mar, 29 (2), 598-607, 2014.

[9] Shahgholian G, Mahdavian M, Ganji E, Eshaghpour I, Matouri M, Janghorbani M, "Transient stability enhancement of a two-machine power system using SVC and PSS: A comparative study," *2017 14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Nov, pp. 103-106, 2017.

[10] Report, *Excitation system models for power system stability studies*. IEEE Transactions on power apparatus and systems. Feb (2):494-509, 1981.

[11] H. B. Tolabi, M. H. Ali, M. Rizwan, "Simultaneous reconfiguration, optimal placement of DSTATCOM, and photovoltaic array in a distribution system based on fuzzy-ACO approach," *IEEE Transactions on sustainable Energy*, Jan, 6(1):210-218, 2015.

[12] JI. Jadric, D. Borojevic, M. Jadric, "Modeling and control of a synchronous generator with an active DC load," *IEEE transactions on Power Electronics*, Mar, 15(2), 303-11, 2000.

[13] H. Chen, Z. Lu, J. Ye, S. Zhou, "A real shipboard power system and its computer simulation," *In Power Systems Conference and Exposition*, Mar, 15 (pp. 1-7). 2009.
[14] K. E. Yeager, J. R. Willis, "Modeling of emergency diesel generators in an 800 Megawatt nuclear power plant," *IEEE Transactions on Energy Conversion*, Vol 8, No 3, September, 1994.
[15] J. J. Justo, F. Mwasilu, J. Lee, J. W. Jung, "AC-microgrids versus DC-microgrids with distributed energy resources: A review,". *Renewable and Sustainable Energy Reviews*, Aug 1, 24, 387-405, 2013.
[16] A. K. Alaboudy, H. H. Zeineldin, J. Kirtley, "Microgrid stability characterization subsequent to fault-triggered islanding incidents," *IEEE transactions on power delivery*, Apr, 27(2), 658-69, 2012.
[17] A. H. Alaboudy, H. H. Zeineldin, J. Kirtley, "Simple control strategy for inverter-based distributed generator to enhance microgrid stability in the presence of induction motor loads," *IET Generation, Transmission & Distribution*, Oct, 7(10), 1155-62, 2013.
[18] Y. Tan, K. M. Muttaqi, P. Ciufo, L. Meegahapola, "Enhanced frequency response strategy for a PMSG-based wind energy conversion system using ultracapacitor in remote area power supply systems," *IEEE Transactions on Industry Applications*, Jan, 53(1), 549-58, 2017.
[19] R. S. Fernandez, "Simulation of the transition from Wind only mode to wind diesel mode in a no-storage wind diesel system," *IEEE Latin America Transactions*, Sep, 7(5), 2009.
[20] R. Kumar, R. Singh, and H. Ashfaq, "Stability enhancement of multi-machine power systems using Ant colony optimization-based static synchronous compensator," *Computers & Electrical Engineering*, vol. 83, p. 106589, May, 2020.
[21] A. Belila, Y. Amirat, M. Benbouzid, E. M. Berkouk, and G. Yao, "Virtual synchronous generators for voltage synchronization of a hybrid PV-diesel power system," *International Journal of Electrical Power & Energy Systems*, vol. 117, p. 105677, May, 2020.