Performance evaluation of microgrid with extreme learning machine based PID controller

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ABSTRACT

The enhanced penetration of the renewable energy sources (RES) is dependent on microgrid (MG) to a power system is impact stability of the system due to a variation in dynamic properties of the MG from a traditional generator. As a result, analyzing the new issues with dynamic stability and controlling the operation of the power system in the connection of rising MG penetration becomes critical. This paper contains a MG system with renewable energy assisted, superconducting magnetic energy storage (SMES) storage and an extreme learning machine (ELM) based proportional integral derivative (PID) controller. The effect of renewable-based MG penetration on a dynamic stability and control of the multi machine multi area system under varied operating situations is comprehensively investigated in this study. Non-linear time-domain simulations and several performance indicators are used to evaluate the controller's ability with the different MG penetration percentages under various disturbances and operational conditions.

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1. INTRODUCTION

As energy demand rises in step with consumer growth and the greenhouse impact rises, the world is moving toward integrating renewable energy (RE) technologies like wind and solar systems with other traditional power sources [1]–[5]. To fullfill the energy needs, usual practice is to utilize the power generated by consolidated usefulness, which results in significant distribution and transmission losses. Additionally, these utilities are generally powered by fossil fuels, resulting in a carbon footprint [6]–[10]. In recent years, the integration of renewable energy sources (RES)-assisted microgrid (MG) in the major power grid increased substantially. The power intake of MG minimizes stress on synchronous generators and the congestion of transmission line [11]–[14].

Traditional systems still regulate the function and energy generation, transmission, and distribution responsibilities in various regions or grid zones across India. However, due to quick changes in consumption patterns and demand, as well as a desire to generate green energy, this trend of centralization has shifted to decentralisation. Various technological challenges can be resolved using this method [15]–[17].

The effect of MG on low-frequency oscillations (LFO), as these oscillations represent a major danger to system stability, needs to be explored. This work comprises the use of artificial intelligence i.e., artificial neural network (ANN) based approach extreme learning machine (ELM) [18]–[22] instead of hybrid differential genetic algorithm (DGA) and binary firefly algorithm (BFA) to reduce complexity and perform better, and it's already known that ANN is better than traditional approach in both aspect of complexity and accuracy due to self-training network and ELM is used due to its lightweight nature (only single hidden layer without affecting outcomes) over support vector machine (SVM) and other artificial intelligence (AI) approaches. To make projected power system more reliable we will use superconducting magnetic energy storage (SMES). Because of its outstanding round-trip efficiency, suitability for loading/unloading and ability to maintain rapid demand spikes and variations along with peak and volume of load renewable energies, SMES saves energy on a magnet field in a superconducting material belt and uses in the event of resource breakdown and low performance. In this article, the damping control system for a MG penetration power system is proposed as the proportional integral derivative (PID) fractional order control (FLC) scheme based on type 2 fuzzy. In addition, a strong algorithm is the optimum tuning of control parameters through ELM. In terms of performance, the fractional ID controller recommended beats the traditional integer PID order because to its flat phase contribution and larger range.

The built-in type-2 fuzzy logic aids the layout approach by compensating for any errors in system modelling while optimising control parameters and reducing computing costs. In contrast to the traditional fuzzy PID controller, the fractional error rate is introduced as the type-2 fuzzy logic controller is a gateway to other FuzzyLite Language **(**FLLs) in this work to enjoy an additional channel in the control process. In addition, this paper considers a scenario with penetration of the MG with a wind-energy-based permanent magnet synchronous generator (PMSG) and photovoltaic (PV) solar generation due to its low grid connection costs as the multi-area system which is vulnerable to an external perturbations like three-phase failures and line outages.

2. METHOD

2.1. Micro grid infrastructure

A basic MG comprises of energy sources, storage devices and controller system. This paper contains a MG system with renewable energy assisted, SMES storage and an ELM based PID controller. Figure 1 shows a complete four generator based two area system having a MG connected in Bus 3.

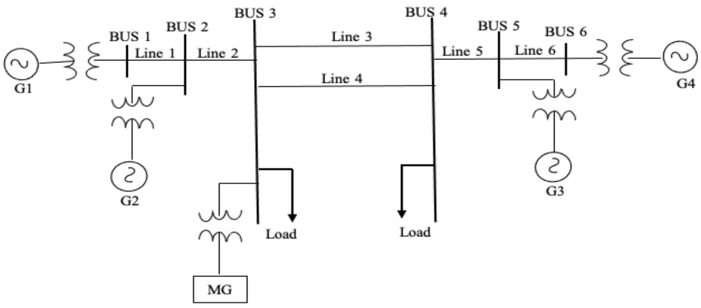


Figure 1. Generator system with MG [23]

2.2. Artificial neural network over traditional approach

Nonlinear statistical data models replicating the function of biological neural networks are called ANN. The cognitive processing system's new structure is the key to understanding this perspective. ANN is able to easily represent sophisticated or multi-complex problems, contrary to conventional patterns. An ANN is a data management framework that is based on how organic nerve systems, such as the brain, interpret things. It consists of several extremely linked processing components (neurons) which work together to address certain challenges. ANNs learn from examples, like people. An ANN is created through a learning opportunity for a particular purpose, such as pattern classification or categorization. Bio-system learning means the synaptic connections between the neurons must be adapted. That's also true of ANN. It gives extensive capacity for the complicated modelling, prediction, monitoring and performing of systems [24], [25].

2.3. Projected method

The development of a condensed model for estimating wind power that is reliant on ELM is undertaken. Then, ANN is used to optimise the wind power model, which is dependent on the ANN-ELM type, bias, weight of the input, and regularisation coefficient of the activation function for the ELM. This process is repeated until the model is optimized. A control approach based on Extreme Learning Machine (ELM) and a proportional-integral-derivative (PID) controller is shown in Figure 2. This method is utilised for controlling the output voltage. The PID algorithm is built in conjunction with ELM, and an examination of the model's stability is carried out.

Proposed algorithm

```
Start
Initialize weights, activation function and learning rate of ELM model
Initialize population, colony size, limit value and number of generations of ANN
Algorithm
Invoke: ELM training process
Randomly set how many neurons are concealed in hidden layer
Assign input weights (wi) and bias(bi) arbitrarily
Compute the outputs matrix H at the hidden layer,
H=f.(x□+w+b)
Compute output weight, δ= H*T
Invoke: ANN algorithm
 Set initial solution population      ←      δ (Final output weight from ELM
model)
Set trial_run(i)=1 (i=1,2…N)
FOR iter=1:max_iter DO
FOR i=1:N DO
Select elements for the i-th employed NN
Perform selection
IF improved_position discovered for i-th employed NN DO
Trial(i)      ←      1
ELSE
trial(i)      ←      trial(i)+1
END IF
END FOR
FOR i=1: N DO
Perform operation on randomly selected element for the i-th NN
Perform selection
IF improved_position discovered for i-th employed NN DO
Trial(i)      ←      1
Else
trial(i)      ←      trial(i)+1
END IF
END FOR
IF trial_run(i)>limit, i ε ψ, DO
Initialize the i-th employed NN with xij=Ij+(uj-Ij). rand (0,1)
END IF
Store current_best solution
END FOR
Output global_optimal solution
Continue
Weights:Bias:No. of hidden neurons      ←      global_optimal solution
Goto
ELM training process
Return
Final global_optimal solution
Stop
```

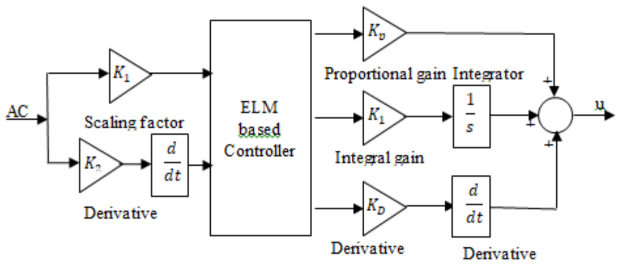


Figure 2. Proposed ELM based PID controller

3. RESULTS AND DISCUSSION

To investigate the proposed controller's effectiveness and robustness in improving the MG's dynamic stability, computer simulation is used. Figure 3(a) illustrates the suggested theoretical model of the

MG controller; Figure 3(b) illustrates the phasor sequence analyzer of the MG; Figure 3(c) demonstrates the output of various parameters at the MG; and Figure 3(d) illustrates the wind profile. The comparison of the performance is performed on the BFA dependent traditional PID-power system stabiliser (PID-PSS) (BFA-PIDPSS), BFA dependent fractional order PID-PSS (BFA-FoPIDPSS), DGA-BFA dependent fractional order PID-PSS (DGA-BFA-FoPIDPSS), and ELM dependent PID controller. At varying penetration levels, for example, the increased power provided by MG, the system's dynamic performance is evaluated, which can be as high as 10 MW and 30 MW. Effect on rotor speed of the generator has shown in the Figure 4. In the below figure, there is a comparison of proposed system with the other previously designed systems (DGA-BFA-FOPIDPSS, BFA-FOPIDPSS, BFA-PIDPSS) where Figure 4(a) show the G1 speed in the presence of time at 10 MW MG and 30 MW MG. Similarly, Figure 4(b) indicate the G2 speed in the presence of time and Figure 4(c) indicate the G3 speed in the presence of time where the rotor speed deviation og generator is minimum in proposed system as compared to others.

It can be stated that the proposed system had lower rotor speed fluctuations as compared to all the situations investigated in this study. The ELM approach enforces time domain performance of a fuzzy inferencing process. By programming these controls, the various parameters are effectively tuned to fulfill control performance objectives. The more uncertainty there is, the greater the performance of this fuzzy based FoPID controller. Model used in simulation:

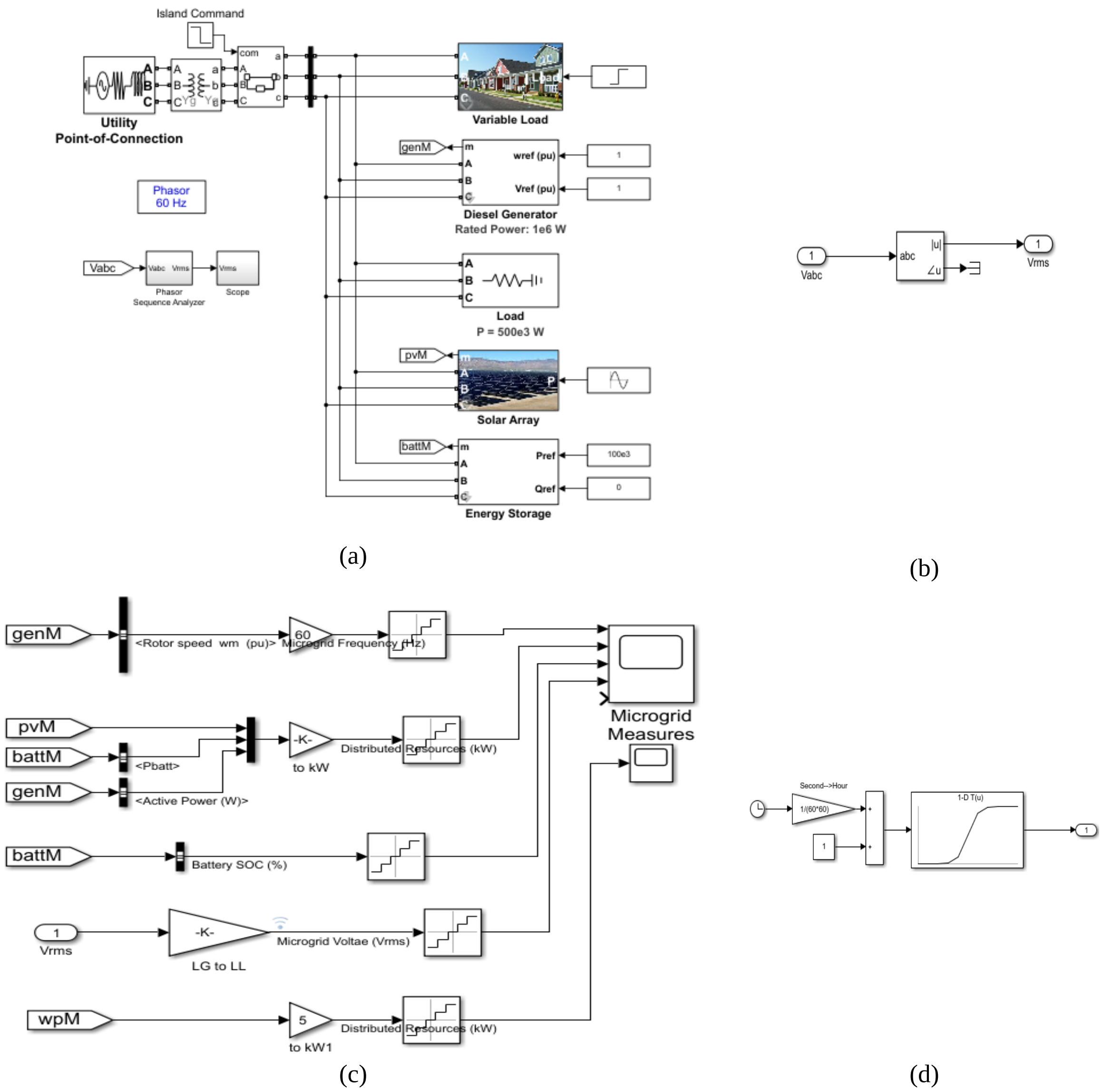
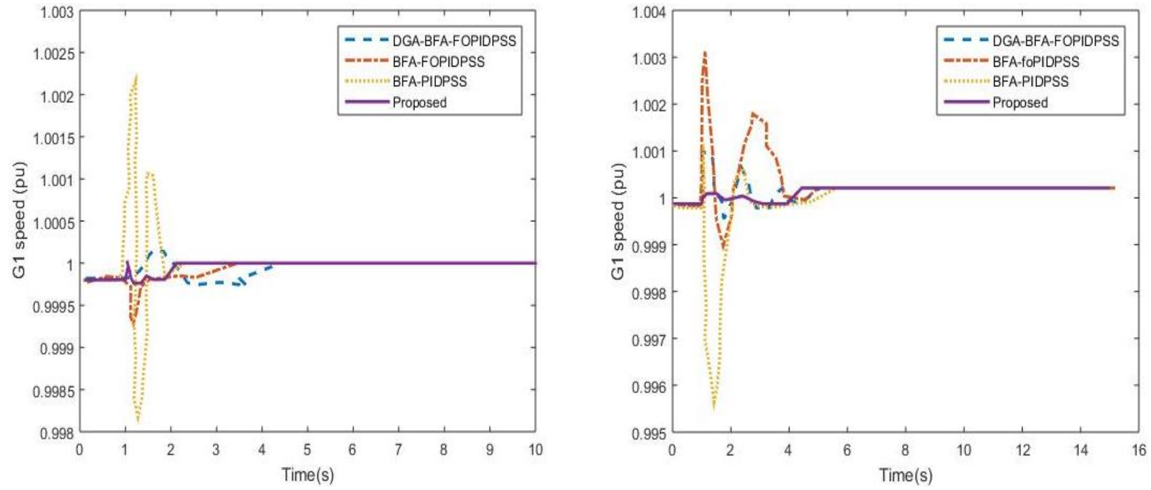
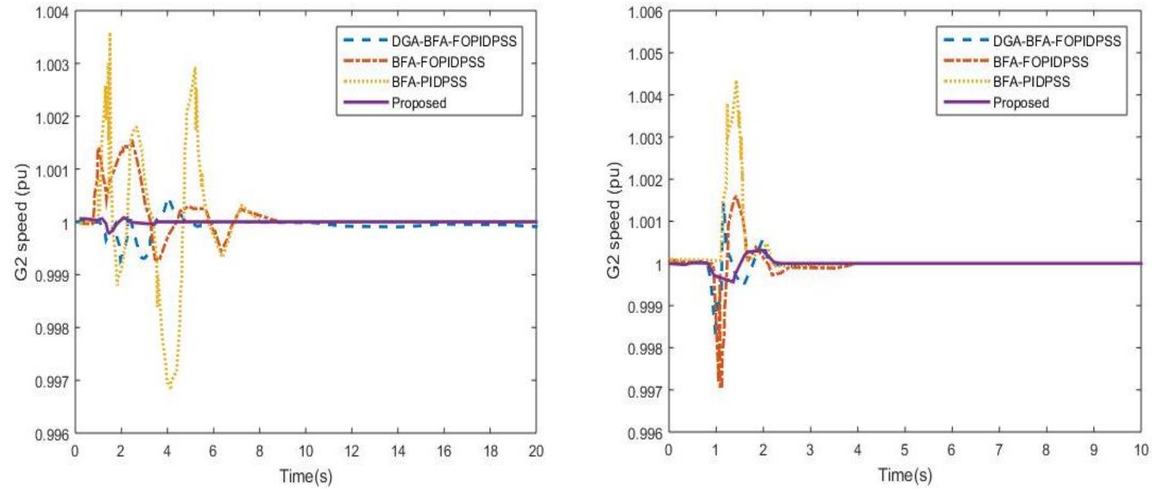


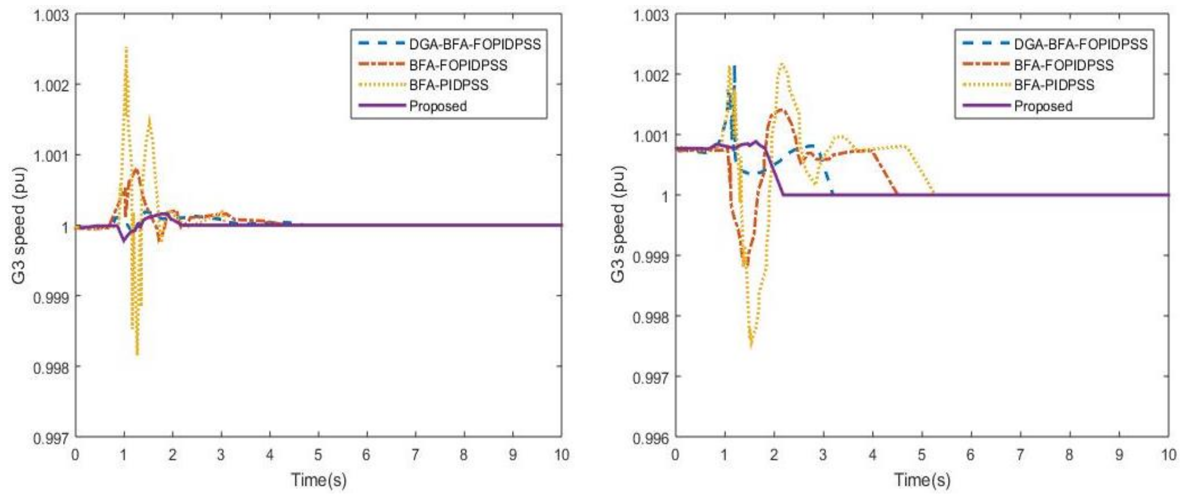
Figure 3. MG Controller (a) proposed theoretical model, (b) phasor sequence analyser, (c) output of different parameters at MG, and (d) wind profile



(a)



(b)



(c)

Figure 4. Rotor speed variation scenario for (a) G1, (b) G2, and (c) G3 at 10 MW MG, 30 MW MG

4. CONCLUSION

RES is employed in a multimachine power system to limit the amount of MG penetration. A novel, resilient ELM-controlled PID-based PSS is suggested for this system. The ELM control approach ensures that the system remains stable in the face of all uncertainty. This in-depth research reveals that, after the ELM is appropriately implemented, the PIDPSS's nominal-tuning process will be sufficient to preserve the dynamic power system's stability and, consequently, the dependability of the system. To highlight the benefits of the suggested system, a comparison analysis with various types of PID-based PSSs is conducted. Therefore, the improved dynamic stability margin provided by this novel damping controller enables for greater MG penetration in renewable energy-based power grids. In this case, next advancements will include the incorporation of type-2 FLC with sophisticated FLC methods (like the fractional order sliding mode control) for dynamic system stability, and the creation of new FLC methods.

REFERENCES

[1] L. A. de S. Ribeiro, O. R. Saavedra, S. L. de Lima, and J. G. de Matos, "Isolated micro-grids with renewable hybrid generation: The case of Lençóis island," *IEEE Transactions on Sustainable Energy*, vol. 2, no. 1, pp. 1–11, Jan. 2010, doi: 10.1109/TSTE.2010.2073723.

[2] J. Farfan and C. Breyer, "Structural changes of global power generation capacity towards sustainability and the risk of stranded investments supported by a sustainability indicator," *Journal of Cleaner Production*, vol. 141, pp. 370–384, Jan. 2017, doi: 10.1016/j.jclepro.2016.09.068.

[3] S. Kakran and S. Chanana, "Smart operations of smart grids integrated with distributed generation: A review," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 524–535, Jan. 2018, doi: 10.1016/j.rser.2017.07.045.

[4] N. M. Kumar, "Blockchain: Enabling wide range of services in distributed energy system," *Beni-Suef University Journal of Basic and Applied Sciences*, vol. 7, no. 4, pp. 701–704, Dec. 2018, doi: 10.1016/j.bjbas.2018.08.003.

[5] P. K. Wong, H. C. Wong, C. M. Vong, Z. Xie, and S. Huang, "Model predictive engine air-ratio control using online sequential extreme learning machine," *Neural Computing and Applications*, vol. 27, no. 1, pp. 79–92, Jan. 2016, doi: 10.1007/s00521-014-1555-7.

[6] M. R. Miveh, M. F. Rahmat, A. A. Ghadimi, and M. W. Mustafa, "Power quality improvement in autonomous microgrids using multi-functional voltage source inverters: A comprehensive review," *Journal of Power Electronics*, vol. 15, no. 4, pp. 1054–1065, Jul. 2015, doi: 10.6113/JPE.2015.15.4.1054.

[7] L. Zhu, H. Shi, and M. Ding, "A chaotic BP neural network used to wind power prediction," in *2018 2nd IEEE Advanced Information Management,Communicates,Electronic and Automation Control Conference (IMCEC)*, May 2018, pp. 1169–1172, doi: 10.1109/IMCEC.2018.8469532.

[8] P. C. Pradhan, R. K. Sahu, and S. Panda, "Firefly algorithm optimized fuzzy PID controller for AGC of multi-area multi-source power systems with UPFC and SMES," *Engineering Science and Technology, an International Journal*, vol. 19, no. 1, pp. 338–354, Mar. 2016, doi: 10.1016/j.jestch.2015.08.007.

[9] N. M. Kumar, K. Sudhakar, and M. Samykano, "Performance evaluation of CdTe BIPV roof and façades in tropical weather conditions," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 42, no. 9, pp. 1057–1071, May 2020, doi: 10.1080/15567036.2019.1602216.

[10] P. Saravanan, N. M. Kumar, M. Ettappan, R. Dhanagopal, and J. Vishnupriyan, "Effect of exhaust gas re-circulation on performance, emission and combustion characteristics of ethanol-fueled diesel engine," *Case Studies in Thermal Engineering*, vol. 20, pp. 1–10, Aug. 2020, doi: 10.1016/j.csite.2020.100643.

[11] M.-B. Li, G.-B. Huang, P. Saratchandran, and N. Sundararajan, "Fully complex extreme learning machine," *Neurocomputing*, vol. 68, pp. 306–314, Oct. 2005, doi: 10.1016/j.neucom.2005.03.002.

[12] J. Z. Shi, "A fractional order general type-2 fuzzy PID controller design algorithm," *IEEE Access*, vol. 8, pp. 52151–52172, 2020, doi: 10.1109/ACCESS.2020.2980686.

[13] H. M. Jabr, D. Lu, and N. C. Kar, "Design and implementation of neuro-fuzzy vector control for wind-driven doubly-fed induction generator," *IEEE Transactions on Sustainable Energy*, vol. 2, no. 4, pp. 404–413, Oct. 2011, doi: 10.1109/TSTE.2011.2160374.

[14] M. Ren, J. Zhang, Y. Tian, and G. Hou, "A neural network controller for variable-speed variable-pitch wind energy conversion systems using generalized minimum entropy criterion," *Mathematical Problems in Engineering*, pp. 1–9, 2014, doi: 10.1155/2014/412027.

[15] L. Luo *et al.*, "Optimal scheduling of a renewable based microgrid considering photovoltaic system and battery energy storage under uncertainty," *Journal of Energy Storage*, vol. 28, pp. 1–12, Apr. 2020, doi: 10.1016/j.est.2020.101306.

[16] O. Hafez and K. Bhattacharya, "Optimal design of electric vehicle charging stations considering various energy resources," *Renewable Energy*, vol. 107, pp. 576–589, Jul. 2017, doi: 10.1016/j.renene.2017.01.066.

[17] V. H. Bui, A. Hussain, and H. M. Kim, "Double deep Q -learning-based distributed operation of battery energy storage system considering uncertainties," *IEEE Transactions on Smart Grid*, vol. 11, no. 1, pp. 457–469, Jan. 2020, doi: 10.1109/TSG.2019.2924025.

[18] A. Chatterjee, A. Keyhani, and D. Kapoor, "Identification of photovoltaic source models," *IEEE Transactions on Energy Conversion*, vol. 26, no. 3, pp. 883–889, Sep. 2011, doi: 10.1109/TEC.2011.2159268.

[19] Y. Li, S. Q. Mohammed, G. S. Nariman, N. Aljojo, A. Rezvani, and S. Dadfar, "Energy management of microgrid considering renewable energy sources and electric vehicles using the backtracking search optimization algorithm," *Journal of Energy Resources Technology*, vol. 142, no. 5, pp. 1–8, May 2020, doi: 10.1115/1.4046098.

[20] F. Najibi, T. Niknam, and A. Kavousi-Fard, "Optimal stochastic management of renewable MG (micro-grids) considering electro-thermal model of PV (photovoltaic)," *Energy*, vol. 97, pp. 444–459, Feb. 2016, doi: 10.1016/j.energy.2015.12.122.

[21] Q. Sun, D. Xing, H. Alafnan, X. Pei, M. Zhang, and W. Yuan, "Design and test of a new two-stage control scheme for SMES-battery hybrid energy storage systems for microgrid applications," *Applied Energy*, vol. 253, pp. 1–13, Nov. 2019, doi: 10.1016/j.apenergy.2019.113529.

[22] F. Dawood, G. Shafiullah, and M. Anda, "Stand-alone microgrid with 100% renewable energy: A case study with hybrid solar PV-battery-hydrogen," *Sustainability*, vol. 12, no. 5, pp. 1–17, Mar. 2020, doi: 10.3390/su12052047.

[23] H. K. Abdulkhader, J. Jacob, and A. T. Mathew, "Robust type-2 fuzzy fractional order PID controller for dynamic stability enhancement of power system having RES based microgrid penetration," *International Journal of Electrical Power & Energy Systems*, vol. 110, pp. 357–371, Sep. 2019, doi: 10.1016/j.ijepes.2019.03.027.

[24] G. Abitova, V. Nikulin, L. Rzayeva, T. Zadenova, and A. Myrzatay, "Neural network modeling of agglomeration firing process for polymetallic ores," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 4, pp. 4352–4363, Aug. 2022, doi: 10.11591/ijece.v12i4.pp4352-4363.
[25] S. A. Zulkifli and M. H. Khan, "Adaptive filter algorithms for state of charge estimation methods: A comprehensive review," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 26, no. 3, pp. 1360–1367, Jun. 2022, doi: 10.11591/ijeecs.v26.i3.pp1360-1367.

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