Integration and Optimization of Renewable Energy Source into Dispatchable Power Generation

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Abstract

This paper presents renewable energy integrated with dispatchable power generation methods of power system operation and optimization with the ultimate goal of accommodating and achieving the ever-increasing level of power generation at all different levels of electricity grids. Renewable energy sources (RESs) such as PV introduce additional advantages in operating and planning for the grid, and also pose challenges in the reliable and secure operation and optimization for system operators. From the simulation output, it shows that the proposed method generated maximum power in MW for same situation as compared to traditional and automatic generation control methods. The maximum power generation in traditional and AGC is lower than that of the proposed method.

Keywords: Renewable Energy, Solar, Dispatchable Renewable Generation, Power Generation.

1 Introduction

The challenges of integrating renewable generation sources into the electricity network operation exist at all different levels and in a range of time frames. The incorporation of renewable resources would significantly alter the traditional approach of economic dispatch. Moreover, the variability of renewable resources would require measures to accommodate fast generation changes. Although no short term marginal costs are associated with renewable generation sources, increased operational costs by utilizing other components in the grid to compensate for the resources' intermittent nature would be incurred and need to be accounted for in the operation optimization.

The modern world is entirely reliant on energy. With the rising demand for energy and the depletion of existing energy sources, discovering new energy sources is becoming increasingly urgent. The share of renewable energy sources (RESs) in power generation over conventional energy sources has been growing year after year. It is because renewable energy sources are both easily available and sustainable [1]. The energy derived from these sources is transformed into a useful form and used for both home and industrial purposes. Solar, wind, geothermal, hydro, biomass, and ocean energy are examples of renewable energies that can be turned into more usable energy such as electricity [2]. They generate energy with minimum environmental effect. These sources are often more environmentally friendly/cleaner than traditional energy sources such as oil or coal. Solar and wind energy are the most important renewable energy sources for electric power generation [3, 4].

2 Related Work

Many researchers solved the challenges of integrating renewable generation sources into the electricity network. The incorporation of renewable resources will significantly alter the traditional approach of economic dispatch. Moreover, the variability of renewable resources will need measures to accommodate fast generation changes. This chapter presents modern approaches to integrate renewable generation sources into grid network.

2.1 Optimal Scheduling for Dispatchable Renewable Energy Generation

Bakhtvar *et al.* [5] introduced an energy management system for dispatchable hybrid renewable generation power plant. Their proposed energy management system architecture for dispatchable hybrid renewable generation power plant is shown in Figure 1. The EMS consists of 4 key units; namely, forecast unit, power estimator, optimal scheduling unit, and real-time control unit. Optimal scheduling unit of the EMS was described in details. It uses resource forecast and optimization techniques to optimize the power output from wind, solar and battery energy storage system (BESS) such that the aggregated power delivered by the hybrid renewable power plant remains constant for a given amount of time.

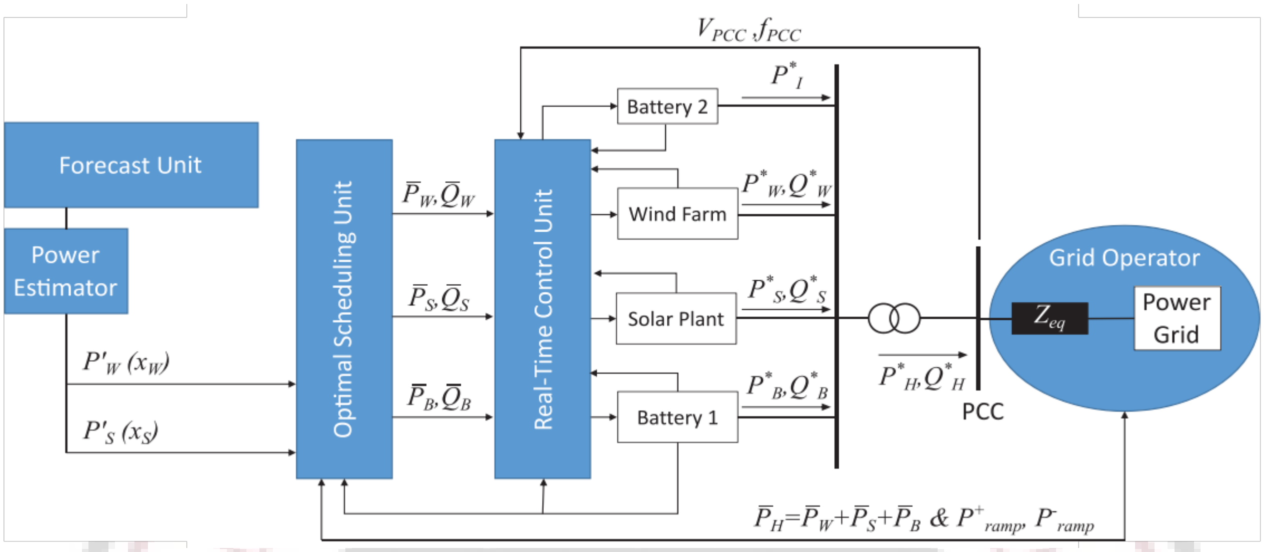

Figure 1: Architecture of the Energy Management System for Dispatchable Hybrid Renewable Generation Power Plant

Hence, the hybrid renewable power plant can participate in the interval-ahead electricity market similarly to conventional units and get dispatched.

2.2 Robust Integration of High-Level Dispatchable Renewables in Power System Operation

Ye *et al.* [6] proposed a robust UC and dispatch model considering the renewable energy sources (RES) bids in the system with high RES level. It is proved that with the dispatchable RES, the worst case for the second stage can be directly identified. The conclusion always holds whether the strong duality holds for the re-dispatch problem or not. With this conclusion, the robustness can be guaranteed by adding only one extra scenario in the original unit commitment (UC) problem.

In their propose model, the RESs are treated as market participants with full roles. They are different from the traditional robust unit commitment (RUC) [7–10], where power outputs of variable RESs are considered as negative loads, and the bids of these power outputs are zeros. In this research, the RESs can bid, and the $P^R_{r,t}$ of RES unit r at time t is a decision variable. Due to the forecast errors, the maximum available power output $\bar{P}^R_{r,t}$ is an uncertain parameter.

$$\bar{P}^R_{r,t} = \tilde{P}^R_{r,t} + \epsilon_{r,t}, \forall r, t \tag{1}$$

where $\tilde{P}^R_{r,t}$ is the expected power output for RES unit r at t, and $\epsilon_{r,t}$ is the uncertainty. The uncertainty set $\mathcal{U}$ is defined as

$$\mathcal{U} := \left\{\epsilon \in \mathbb{R}^{N_R N_T} : -u_{r,t} \leq \epsilon_{r,t} \leq u_{r,t}, \forall r, t\right\} \tag{2}$$

2.3 Research on Large-Scale Dispatchable Grid-Connected PV Systems

Han *et al.* [11] A centralized, large-scale grid-connected PV system with a battery-supercapacitor hybrid electricity storage has been described. Taking advantage of their complementary characteristics, the batteries and super capacitors have been used as the main and secondary storage devices to provide a high quality of supply and efficiency. The PV system was modeled in the MATLAB/Simulink and the control strategies demonstrated. Two sets of weather data were collected from an existing PV site and used as the input for the system to demonstrate its feasibility. The first day was sunny, while the second was cloudy.

2.4 Optimal Power Flow with Renewable Generation: A Modified NSGA-II-based Probabilistic Solution Approach

Araujo *et al.* [12] proposed a modified non-dominated sorting genetic algorithm (NSGA)-II based solution approach for the medium-term operation of SOs within the context of high penetration of renewable generation. The modification is based on an adaptive recombination and mutation mechanism. A life-like multi-objective proton exchange membrane (PEM)-based probabilistic AC optimal power flow (OPF) model is presented. This model explicitly includes the operation of dispatchable and non-dispatchable generation units, shunt reactive power sources, and under-load tap-changing (ULTC) transformers.

2.5 Optimal Distributed Generation Allocation and Load Shedding for Improving Distribution System Reliability

Awad *et al.* [13] a probabilistic approach is proposed for allocating dispatchable distributed generation (DG) units in distribution systems. A value-based reliability approach is adopted in this work that considers customer “willingness to pay (WTP)” as the reliability value that distribution utilities gain from improving system reliability. The total annual costs comprising the costs of installation and operation of DG units as well as the interruption costs are minimized to determine the optimal combination between DG units to be installed and loads to be shed during all possible contingencies.

2.6 A Fast Flexibility-Driven Generation Portfolio Planning Method for Sustainable Power Systems

Dhaliwal *et al.* [14] presented a time-independent approach for long-term capacity planning capable of reflecting power system flexibility needs associated with deep penetrations of variable renewable energy sources. The proposed approach, similar to classical load-duration curve planning, is driven by empirical capacity-ramp characteristics of renewable generation. It also provides for a computationally inexpensive solution to design dispatchable generation portfolios in comparison to current state-of-the-art approaches, which have to rely on high-dimensional finely-grained representations of time-domain operations. In fact, it can take into account intra-hour flexibility requirements; this is something current long-term planning approaches have not been able to address adequately so far.

Initially, they computed the net load $D(t)$ from intra-hour (e.g. five-minute) historical (and/or synthetic) time series data of wind power $W(t)$ and load $L(t)$, as presented in Equation 3:

$$D(t) = L(t) - W(t) \tag{3}$$

Then, the corresponding ramp $R(t)$ at time t is approximated using a first-order forward difference as presented in Equation 4, where ΔT is the time span between two wind power and demand observations:

$$R(t) \approx \frac{D(t+1) - D(t)}{\Delta T} \tag{4}$$

The net load $D(t)$ (in MW) and the corresponding calculated ramps $R(t)$ (MW/min) of the net load in a typical power system are critical factors. They observed that the distribution of ramps up (positive values) and down (negative values) is conditioned by the value of the net load.

2.7 Dynamic Economic Emission Dispatch Considering Renewable Energy Generation: A Novel Multi-Objective Optimization Approach

Liu *et al.* [23] proposed a novel solving approach based on enhanced moth-flame optimization algorithm and contributed to construct the mathematical model of hybrid dynamic economic emission dispatch (HDEED) considering renewable energy generation. Renewable energy power generation technology has an important impact on reducing pollutant emissions and promoting sustainable development. Therefore, their research aimed to investigate the HDEED problem in consideration of renewable energy generation and improve the economic and environmental benefits of the power system.

HDEED is a multi-objective optimization problem, including cost (F_{COST}) and emissions (F_{emission}). Based on the statistical analysis of the fuel cost of a large number of thermal power units, researchers believe that the relationship between the fuel cost and the output of thermal power units is a quadratic function when the valve point effect is not considered [24]. When wind energy conversion systems and solar energy conversion systems are owned by the system operator, renewable energy represented by wind energy and solar energy does not consume fuel in the process of power generation, so the cost of wind and solar power generation does not need to be considered in the cost function objective. Hence,F_{COST} is expressed by a quadratic equation as Eq. (1) [25].

$$F_{\text{COST}} = \sum_{i-1}^{T} \sum_{j=1}^{\text{Num}} \left(v_j P_{j,i}^2 + t_j P_{j,i} + u_{j,i} \right) \tag{5}$$

where T is 24 h; Num is the number of generators; $v_j\left(\$/\text{MW}^2\text{h}\right), t_j(\$/\text{MWh}), u_j(\$/\text{h})$ are the cost coefficients of the j^{th} generator; $P_{j,i}(\text{MW})$ represents the output power of the j^{th} generator at the i^{th} hour.

3 Proposed Method

Renewable energy sources (RESs) penetrate the electricity networks at various levels and in all different forms. It introduces concepts such as power flow models and optimal power flow (OPF), to incorporate intermittent renewable energy generation into the electricity network operation under security consideration, via a robust model, which adopts preventive control as the security control strategy. Given the significant growth in microgrid (MG) deployments across the world and appealing merits of strategies.

3.1 Photovoltaic System

Renewable energy is the one of the efficient way to overcome the upcoming crisis which will be occurred due to the extinction of non-renewable energy. Solar energy is the one of best form of renewable energy due to its availability, which is extracted from sunlight with the help of photovoltaic cell. Photovoltaic cell or solar cell is the devices which convert solar energy to electrical energy. There are many application of photovoltaic cells like individual cells can be used to power small electronics devices, also the electricity can be generated in the ruler areas where the electrical energy from the grid has not reached yet, and the satellites in the earth's orbit and many more. As solar energy is used for many purposes but still the generation rate of photovoltaic cell is not adequate. Many researches are going on to improve the generation rate of the photovoltaic cell. And among them the tracking the position of the sun and rotate the panel in the direction of maximum intensity of sunlight is one of the best way to improve the generation rate of the photovoltaic cells [27].

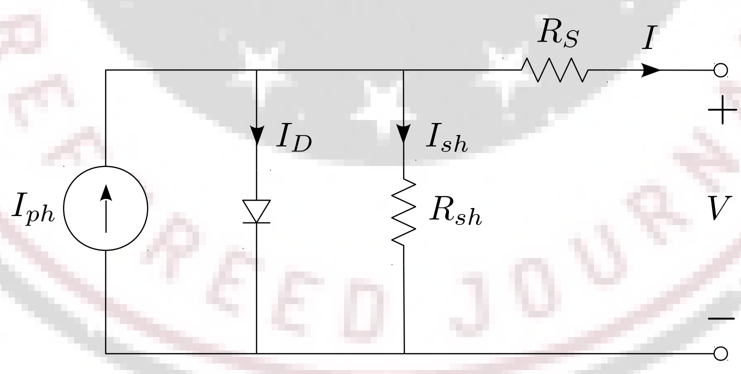

Figure 2: PV Cell Equivalent Circuit

In this dissertation, a tracking system is introduced which will continuously track the position of sun and turn the solar panel in the direction of sunlight. This tracking system will increase the generation rate of solar panel as it will always track the position of sun and turn the solar panel toward maximum intensity. Here, the light-dependent resistor is a sensor used to detect the intensity of sunlight based on which our *Arduino* processes and calculates the position of sun and gives commands to servo motor to rotate to a certain angle. And two servo motors help solar panel to move in both possible ways (horizontally and vertically) in order to extract the maximum solar energy. Figure 2 shows the equivalent circuit of PV cell, and the mathematical modeling of PV cell is explained in the following section.

3.2 Proposed Mathematical Model for Solar Integrated Dispatchable Power Generation

Phase current:

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times \frac{I_r}{1000} \tag{6}$$

where,
I_{ph} is photo current (A).
I_{sc} is short circuit current (A).
K_i is short circuit current of cells at 25 ℃ and 1000 W/m^2.
T is operating temperature (K).
I_r is solar irradiation (W/m^2).
Module reverse saturation current I_{rs}:

$$I_{rs} = \frac{I_{sc}}{\left[\exp\left(\frac{qV_{oc}}{N_s K_n T}\right) - 1\right]} \tag{7}$$

where,
q is electron charge (1.6×10^{-19} C).
V_{oc} is open circuit voltage at 25 ℃ and 1000 W/m^2.
N_s is number of cells connected in series.
n is ideality factor of diodes (1.2).
K is Boltzman's constant (1.3805×10^{-23} J/K).
Module saturation current I_o, it varies with cell temperature given by:

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^2 \exp\left[\frac{qE_{go}}{nK}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \tag{8}$$

where,
T_r is nominal temperature (298.15 K).
E_{go} is band gap energy of semiconductor (1.1 eV). Total output current of PV module is:

$$I = N_p I_{ph} - N_p I_o\left[\exp\left(\frac{V/N_s + IR_s/N_p}{nV_t}\right)\right] \tag{9}$$

The diode thermal voltage is given by

$$V_t \frac{KT}{q} \tag{10}$$

The shunt current flowing through the shunt resistance $R_s h$ will be calculated by

$$I_{sh} = \frac{VN_p/N_s + IR_s}{R_{sh}} \tag{11}$$

where,
N_p is number of PV modules connected in parallel.
N_s is number of PV modules connected in series.
R_s is series resistance.
R_{sh} is shunt resistance.
R_s value will be very low around 0.0001 Ω, and R_{sh} value is very large around 1000 Ω.

3.3 Operation of the Proposed System

When the output of each light-dependent resistor (LDR) is changing based upon the change in position of sun, the arduino compares the values of each LDRs and based on the difference between LDRs values arduino send digital signal to the servo motor to rotate in some certain angle through which the maximum solar energy is extracted. A block diagram is shown in Figure 3.

When the intensity of sunlight changes the light-dependent resistor senses. Here, we have used four light-dependent resistors, the combination of two LDRs is meant for vertical movement, and the other two is meant for

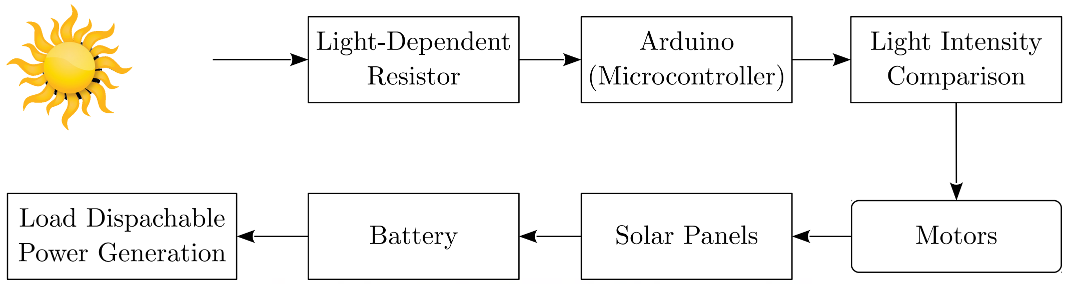

Figure 3: Operation of the Proposed System

horizontal movement. So basically when the intensity changes the resistance of each LDRs starts varying. And this change in resistance is given as input to Arduino where the further processing takes place. Where as in arduino, it compares all the values of LDRs, and it takes the difference between each LDR value. Depending upon the difference, the arduino tries to minimize the difference (as low as possible) by rotating the panel using servo motors (which rotates based upon the digital signal received from the arduino); as the difference is low, the intensity of sunlight received by individual LDR is similar when compared with other LDRs; it means that the set of LDRs is receiving the maximum intensity. And this set of LDRs is parallelly mounted with solar panel so the intensity received by LDRs set will be similar to intensity received by solar panel.

4 Result Analysis

This section summarizes the outcomes of this research work. The optimal locations and sizes of distributed generation units as well as the load points and other parameters to be shed are presented same for each generation technology under consideration.

4.1 Simulation Parameter

For simulation in MATLAB, the following parameters are considered as presented in the Table 1. The simulation

Table 1: Parameters for MATLAB Simulation

Parameter	**Value**
PV Specification	– SunPower SPR-305
PV Power (upper limit)	– 15.5kW
Frequency	– 50 Hz
Sampling Time	– 50 μs
RLC Filter Resistance	– 0.2 Ω
RLC Filter Inductance	– 9.5 mH
RLC Filter Capacitance	– 300 μF
DC Voltage	– 550 V
Grid Voltage	– 120 V
Load Resistance	– 2,000 Ω(variable)
DC Link Capacitor	– 2,500 μF

is carried out using MATLAB 2021 in Ubuntu (Linux) Operating system using these parameters.

4.2 Simulation

Tradition power generation and automatic generation control (AGC) are two scenarios that are considered for simulation studies to assess and compare the renewable energy integrated generation (proposed method) capability to optimize power generation and maintain tie-line flow thermal limits. In all the scenarios systems do not provide any frequency support. The performance of the proposed optimal renewable energy integrated generation is compared with the traditional and AGC, and with assuming the same AGC gains.

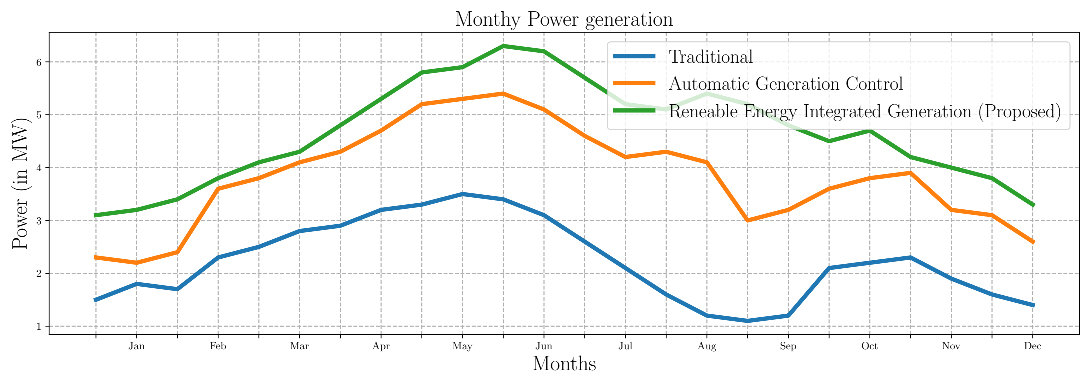

Figure 4: Simulation Result

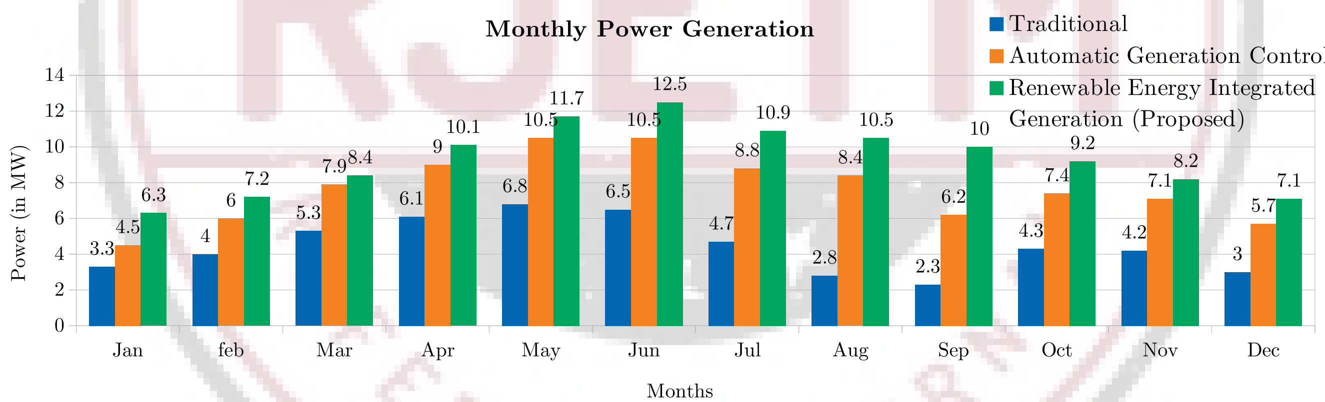

Figure 5: Simulation Result (Bar Graph)

The Figure 4 and 5 represents the MATLAB simulation result, the power generated in MW of each month for a particular year. The traditional method is presented as blue curve, the automatic generation control (AGC) is presented in orange curve and the proposed renewable energy integrated generation method is presented as green curve. From the simulation output, it shows that the proposed method generated maximum power in MW for same situation as compared to traditional and automatic generation control methods. The maximum power generation in traditional and AGC is lower than that of the proposed method.

5 Conclusion and Future Work

This paper presents a concept of maximum power generation method by using integrated methods. For a comprehensive evaluation of the impact of distributed generation and solar plantation, an analytical method is used. Simulation results show that proposed method gain to maximum power generation that is close to the desired value, while all the constraints, including the switching number limits of voltage control devices, are satisfied. In addition, the proper operation mode of dispatchable generations can also be determined by the proposed method.

Since the integration of renewable energy with dispatchable power generation continues to increase in the electricity grid, some interesting research features that can be investigated in future and can be formulated here as inspiration for future studies in mainly two aspects: modeling and computation.

- Models for proposed system considering uncertainties should be further developed. Control strategies of multiple grids should be investigated. It might be valuable to study and develop a concept of operational flexibility to evaluate the capability of grids to participate in system operations and the electricity market.
- Models of high or 100% power electronics-based grid with small or no inertia need to be studied. An micro-grid is a good candidate for a heavy inverter-based grid, which features high penetration of renewable sources and distributed generators, as well as low inertia. A plug-and-play feature with its enabler controller design and granular integration into the grid might change the basic structure of the electricity grid operation.
- Since there are few meshed systems in operation now, it would be of great value to further investigate detailed models. This includes different converters, losses models, droop control strategies and different operation schemes.
- Relaxation and approximation can be applied to reduce the complexity of calculating the system under uncertainties, apart from linearization.
- Data-driven optimization and machine learning can be more suitable techniques to deal with uncertainties brought by renewable sources with advanced development in computation and communication technologies.

References

[1] M. A. Laughton, *Renewable Energy Sources.* Elsevier Applied Science ; New York, NY, USA, 2003.

[2] M. R. Islam, N. K. Roy, and S. Rahman, *Renewable Energy and the Environment*, 1st ed., ser. Renewable Energy Sources & Energy Storage. Springer Singapore, 2018.

[3] M. S. Akbarali, S. K. Subramanium, and K. Natarajan, "Real and reactive power control of seig systems for supplying isolated dc loads," *Journal of The Institution of Engineers (India): Series B*, vol. 99, no. 6, pp. 587–595, Dec 2018. [Online]. Available: https://doi.org/10.1007/s40031-018-0350-8

[4] A. S. Marek Wróbel, Marcin Jewiarz, *Renewable Energy Sources: Engineering, Technology, Innovation: ICORES 2018*, 1st ed., ser. Springer Proceedings in Energy. Springer International Publishing, 2020. [Online]. Available: https://doi.org/10.1007/978-3-319-72371-6

[5] M. Bakhtvar, A. Al-Hinai, M. S. E. Moursi, M. Albadi, A. Al-Badi, A. A. Maashri, R. A. Abri, N. Hosseinzadeh, Y. Charaabi, and S. Al-Yahyai, "Optimal scheduling for dispatchable renewable energy generation," in *2020 6th IEEE International Energy Conference (ENERGYCon)*, 2020, pp. 238–243. [Online]. Available: https://doi.org/10.1109/ENERGYCon48941.2020.9236559

[6] H. Ye, J. Wang, Y. Ge, J. Li, and Z. Li, "Robust integration of high-level dispatchable renewables in power system operation," *IEEE Transactions on Sustainable Energy*, vol. 8, no. 2, pp. 826–835, 2017. [Online]. Available: https://doi.org/10.1109/TSTE.2016.2621136

[7] R. Jiang, J. Wang, and Y. Guan, "Robust unit commitment with wind power and pumped storage hydro," *IEEE Transactions on Power Systems*, vol. 27, no. 2, pp. 800–810, 2012. [Online]. Available: https://doi.org/10.1109/TPWRS.2011.2169817

[8] R. Jiang, M. Zhang, G. Li, and Y. Guan, "Two-stage network constrained robust unit commitment problem," *European Journal of Operational Research*, vol. 234, no. 3, pp. 751–762, 2014. [Online]. Available: https://doi.org/10.1016/j.ejor.2013.09.028

[9] H. Ye and Z. Li, "Robust security-constrained unit commitment and dispatch with recourse cost requirement," *IEEE Transactions on Power Systems*, vol. 31, no. 5, pp. 3527–3536, 2016. [Online]. Available: https://doi.org/10.1109/TPWRS.2015.2493162

[10] D. Bertsimas, E. Litvinov, X. A. Sun, J. Zhao, and T. Zheng, "Adaptive robust optimization for the security constrained unit commitment problem," *IEEE Transactions on Power Systems*, vol. 28, no. 1, pp. 52–63, 2013. [Online]. Available: https://doi.org/10.1109/TPWRS.2012.2205021

[11] X. Han, X. Ai, and Y. Sun, "Research on large-scale dispatchable grid-connected pv systems," *Journal of Modern Power Systems and Clean Energy*, vol. 2, no. 1, pp. 69–76, Mar 2014. [Online]. Available: https://doi.org/10.1007/s40565-014-0043-5

[12] E. X. S. Araujo, M. C. Cerbantes, and J. R. S. Mantovani, "Optimal power flow with renewable generation: A modified nsga-ii-based probabilistic solution approach," *Journal of Control, Automation and Electrical Systems*, vol. 31, no. 4, pp. 979–989, Aug 2020. [Online]. Available: https://doi.org/10.1007/s40313-020-00596-7

[13] A. S. A. Awad, T. H. M. El-Fouly, and M. M. A. Salama, "Optimal distributed generation allocation and load shedding for improving distribution system reliability," *Electric Power Components and Systems*, vol. 42, no. 6, pp. 576–584, 2014. [Online]. Available: https://doi.org/10.1080/15325008.2014.880962

[14] N. K. Dhaliwal, F. Bouffard, and M. J. O'Malley, "A fast flexibility-driven generation portfolio planning method for sustainable power systems," *IEEE Transactions on Sustainable Energy*, vol. 12, no. 1, pp. 368–377, 2021. [Online]. Available: https://doi.org/10.1109/TSTE.2020.2998408

[15] X. Lu, H. Li, K. Zhou, and S. Yang, "Optimal load dispatch of energy hub considering uncertainties of renewable energy and demand response," *Energy*, vol. 262, p. 125564, 2023. [Online]. Available: https://doi.org/10.1016/j.energy.2022.125564

[16] S. Roy, "Uncertainty of optimal generation cost due to integration of renewable energy sources," *Energy Systems*, vol. 7, no. 3, pp. 365–389, Aug 2016. [Online]. Available: https://doi.org/10.1007/s12667-015-0162-8

[17] D. L. Yao, S. S. Choi, K. J. Tseng, and T. T. Lie, "A statistical approach to the design of a dispatchable wind power-battery energy storage system," *IEEE Transactions on Energy Conversion*, vol. 24, no. 4, pp. 916–925, 2009. [Online]. Available: https://doi.org/10.1109/TEC.2009.2025331

[18] G. M. Masters, *Renewable and Efficient Electric Power Systems.* Wiley-IEEE Press, 2004.

[19] M. Khasanov, S. Kamel, C. Rahmann, H. M. Hasanien, and A. Al-Durra, "Optimal distributed generation and battery energy storage units integration in distribution systems considering power generation uncertainty," *IET Generation, Transmission & Distribution*, vol. 15, no. 24, pp. 3400–3422, 2021. [Online]. Available: https://doi.org/10.1049/gtd2.12230

[20] O. Ausavanop, A. Chanhome, and S. Chaitusaney, "An optimal allocation of distributed generation and voltage control devices for voltage regulation considering renewable energy uncertainty," *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 9, no. S1, pp. S17–S27, 2014. [Online]. Available: https://doi.org/10.1002/tee.22041

[21] A. Shapiro, "Monte carlo simulation approach to stochastic programming," in *Proceeding of the 2001 Winter Simulation Conference (Cat. No.01CH37304)*, vol. 1, 2001, pp. 428–431. [Online]. Available: https://doi.org/10.1109/WSC.2001.977317

[22] W. Li, J. Zhou, K. Xie, and X. Xiong, "Power system risk assessment using a hybrid method of fuzzy set and monte carlo simulation," *IEEE Transactions on Power Systems*, vol. 23, no. 2, pp. 336–343, 2008. [Online]. Available: https://doi.org/10.1109/TPWRS.2008.919201

[23] Z.-F. Liu, L.-L. Li, Y.-W. Liu, J.-Q. Liu, H.-Y. Li, and Q. Shen, "Dynamic economic emission dispatch considering renewable energy generation: A novel multi-objective optimization approach," *Energy*, vol. 235, p. 121407, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360544221016558

[24] A. Askarzadeh, "A novel metaheuristic method for solving constrained engineering optimization problems: Crow search algorithm," *Computers & Structures*, vol. 169, pp. 1–12, 2016. [Online]. Available: https://doi.org/10.1016/j.compstruc.2016.03.001

[25] M.-R. Chen, G.-Q. Zeng, and K.-D. Lu, "Constrained multi-objective population extremal optimization based economic-emission dispatch incorporating renewable energy resources," *Renewable Energy*, vol. 143, pp. 277–294, 2019. [Online]. Available: https://doi.org/10.1016/j.renene.2019.05.024

[26] P. Shah and B. Mehta, "Microgrid optimal scheduling with renewable energy sources considering islanding constraints," *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, vol. 44, no. 2, pp. 805–819, Jun 2020. [Online]. Available: https://doi.org/10.1007/s40998-019-00254-y

[27] S. Siddula, A. pariyar, and P. G. Kumari, "Solar panel position monitoring system for maximum power generation," in *Advances in Automation, Signal Processing, Instrumentation, and Control*, V. L. N. Komanapalli, N. Sivakumaran, and S. Hampannavar, Eds. Singapore: Springer Nature Singapore, 2021, pp. 1159–1167. [Online]. Available: https://doi.org/10.1007/978-981-15-8221-9_109