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Multi-Dimensional Energy Management based on an Optimal Allocation of Hybrid Wind Turbine Distributed Generation and Battery Energy Storage System in a Flexible Interconnected Distribution Network Considering Seasonal Uncertainties

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Abstract: In recent years, the incorporation of wind turbine distributed generation (WTDG) in addition to battery energy storage system (BESS) into an electrical distribution network (EDN) has grown into a beneficial solution for ensuring a satisfying balance between energy generation and consumption. The principal approaches used to locate and size multiple WTDG and BESS units inside EDN are described in this article. To optimize overall multi-objective functions, this research investigates the optimal planning of multiple hybrid WTDG and BESS units in EDN. In the first scenario, injecting active power to the EDN is accomplished by installing WTDG. In contrast, in the second scenario, hybrid WTDG and BESS units are deployed concurrently to provide the EDN, taking into consideration the seasonal uncertainty of load-source powers variation, for a reason to approach to the practical case, where there are many parameters to be optimized, considering different constraints, during the uncertain time and variable data of load and power generator. The suggested work's originality is to completely design a novel multi-objective function (MOF) based on the sum of three technical metrics of active power loss (APL), voltage deviation (VD), and operating time of overcurrent relay (OTR). The proposed MOF is validated on the standard IEEE 69-bus distribution network by applying a new, recently published meta-heuristic algorithm called the Light Spectrum Optimizer (LSO) algorithm. The optimized outcomes revealed that the LSO showed good behavior in minimizing each parameter included in the MOF during the year season.

Keywords: optimal allocation; seasonal uncertainties; wind turbine distributed generation; battery energy storage system; electrical distribution network; multi-objective functions.

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1. Introduction

Today's power networks' load variation and energy flow are becoming more unstable owing to the sporadic production of renewable resources (RERs). In consequently, electrical grids are undergoing an interval of transition caused by an array of issues, such as grew power system reliability and development, enhanced energy quality, increased load management, renewable energy penetration, and lower emissions of greenhouse gases.

Wind turbines are often employed in distribution systems as they offer clean energy that is reliant on renewable sources with an elevated state of inertia. Using wind turbines (WTs), we can convert kinetic energy into an EDS system. In recent years, there has been a rapid increase in the use of RERs in electrical distribution systems (EDSs), such as wind turbine distributed generators (WTDGs) [1]. Yet, the inconsistency of WTDG output power has caused a number of issues for distribution networks. A battery energy storage system (BESS) is used in conjunction with WTDGs to seamlessly inject output power into the grid [2]. The BESS, with its separate charging and discharging abilities, provides an efficient method to minimize RER output fluctuations and improve EDS interaction.

The RES may have significant benefits if properly deployed. A variety of methods for optimization, involving conventional and artificial intelligence approaches, were recently examined and compared in [3]. This study proposes a practical method for best placing hybrid WTDG and BESS units in EDS to minimize overall system losses and improve voltage profiles [4]. Recently, a number of researchers studied the most effective WTDG and BESS location in the EDS via a number of algorithms and methods: dynamic programming optimisation to minimize the total costs including uncertainty of WTDG [5]

Additionally, using the marine predators algorithm to optimize a multi-objective function included power losses, volage deviation and relays operating time indices [6]. Modified African buffalo optimization to minimize the daily energy losses [7], novel inherited competitive swarm optimization for reducing the annual energy losses cost [8]. A variety of proposed chaotic grey wolf optimization techniques to minimize a novel multi-objective function included the total of three techno parameters [9], and crow search algorithm to minimize the annual and of flicker emission cost produced by WTDG units [10].

Recently, researchers utilized new metaheuristic algorithms that involved a unique chaotic student psychology-based optimization including load models and the hourly load profile average [11]. The search group algorithm in aim of maximizing the technological, economic and environmental objectives [12], also a hybrid multi-objective algorithm that incorporate the GA-PSO algorithms in order to optimize a simultaneous total cost of BESS and power loss [13].

The practical objectives are diametrically opposed. As a consequence, deciding where to put the hybrid WTDG and BESS is a difficult multi-objective function (MOF) problem that has to be resolved whereas optimizing several competing goals. In this study, a hybrid WTDG-BESS system allocation problem is intended to minimize the MOF, which can be resolved by using a new recent meta-heuristic algorithm identified as the light spectrum optimizer (LSO) algorithm and examined on the IEEE 69-bus standard.

2. Problem Formulation

This article is considered to optimally locate and size the hybrid WTDG and BESS sources into EDN by simultaneously reducing the technical parameters of Total Active Power Loss (TAPL), Total Voltage Deviation (TVD), and Total Operation Time (TOT) of relays.

$$MOF = Minimize \sum_{i=1}^{N_{Bus}} \sum_{j=2}^{N_{Bus}} \sum_{i=1}^{N_{Relay}} TAPL_{i,j} + TVD_j + TOT_i \quad (1)$$

Starting with the TAPL of the distribution line, which can be expressed by [13].

$$TAPL_{i,j} = \sum_{i=1}^{N_{Bus}} \sum_{j=2}^{N_{Bus}} \alpha_{ij}\left(P_i P_j + Q_i Q_j\right) + \beta_{ij}\left(Q_i P_j + P_i Q_j\right) \quad (2)$$

$$\alpha_{ij} = \frac{R_{ij}}{V_i V_j}\cos(\delta_i - \delta_j),\ \beta_{ij} = \frac{R_{ij}}{V_i V_j}\sin\left(\delta_i - \delta_j\right) \quad (3)$$

where R_{ij} is the line resistance. (δ_i, δ_j) and (V_i, V_j) are angles and voltages, respectively. (P_i, P_j) and (Q_i, Q_j) demonstrate active and reactive powers, respectively. The second term is the TVD, which is defined as [14].

$$TVD_j = \sum_{j=2}^{N_{Bus}} \left|1 - V_j\right| \quad (4)$$

The final term, the TOT of Overcurrent relays, which is defined as [15].

$$TOT_i = \sum_{i=1}^{N_{Relay}} OT_i \quad (4)$$

$$OT_i = TDS_i \left(\frac{A}{M_i^B - 1} \right) \quad (4)$$

where T_i is the operation time of relay, *TDS* is the time dial setting, *M* is the multiple of pickup current. *A*, and *B* are relay constants set to 0.14 and 0.02, respectively. N_{Relay} is the number of overcurrent relays.

3. Application and Results

The algorithm used in this study has been verified on the standard IEEE 69-bus, which is depicted in Figures 1 as single line diagram. The test network has a baseline voltage of 12.66 kV and a total active load of 3790.00 kW and a reactive load of 2690.00 kVar. Each bus of tested network would be secured via an overcurrent relay (OCR) and backed up by another OCR, with a coordination time interval (CTI) set above 0.2 seconds.

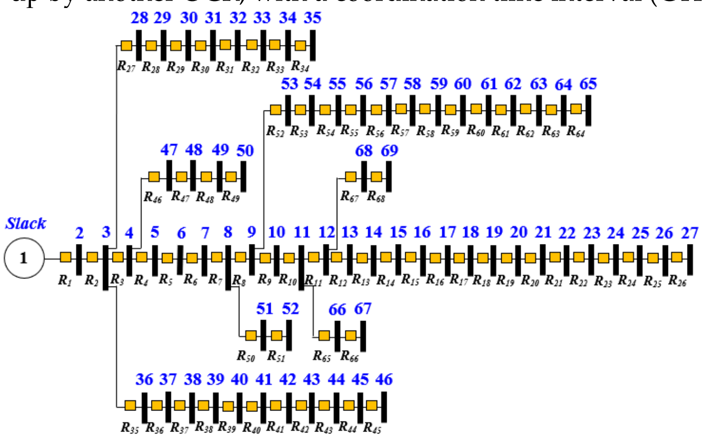
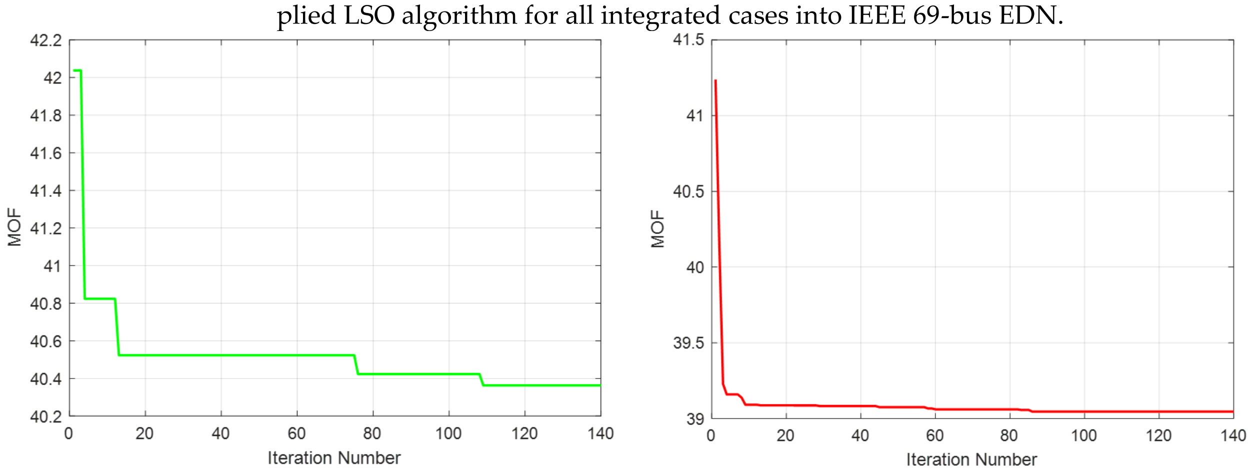


Figure 1. Single line diagram of the IEEE 69 bus EDN.

Figure 2 represents the convergence curves while minimizing the MOF using the applied LSO algorithm for all integrated cases into IEEE 69-bus EDN.



(**a**) (**b**)

Figure 2. Convergence curves of applied LSO algorithm for various case studies:

(**a**). WTDG case; (**b**). Hybrid WTDG-BESS case.

For a maximum number of iterations equal 100, involving an average population size of 10, demonstrate the LSO algorithm superiority when generating the most effective outcomes and remedies for the established problem. The case of hybrid WTDG-BESS was the best one that provided the minimum MOF results, also with a fast convergence characteristic, where settles down around 90 iterations.

Tables 1 stated the outcomes of optimization utilizing LSO algorithm, contrasting the studied integrated cases into IEEE 69-bus EDNs.

The outcomes of optimization displayed in tables 1 indicate the LSO algorithm advantage and effectiveness in producing the most effective results reflected as the minimum of MOF across all studied cases. Another point to mention is that hybrid WTDG-BESS units were the best option for providing the least number of results for EDNs at the same time until 39.04, including the minimum values of TAPL with 65.58 MW, TVD with 0.43 p.u. and TOT with 38.46 seconds.

Table 1. Optimal results for all studied cases integration into IEEE 69-bus EDN.

Cases Studies	WTDG			BESS		*TAPL* (MW)	*TVD* (p.u.)	*TOT* (sec)	*MOF*
	Bus	P_{WTDG} (MW)	Q_{WTDG} (MVar)	Bus	P_{BESS} (MW)				
With WTDG	6	1.0131	0.9809	…..	…..	76.30	0.973	38.62	40.36
	29	1.5902	0.7091	…..	…..				
	58	0.9019	0.4111	…..	…..				
With WTDG and BESS	3	0.9830	0.3989	22	0.5460	65.58	0.630	38.46	39.04
	7	1.7390	0.6964	44	0.3718				
	56	0.9211	0.7309	61	1.2233				

Figure 3 depicted the seasonal variation of active power losses variation displayed in 96 hours, for all studied cases integrated in the IEEE 69-bus.

The seasonal total active losses decreased substantially for test system EDNs, following the optimum setup of all the studied cases, with greater efficiency and reduction stipulated from the case of hybrid WTDG-BESS units coming from an overall value of 11.84 MWh to 6.72 MWh for the test system EDN with a minimization rate of 56.76%. Because hybrid WTDG-BESS units incorporate two power sources that produce both active and reactive power, the supply is guaranteed and ongoing throughout the year, almost without disruption.

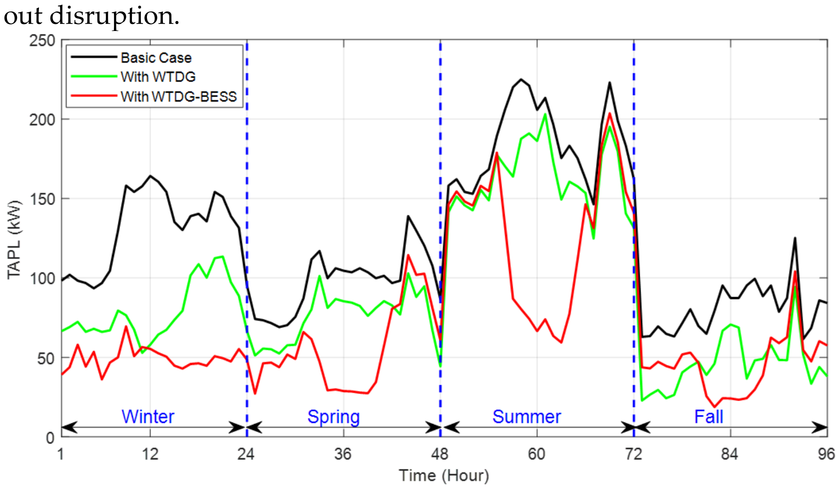


Figure 3. Seasonal active power loss variation.

Figure 4 represented the seasonal variation of total voltage deviation in test system EDN displayed in 96 hours for all studied integrated cases. The illustrations shown in Figure 4 show that the optimal inclusion of all studied cases, using the LSO algorithm, significantly influenced and lowered the seasonal voltage deviation in test system EDN.

The hybrid WTDG-BESS unit case was deemed to be the most suitable choice between the studied cases because it effectively ensured the lowest and best results in terms of seasonal voltage deviation, coming from an overall value of 131.20 p.u. to 92.71 p.u. including a minimization rate 70.6 %.

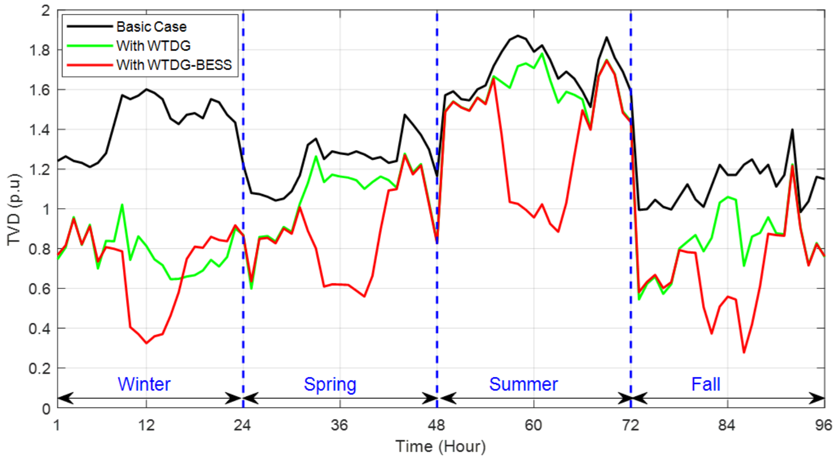


Figure 4. Seasonal variation of total voltage deviation

Figure 5 represented the seasonal variation of total operating time of overcurrent relays in test system EDN displayed in 96 hours for all studied integrated cases.

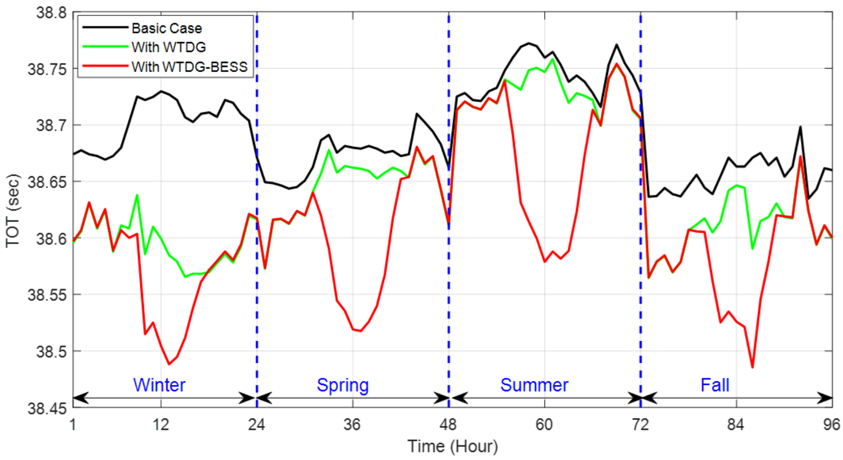


Figure 5. Seasonal variation of total operating of overcurrent relays.

Overcurrent relays are dedicated to identify and correct the fault current. Reducing their operating time is so favorable in many aspects as system protection, continuity of service, and extending the lifetime of equipment. Using the LSO algorithm obviously led to mitigating of the seasonal operation time of the overcurrent relays in EDN., with superior results from the case of WTDG-BESS units, where minimizing the TOT until 38.46 seconds.

4. Conclusions

This research was devoted to apply a new optimization algorithm called LSO, to optimally locate and size of the hybrid WTDG-BESS into IEEE 33-bus EDN, considering the seasonal uncertainties of load-source powers variation. The purpose of that implemented optimization was to enhance the performance of tested network while reducing a MOF, comprised the technical parameters of TAPL, TVD, and TOT. The outcomes revealed the effectiveness of LSO algorithm in optimizing and solving the formulated problem, also clearly the case of WTDG-BESS was the best choice that provided the best results to distribution network, as long as the active/reactive power been provided during all seasons.

Future research will concentrate on proposing a complex MOF, that may comprise different techno-economic issues. Besides, focusing on the topic of EVCS as load to better improve the performance of the distribution network.

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