

Dynamic Analysis for Optimal Power Flow of Wind, Solar PV and BESS-Based Short-Term Hydro-Thermal Scheduling for Tri-Objective Operation Using Ubrid Hybrid Adaptive Encoding Learning, Artificial Bee Colony, and NSGA-II

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INTRODUCTION & AIM

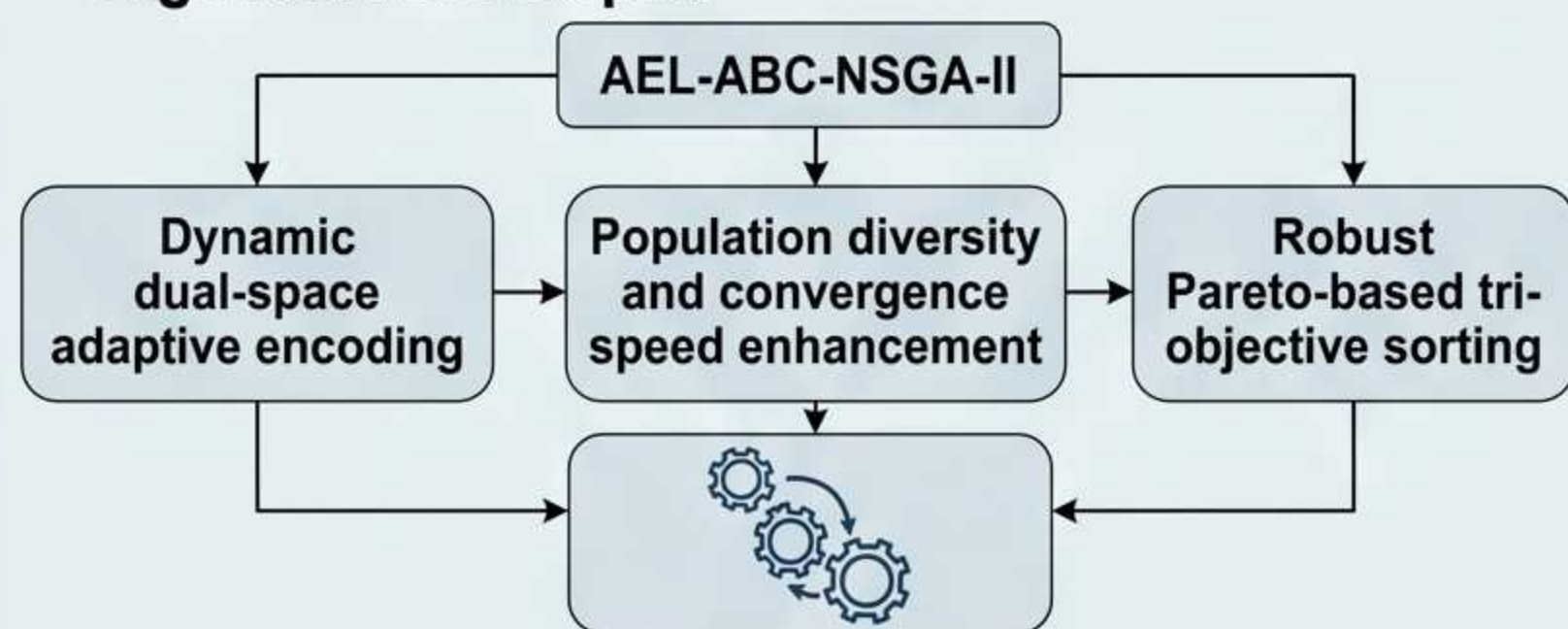


- **Background**
 - Rapid depletion of fossil fuels
 - Increasing pressure to mitigate environmental impacts
 - Large-scale integration of renewable energy
- **Challenges**
 - Coordinating diverse energy sources: hydro, thermal, wind, solar PV, BESSs
 - Managing significant uncertainty, non-linear physical constraints, highly conflicting operational goals
- **Aim**
 - Presents comprehensive tri-objective optimization framework
- **Objectives**
 - Simultaneously minimize total generation cost, atmospheric emissions, voltage deviation
 - Under wide range of nonlinear operational constraints, including valve-point loading, hydro reservoir dynamics, renewable generation uncertainty, battery charging-discharging behavior

METHOD



Algorithm Developed



'AEL-ABC-NSGA-II' hybrid algorithm framework

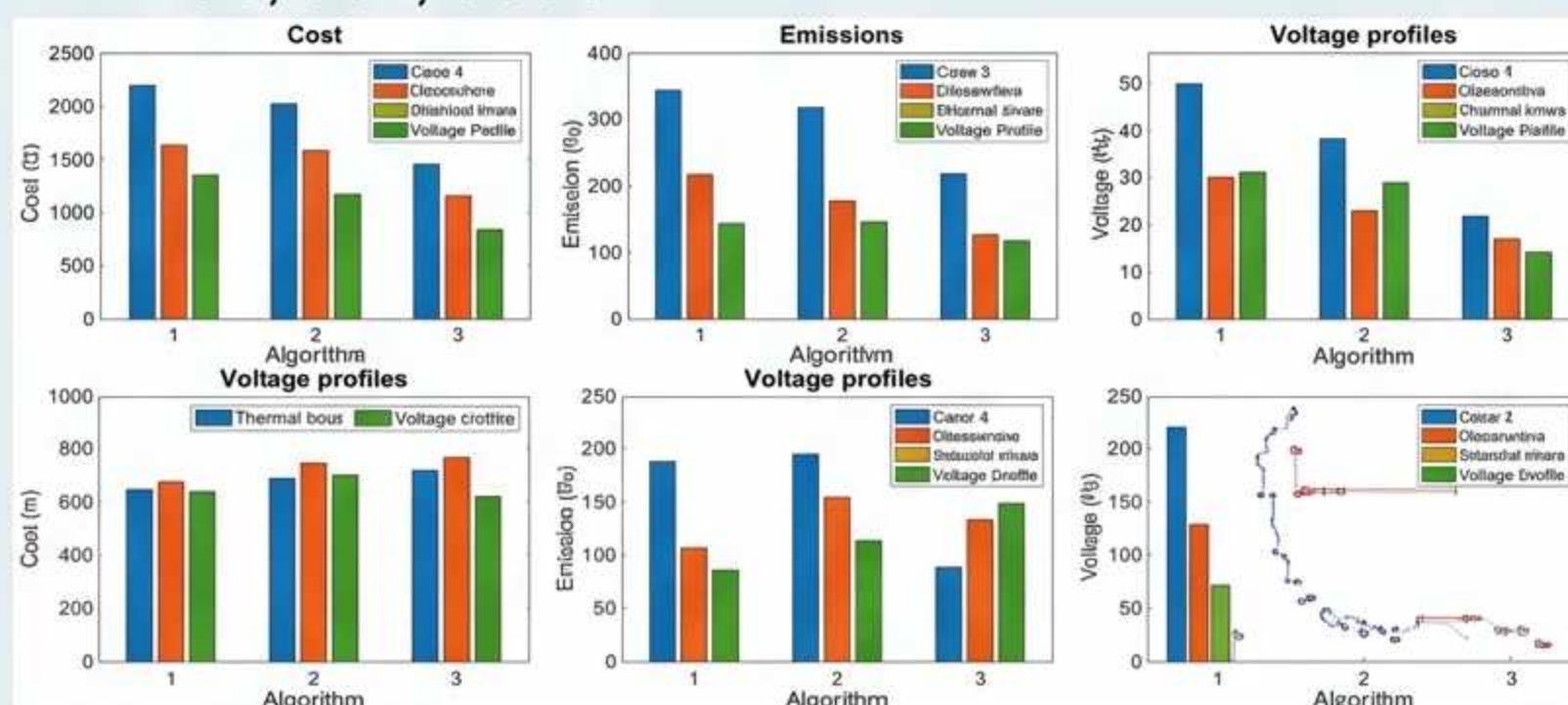
- **Mechanism**
 - Dynamic dual-space - adaptive encoding, population diversity and convergence speed enhancement
- **Testing Framework**
 - Validated on IEEE 39-bus test system
 - 24-hour dynamic load conditions
- **Study Cases**
 - Thermal-only
 - Thermal+Wind
 - Thermal+Wind+Solar PV
 - Thermal+Wind+BESS



RESULTS & DISCUSSION



- **Optimal Configuration Found**
 - Case 4: Thermal + Wind + Solar PV + BESS configuration
 - Driven by dynamic stabilization and peak-shaving capabilities of BESS
- **Key Statistical Improvements (Case 4 vs. Case 1)**
 - Cost Reductions: **Up to 12.73%**
 - Emission Reductions: **Up to 28.31%**
 - Voltage Profile Improvement: **Up to 50.9%**
- **Optimiser Superiority**
 - Convergence analysis, Pareto front assessment, statistical validation using ANOVA and box-plots demonstrate AEL-ABC-NSGA-II consistently achieves superior quality global solutions, robust stability, and significant reductions to established metaheuristics GA, PSO, SCA, COSCA



CONCLUSION



- Effective framework, addressing non-linearity, non-convexity, and uncertainties
- Balancing economic cost, environmental impact, and grid stability
- Robust tool for sustainable energy planning

FUTURE WORK / REFERENCES



- **Future Work**
 - Multi-area interconnected power systems
 - Coordinated market participation
 - Incorporate flexible demand response
 - Emerging storage like EVs and hydrogen storage

[1] S. Dutta et al., *Journal of Energy Storage*, vol. 141, 119069, 2026
 [2] M. R. Behnamfar et al., *Journal of Electrical Engineering & Technology*, vol. 16, no. 3, 1327-1347, 2026