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Transmission Expansion Planning with Photovoltaic Generation Penetration

PROBLEM

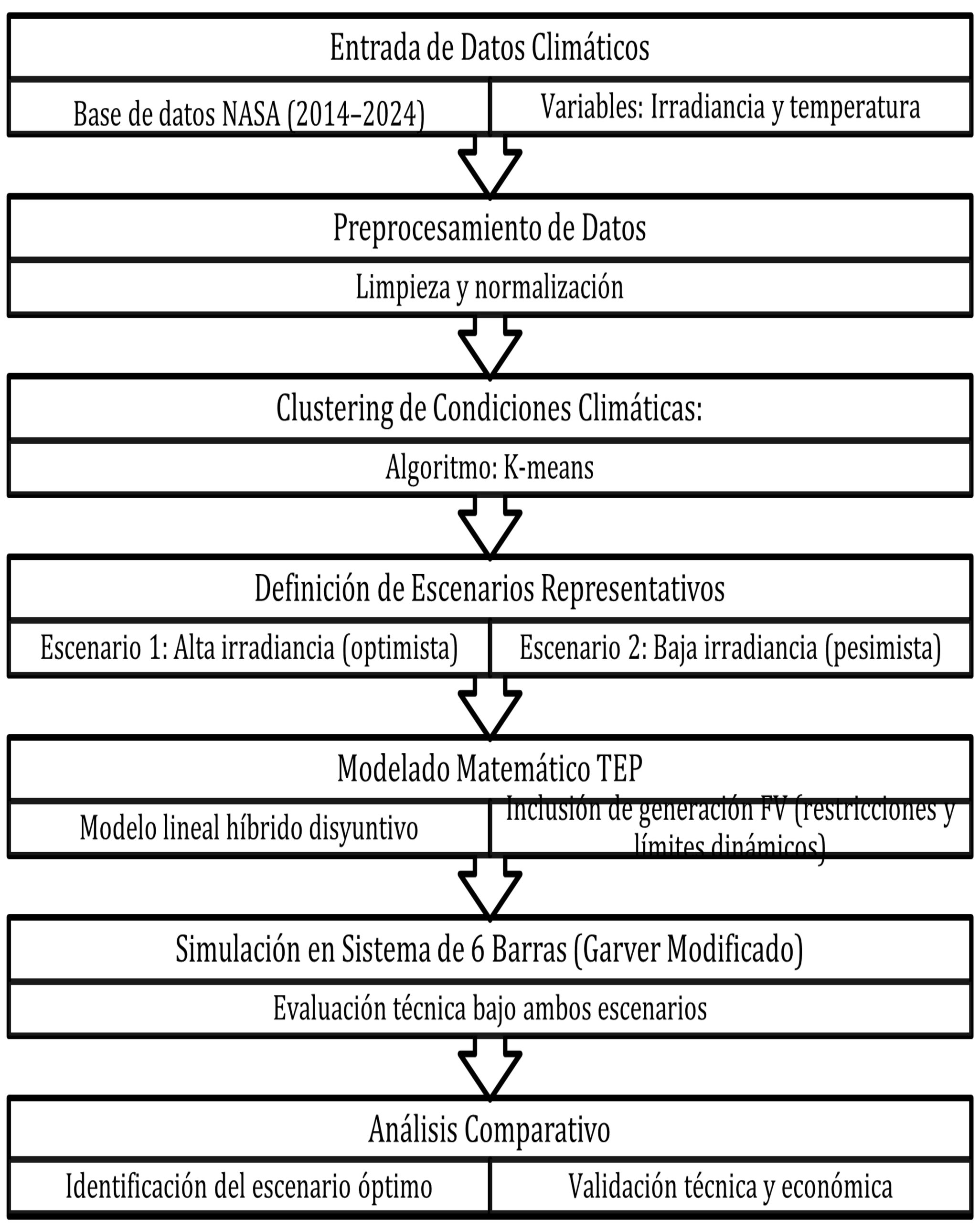
Transmission Expansion Planning (TEP) faces increasing complexity due to the integration of photovoltaic (PV) generation. Traditional models often fail to incorporate the stochastic behavior of solar resources, leading to inefficient infrastructure expansion and increased investment costs. Additionally, high variability in irradiance and temperature conditions further complicates the modeling process.

GENERAL OBJECTIVE

To develop and validate a modified hybrid linear TEP model that integrates photovoltaic generation by incorporating irradiance and temperature variability through machine learning techniques, particularly K-means clustering, enabling cost-effective and sustainable infrastructure expansion.

PROPOSAL

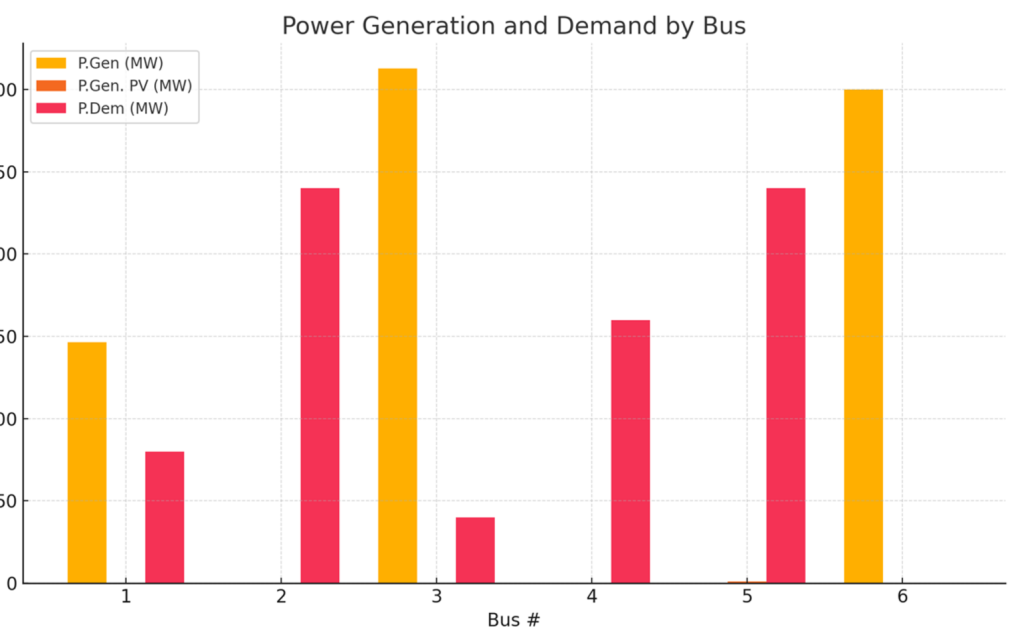
This study proposes an improved methodology for transmission expansion planning (TEP) that considers the integration of photovoltaic (PV) generation.
A traditional hybrid linear model was adapted to include new constraints associated with the characteristics of solar energy.
Ten years of historical solar irradiance and temperature data from Ecuador were analyzed using the K-means clustering technique. This process allowed the identification of representative climate conditions—specifically, typical scenarios for high and low irradiance—which were then used to define limits on PV generation within the planning model.
To ensure technical feasibility and reflect the real behavior of solar panels, additional constraints were introduced that link the output of PV systems to environmental factors such as irradiance and temperature.
In addition, the objective function of the model was modified to incorporate the cost of I^2R losses, encouraging the use of local generation and reducing the need for long-distance energy transport.
The methodology was tested on a modified version of the Garver 6-bus system. Through this case study, it was possible to evaluate different investment scenarios, compare the installation of new transmission lines, and analyze the system's behavior under both optimistic and pessimistic solar conditions.

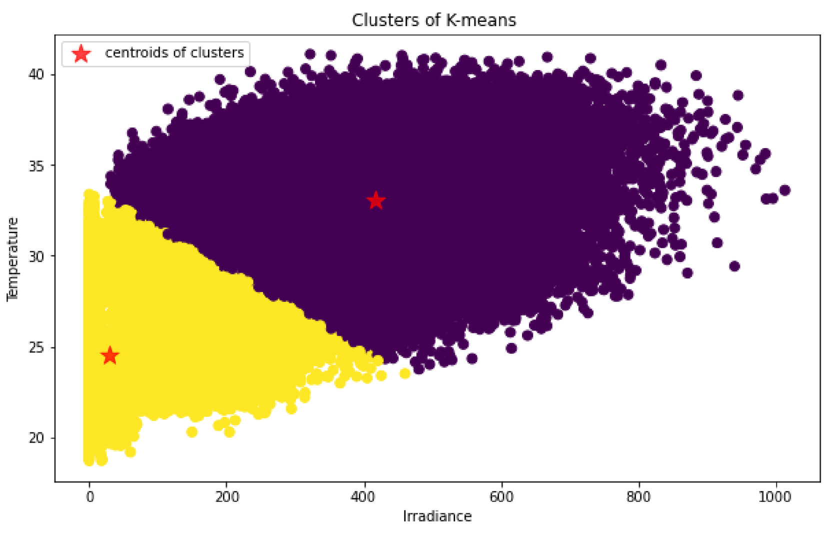


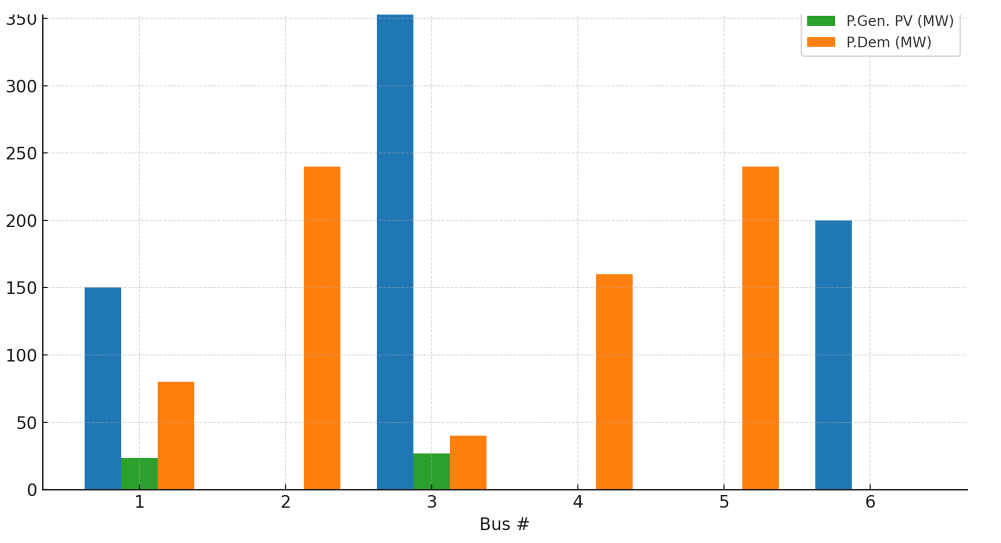
RESULTS

Clustering: K-means identified two distinct climate clusters (dry and rainy seasons).
High Irradiance Scenario:50 MW of PV recommended (buses 1 and 3),4 new lines required,
Total cost: $104,751.
Low Irradiance Scenario: Only 0.98 MW PV installed (bus 5),4 new lines required (including different ones),
Total cost: $118,876.
Optimal planning is achieved under the high irradiance condition due to better cost-benefit ratio.

RESULT OF BARS, SCENARIO WITH LOW IRRADIANCE







CONCLUSIONS

- The inclusion of PV generation using K-means clustering enables TEP to reflect realistic seasonal conditions.
- Planning based on the optimistic scenario (high irradiance) is economically advantageous and reduces system losses.
- The methodology is a practical step toward integrating AI and renewables into power system expansion planning.

ACKNOWLEDGMENTS

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