[*INTEGRATED GRID PLANNING MODEL UNDER UNCERTAINTY: TOWARDS SUSTAINABLE FUTURE GRID*]

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Overview

A significant capacity of distributed solar PV has been installed in the distribution network and this will continue to grow. However, the current approach for transmission and generation expansion planning does not account for distribution network constraints. Also, the risk of uncertainty represented by economic, regulatory and technology are not considered in a deterministic least cost optimisation grid planning model.

As a consequence, we do not know the impact of distribution network constraints on grid expansion planning and how uncertainty may influence the transmission and distribution level investment decisions. This paper presents a novel stochastic integrated grid planning approach considering distribution network constraints, combining a two-stage optimization grid expansion model with a distribution network hosting capacity assessment for a stylized representation of the Malaysian grid.

Initial deterministic result shows that distribution constraints are important: the overall system cost is increased significantly by 0.45% and the cost to mitigate voltage violations in distribution network are around 0.1 percent of the initial cost. Significant transmission investments are still necessary due to non-dispatchable characteristic of distributed solar PV. Also, integrating battery technology at different level of networks (transmission and distribution) will significantly reduce the overall cost and carbon emission. Finally, this approach provides considerable insights into the interaction between transmission and distribution networks in grid expansion planning under uncertainty.

Methods

The model combines a stochastic two-stage optimization-based grid expansion model with a distribution network hosting capacity assessment. We develop six scenarios which generally represent economic, regulatory and technology uncertainty. Together, they capture different anticipated relationships among model parameters such as capital costs, demand growth and renewable targets. First, the transmission and generation expansion model calculates an optimal solution considering only transmission grid constraints. Then, at the distribution level, the proposed capacity of distributed solar PV energy mix is assessed subject to distribution network hosting capacity limits that consider reverse power flow and voltage constraints. This cycle iterates until the proposed optimal solution satisfies the transmission level constraints and distribution network constraints as depicted in figure 1.

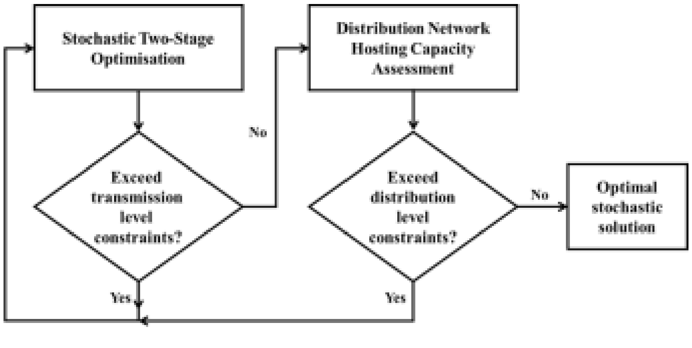

Figure 1 Stochastic integrated grid planning model flowchart

The optimization model is established based on linearized DC power flows, while the distribution network hosting capacity is assessed using non-linear steady state power flow analysis. To evaluate the effects of distributed solar PV, we introduce a distribution corridor that connects the transmission and distribution nodes. Also, we consider two distinct types of solar PV in the case study; dispatchable large-scale solar (LPV), which is connected to the transmission network, non-distpatchable distributed solar (DPV) which is connected to the distribution network. In addition, we include three battery storage types in this model: grid scale, controllable Distribution Service Operator

(DSO) owned storage, and uncontrollable distribution-connected domestic storage. We conduct a sensitivity analysis for different configurations of battery types in the network.

Results

Using deterministic approach, the initial result shows that including distribution constraints leads to significant cost differences resulting from reallocation of solar PV investment within transmission and distribution networks. Connecting battery storage in both networks (transmission and distribution) result in lowest expected cost and lowest CO_2 emission as depicted in table 1 and figure 2. Thus, this configuration is studied throughout stochastic analysis.

	No storage	All storage	Tx	TxHome	TxDx	Home	Dx	DxHome
Total cost ($ Billion)	184.69	157.66	159.07	157.74	158.41	167.24	168.64	163.57
Line Investment (GW)	15.02	14.69	18.37	16.12	16.40	11.82	21.25	15.91
CO2 ('000 Tonne)	375.84	371.10	385.49	371.17	375.84	454.85	462.71	426.28

Tx – transmission connected battery
Dx – Distribution connected battery
Home – Home battery storage

Table 1 Sensitivity analysis of battery storage configurations

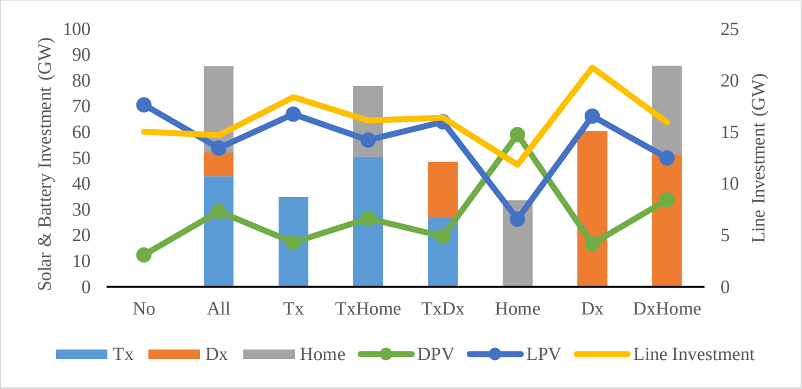

Figure 2 Solar and battery storage investment

Conclusions

From the preliminary deterministic results, we find that distribution constraints are important; the overall system cost is increases significantly by 0.45%, and the costs to mitigate voltage violations in distribution network have a $500M net present value over the planning horizon. Despite significant investment in distributed solar PV (DPV), transmission investments are still necessary due to distributed solar PV non-dispatchable characteristic. Integrating a range of battery types in the network results in lowest overall cost and CO_2 emission. Finally, it is important to consider uncertainty to analyse the interactions between transmission and distribution networks in grid planning.

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