Interconnected Smart Transactive Microgrids

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Smart transactive microgrids (STMs) are defined as specialized microgrid systems that can autonomously regulate the generation, storage, and consumption of electricity among a network of users within a localized area. They enhance both economic and environmental efficiency by employing real-time pricing mechanisms and digital technologies. In a more general sense, STMs can be considered as a subset of microgrids (MGs) that incorporate principles of transactive energy, along with energy and information sharing among consumers. The United States Department of Energy (DOE) initially conceptualized this idea in the early 2000s, inaugurating the Grid Wise program in 2005 to modernize the national electric grid, which included the advancement of transactive energy systems.

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1. Overview of Interconnected Smart Transactive Microgrid

An interconnected smart transactive microgrid (ISTMG) serves as a network formed by interconnecting multiple MGs. This network integrates various energy sources, loads, and storage mechanisms. While resembling a small-scale version of the primary power grid, it has the capability to function either autonomously or in coordination with it [1].

Similar to an MG, ISTMGs also possess the capability to switch between two operational modes. In grid-connected mode, it either draws power from or supplies excess energy to the electrical grid. In islanded mode, it autonomously generates and stores electricity. As shown in **Figure 1**, various distributed energy resources (DERs), including solar panels (PV), wind turbines (WT), small-scale generators, and storage systems, are typically integrated into ISTMGs. These resources contribute electricity to the MGs or main grid as well as store surplus energy for future use [2].

As illustrated in **Figure 1**, the interconnected configuration of MGs can enable the efficient distribution and optimization of energy amongst them. This feature can enhance efficiency, reliability, and resilience, thus proving particularly advantageous in remote or isolated areas where the connection to the main grid poses challenges [3]. Moreover, such a configuration can aid in the incorporation of renewable energy sources, thereby facilitating a transition to a more sustainable and decentralized energy system. Consequently, researchers will attempt to highlight a few primary characteristics of ISTMGs along with a brief discussion of their operational modes and benefits.

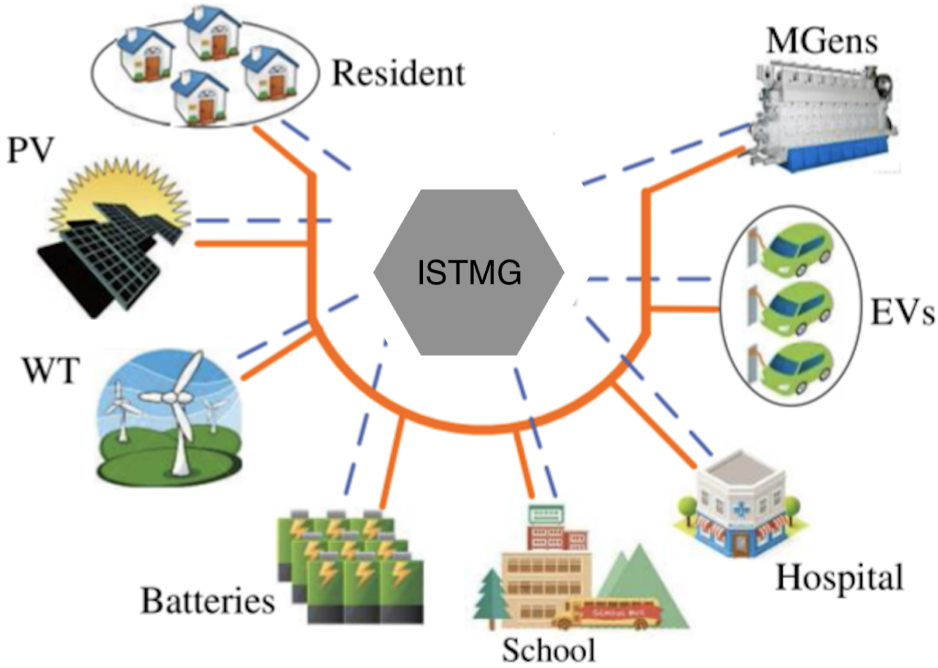

Figure 1. A high-level schematic of an ISTMG depicting the interconnected elements including MGs and DERs [4].

2. Characteristics of an Interconnected Smart Transactive Microgrid

There are a number of characteristics and functionalities expected in a typical ISTMG, and key aspects among these are outlined as follows:

- Integration of Distributed Energy Resources: ISTMGs are required to serve as advanced platforms for the efficient integration of DERs, such as solar panels, wind turbines, energy storage systems, and electric vehicles. By using sophisticated control algorithms and real-time data analytics, these interconnected MGs will enable the seamless pooling and optimization of energy assets located across various spatial configurations. Consequently, ISTMGs will not only facilitate autonomous energy exchanges between multiple MGs but also optimize energy supply and demand at more granular levels (i.e., below the main grid level). Thus, by deploying such intricate systems, ISTMGs will enhance the energy resilience of the larger grid, further contributing to improved grid stability, and minimal dependence on centralized energy infrastructures. This will offer a scalable and flexible solution for the future energy landscape [5].

- Control and Real-Time Monitoring: Advanced monitoring, control and management technologies are required within an ISTMG in order to continuously analyze the operational efficacy and status of DERs. Such real-time data-capturing mechanisms in ISTMGs will allow for efficient resource distribution and load balancing, thus promoting proactive regulation of energy production, its use and storage. Furthermore, such control structures in ISTMGs will facilitate the capability to identify and correct system issues, such as equipment malfunction or grid network perturbations [6].

- Transactive Energy Market: In most cases, ISTMGs should include one or more transactive energy marketplaces. Within such specialized marketplaces, the cost of electrical power is determined by a stochastic process that is impacted by a combination of supply and demand variables. This process determines the price. According to [7], multiple market actors, including owners of DERs, end consumers, and aggregators (i.e., MGs), are able to take part in energy transactions. This market-oriented approach is envisioned to improve the efficiency with which DERs are used and to foster electrical grid infrastructures that are both resilient and adaptable.

- Grid Interaction: Because of its connectivity, an ISTMG should have the capacity to exchange energy with the larger grid in both directions. This is made possible by the ability of the ISTMG to interact with the larger grid via specialized control systems. Thus, when there is a surplus of electricity generated, it is possible to send some of it back to the main grid. This will reduce the strain on the main system and result in financial gains for the owners of the ISTMGs. In contrast, an ISTMG should also be able to ensure a consistent supply of energy by drawing electricity from the main grid during times of high demand or when there is a shortage of generation [8].

3. Operation Modes

In this subsection, researchers highlight the two primary modes in which ISTMGs can function, which are as follows:

- Grid-Connected Mode: When operating in grid-connected mode, an ISTMG is physically connected to the primary power grid via a single point-of-connection (PoC). Consequently, an ISTMG is able to use this mode to receive electricity from the grid in the event that there is a high demand for electricity or when there is insufficient capacity for the generation of electricity locally. In addition, if an ISTMG generates more electricity than is required by constituent MGs, it can transmit the excess electricity back into the larger grid, which will improve the grid's overall stability [9].

- Island Mode: When an ISTMG is not connected to the primary power grid, it is said to be functioning in an islanded mode. This mode is activated whenever the primary grid is rendered inoperable, such as in the event of a power outage or a natural disaster, as well as in distant areas where it is impossible to connect to the grid. When operating in such an island mode, an ISTMG will rely only on its internal energy resources situated within each MG and its respective energy storage systems to provide all of the connected loads with the necessary amount of electricity being demanded [9][10].

4. Benefits of Interconnected Smart Transactive Microgrid

ISTMGs offer many benefits that contribute to an increase in the overall efficiency, dependability, and resiliency of an energy system. Listed below are some of these benefits:

- Enhanced Energy Efficiency: By generating power closer to where it is needed, ISTMGs like any MG reduce the transmission and distribution losses that are typically experienced in centralized grids. These losses occur when electricity must travel a greater distance to get to its destination. Thus, increasing energy efficiency and reducing reliance on fossil fuels are two additional benefits that come from tapping into the full potential of renewable resources and making use of local sources of energy situated within ISTMGs [11].

- Increased Reliability: Microgrids that are connected to one another can boost the reliability of the electricity supply by including energy storage devices as well as a wide array of energy sources. When they are functioning in grid-connected mode, they are able to maintain a continuous supply of electricity by drawing power from the primary grid during periods of high demand [12]. When functioning in island mode, they are able to continue generating electricity on their own, despite the fact that there may be issues with the main grid.

- Increased Resilience: The resilience of the energy system can be increased by ISTMGs because each constituent MG has the capability to operate independently in the event of an emergency or a natural disaster [13]. They decrease the consequences of power outages and guarantee that essential services can continue to be delivered by supplying a reliable source of electricity for essential facilities such as hospitals, emergency response centers, and rural settlements. This ensures that essential services can continue to be rendered without interruption.

- Local Energy Sharing: ISTMGs make it possible for multiple MGs to work together on sharing energy resources. Thus, if one MG has more electricity than another, the one with more electricity can send power to the one with less, so maintaining the system's equilibrium and ensuring a constant supply of energy. This kind of energy trading between neighbors fosters efficiency and helps communities become more resistant to disruption [14].

5. Trading in Interconnected Smart Transactive Microgrid

Trading in an ISTMG is a procedure that refers to the purchase and sale of electricity or other energy resources among multiple participants [15]. These participants will include MGs comprising different residences, businesses, institutions and independent providers of renewable energy. Consequently, participants in ISTMGs will have the capability to generate as well as consume electricity, hence opening up the potential for dynamic energy trading. This contrasts with conventional power flow, where electricity travels unidirectionally from large power plants to consumers [16].

Thus, in order for ISTMGs to participate in this form of energy trading, research and development will be needed to implement cutting-edge technologies. Advanced tools like smart meters, communication networks, and automated algorithms will be required to enable users to monitor their energy production, consumption, and interaction with other users in real time [17]. Consequently, these technologies will form the foundation of active energy platforms or marketplaces, thus optimizing the energy flow within the ISTMG by matching consumers and sellers based on their preferences [18].

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