Virtual power plant 330 kWh

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The energy system is changing fundamentally and new grid management strategies are needed to manage this transition. Decarbonization goals in 24 states and the District of Columbia are accelerating the shift to renewable generation and the electrification of end-uses in transportation, industry, and the built environment. At the same time, utilities are forecasting rapid demand growth for data centers, which could triple peak load in some areas. Throw in operational challenges stemming from changing demand profiles, volatile fuel costs, intermittent renewables, and extreme weather events and you have enough to keep utilities and their regulators up at night.

As we move into this new age of energy management, the potential of VPPs is becoming increasingly clear. However, we can"t overlook the role of a complementary tool in the load flexibility toolbox: Time-Varying Rates (TVRs).

While the rapid growth of DERs - expected to expand by 217 GW through 2028 - presents exciting opportunities, it also raises concerns about grid integration and complexity in management. Fortunately, TVRs can significantly help with VPP planning by aligning energy consumption patterns with the availability and characteristics of these DERs. In fact, though TVRs and VPPs are often considered and implemented as distinct solutions, they are fundamentally complementary.

Ultimately, customer engagement will depend on the practicalities of interacting with a utility. Although VPPs, TVRs, and DERs offer immense potential, their success hinges on how easily customers can access and understand these offerings. A bleak but powerful finding by Accenture noted that consumers spend less than 10 minutes per year engaging with their utility. Providing customers with insight into their DER options and related cost impact so they adopt more clean energy and electrified technologies is critical to achieving decarbonization targets.

Overcoming obstacles is a necessary step towards realizing full VPP potential. For VPPs to be widely adopted, it is still essential to address technological and operational challenges as they arise. Diverse stakeholders must work together to overcome market obstacles and promote the expansion of the VPP market. This analysis highlights the potential for VPPs to propel the evolution of contemporary power systems toward a more

sustainable and effective future by highlighting areas for future research and development.

There is an urgent need for creative and sustainable alternatives as the world"s need for energy rises, while fossil fuel-based power generation methods are increasingly scrutinized for their environmental effects [1]. Centralized alternating current power networks have been widely installed and used worldwide since the 1880s. Evaluations from the 2023 statistical global energy review [2] revealed that about 82% of the world"s primary energy source comes from fossil fuels like coal oil, and natural gas but their utilization produces greenhouse gas emissions that harm the environment and cause climate warming which has triggered the current global climate crisis [3]. The contribution of the different sources to world energy consumption is shown in Fig. 1.

Over the years, various research has been conducted to address the above challenges and many solutions have been proposed. VPPs have emerged as a ground-breaking solution in an era of energy transition and growing emphasis on sustainable power generation, altering the landscape of contemporary power systems [11]. VPPs have evolved as key players in promoting efficiency, flexibility, and resilience in the energy industry thanks to their capacity to integrate a variety of energy supplies and improve grid management [12, 13].

A VPP is an energy management system that aggregates and coordinates diverse array of DERs, including photovoltaics, wind turbines, battery energy storage systems (BESS), and demand response technologies. The primary function of a VPP is to optimize the collection of these DERs in response to grid conditions, energy demand, and market signal. Through advanced control algorithms and real-time monitoring capabilities, VPPs dynamically adjust energy dispatch schedules, balances supply and demand, and enhance grid stability and reliability.