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AN EFFICIENT ENERGY MANAGEMENT APPROACH FOR A SOLAR POWERED EV BATTERY CHARGING FACILITY TO SUPPORT DISTRIBUTION GRID

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ABSTRACT

The home photovoltaic (HPV) system integrated with energy storages can supply power to the distribution grid which may be reliable and free from HPV intermittency effects. However, this is always associated with the high cost of energy storages. On the other hand, the growth of electric vehicles (EV) in the market has a potential to place the distribution grid in a high risk as the EV owners may charge the EV battery on demand which may cause an unexpected increase in the evening and power quality problems. This paper proposes an efficient energy management approach for the HPV systems to power the electric vehicle battery (EVB) charging facility while utilizing the EVB as an energy storage system (ESS) that can mitigate the HPV impacts and allow the growth of HPV systems in power grids. This research is aimed for electric vehicles (EVs) that are compatible with the dc fast charging CHAdeMO standard. The operation strategy of the HPV-EVB charging system is designed in such a way that the EVB is either charged efficiently by the HPV or by the distribution grid. The proposed energy management strategy will help to reduce the unexpected peak power demand, and can help in the implementation of the vehicle-to-grid (V2G) to improve the stability of the grid during peak load. In addition, the EVB can provide power to the critical loads in the home when there is a loss of power supply from the grid. In the proposed system, the HPV, the grid, and the EVB converters share a common dc bus. Both the simulation and experimental results show that the proposed energy management of the HPV-EVB system can reduce the impacts of the high penetration of EVs and HPVs on power distribution grids and can effectively improve the self-consumption of the HPV systems.

INDEX TERMS— Charging facility, electric vehicles, local grid support, solar photovoltaic (PV) system.

1.INTRODUCTION

Nowadays, vehicles are considered vital elements in everyday life for personal mobility and transport of goods as reflected by the continuous demand for petroleum. Along with such a demand, the rise in fuel

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costs and increasing global concerns over the environment because of air pollution and climate change have elicited apprehensions. Consequently, certain governments have encouraged car manufacturers to create environmentally friendly and low-emission transportation alternatives. In this context, Electric Vehicles (EVs) have been developed and utilized to minimize dependency on fossil fuels; this has resulted in the reduction of emissions of greenhouse gases and other pollutant. Furthermore, vehicle emission standards have been imposed to avert environmental damage caused by conventional vehicles; several countries, such as the United States, the United Kingdom, Japan, and Europe, have adopted standards on transportation systems to reduce vehicle emissions. In this context, the net percentage of ‘‘atmospheric aerosol particles’’ produced by vehicles exhaust have been significantly reduced by 99 %, since the Euro 5 emission standards. Besides, carbon dioxide and nitrogen dioxide have been significantly reduced since Euro 1 emission standard onwards. However, vehicle emissions are targeted to be reduced by 35 mg/km of nitrogen dioxide and 95 g/km of carbon dioxide by 2020 in Europe.

	Sales (k)	Δ 2018 vs 2019
China	430.7	+ 111%
USA	116.2	+ 87 %
Norway	36.3	+ 74 %
Germany	33	+ 72 %
France	24.3	+ 38 %
Netherlands	17.8	+ 118 %
Korea	17.7	+ 63 %
Canada	13.1	+ 37 %
UK	12.7	+ 62 %

Table 1.1: Global sales of EV.

Under such a paradigm shift, EVs are becoming more competitive in terms of cost compared with Internal Combustion Engine Vehicles (ICEVs). Aware of the performance of EVs, several countries,

among them the USA, UK, China, and European countries, have formulated a number of resolutions and extended important funding to encourage the extensive adoption of EVs. Table 1.1 depicts the mass integration of EVs in several countries. Based on future planning scenarios, by 2050, all EV fleets will be supplied by Renewable Energy Sources (RES). In fact, the increasing adoption and use of EVs are the outcome of the advance in battery technology and the expansion of battery charging facilities in an attempt to satisfy their energy requisites. Thus, the general infrastructure of the charging system is essential for the promotion of EVs. However, the main weakness of EV charging infrastructures is that their use is not environmentally friendly as they depend only on the grid as power source. Indeed, renewable represent a distributable and time-bounded energy source, whereas the charging of EVs can be controlled; evidently, it logically relies on the combination of RES and EVs. Accordingly, it is necessary to balance electrical production and EV charging to guarantee and preserve secure constant grid operation. The irregular nature of RES production is considered as one of the main problems that must be resolved for the future operation of the electricity grid. Conventionally, load fluctuation control is generally not effective to balance the grid and execute operational strategy as well as power control under various load operating states. Generally, a potential solution is load scheduling by controlling the progress of the RES production; this has been proposed because further electricity production scheduling is crucial during power system functioning. Moreover, EVs have proven their ability to support the main grid in preserving certain equilibrium between demand and supply; this increases the potential for the RES penetration. In fact, numerous published research articles as those in discussed this subject. Furthermore, PV production may lead to the further penetration of EVs because the energy requirement of these vehicles do not result in a considerable rise in the total load. However, the integration of EVs and PVs into the grid, either separately or in combination, necessitates adequate planning; otherwise, system consistency can be compromised. As far as power grid operators are concerned, time uncertainty is the most crucial aspect in PV production. The problem with EVs is that they can disturb the demand side and cause grid overload; this condition can result in a decrease in both power quality and grid stability. The authors in, concluded that the integration of EV and PV into the grid has to be planned and controlled; for example, through the employment of a scheduled load approach, the number of PVs and EVs penetrating into the grid can increase. Evidently, the employment of renewable in the EV charging system is beneficial in the sense that it: (i) minimizes the loading effect of EVs on the grid; (ii) resolves the voltage regulation problems associated with the electricity grid; (iii) reduces utility supply costs; (iv) expands the energy storage

by increasing renewable production; (v) improves the effectiveness of both Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H) strategies; (vi) decreases fuel cost and (vii) prevents CO2 emissions. RES such as Photovoltaic (PV), Wind Turbine (WT), Fuel Cell (FC), hydroelectricity, biogas and other RES are ideal potential sources to charge and power EVs. These systems together with the energy storage systems (ESS) and the related electrical equipment's, combined by appropriate connection methods provide the charging requirements of EV's. The use of the local power sources, including the RES, allows feeding EVs with more employment of RES. Currently, RES are able to scale up electricity production in power grid including mainly PV, WT and biomass energy. Generally, they are easily employed to charge EVs due to their high energy density, their low cost of construction as well as their simple implementation and the increased efficiency of electricity production. Solar energy becomes widely used due to the high magnitude of solar energy on the Earth surface and its non-polluting and noiseless nature. The PV system in the stand-alone mode is generally unreliable as PV electricity production is influenced by the weather and environmental conditions. However, the PV modules are characterized by their simple structure, small size, lightweight and their stability in transport and installation. Moreover, the PV system takes short construction period and can be easily installed with other power sources and simply used at homes and/or public spaces. An energy storage device at the charging station can significantly mitigate the variability in PVs power output. PV solar panels to charge EVs are employed for several reasons

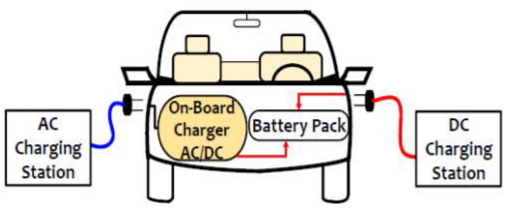

Fig. 1: On-board and off-board of EV chargers.

The fast charger as an on-board option for an EV is hampered by the cost of the electronic components required for energy conversion, which increases the overall cost of EVs. However, onboard chargers cannot provide fast EV charging because of the power electronics high costs associated with the EV and the necessity to increase the capacity of the charger in the vehicle. To ensure fast EV charging, off-board chargers providing high DC power are used It is noteworthy that, for off-board chargers, every AC/DC power conversion is performed through an independent inverter. Therefore, it is essential to raise the power of the converters to guarantee the vehicle fast charging. The findings obtained by numerous published studies have been implemented on EV charging stations to design and develop efficient and reliable EV charging systems. Accordingly, it is relevant to study the concept of a public facility installed with high-power off-board chargers functioning as a charging station. Such a station can provide EVs with the same functionality as a fuel station by supplying the EV batteries with direct current and allow rapid recharging. As for the charging station architecture relying on grid connection, only two options (AC and DC) can be considered. In the first architecture, the secondary side of the step-down transformer is used as a common AC bus where each load is connected to the bus via independent AC/DC stages. In the second architecture, a single AC/DC stage is configured to provide a common DC bus service for the system load.

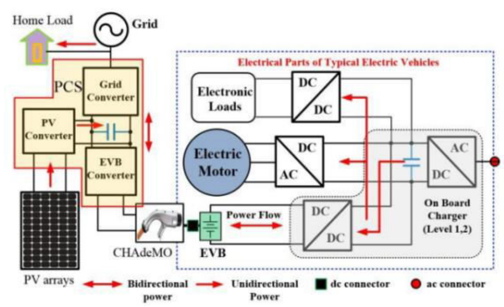

Fig. 2. Proposed charging facility; electric vehicle battery- integration with the HPV system.

2.LITERATURE SURVEY

In recent years, the integration of renewable energy sources into the power grid, particularly solar energy, has gained significant attention. The use of solar-powered electric vehicle (EV) battery charging facilities not only addresses the growing demand for EV charging infrastructure but also contributes to reducing the environmental impact of transportation. Researchers have explored various methods to optimize the use of solar power for EV charging, with a focus on energy management strategies that can enhance the performance and sustainability of these facilities while supporting the distribution grid.

Several studies have examined the potential of solar energy for EV battery charging. According to Patel et al. (2021), solar-powered EV charging systems are a promising solution to meet the growing energy demand for electric vehicles. The authors highlight that energy management plays a key role in the efficiency of these systems, particularly in terms of balancing the intermittent nature of solar power generation with the demand for charging services. In their work, Patel et al. propose an energy management strategy that prioritizes the use of solar power for charging and utilizes grid power only when solar energy is insufficient. This hybrid approach helps to reduce energy costs and the overall carbon footprint.

A key challenge in integrating solar power into EV charging facilities is the efficient management of energy between the solar panels, battery storage, and the grid. According to Zhang et al. (2020), an intelligent energy management system (EMS) is crucial for optimizing the use of solar energy in EV charging stations. Their study proposes an EMS that dynamically adjusts the charging process based on solar generation, battery state of charge (SOC), and grid conditions. The authors also emphasize the importance of energy storage systems, such as batteries or supercapacitors, to store excess solar energy for use during periods of low solar irradiance or high demand.

In a similar vein, Liu et al. (2022) focus on the role of smart grid technology in integrating solar-powered EV charging stations into the existing distribution grid. They propose a system where the charging facility can communicate with the grid and adjust its power consumption based on real-time grid conditions. This allows for better coordination between the solar charging station and the grid, ensuring that the facility supports grid stability while maximizing the use of renewable energy. Liu et al. also discuss the potential for vehicle-to-grid (V2G) technologies, where EVs can return stored energy to the grid, further enhancing the sustainability of the system.

A significant aspect of energy management in solar-powered EV charging stations is the use of optimization algorithms to balance solar generation, charging demand, and grid support. According to Yang et al. (2023), optimization techniques such as linear programming and dynamic programming can be used to minimize energy costs and improve the overall efficiency of the system. Their work demonstrates how optimization algorithms can help to forecast solar power generation, predict charging demand, and schedule energy usage accordingly, resulting in cost savings and enhanced system performance.

Additionally, studies have also investigated the economic and environmental impacts of solar-powered EV charging facilities. As highlighted by Wang et al. (2021), while the

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initial investment for solar panels and energy storage systems can be high, the long-term benefits include reduced operational costs, lower carbon emissions, and enhanced grid resilience. The authors stress that energy management strategies that incorporate both cost-effective and environmentally sustainable practices are essential for the success of solar-powered EV charging stations.

The literature reveals that efficient energy management strategies are central to the success of solar-powered EV charging facilities. By integrating intelligent EMS, energy storage systems, optimization algorithms, and grid interaction, these facilities can provide reliable, sustainable, and cost-effective charging solutions while supporting the broader distribution grid.

3.METHODOLOGY

The proposed methodology for an efficient energy management approach for a solar-powered EV battery charging facility involves a multi-layered strategy that focuses on the efficient use of solar energy, optimization of grid interaction, and the incorporation of energy storage systems. The first step in the methodology involves assessing the energy requirements of the charging facility and the solar power generation potential. This includes conducting a detailed analysis of solar irradiance data for the location and determining the energy needs of the EVs being charged.

The next step is to design an energy management system (EMS) that can monitor and control the flow of energy between the solar panels, energy storage system, and the grid. The EMS must account for various factors such as solar power availability, the state of charge (SOC) of the storage system, and the charging demand. The system must also be capable of adjusting the charging rates of the EVs in real-time to ensure optimal use of solar power and minimize reliance on the grid. This involves integrating advanced forecasting algorithms to predict solar generation and demand patterns, which can help in planning and scheduling the charging operations.

The energy storage system, typically composed of batteries or supercapacitors, plays a crucial role in balancing the intermittent nature of solar power generation. The methodology includes the integration of an energy storage system that can store excess solar energy generated during peak sunlight hours for use during periods of low solar generation or high demand. The energy storage system is managed by the EMS, which decides when to charge and discharge the storage based on real-time conditions.

Additionally, the methodology incorporates grid interaction as a key element of the energy management strategy. The EMS should be able to communicate with the distribution grid, adjusting the power consumption of the charging facility based on real-time grid conditions. This can help alleviate grid congestion and reduce the facility’s reliance on grid power during peak hours. The methodology also includes the potential for integrating vehicle-to-grid

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(V2G) technology, allowing EVs to supply stored energy back to the grid when needed, further enhancing grid stability.

Optimization algorithms, such as dynamic programming or linear programming, are employed to minimize energy costs and improve the system's overall performance. These algorithms take into account various parameters, including solar power generation forecasts, energy storage capacity, grid conditions, and EV charging demand, to create an optimal charging schedule. By adjusting the charging rates dynamically and prioritizing solar energy usage, the system can ensure cost-effective and sustainable operations.

The final step in the methodology is the implementation of the EMS in a real-world testing environment, followed by rigorous monitoring and performance evaluation. This involves collecting data on solar generation, charging demand, energy storage performance, and grid interaction to assess the system's efficiency, cost-effectiveness, and impact on grid stability. The results of the evaluation are then used to refine the energy management approach and optimize the system further.

4.PROPOSED SYSTEM

The proposed system is an advanced energy management solution for a solar-powered EV battery charging facility that aims to optimize the use of solar power, minimize reliance on the grid, and support the stability of the distribution grid. The system incorporates a robust energy management system (EMS) that dynamically adjusts the charging rates of EVs, controls the flow of energy between the solar panels, energy storage, and the grid, and optimizes the use of renewable energy sources.

At the core of the proposed system is the EMS, which is designed to monitor and manage energy flows in real-time. The EMS uses advanced forecasting techniques to predict solar power generation and charging demand, allowing the system to plan and schedule charging operations accordingly. The system prioritizes the use of solar energy for EV charging, reducing energy costs and reliance on grid power. During periods of excess solar generation, the system stores the surplus energy in an energy storage system, which can be used later when solar power generation is low or when there is a high demand for charging.

The energy storage system plays a vital role in ensuring a continuous power supply, especially during periods of low solar irradiance or high charging demand. The storage system is managed by the EMS, which decides when to charge or discharge the batteries based on real-time conditions. This helps to balance supply and demand, ensuring that the charging facility can meet the needs of EVs without overloading the grid.

In addition to the energy management capabilities, the proposed system includes a smart grid interface that allows the charging facility to communicate with the distribution grid. This enables the facility to adjust its power consumption based on grid conditions, supporting grid stability during peak demand periods. Furthermore, the

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system integrates vehicle-to-grid (V2G) technology, allowing EVs to return stored energy to the grid when necessary, contributing to grid resilience.

Optimization algorithms are also incorporated into the proposed system to improve the overall efficiency of the energy management process. These algorithms optimize the charging schedule, taking into account factors such as solar generation forecasts, storage capacity, and EV demand. By minimizing the reliance on grid power and maximizing the use of solar energy, the system reduces operational costs and enhances sustainability.

The proposed system also includes a user-friendly interface that allows operators to monitor the performance of the charging facility in real-time. This interface provides detailed information on solar generation, energy storage levels, grid interaction, and EV charging status, allowing for easy management and troubleshooting.

5.EXISTING SYSTEM

Existing systems for solar-powered EV charging typically rely on a simple integration of solar panels, energy storage, and the grid. These systems often use basic energy management strategies that focus on charging the EVs directly from solar power during daylight hours, while relying on grid power when solar generation is insufficient. While this approach is effective in some scenarios, it fails to fully optimize the use of solar energy and may not adequately support the distribution grid during peak demand periods.

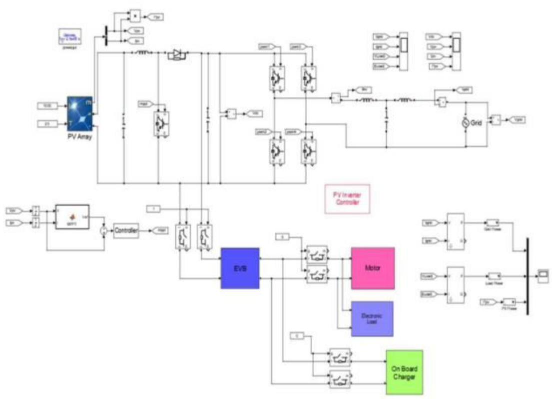
Many current systems lack the advanced forecasting and optimization techniques required to balance solar power generation with EV charging demand effectively. These systems often do not account for the intermittent nature of solar energy and are unable to dynamically adjust charging rates or store excess solar power for later use. This can result in suboptimal energy usage, higher energy costs, and increased reliance on the grid.

Another limitation of existing systems is the lack of smart grid integration. Most solar-powered EV charging stations operate in isolation from the grid, which means they cannot adjust their energy consumption based on real-time grid conditions. As a result, these facilities may exacerbate grid congestion during peak demand periods, contributing to instability in the distribution network.

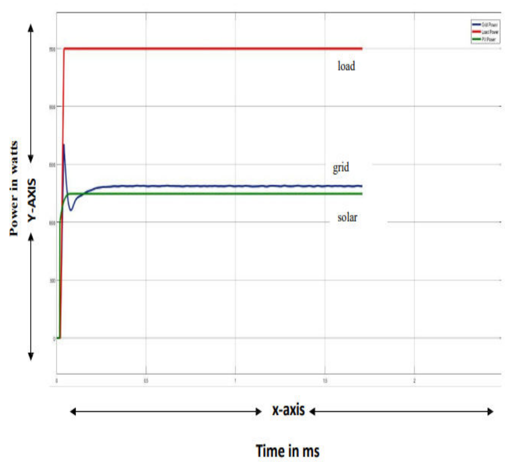
Furthermore, existing systems often do not incorporate vehicle-to-grid (V2G) technology, which can help support grid stability by allowing EVs to supply stored energy back to the grid when needed. Without V2G integration, the system's potential for contributing to grid resilience is limited.

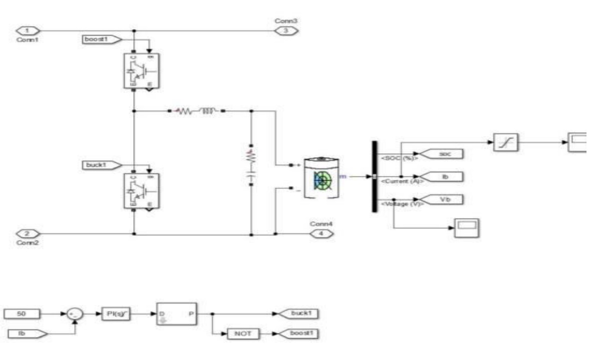
In contrast, the proposed system offers a more integrated and dynamic solution by incorporating advanced energy management strategies, smart grid communication, energy storage, and optimization algorithms. These features allow for better integration with the distribution grid, improved energy efficiency, and enhanced sustainability in solar-powered EV charging facilities.

6.SIMULATION RESULTS AND DISCUSSION



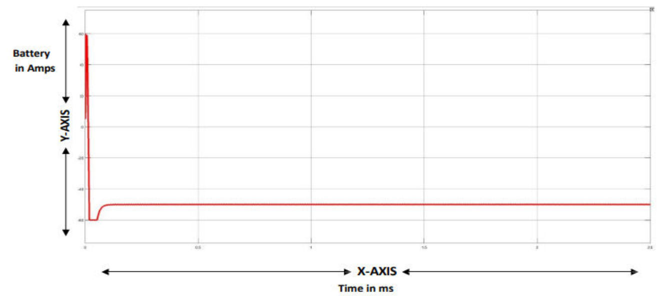
6.1 WAVEFORM OF A LOAD POWER

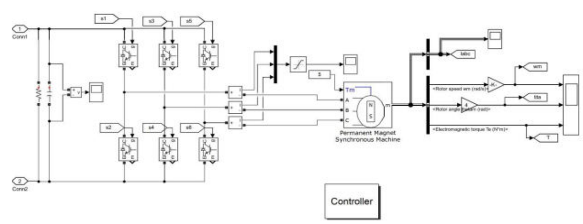




BATTERY POWER

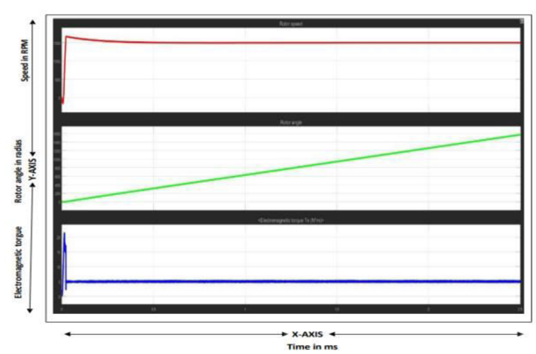
BATTERY STATUS

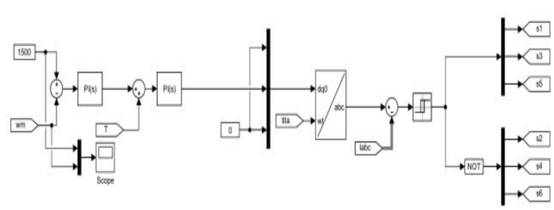




PERMANENT MAGNET SYNCHRONOUS MACHINE BLOCK DIAGRAM

ROTOR SPEED,ROTOR ANGLE,ELECTROMAGNETIC TORGUE RESULTS





MOTOR SPEED BLOCK DIAGRAM

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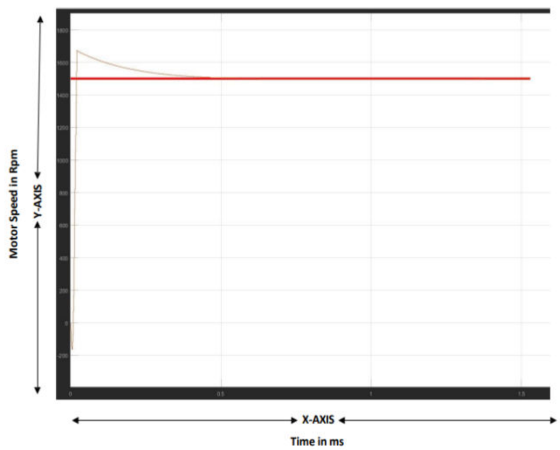
MOTOR SPEED RESULT



An efficient energy management approach for a solar powered EV battery charging facility aims to optimize power flow, maximize renewable energy utilization and support the distribution grid in the Electrical vehicle it is done.

7.CONCLUSION

In this paper, a novel HPV-EVB technology for the integration of the residential HPV and EV has been proposed. The energy management system successfully controls the power balance between the HPV source, EVB energy, the home load and the grid demands. This will help to mitigate the intermittency and uncertainty effects of the HPV and to provide a reliable power output. It is envisaged that the proposed system with its control algorithm will have a great potential for the future smart grid and EV applications. In this paper, it is considered that the home has two cars, and one is rarely used except for a short travel, which is quite common in most developed countries. For future work, the authors will investigate the proposed algorithm under a more complex network and during grid faults.

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