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TRANSFORMATIVE AND DISRUPTIVE ROLE OF LOCAL DIRECT CURRENT POWER NETWORKS IN POWER AND TRANSPORTATION SECTORS *

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Abstract. *The power sector is about to undergo a major disruptive transformation. In this paper, we have discussed the best possible energy solution for addressing the challenges of climate change and eradication of energy poverty. This paper focusses on the decentralized power generation, storage and distribution through photovoltaics and lithium batteries. It encompasses the need for local direct current (DC) power through the factors driving this change. The importance of local DC power in the transportation sector is also established. Finally, we conclude with data bolstering our argument towards the paradigm shift in the power network.*

Key words: *Photovoltaics, Lithium-ion batteries, Electric Vehicles, Nano-grid, Internet-of-Things, Blockchain*

1. INTRODUCTION

Renewable energy is the key to a sustainable power network for the future. The major sources of renewable energy today would be solar energy and wind energy. There is no direct competition between solar and wind energy since solar works during the day time and wind energy works mostly during night time. Off shore wind power generation and long-haul transmission of wind power is not cost effective. Only local power generation of wind power is cost effective. Thus, local generation and distribution of solar and wind energy-based power can provide an effective source of clean power for mankind. The focus of this paper, however, is solar energy based Photovoltaic (PV) systems and a power network consisting of PV and lithium-ion battery systems.

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Alternating current (AC) has been dominating power networks in the world ever since it won the battle against direct current (DC) in the late 19th century. The invention of the transformer allowed AC power to transmit over long distances with minimal losses by stepping up/down voltages with ease. However, the scenario is very different today. Most of the loads used today, except for a few inductive ones, are DC powered. Owing to the prowess in photovoltaic (PV) and lithium-ion battery technologies today, we can generate and store DC power locally. Minimal losses are encountered in local direct current power networks and the use of DC loads is much more energy efficient than the current AC network. PVs coupled with batteries provides an ultra-low-cost, secure and self-sufficient power network. No other energy source currently can match the declining costs for PVs as they work on the principle of free fuel based solar energy. Batteries are also experiencing a similar trend in their cost owing to the increasing demand for electric vehicles across the world. Fig. 1 displays a slope for the cost reduction in PV and lithium-ion batteries. We will be discussing the current status of PVs and batteries in section 2.

2. Current Status of Photovoltaics and Batteries

The exponential growth of the PV and battery industries leading to a substantial reduction in their cost, can enforce the paradigm shift from AC to DC power. In 2018 the global PV installations has reached 108 GW [3]. The University of New South Wales in Sydney has signed an agreement for a period of 15 years to have all its energy demands met by Solar PV. This agreement ensures the university to purchase 124,000 MW hours of electricity from a future solar farm called Sunraysia that is being constructed in the state. The university aims to achieve its goal of carbon neutrality of energy use by 2020 through this step. The facts about this agreement can be found in [4].

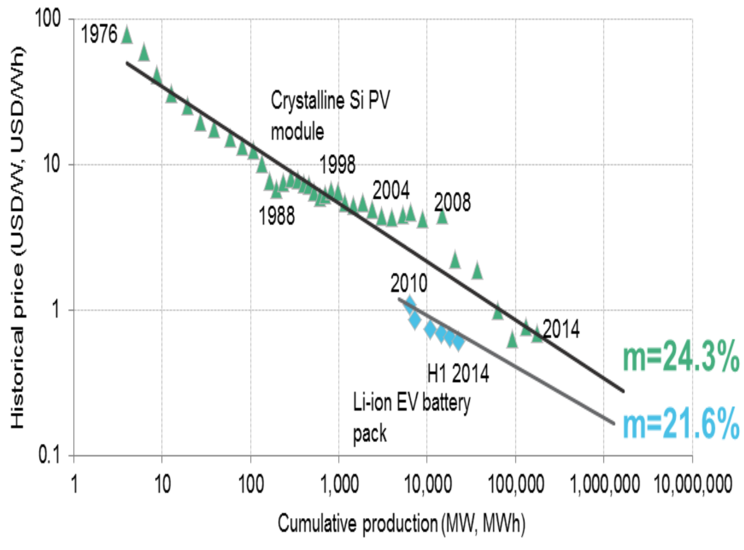

Fig. 1 Cost reduction trends of photovoltaic modules and Lithium batteries [2]

A solar project in Saudi Arabia led by Masdar, Abu Dhabi's renewable energy company, and its French partner EDF have submitted the lowest bid in the world for solar power generation at 1.79 US cents per kilowatt-hour (kWh) [5]. Fig. 2 shows data analytics from last year in which there is a clear exponential decrease in cost for PV systems and an exponential increase in the installation volume across the globe. At the end of 2018, the price of mono crystalline silicon panel has fallen to $0.25 per watt [6].

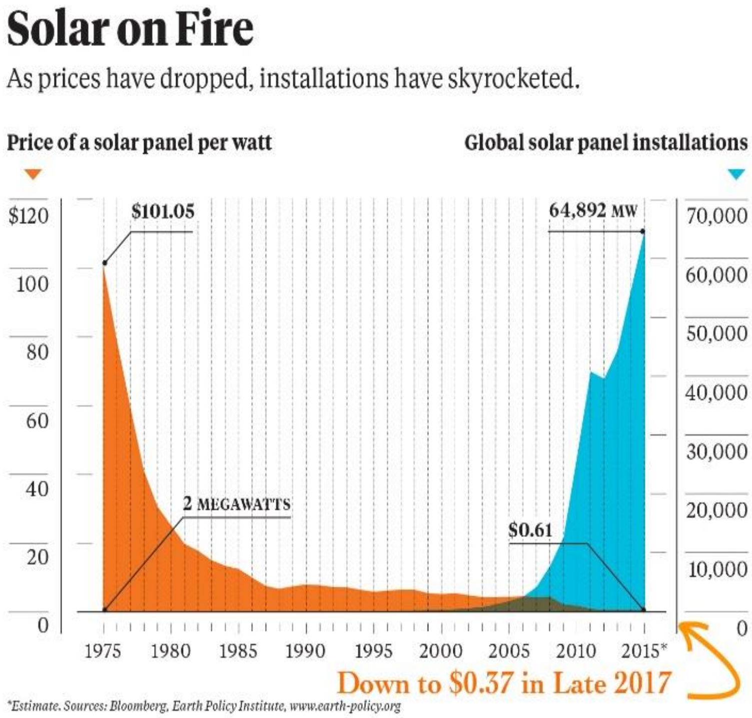

Fig. 2 Cost vs Installation Volume for PV systems [7]

Due to demand for EVs, consumer products and storage for PV power, the battery industry is also experiencing a similar trend in the cost and manufacturing. Lithium batteries are an attractive option for these markets as they have the highest energy density per weight. Lithium batteries are already dominant in the consumer goods market such as mobile phones and laptops. They are also considered extremely viable for the EV industry owing to their weight benefits. To meet this increasing demand for lithium batteries, gigawatt factories like TESLA's and Panasonic's $5 billion Giga-factory, are being built across the globe [8]. According to Fig. 3, the average lithium battery cost is forecasted to fall below $100 per kWh by 2022. We have already concluded in our paper [10] in 2014 that if current trends of PV growth continue, we expect PV electricity cost with storage to reach $0.02 per kWh in the next 8-10 years (2022-2024). With the data that is available today, the goal of $0.02 per kWh can be seen to be achieved well ahead of the predicted time.

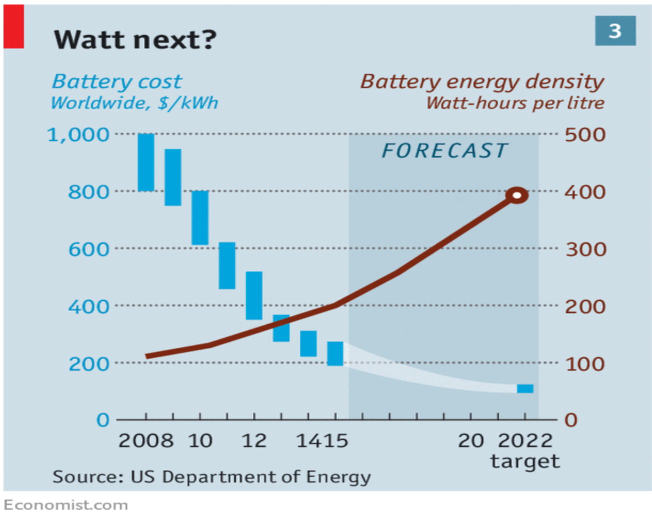

Fig. 3 Lithium-ion battery cost vs Energy Density [9]

3. Need for Local DC Power

The electricity industry is at the cusp of a dramatic transformation. The drivers for this paradigm shift are real-time grid monitoring, emergence of microgrid and nanogrid in place of centralized integrated electric grid, improved energy efficiency, cyber security in the grid, weather tolerant electricity infrastructure and intelligent loads [11]. We can discuss the importance of these factors and their fulfillment through a local DC power network.

3.1. Real-time grid monitoring

The concept of localized PV and battery-based DC power is further reinforced by the connectivity aspect of the Internet-of-Things (IoT). IoT is a boon in the domain of predictive analysis. The data collected over time can be utilized for predictive analysis to generate more efficient future outcomes. A solar energy company can install various IoT-based sensors on the solar panels and monitor their performance and provide real-time insight. Since these sensors can collect massive amounts of data, companies can utilize this to have a more granular oversight over their systems [12]. Various IoT based sensor techniques are available for monitoring solar energy grids for maximum power efficiency. We can see in [13], how an IoT-based network is created to monitor and control a smart farm utilizing solar panels as the power source.

Like PV systems, batteries can also be monitored through IoT based devices for enhanced performance in the grid. In [14], we can see the development of a battery monitoring system for the grid with the utilization of IoT. The combination of real time monitoring of the energy grid and utilization of intelligent DC loads can lead to immense power savings as opposed to the current power networks by optimizing the power-time function of a building grid access.

3.2. Emergence of micro-grid and nano-grid in place of centralized energy grids

In remote places, where the number of consumers is relatively small, it is quite challenging to draw transmission lines or to operate a generator that requires fuel delivery. On such instances, the PV and battery-based DC nano-grid system can provide optimum solution by eliminating the transmission challenges and by almost hassle-free operation. This holds the key to open the door of energy accessibility even to the people of underdeveloped economies where power for everyone is still a genuine issue [15]. Thus, such a decentralized power network empowers economic growth, creates a global middle-class and establishes social justice.

The local DC nano-grids and micro grids can operate at a lower voltage (<1500V), and thus eliminate the environmental, health and safety issues associated with high voltage AC transmission and distribution. Local distribution will also get rid of expensive tree branch pruning and vegetation clearance activities that are associated with high voltage AC lines running through forests. There is no significant issue of safety for 48V DC applications. For the data center and other general-purpose higher voltage applications, several companies supply DC power distribution hardware operating at 380V including circuit breakers with rated currents ranging from 15A to 2,500A [16].

Local generation, storage and transmission of power do not require massive transmission network infrastructure and its associated investment. The operational cost is greatly reduced for a local network due to this exclusion of long-distance transmission networks.

3.3. Improved energy efficiency

Most of the loads that we use today (except for a few inductive ones) are all DC powered. There is a need for conversion of power for AC to DC at the device level with the existing centralized AC power network. This conversion of power results in power losses at each stage of conversion. As reported by Singh and Shenai [17], over 30 % of electrical power can be saved by converting all appliances running currently on AC to high-efficiency and DC-

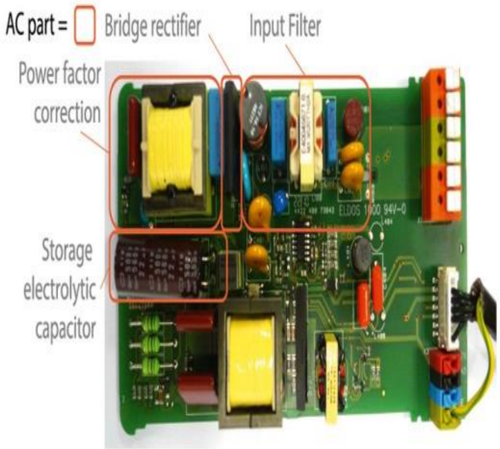

Fig. 4 Conversion circuitry for AC to DC conversion for a 35W LED bulb [18]

internal technology. Implementation of local DC power through PV and battery can eliminate majority of the conversion losses leading to a much more efficient network. Fig. 4 demonstrates the extra internal circuitry required for conversion of power from AC to DC in a 35W LED bulb. The amount of power wasted in generating AC power from a DC source like PV is discussed in detail in the following subsection of this paper.

A local DC network consists of DC power at generation and utilization. The elimination of conversion components leads to lesser capital cost for the network. Also, due to fewer components, the whole network has considerably lesser probability of component failures. Ultimately, it provides enhanced system reliability. Another important enabling prospect with fewer components in the system is the availability of less area for cyber-attacks. We would be discussing the overall aspect of cyber security in the following sub-section.

3.4. Cyber security in the grid

PV based DC microgrids are less vulnerable to cyber-attacks [19]. It is difficult for a remote attacker to access an isolated and self-contained PV based DC microgrid/nanogrid. Situational intelligence, real time monitoring, physical security and user control –all can be incorporated in PV based DC microgrid/nanogrid. Large grids and distributions require a lot of nodes where monitoring data are generated .and collected, and commands are sent to be executed. This transmission and reception of data creates opening for malicious intruders who might gain access to systems or data through sophisticated attacks [19].

In the age of internet of things (IoT) and remotely connected servers, a possible attack may come from any point, even from far ends of the internet. PV based DC microgrids/ nanogrids will employ intelligent control systems that are local and can remain secured from cyber-attacks. A leading networking company, Cisco, reported that about 73% of IT professionals in (centralized) utility service experienced security breach whereas the other industry's average is 55% [20]. Hence, by decentralizing the energy grid through local DC power, the risks of cyber-attacks to the grid can also be minimized.

3.5. Energy wasted in current AC based PV systems

The current power network is based on AC power. Majority of the loads that we use today draw AC power from the grid-supplied power. If PV systems are used as the source of power and batteries for storage, both these sources run on DC power. With the existing electrical system, this DC power must be converted into AC power and supplied to the loads. Solar inverters are used for this conversion from DC to AC power. While considering inverters, their sizing factor also must be taken into consideration. The sizing factor takes into account the watt rating of the solar panel array and the rated wattage of the inverter. For instance, a 150-kW array connected to a 100-kW inverter has a sizing factor of 1.5. The simulations run estimating the energy loss due to the oversizing of inverters yielded the results as in Fig. 5. The energy data is generated using Clemson's irradiance data for worst-case and best-case operating temperatures. The inverter sizing factors are derived from inverter efficiencies obtained from [21].

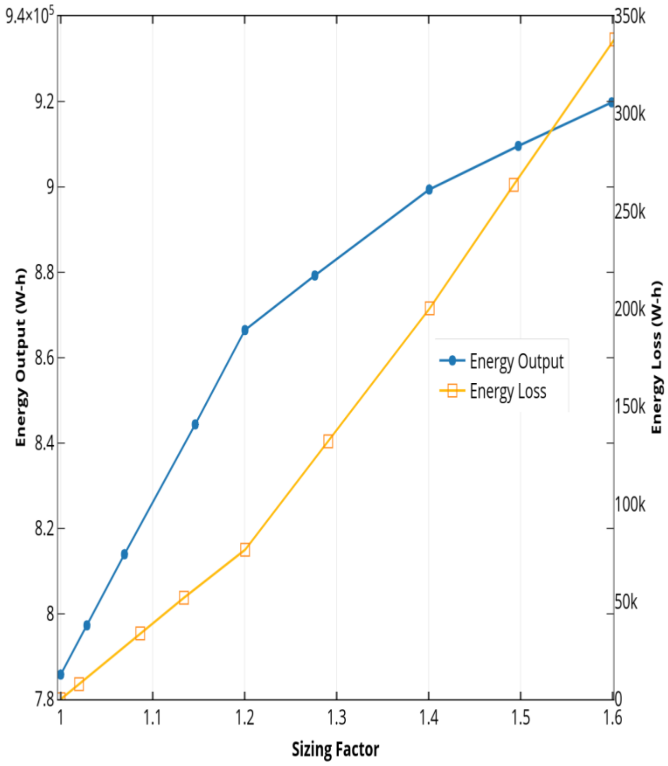

Fig. 5 Energy Loss and Output vs Sizing Factor

3.6. Weather tolerant electricity infrastructure

Recently, United States and other nations have been witnessing nature's wrath through frequent hurricanes and hail storms causing power outages in many parts of the world. Recently, NERL's main campus in Golden, Colorado was hit by a hail storm. Only one broken panel was reported broken among the 3000 panels that were installed on the roof of a net-zero energy building [22]. To further reiterate the claim for resiliency of PV based solar systems in times of natural disasters, Hurricane Irma's path can be taken into consideration. A 650-kW rooftop solar array on San Juan's VA Hospital continued to operate at 100% post-storm even after being exposed to wind speeds of about 180 mph [23]. Resiliency to harsh weather conditions is not the only advantage to PV and battery-based power networks. A power failure of a plant in a centralized AC power network impacts a very large area that is incorporated under the same network. With the implementation of decentralized local DC power grids, the area impacted by such failures would be much smaller. PV and battery-based local DC power networks are also much more resilient to geomagnetic storms caused by Coronal Mass Ejections (CMEs) [10].

3.7. Intelligent loads

The advent of IoT is a major revolution in the technological aspect of humanity. Every sector is working on incorporating smart devices that are embedded with sensors that relay information on the internet. From home appliances to automated robotics in manufacturing plants IoT-based products are being designed and implemented everywhere. The energy sector is also following the same path. As already discussed in this paper, IoT-based sensors enable real time monitoring of the grid for efficient energy output. However, IoT-based intelligent appliances can further enhance energy efficiency by demand-based utilization of power.

Such intelligent loads/appliances are already commercially available in the market. These loads can monitor electricity generated by solar and instruct ON/OFF times based on peak energy generation periods. For example, an automated washing machine can be instructed by the intelligent control hub to turn on only during periods of minimum load utilization and maximum free fuel based solar energy generation. Hence, a local DC power network has the incentive of easily coupling with the abundance of IoT-based intelligent loads that are making an entry into human lifestyle. To further bolster this idea of incentivization, we can refer to the recent article on the new range of EVs from BMW. According to the article [24], BMW i3 EV can be turned into cash cows by delaying their charging time to offset peak demand and align with maximization of renewable energy utilization [24].

4. Importance of DC Equipment and Appliances in Local Dc Power Networks

Availability and options for DC equipment are a major concern among the consumers as well as policy makers. Right now, the appliances are mostly sold with AC standard (110V or 220V). Though most of the appliances use DC internally, the connection to the wall outlet is still AC. With suitable policy, the market for DC appliances can grow and many manufacturing industries will find potential, even untapped, markets.

As mentioned in a previous publication [25] inside modern electronic equipment and appliances, a portion of the printed circuit board (PCB) is dedicated for converting AC into DC, and DC power is used in most areas of the PCB. The use of local DC power in place of AC will eliminate rectifier, smoothing filters, etc. from PCB. In addition to the cost reduction of components, time will be saved when we do not need to solder the AC/DC conversion rectifier, filters, etc. on the PCB. Manufacturing of all the loads that operate on DC power will provide significant cost reduction. For inductive loads connected to local DC power network, an internal inverter can be added as part of the inductive load.

5. Local DC Power in Transportion Sector

The recent data released by Environmental Protection Agency (EPA) signifies the growth of transportation sector as one of the major contributor to US greenhouse gas (GHG) emissions [26][27]. Transportation surpassed various economic sectors like electricity and industry to contribute for 28.5% of total US GHG emissions in 2016 [27]. This has raised several concerns about the petroleum-based transportation sector and has called for transformation. In case of surface transportation, there are four major drivers of change viz. – Electrification, Diverse Mobility, Autonomous Driving and Connectivity.

The need for a cleaner, cheaper and cost-efficient alternative technology for surface transportation has created the need for electrification. Increased carbon emissions and rising global temperatures have led to stricter laws and preventive measures by many EU countries [28]. Low cost and improved battery technology has also fueled electrification of surface transport sector which in-turn benefits the PV sector. Thereby establishing a triangular relationship between PV, EV and batteries. Furthermore, the cost of maintenance and operation aka Return on Investment (ROI) of electric DC vehicles is way cheaper than traditional IC engine-based automobiles [29][30]. As the sharing economy expands and consumer preferences change, the standard one person-one car model will continue to evolve from outright purchase or lease to rentals and carpooling, thus creating diverse mobility. The new era of IoT, wireless sensor networks, DC electric vehicles and improved battery technology have made it possible to envision autonomous driving and connected vehicle technology.

The rise in sales of EVs has accentuated the concept of localized DC charging using PV and battery-based systems. Localized charging for electric vehicles can be achieved in two ways; plug-in charging and onboard on-the-go charging.

5.1. Plug-in charging

Plug-in charging of electric vehicles is achieved by installing a charging station also known as electric vehicle supply equipment (EVSE) in your house or by accessing a public charge station in the neighborhood. The primary objective of local plug-in charging is to use current wall-outlet or some additional circuitry to charge the battery of electric cars. There are three types of electric charging stations available, Level 1, Level 2 and DC fast chargers. A key observation is that both Level 1 and 2 chargers operate on AC input power (120 V and 240 V respectively). The Plug-in EVs internal battery charger converts it into DC power to charge up the car’s traction battery [31]. This results in conversion losses and increases the charge time of the battery. The DC fast charging usually implements a direct link between a DC power source (either solar or battery) and the battery charging circuitry, thereby eliminating intermediate stages of conversion and rectifying [32]. This considerably reduces charge-time and has generated areas of smart control and PV based techniques for DC fast charging stations. Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies that ensure smart control and flow of energy, to and fro form the grid are also be implemented. However, reducing conversion and step-up/ step down losses is the primary reason for utilizing direct localized DC systems instead of grid dependent AC [32].

5.2. Onboard PV charging

On-board DC charging of electric vehicles aims at continuously charging the batteries on-the-go. In this technique, energy is usually harvested from an on-board solar panel and smart control techniques for efficient charging of the traction battery are implemented. This method is challenging as it involves smart control algorithms to mitigate effects of variability of solar energy as the vehicle is moving from point A to point B. Effects of partial shading, tracking maximum power point, variability of irradiance and temperature have to be compensated by intelligent control techniques and algorithms [33] [34]. Another critical challenge lies in retrofitting the design of existing EV drivetrain to integrate PV modules and additional PV circuitry. Sometimes integrating the solar panel might be bulky and undermine speed and performance. But many lightweight, small distance and low speed prototypes have successfully integrated PVs in their design. The Ford C-Max Solar, Toyota Prius, Volkswagen ID Buzz and Lightyear one is some examples. According to [35], a light weight aerodynamically efficient, small distance, car can travel up to 60 kms using bulk Si-PV modules. As battery technologies improve and design principles are tweaked, there would be many more local DC generated and powered automobiles, primarily relying on PV modules for functional power. The following section elaborates our work in studying benefits of localized DC power in field of transport.

5.3. Air Transportation

Other than surface transportation, advancements in battery technology is also impacting air transportation. Last year Boeing unveiled a new unmanned electric vertical-takeoff-and-landing (eVTOL) cargo air vehicle prototype that will be used to test and evolve Boeing's autonomy technology for future aerospace vehicles [36]. It is designed to transport a payload up to 500 pounds for possible future cargo and logistics applications. This year on January 23, Boeing announced that it recently conducted the first test flight of its all-electric autonomous passenger air vehicle [37]. The unpiloted vehicle took off vertically, hovered for a few seconds, and then landed at the designated site. Powered by an electric propulsion system, Boeing says the prototype is designed for fully autonomous flight from takeoff to landing, with a range of up to 50 miles (80.47 kilometers). Measuring 30 feet (9.14 meters) long and 28 feet (8.53 meters) wide, its airframe integrates the propulsion and wing systems to achieve efficient hover and forward flight. A number of startup companies are developing eVTOL based urban air mobility vehicles. Startup Eviation Aircraft and Siemens will jointly develop propulsion systems for the Alice, a nine-passenger electric commuter plane [38].

5.4. Water Transportation

Fossil fuel-based diesel is a problem not only on land, but also at sea. The environmental impact of Ferries, cargo ships or cruise ships includes greenhouse gas emission, acoustic and oil pollution. Shipping industry is one of the dirtiest. In collaboration with Norwegian shipyard Fjellstrand, in 2015 Siemens has developed the technology for the first electric car and passenger ferry in the world [39]. The electric ship has been moving silently through the Norwegian fjords – 34 times every day at 20-minute intervals between Lavik and Oppedal. A conventional ferry on this route consumes roughly one million liters of diesel per year and emits 2,680 tons of carbon dioxide as well as 37 tons of nitrogen oxide into air. On the other hand, the new 80-meter-long electric ship is powered by two 450 kilowatt electric motors, which take their energy from lithium-ion batteries [39]. The electric ferry reduced carbon emission by 95% and operating cost by 80 % [39].

6. Proof of Concept Experimental Results

We have established the energy efficiency of local DC Power through our experiments.

6.1. Li-ion battery charging

Firstly, we will demonstrate the power savings of direct DC charging of Lithium battery through Solar Panels as compared to AC charging networks. Fig. 6 demonstrates the experimental setup for direct DC charging.

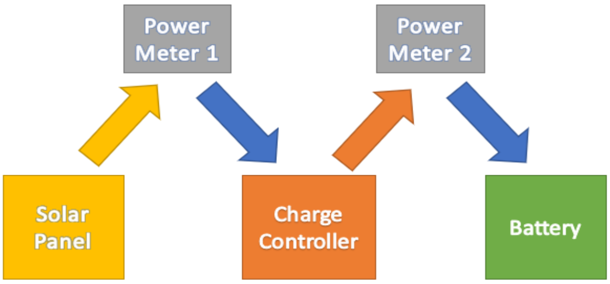

Fig. 6 DC Charging Experimental Setup

In the DC charging circuit, we connected the solar panel (320W) with an initial voltage of 41.7V to a Tristar MPPT charge controller at 1.19 PM when it was sunny. The charge controller is used to regulate the current and voltage for smooth charging process. The battery was previously discharged by connecting it to a DC powered refrigerator. The initial battery voltage was recorded as 15.7V. The charge controller equalizes the battery charging and hence, readings were taken every minute before and after the absorption state for 30 minutes.

Before reaching the absorption state, the panel delivered approximately 40W of power with voltage reading of 39.7V and current reading of 0.74A. The charging voltage and current delivered by the controller to the battery were 13.89V and 2.52A respectively. After reaching the absorption state, the power output from the solar panel stabilized at around 20W with a voltage and current reading of 39.5V and 0.5A respectively. The controller delivered constant power of approximately 18W with voltage and current readings of 13.93V and 1.3A respectively.

A charging network for the same battery was designed using an AC network as seen in Fig. 7. Such AC networks are prevalent today as the AC power network is dominant almost everywhere. We constituted for all the elements in the AC network and took reading every minute for 30 minutes. The battery charger used was the Lithium-ion battery charger by HCT Electric Co Ltd [39]. The initial voltage recorded for the AC mains was 119.7 V with a current of 2.66 A. The initial battery voltage recorded was 12.7 V. While charging, the AC input power was approximately 154.79 W (average) and the DC charging power was approximately 121.66 W (average). The charging voltage through the charger output was recorded as approximately 13.06 V and the current was recorded as approximately 9.55A.

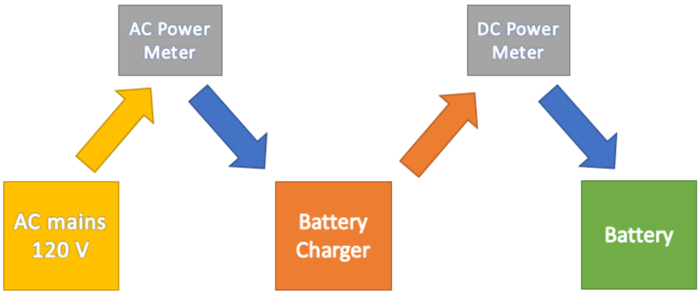

Fig. 7 AC Charging Experimental Setup

We recorded the average power readings for both DC and AC mechanisms and calculated average power losses. Table 1 demonstrates the charging efficiency and power losses incurred in the DC vs AC charging mechanisms.

Table 1 DC vs AC Charging efficiency

Parameters	Power Calculations		
	Average input power (W)	Average output power (W)	Average Power Loss (W)
DC Power (W) (Before Absorption State)	43.2	39.375	3.825
DC Power (W) (After Absorption State)	20.31	17.44	2.87
AC Power (W)	154.79	121.66	33.13

The DC charging incurs lesser losses due to fewer conversion components involved in its network. This experiment demonstrates the increased energy efficiency of DC charging as compared to the current AC technique.

6.2. Importance of new-age DC Loads

Along with the implementation of Local DC power, it is important to give significance to the emergence of DC loads. As an extension of this experiment, we conducted some power readings using a refrigerator that has both, DC and AC power, inputs. The Grape Solar Glacier 5-cu. ft. AC/DC Fridge/Freezer used for this purpose was purchased from Home Depot. These refrigerators are utilized in recreational vehicles (RVs). It was found that, in AC mode, there is ‘leakage’ or wastage of electrical energy when the refrigerator’s compressor is not running. This is due to idle-losses in the rectifying transformer. In DC, such phenomena do not exist. Fig. 8 shows a comparison of the power savings.

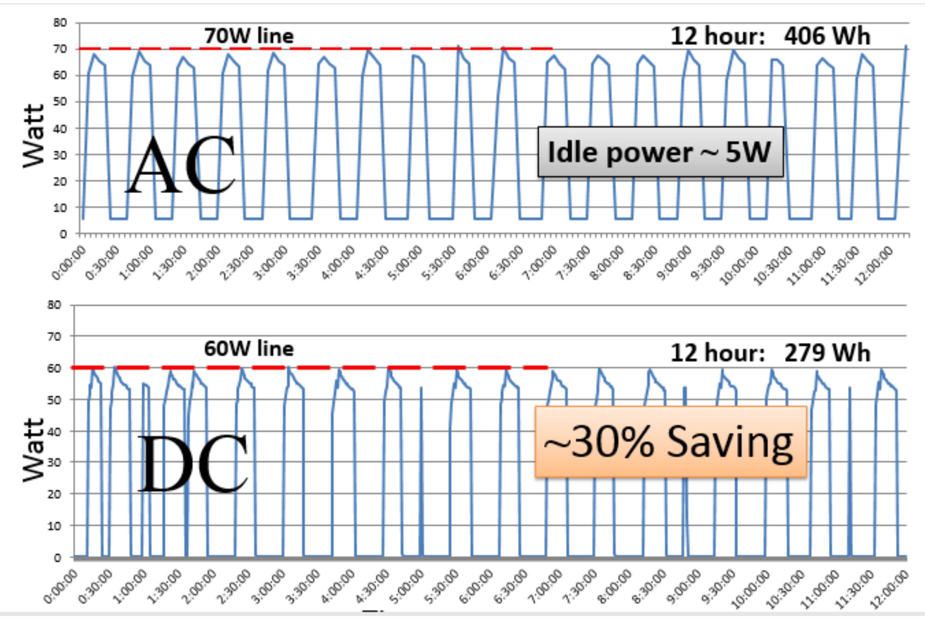

Fig. 8 Comparison of idle energy usage of the same appliance in DC and AC mode

6.3. Onboard PV for battery operated golf cart

In this experiment, we designed and analyzed a simple on-board PV powered DC golf cart. Using localized DC charging we increased the run-time and distance traveled by the golf cart and got comparable results even on cloudy and rainy days. In order to determine how the on-board solar panel would improve the electric golf cart performance, four types of trials were conducted in different weather conditions. For trial 1, the golf cart was driven on a set route on battery alone (without any solar panel). For trials 2, 3 and 4, the golf cart was driven on the same route as trial 1, but this time with battery and on-board PV solar panel. Trials 2, 3, and 4 were conducted on a hot sunny day, partly cloudy day and rainy day, respectively. Every 30 minutes, the golf cart was brought back to the initial start point to have battery voltage tested. The distance traveled by the golf cart during each trial was measured using a GPS phone-based application. The circuit was retrofitted to include, a MPPT charge controller, a circuit breaker switch, an on-board solar panel rated (320W), along with the 6 batteries of 6.6 V each connected in series to produce a net 40 V golf cart battery. Fig. 9 shows the increased on-road distance travelled by the golf cart with on-board PV charging. In Fig. 10 we can clearly see that with the help of on-board solar panel, the on-road run time has increased considerably. Table 2 summarizes the results of this experiment.

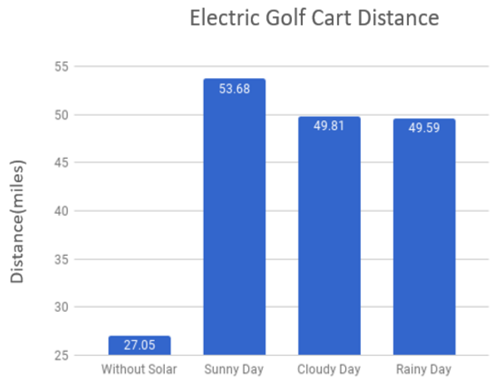

Fig. 9 Enhanced Distance travelled by PV golf cart

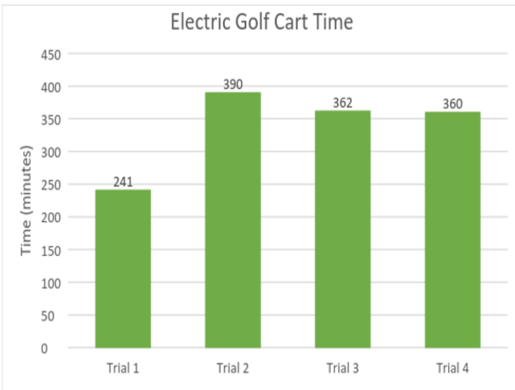

Fig. 10 Enhanced time traveled by PV golf cart

Table 2 Improvement in DC Golf cart parameters using on-board PV

Parameters	Without Solar	With Solar		
	Sunny	*Sunny*	*Cloudy*	*Rainy*
Distance in miles	27.05	53.68	49.81	49.59
Time in minutes	241	390	362	360
Improvement in Distance over Without Solar	--	98.45%	84.14	83.33
Improvement in Time over Without Solar	--	61.83%	50.21%	49.38%

7. BLOCKCHAIN TECHNOLOGY WITH LOCAL DC POWER

Blockchain technology is gaining its niche in today's digital world. The blockchain provides a decentralized platform to record transactions and distribute information without being copied. Therefore, instead of one central agency controlling the transaction and its data, blockchain allows the transaction to be distributed across a network and protects it using encryption mechanisms. In a central network with many nodes, a hacker may have many points of centralized vulnerability to attack on. This is eliminated in a decentralized network as the data is distributed over network. A similar concept can be applied to the power grid. The current AC system is equivalent to a centralized grid that controls the power generation and distribution. The central grid is connected to millions of nodes that utilizes power from the grid. With digitization venturing into every aspect of human life, the grid is also being digitized to enhance its efficiency. A centralized grid if attacked can affect all the nodes connected to it.

Moreover, the computation power required to operate millions of computational nodes is very large. However, with local DC networks, the grid is decentralized like the block chain technology. With a decentralized DC network, the number of nodes connected to the grid will be greatly reduced with the maximum number of nodes being in the order of thousands. As for the blockchain technology, the cyber security risks for this decentralized grid is greatly reduced. The computational power for thousands of nodes in a local nanogrid is also miniscule compared to the millions of nodes in a centralized grid. To give a clearer picture, a company called LO3 Energy has initiated a project called the Brooklyn microgrid [41]. Under this initiative, the participants can buy and sell locally generated solar power within their community and blockchain technology is used to record these energy transactions [41].

As the blockchain technology is beneficial for local DC networks and grids, PVs and batteries also compliment the cryptocurrency infrastructure prevalent on the blockchain architecture. There is a significant amount of energy consumed in mining of cryptocurrency. Since, free fuel-based PV and battery combination is the cheapest source of energy network available today, the cryptocurrencies can be mined at lowest energy expense using PV and batteries. This bidirectional advantage will further enforce the implementation of local DC power along with the booming blockchain architecture.

8. CONCLUSION

Based on the research conducted in this paper, we conclude that local DC power is shaping to be the energy network for the future. Our data indicates that local DC power has potential of providing disruptive transformation in power and transportation sectors.

With the introduction of proper policies, PV and battery-based local DC power grids will be the main mode of the energy generation, storage and consumption.

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