Review and Outlook on Energy Transition

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***Abstract*—The global shift away from fossil fuel-based electricity generation to resources such as wind and solar photovoltaic (PV) generation, electric vehicles and building electrification, and the increasing usage of energy storage, are critical enablers of the global energy transition now underway. Utilities are faced with various generation sources given the growth of renewable and must consider developing a new business model to enable an efficient delivery system. Intermittent generation (PV and wind energy) as well as distributed energy resources (DER) may well prove to be the single most disruptive and transformational influence in the history of the electric grid. The proposed work highlights transformation business models for electric utilities to manage the modern resilient grid maximizing decarbonization employing a large number of DER.**

Keywords— Decarbonization, distributed energy resources (DER), energy transition, innovation, renewable.

I. Introduction

Techno-economic advances are desired to decrease carbon emissions in the power sector [1-2]. Regardless of economically feasible and scalable renewable-based solutions accessible for around two-thirds of the global power supply, population growing and intensifying energy demand could outperform energy decarbonization without urgent investments in research and development. International Renewable Energy Agency (IRENA) inspects the elementary constraints vital to cultivate innovation and yield novel technologies for future low-carbon power system.

India has set ambitious targets in the direction of the accomplishment of the twin objectives of climate action and sustainable development via its nationally determined contributions and energy access promises [3]. As India starts a new era of energy shift, it is an opportune time to consider where India positions in attaining its goals as well as to recognize the main threats being faced throughout this shift. Techno-economic threats remain with integration of renewable in the power system – dynamics in consumer behavior, electricity generation ownership designs, and institutional associations rise queries on consumer tariff scheme and utility revenue business models. It demands discovering the correct equilibrium between stability and flexibility in this decade of decreasing costs of renewable and upgraded performance of emerging technologies. Moreover, there should be boosted robustness and certainty to lift investments.

The three Ds will play a massive role in imminent energy industry: Decarburization, Decentralization and Digitalization [4]. FERC Order No. 2222 outlooks to reform the power sector, upgraded analytics may decrease the severity of the Texas energy catastrophe and the practice for buying energy might one day become to bear a resemblance to booking an Uber — on cell phone and whenever required. Digitalization crafts novel prospects for power system operators to alter and convert multi-directional, receptive and integrated. With this background, energy efficacy and demand response and supplementary demand side resources can play a pivotal role in ancillary resilience, offering flexibility and depressing investment needs [5].

Fig. 1 illustrates key roadmap to achieve the sustainable energy transition. Cultivate invention means placing appropriate policy incentives in place, based upon a long-term outlook. As enduring innovation and economies of scale tailor to reduce renewable generation costs, the consequent step is to incorporate variable renewable energy (VRE) resources, detonating solar and wind, into existing grids. Electrification of transport, buildings and other end uses provides the opportunity to reduce emissions while integrating large-scale VRE. Technological developments have to go hand in hand with inventive policy frames, novel business models, appropriate fiscal instruments and a variety of social events to promote renewable and energy efficiency [6-7].

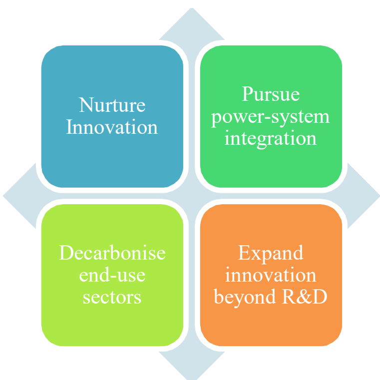


Fig. 1 Key roadmap to achieve the sustainable energy transition

Mission Innovation, Clean Energy Ministerial, and UNFCCC interpret prosperous invention would embrace the comprehensive technology lifespan. The guiding principle frame for invention, likewise, committed to offer balanced support, addressing both technologies themselves and features beyond technology, together with system operations, market design and protocols, and the empowering infrastructure to scale up renewable.

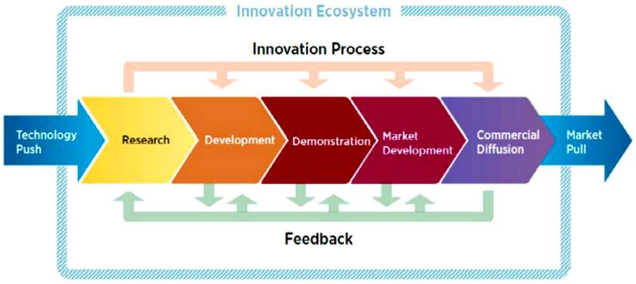


Fig. 2 Energy sector innovation ecosystem [8]

The advent of immediately necessary solutions to decarbonizes the global power segment necessitates uniting several guiding principles take hold of entire technology lifespan, from R&D to market scale-up. More invention is essential in empowering set-ups, system operation, and business models to step up adoption. Fig. 2 depicts energy sector innovation system with cyclic changes desired for paradigm shift from technology push to market pull. Established innovation initiatives involve mission innovation, TEA TCP and clean energy ministerial. Next stage of innovation will be sector transformation innovation under the efforts of G20- Leadership, Coordination, and collaboration. Fig. 3 details the innovation necessitated for power sector transformation. The energy segment has a robust business case for adoption of renewable, concerning for a substantial share of the emission reduction competency. Industry is the utmost exciting segment where more attention is required to exploit its capability and decrease the costs of technologies. Major investments for decarbonization will be desired for buildings.

Fig. 3 Innovation for power sector transformation

II. Ways to Accelerate Energy Transition for a Sustainable Future

The contemporary energy shift stratagem is portion of the wider objective of dropping carbon emissions, greenhouse gas emissions and the upsurge of worldwide temperatures. One of the key stone aims of the Paris Agreement is to retain global warming underneath 2°C and rather lower than 1.5°C.Energy efficiency is a cost-effective means to improve the sustainability of the energy sector. Combating Climate Change, Shifting Focus at Integrated Oil Companies, Economics Change the Energy Landscape, Electrifying Transportation, Moving Away from "Carbon-Intensive" Portfolios, and Promoting environment, social and governance (ESG) Scores are some of the ways to accelerate transition pathway. Fig. 4 represents the Key factors accelerating De-carbonized Energy Transition.

Blueprint for accelerating energy transition strategic plan may amalgamate:

a) The energy-proficient prospect. Energy proficiency is the utmost cost-effective solution, both short-term and mid-term.

b) Incorporating renewable and energy efficacy for elasticity and resiliency.

c) Unlocking the full potential by functioning organized and harmony to speed up the energy paradigm shift.

d) Clean energy move is gently hit out amidst the fourth industrial revolt. The clean energy shift targets at swap high-carbon fossil fuels with low-carbon green energy. Green energy mostly comprises of low-carbon RE resources such as solar, wind, hydro, bio energy, geothermal, etc.

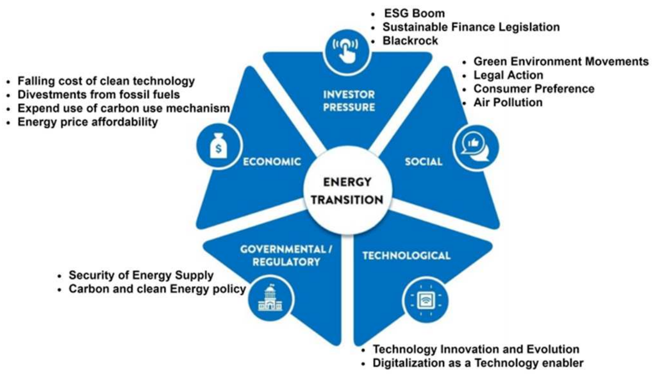


Fig. 4 Key factors accelerating De-carbonized Energy Transition [11]

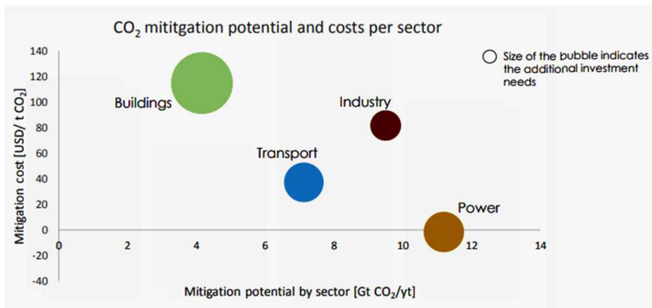


Fig. 5 Mitigation potential and costs by sector [8]

Sector-wise segregation for mitigation potential and costs are represented in Fig. 5. Green and clean renewable energy (RE) will signify half of all the emission reductions vital for decarbonization. RE technology prices vary. RE grid integration actions and biomass-based heating/transport technologies demand additional development emphasis on cost-reduction as they raise the average cost of RE. Energy efficiency interprets for main part of the other half, trailed by CCS and other low-carbon technologies such as material efficacy upgrading. Electrification results in savings, presuming that electric vehicle prices will be on same levelas internal combustion engines.

III. Emerging Technologies and Their Applications

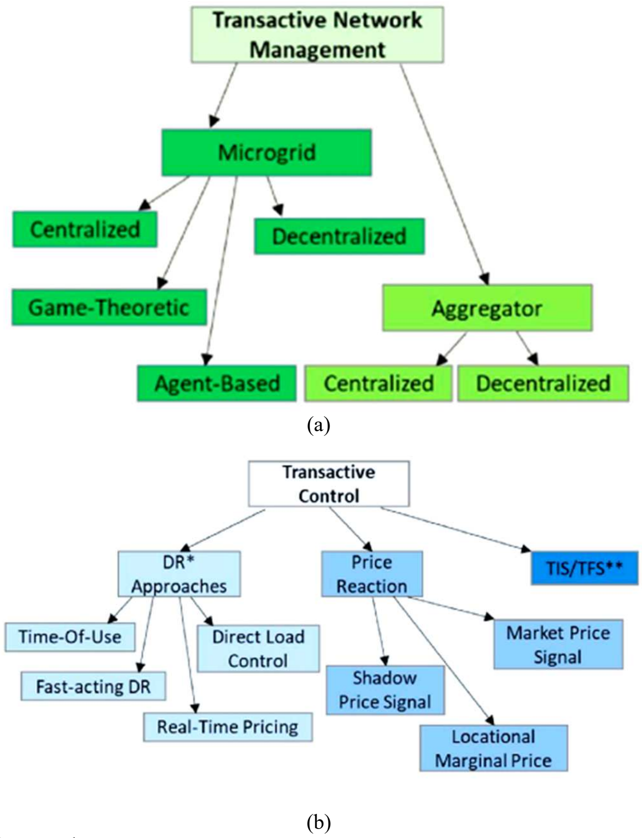
Artificial intelligence (AI) has offered a substantial prospective and opportunity for optimization in the area of power system. This can not only convey about a remarkable upgrading not only with concerns to the fiscal features but also in the protection and the real regulation of the operation.

AI techniques have cultivated prevalent for cracking diverse problems in energy sector such as controller, design, scheduling, prediction, etc. These techniques can address challenging assignments faced by submissions in contemporary large power systems with even more interconnections installed to meet cumulative load demand. The use of AI in smart grid offers commanding technical support for digital power system. Scenarios of AI in smart grid comprise of power resources, power system optimization, energy consumption pattern recognition, fault analysis, etc.

Internet of Things (IoT) mentions to the shared network of linked devices and the technology that smoothens communication among devices and the cloud, as well as among the devices themselves. One of the most significant practices of IoT is the Smart Grid (SG). SG is a data communications system which is unified with the grid to gather and explore data that are attained from transmission lines, distribution substations, and customers. Applications of IoT in Energy Generation are Energy system management, automated process, Disaster prevention, increased efficiency, Smart Energy Meters, Zero Net Energy Buildings, and Smart Decision Making. Blockchain technologies have fascinated the consideration of multi-control, process, and scheduling entities in the power sector. Blockchain technologies, which permit a mutual and disseminated database, consent for secure, transparent, economic, and robotic actions in distribution networks [18].

Transactive Energy (TE) fully exploit the capabilities of future smart power systems as a mean to manage consumption based on the generation rate and to provide solutions to manage the rate of generation in grid and demand sides [19]. Transactive energy portrays the amalgamation of proficient technology, policies, and fiscal drivers in proactive prosumer market where prosumers are buildings, electric vehicles, microgrids, Virtual Power Plants (VPPs) or other assets [20]. Fig. 6 depicts the taxonomy of TE management and control in smart grid paradigm.

The espousal of low-carbon technologies will emerge as solutions progressively attain market maturity. The move to green and secure energy will place the basis for end-use electrification. Emerging advanced low-carbon technologies such as Carbon Capture, Utilization and Storage (CCUS) and low-carbon hydrogen has potential longer-term options to reduce carbon emissions [9]. Further other low and zero carbon technologies such as solar hot water, air source heat pumps, ground source heat pump, Combined Heat and Power (CHP), Biomass heating, Efficient gas boiler, Solar photovoltaic (PV), Wind turbines may be employed to decelerate the climate change mitigation.



*Demand Response

**Transactive Incentive Signal (TIS) - Transactive Feedback Signal (TFS)

Fig. 6 Taxonomy of TE management and control (a) Transactive Network Management, (b) Transactive Control

By decreasing the reliance on fossil fuels, and petroleum products in particular, through applying locally applicable technologies of recovery and recycling, the global waste plastic issue could be tackled while reducing landfills. Regardless of the revealed performance of a green energy network via the emergency to offer cost-effective, reliable, low carbon energy when needed, threats persist in mid and long terms.

The main challenges of the energy transition [10]

- Optimal Energy mix and system flexibility needs.
- Grid-to-Vehicle charging set-ups.
- The requirement for long-term reserve capacity and ancillary services.

IV. Targets and Action Plan

Worldwide the concerns of global warming are accelerating. To fight against climate change, the Paris Agreement has brought together several nations with the target of restricting the global temperature rise this century below 2 degrees Celsius [11]. The energy shift is massive and needs continuous action plan in multi-areas: guiding principles, business supremacy, investor commitment, consumer and societal focus, and innovation in technological advances.

A. Tomorrow's electricity systems

Future energy systems will necessitate flexibility to sustain secure, reliable and green power services. Digitalization will be significant to observe the multifaceted system, pragmatic consumer behavior and flexible storage

[12]. Energy storage is pivotal for the cost-effective shift on the way to low-carbon paradigm. Battery storage set-ups are anticipated to turn out to be regular components of energy frameworks. The modernization pathway and the dropping cost of battery systems offer opportunity for exponential growth in the upcoming years. Storage-focused course of action and governing structures, and devoted fiscal incentives, will lead to technological acceptance to market realism. The transportation electrification will also uplift the appearance of the storage industry, further than static usage in the energy sector.

B. *Innovative Solutions*

Innovative solutions are desired to deal with deficit minerals requisite for battery built-up and sustainable resource chains. Shortage of flexibility alternatives to address resource inadequacies and response to market price signals may results into adverse outcomes, *viz*, severe price volatility to service disorders. One of the possible solutions to alleviate adverse consequences is integrating demand-side response (DR) offering additional flexibility to system operators. DR programs are executed for improved market operations. Intelligent energy management and behind-the-meter solutions, together with on-site generation and mini-grids, provide significant potential to regulate residential demand, to decrease energy tariffs during off-peak hours and minimize resource inadequacies through load shifting to timeslots of lower rates. Improved management of system operation and control, efficient utilization and monitoring of prevailing assets, consistent maintenance scheduling and smart coordinated transmission and distribution systems also defer and/or minimize expensive network reconfigurations, mostly in low to middle income countries which undergo from chronic underinvestment in system architectures.

C. *Sector Coupling*

"Sector coupling" will strengthen the centrality of distribution systems, implanting them with end utilization sectors, and shaping an intense and interoperating energy supply framework. Digitalization can significantly elevate grid resiliency and the penetration of DERs, profit-making, business and domestic storage units as well vehicle batteries. Aggregated batteries may drive as "virtual power plants", performing as buffers among fossil-fuel based power plants and load centers.

Green hydrogen, generated from low carbon energy, may appear as an additional valuable source at large and long-term, seasonal storage capacity. Captivating the elevated road to decarbonization, via orderly exploitation of energy-saving alternatives, supporting synergies among transport, digital, heating, cooling and industry sectors will convey substantial declines in CO2 emissions and will probably renovate fiscal frames.

D. *Holistic Assessment*

A holistic assessment is obliged to update energy system scheduling, drafting fiscal guidelines, and other policies essential to make sure a fair and comprehensive energy transition at the worldwide, provincial, national, and local levels. Scheduling should effort bottom-to-top approach to the target and reflect on the pace required to fabricate circular economies [16]. Fig. 7 represents the Enabling Policy Framework for a fair Energy Transition. The inherent variability and uncertainty of several renewable technologies depicts that energy systems will require to be more elastic to make sure supply-demand balance.

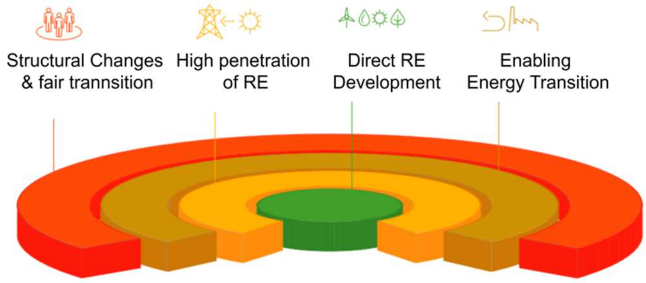


Fig. 7 Enabling Policy Framework for a Just Energy Transition [16]

Adequately healthy transmission and distribution systems are desired to address growth in power consumption pattern due to enhanced access to and electrification of end-use sectors, such as transport, heating, and cooling. In addition, energy systems should acclimatize to accommodate local energy resources, which introduce threats and opportunities for energy schedulers and system operators. Fig. 8 illustrates the Avoid-Shift-Improve Approach for travel activity, employing techno-economic instruments viz planning, regulatory, economic, information, investment. Fig. 9 depicts the Archetypes of collaboration to accelerate the net-zero transformation of industries.

E. *Collaboration Approach and Architectures*

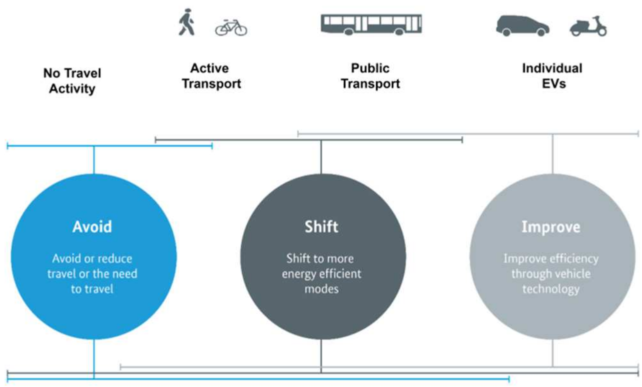


Fig. 8 Illustration of the Avoid-Shift-Improve Approach [13]

DER are physical and virtual assets set up across the distribution (comparatively low voltage) grid, usually near the load side, generally behind the meter, which can be employed in isolation or combined to offer value to the grid operator, individual consumers, or in coordination [17]. DER offer capacity value at system-level when they defer or avoid investment in generation and transmission assets. The system capacity value of DER depends on their utilization during system peak periods. DER also provides distribution-level capacity value when utilities defer or avoid investment in distribution assets. Electricity production from renewable and DER will undoubtedly grow as the life-cycle ownership cost decreases. The global DER targets are enormous and will eventually lead to highly complex and unwieldy distribution systems.

The electric grid — both transmission and distribution — must evolve rapidly to facilitate the bulk movement of carbon-free electricity if decarbonization goals are to be met. It necessitates disseminating growth in the association and constitution of swiftly developing multi-energy supply and demand systems. It emphasizes energy system frames, guiding principles, and directives, such as multi-tier energy market designs, pricing strategies, and auction regulations. Further, the decarbonization of generating resources, distribution, and consumption in multi-energy systems requires to drive vigorous and sustainable assets in flexible and renewable energy system models, techniques and tools considering all stakeholders' needs.

Fig. 9 Archetypes of collaboration to accelerate the net-zero transformation of industries [14]

F. The challenge with DER management

The rising volume of DER on distribution grids has caused many problems for grid operators. The challenges include back feeds, voltage control, hidden loads, as well as balancing and inertia issues, particularly at the distribution level. These complex systems cannot be managed, controlled, and protected using traditional processes. Renewable electricity and DER resources must be able to physically move energy between distant stakeholders, typically through a transmission grid. Further, these complex renewable and DER systems are often interconnected within a localized distribution system that cannot be adequately managed, controlled, or protected. With the rapid proliferation of DERs, grid operators must retain situational awareness, particularly the location, type of asset, asset status, and energy consumption and production. Traditional grid standards and practices do not provide operators with the tools to better manage grids increasingly laden with DER.SCADA communications cannot provide control of complex grid configurations, nor is it economically feasible to use SCADA to control hundreds or thousands of DER connected to a local or regional grid. Further, any solution must allow RTOs/ISOs to scale the volume of connected DER.

One solution is the IEEE 2030.5 protocol that uses Internet-based communications to interface and coordinate DER across the utility and non-utility ecosystems. IEEE 2030.5 is a communication protocol that allows grid operators to connect and operate DER of all types, sizes, as well as aggregated DER using well-known Internet of Things (IoT) communication technologies. The protocol uses the most advanced DER data models available that encompass the technical and contractual constraints of individual DER, from an individual thermostat to a large aggregator of various DER technologies. The use of IEEE 2030.5 is rapidly becoming the standard for DER interconnects (e.g., California Rule 21) to ensure future DER can provide their full range of grid services.

G. Transitioning grid operations from Distribution Network Operation (DNO) to a Distribution System Operation (DSO)

The fundamental shift from DNO to DSO operations is required because consumers have become producers and flexibility providers of electricity. Consumer energy consumption patterns have shifted to a new generation of proactive consumers with more complex energy profiles. This unpredictability in consumption and generation causes technical and operational challenges for DNOs.

The DSO model provides visibility into the distribution level systems to allow more detailed network analysis, planning, and operations of DER and intermittent renewable generation sources. DSOs are able to actively manage distribution networks by using advanced measurement and automation technologies to capture highly granular, ultra-fast measurement data through an intelligent and centralized management solution. The DSO will then be able to coordinate and optimally manage real-time a high penetration of small, dispersed renewable and DER to maximize reliability and efficiency.

H. Distributed Energy Resource Management System (DERMS) empowers a mature grid

The future grid must consider the influence of the worldwide energy transition, the changing regulatory framework, and a more flexible grid operations model. A DERMS performs these essential tasks. System owners and operators will realize these increasingly complex distribution systems' full operational and economic potential only when DERMS is fully implemented. DERMS economically optimizes the dispatch of a system of DER within the context of a security-constrained grid or to meet carbon targets. Further, it can project the future performance of a system of DER to anticipate and avoid different types of operating violations.

V. Conclusion

Energy will be drifted towards less reliable sources like wind and solar with effective energy transition. Consequently energy generation will be decentralized in the local electricity market or transactive energy market. The massive growth of electric vehicles and solar rooftop panels will have a colossal impact on the existing infrastructure. To deal with this realization of a large-scale energy data network, one of the possible solutions is installing a vast number of sensors that measure in high frequency and share data in almost real-time with each other and the operational systems. Connecting and operating slow-paced conventional systems with high-frequency networks (steering and mass data processing) will have adverse effects due to mismatch of technical specifications. It requires developing cost-effective business cases on this fast energy data network including real-life cases and best practices alleviating pin fall.

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