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# REALIZATION AND CONCEPT OF ENERGY INTERNET

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***Abstract*** - The growth in consumption of the energy has resulted in increased greater generation and dependence on the fossil fuels. This is harmful to the environment in terms of the released greenhouse gas (GHG) emissions and it also contributes towards the deficiency of finite resourses. The evolution of the power grid has, in its current iteration, brought the Smart Grid which has more connectivity, autonomous control and higher efficiency. However, with the devlopment of distributed generation stations and use of renewable sources for energy such as solar and wind, it is essential to incorporate these contributors into the centralized power grid scenario, resulting in a distributed grid. This requires real-time dependable communication with complex management and high reliability. In this paper, an overview of the development of Energy Internet (EI) is presented along with the challenges and key aspects that may contribute towards the smooth functioning of a developed EI.

***Keywords*** - Energy Internet, Smart Grid, Multi-Agent, Renewable Energy Sources (RES), distributed generation, Demand Side Management (DSM)

## I. Introduction

Electricity is an integral component in the day to day working at households and industries. In the past decades, the energy infrastructure has been evolving to encompass the growing population along with the growing use of it in industries. In the current energy consumption scenario, there is a heavy dependence on fossil fuels for generation. As a consequence, there is an increase in the release of greenhouse gas (GHG) emissions, specifically $CO_2$ [1][2]. Furthermore, the increasing dependency on the fossil fuels may result in a future energy resource deficiency [1][3].

The control of GHG emissions due to generation and production requires an increased use of renewable energy sources (RES) for generation. Furthermore, it requires contributions from different sectors such as the government, private, and society groups. A challenging aspect remains that the cost of the RES generated energy has to be brought down so as to compare with that of the fossil fuel energy. In addition, the generation and usage efficiency of the energy needs to be improved alongside the exploration of new energy pathways that may offer more encouraging solutions [2]. It is impossible to shut down the existing grid, but with the addition of the RES energy, the grid may evolve into a better version of itself.

### A. Evolution of the Power Grid

The energy production/ consumption can be said to have gone through four distinct phases for production and consumption, i.e.decentralized, centralized, distributed, and smart & connected[4]. The meaning of centralized control is that all production and consumption is handled by a single entity i.e, generation occurs at a single point and is then transferred through the grid to locations as per the demand. Decentralized production is generally done close to where it would be used, resulting in reduced transmission losses and carbon emissions. In comparison, distributed generation is a result of a number of varied grid-connected devices that have low capacity and can comprise of multiple generation and storage components. A comparison between the three can be pictographically depicted as in Fig. 1.

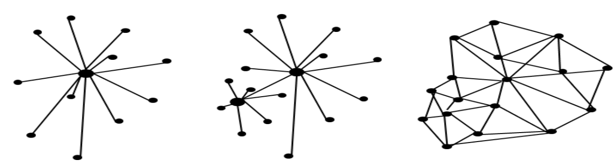

Fig. 1 Grid connected devices as: a) Centralized b) Decentralized c) Distributed Systems [28]

Centralized failures result in failures of the whole system whereas failure at a point in the distributed system and decentralized systems results in lower impacts on the rest of the system. On the other hand, centralized systems are easier to manage as there is only a single point of management whereas decentralized and distributed both have multiple points to maintain. Each phase of the evolution of the power grid had its merits and demerits [4].

i. Decentralized System – This was the initial state of the grid at the time of invention of electric power where most of the requirement was satisfied by small localized generators. However, they had low efficiency.

ii. Centralized System – Large scale centralized production plants for energy, specifically thermal, followed the decentralized systems. These had increased efficiency in comparison, along with reduced energy costs, however, they added to the growing pollution problem.

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iii. Distributed Systems – Development of renewable energy related technologies such as wind and solar power, have enabled the establishment of distributed energy systems and microgrids. They are more self-sufficient and observe fewer losses.

iv. Smart Grid and Grid Connectivity in Energy System - with the digitalization of the existing energy systems and the increase in feedback from the grid, the grid is more connected both for the user and for the supplier. This includes the ability to monitor individual consumption etc…

### B. Smart Grid & Evolution to Energy Internet

The Smart Grid (SG) offers numerous advantages over the traditional grid in terms of utilization of energy sources, intelligent network, along with monitoring and control. A controlled generation along with efficient utilization of energy resources results in fewer carbon emissions as compared with the traditional grid [1]. Certain shortcomings presented by SG are handled by its evolution into the Energy Internet (EI).

The Energy Internet has been defined in several different ways through several different sources. EI is a responsive, decentralized energy network along with a communication network that includes the smart grid and distributed energy resources (DER). Furthermore, it encompasses the internet connectivity to ensure the supply of energy to a location where it is needed [1],[2], i.e. it includes the features of the Smart Grid as well as the advantages of using the information internet. The advantages of EI over SG may be briefly discussed as follows [1][3]:

i. EI involves the integration of energy distribution technology, smart metering, real-time monitoring along with required adjustments [1]. In comparison, SG involves communication, control, and information technology.

ii. EI supports large scale distributed generation along with the distributed energy storage, i.e. it has a large scale control.

iii. EI focuses on the user of DER that are sustainable whereas SG primarily focuses on a centralized generation with some new forms of energy.

iv. In terms of communication, EI deals with a plug-and-play system for a multi-directional communication of energy and information sharing. The SG however, referes to uni-directional communication.

DERs that are generally involved include environment friendly and renewable resources such as solar and wind power. The EI incorporates in itself the functionality of the SG.

With the evolution to the smart grid, it became evident that it was important to integrate all elements of an energy supply chain (Generation → Grid → Storage → Consumption) in a manner, so as to create an interactive system. In addition, it also includes ensuring the availability and delivery of the energy to a consumer when and where required. The key parallel that may be drawn with Information Internet is in terms of the connectivity and communication with its users. The Energy Intenet ensures not only the bidirectional communication between different stakeholders but also the storage and delivery of the energy packets based on the requirement. Furthermore, EI deals with distributed generation and DERs [1].

In this paper, Section II presents the important features of the Energy Internet and its benefits. Section III discusses the challenges faced in the development and implementation for the evolution of the Smart Grid to the Energy Internet. Section IV presents a few of the modelling approaches that are considered for the implementation of the Energy Internet which is followed by conclusions in Section V.

## II. Energy Internet & Key Concepts and Features

The ongoing EI development includes integrating distributed and scalable RES and internet technology with the existing smart grid [1]. The EI assumes the inclusion of a Plug-and-Play (PnP) system, an information router and an open standard operating system [3] (Fig 2).

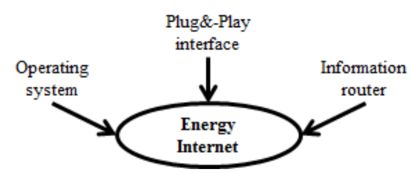


Fig 2: Essential components of Energy Internet

As it stands, there are several different inspirations for evolving towards the energy internet from the Smart Grid. These motivations include not only the grid as a stakeholder but also the customer and their ease-of-use [1]. These benefits can be categorized in different manners and can be summarized as:

i. The end-users, i.e. customers have a contribution in terms of selection of energy source , production and sales. The EI allows for an improved customer satisfaction through involvement and satisfy the customer demands.

ii. The communication technologies implemented in the energy internet, real-time data on the DER, the SG and customer requests will be available, making it easier for the utility to react appropriately.

iii. EI provides the lowest cost option in a market environment where a large number of consumers as well as providers may interrelate [7].

iv. Encouraging the use of renewable energy production, availability and consumption as compared to traditional fossil fuel based energy production. This is further enhanced by the use of appropriate storage technologies.

Majority benefits of the EI center jointly on customer satisfaction and the utility welfares rather than just on one stakeholder. This presents as a unique advantage of Energy Internet.

In the Energy Internet, a common term used is *prosumer*. A prosumer is a consumer that also behaves as a producer. This concept is presented due to the use of distributed generation [1][4]. A consumer may be a part of the distributed generation where it is able to feedback the excess generation back to the grid and receive revenue. So the consumer from the traditional/ Smart Grid may be converted to a prosumer. The major contributors of the EI may broadly be grouped as (Fig 3), Prosumer, Microgrid, Virtual Power Plant (VPP), Smart Grid, and Smart Energy [4].

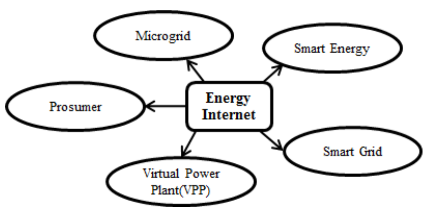


Fig 3. Contributors in the Energy Internet

Microgrid, Smart Grid and Smart Energy are features that have been discussed in numerous literature works. Innovative to the Energy Internet concept is the development and management of Virtual Power Plants (VPP). VPP refers to the central aggregative operational hub that coordinates the communication between DGs, manages the scheduling and concerns itself with optimal utilization of the resources. Further, VPPs also monitor the stability of the individual DGs along with load prediction. The scheduling management of loads may again be dependent on various factors as determined by the service operator/ aggregator [3]. With a combination of the contributors in Fig. 3, load management and implementation of EI may be considered through cyber physical systems (CPS) scheduling and load management may also be carried out through CPS using reward based and/ or cost minimization approach [15].

## III. Energy Internet - Challenges & Requirements

### A. Challenges of Energy Internet

Although the concept of EI is of dual benefits of the consumers and the utlitiy, it poses a few challenges as well:

i. Complexity – EI infrastructure may be depicted as a collection of systems that communicate and interact [3]. As a result, the modelling of the EI requires modelling of these complex structures. The contributors towards the complexity can be given as:

a. The EI is built on the concept of distributed generation. As discussed in Fig 1 c), even though the distributed generation offers its advantages, such as higher stability compared with the traditional grid, the complexity is high simply due to the fact that there are more nodes to manage. In addition, the large amount of energy that is to be produced has to include the specific and varied requirement of each consumer [5].

b. Requirement of diverse control with a fast response time. Furthermore, maintaining a level of power quality while energy routing to various customers from traditional energy sources and DERs.

ii. Efficiency – the challenge presented for EI is to maintain a balance between the energy supply and consumption, which again, requires real-time, fast communication.

a. The efficiency of the EI network will depend on the structure of the network which in turn is based on the source of energy and/ or the working methods.

b. Aside from other features, scheduling management will be a key factor that contributes to the implementation and real-time analysis of the requests received for energy.

iii. Reliability – the EI system will have to ensure that stress is not applied to any section of the network while fulfilling/ scheduling energy requests, i.e. a balance would have to be maintained while managing the generation and transfer of energy from one part of the network to another [1][3]. This is applicable to management of resources, load management, and energy storage. Different techniques and models are being implemented so as to increase management such as demand side management (DSM)[5][6][16], multi-agent systesms (MAS) [22]-[25].

v. Security – An everpresent concern even in the Smart Grid, which further increases two fold in the EI due to the distributed generation and a wider area under the influence of the EI. The security can further be analysed as energy security, information network security, and consumer security i.e. the privacy of the consumer [20].

### B. Requirements for development of Energy Internet

The management of a vast energy network requires understanding the generation patterns, specifically through renewable sources so as to reduce the burden on the tradiutional fossil fuel based generation, and the usage patterns of the consumers. These both are contributors towards appropriate generation management and load management.

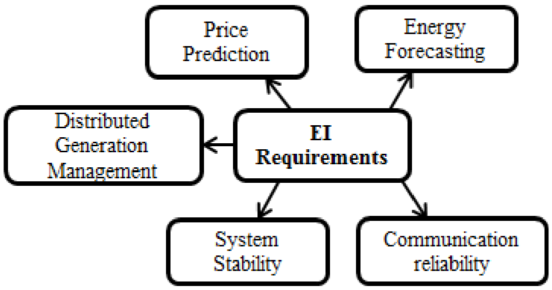


Fig 4. Requirements for EI development.

First is the development of Energy Forecasting Models that will not only predict the load requirements but also the potential of generation from renewable sources for a given day. Load demands give the service provider an idea of the energy requirement and allow them to schedule the load/ energy appropriately. With the inclusion of smart loads and newer loads such as electric vehicles (EVs) that add a significant load to the residential grid [10], appropriate forecasting and scheduling techniques are integral, specially in EI management [8]. A majority of the RES generation is through solar and wind which may be hindered due to natural causes such as it being a cloudy day. Therefore, proper prediction techiques are essential as they allow the following:

i. Based on the load requirement, the share of energy to be taken from distributed RES generation can be determined.

ii. Areas that may not have sufficient distributed RES generation may be identified and the fulfilment of the load requirements may be managed through other sources/ areas.

Second aspect is the *Price Prediction/ Adjustment Model* which requires a method that allows for development of a pricing system that is available to users and service providers. Day-ahead prices are available in a few countries which allow the user to witness the change in proce specifically during peak hours. However, as the consumption of the consumers vary, a more accurate price prediction is required that would satisfy the needs of the consumers. Further, as in the Energy Internet, the consumers are, in fact, prosumers, a price prediction is necessary so as to accommodate the energy that is being sold by the prosumer. Pricing management techniques have majorly focussed on the consumer side and not necessarily their benefit. Demand Side Management (DSM) has been implemented which allows the user to be charged a price based on their time/ season of consumption in addition to the amount of consumption. However, this does not consider the individual requirements of the consumers which have the potential to be included in the energy internet [8].

*Communication realiablity* refers to the ease of exchange of information between different systems [20]. This requires the development and establishment of extensive communication protocols that are able to handle the highly complex nature of the communication requests while maintaining the response time in the communication between two systems.

Development of *distributed generation management* techniques lends itself a new complexity as there are now multiple nodes that have to be maintained (Fig 1c)). The advantage of distributed generation is that with the failure of one of the nodes, the remainder of the system is not severely, if at all, affected. The challenge appears in terms of their management and communication management. The DG will further contribute to the power fow of the EI resulting in an impact on the stability of the grid [11]-[14].

The power grid stability is a key factor in the continual management of the grid that supplies the users with the power. A major part of this involves transient stability analysis of the grid which is even more complex when dealing with the energy internet as it will involve the DGs as well as the primary grid.

## IV. Modelling Approaches for the Energy Internet

With the challenges and requirements of the Energy Internet, in order to develop models that will allow for realistic practical implementations of the same, different approaches have been developed and modelled. These include the development of multi-agent systems (MAS) [22]-[25], demand side management (DSM) techniques, and the future renewable electric energy delivery and management (FREEDM) [3][21] system, Smart Grid with Intelligent Periphery [19], peak load shifting through energy trading amongst the end users [16], Peer-to-peer energy sharing [17]. Other approaches also include sending energy in packets which involves the application of network theory to power systems [18].

A multi agent system offers a distributed control approach where each agent may perform a separate function. A multi-agent system can be simply realized as a group of separate agents performing a particular action in their specified area but moving towards a common goal. Different applications of MAS have been implemented in DSM and EV scheduling [24][25]. The agent based control system may be utilized in load management, control, scheduling and a hybrid version that includes different DRERs and DGs [22][24].

As a major contributor to the development of the EI, a few points of notice of the FREEDM infrastructure are detailed. The future renewable electric energy delivery and management (FREEDM) is a new grid infrastructure that involves the DGs, specifically Distributed Renewable Energy Resource (DRER) generation while affording a high degree of scalability alongside respective storage which is termed as Distributed Energy Storage Device (DESD) [3]. The aim of the FREEDM model is to offer interfaces between the grid, DRER, DESD, household users, and industrial users. Key features of the FREEDM model of the EI can be narrowed down as [3][21]:

i. Plug-and Play interface - this implies that the DGs (DRERs) and the energy storage devices may be added and/or removed based on the requirement. This offers a parallel to the connectivity of the information internet.

ii. A real-time equipment monitoring of the loads along with control of these loads. The main aim of the real time monitoring device is to ensure efficient management of the power generation and the energy resource.

iii. In order to manage the price and its prediction, an intelligent software system is of high importance. This software will also manage the scheduling of loads and DRSR/DESD/DG. Software management is also required for application of control and rescheduling in case of heavy loads during peak hours.

iv. In the FREEDM system, transformers (called as solid state transformers [21]) fault isolation systems can respectively help in the integration and/or isolation of DRER/DESD/DG [1],[4] as needed. Fault isolation is important so that other DRERs do not get impacted.

Demand Side Management (DSM) deals with smart management of the consumer demand so as to minimize the load on the grid. The management is mostly carried out through finanacial incentives for utilization of energy at low peak hours. In the Energy Internet, DSM at the VPP may be carried through game theory, MAS and other techniques [9] [6][26]. Furthermore, with the development of smart homes and smart load management allows for a more user specific control [16][26] where the switching times of the loads may be predicted.

## V. Conclusion

This paper presented an overview of the Energy Internet as the next technological advancement to the traditional and the Smart Grid. Enhancing the features of the Smart Grid, the EI proposes to integrate distributed generation with the communicativity of the information internet, making energy conveniently accessible. The challenges facing the development of the Energy Internet focus on the complex nature of the infrastructure of the EI. With a large number of DGs/DRER/DSEDs, it will require the management at VPPs and real-time communication between the prosumers and the grids. The Energy Internet offers a solution to the uneven distribution of the energy supply in differernt areas by proposing the transfer of energy via different methods.

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