ENERGY INTERNET AND GRAPH THEORY BASED ENERGY ROUTING IN ENERGY LOCAL AREA NETWORKS (e-LAN)

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ABSTRACT: Energy internet is the vision of future power systems which is evolution of smart grids to internet. The rounded data of energy internet evolution in terms of architecture and integration with heritage power system is presented in this thesis along with the critical features of Energy Internet architecture at each level. The Energy router (ER) is a core device of energy internet, which connects all devices together and manages power flows among them. Therefore, to dynamically control and manage the energy distribution in grid, energy routers (E-routers) are required in energy internet. This thesis summarizes the designs and architecture of different types of energy routers proposed in literature for energy internet in order to achieve flexibility of power flow. Consensus algorithm is proposed in this paper which uses hierarchical control and management model for the power distribution. Finally, the Future scope of the survey and architecture is listed.

I. INTRODUCTION

Energy Internet is an advanced power grid architecture which integrates the smart grid with internet. With the help of information and communication technology it improves the reliability of power grid and provides increased utilization of energy resources [1]. The routing or managing of electrical energy is performed through an energy router synonymous with communication router which routes energy packets instead of data packets.The steady and continuous development of renewable energy resources around the world has stimulated the active research on optimum and efficient utilization of grid interconnections [2]. The energy internet architecture of the power network extends the functionality of the internet to the energy sector. In energy internet the access and management of widely distributed energy resources (DERs) such as prosumers (i.e end users equipped with energy sources) is achieved through energy routers [3]-[7]. Equipped with power electronics and information and communication technology (ICT) the topology of energy router plays major role in energy internet. Consequently, the modelling of E-router and steering directs the performance and economic operation of grid. This encourages the prosumers participation in power trading which reduces the network reliance on main grid.Inspired from the concepts of computer science similar concepts such as ‘‘Energy Hub” and “Digital Router” are presented in literature and the problem of interconnection and conversion of multiple types of energy producers and consumers is addressed. But the efficiency of the system is low as energy conversions are involved at each step of power sharing in this method. Proposed consensus algorithm focuses on the power sharing between the main grid (MG) and energy internet structure [8]-[10].

The following paper is organised as follows. Section II overview of the architecture energy internet and energy routers. Section III IEC 61850 information modelling is discussed. Section III Consensus algorithm is proposed and energy exchange possibilities are calculated. Section IV Future scope and research areas need to be focused are presented.

II. ARCHITECTURE OF ENERGY INTERNET

Overdependence on fossil fuels such as coal, natural gas, oil etc. for energy needs in current energy consumption scenario leads to two major issues, fast exhaustion of conventional energy resources and global warming. To address these issues, harnessing of energy from non-conventional energy resources such as solar, wind, biomass, ocean, geothermal etc and development of an efficient and reliable energy utilization regime is required. These non-conventional energy resources are usually distributed in geographic area and demands energy utilization from distributed energy resources (DERs) [6]. The comparisons between EI and smart grid are presented asfollowing.1) Smart grid involves intelligent communication technology,information technology, and control technology,whereas EI is an integration of energy distribution technology,smart metering technology, real-time monitoringtechnology, and autoadjust controlling technology.2) Smart grid is always under regional system control,whereas EI supports the access of large-scale distributedgeneration (DG) system as well as distributed energy storagesystem access.3) Smart grid mainly refers to centralized electricity powerand preliminary involve some new energy, whereas EIfocuses different types of distributed energy

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resources(DERs), especially the renewable and environmentalfriendlyenergy, such as solar power, wind power, nuclearpower, ocean power, etc.4) Smart grid refers to one-way communication, whereas EIcomes up with an advanced plug-and-play interface torealize multiple way of energy sharing and informationexchange.5) Smart grid is dominated by communication system andtraditional industry, whereas EI is dominated by Internetand other forms of information network or Web.Based on smart grid, EI enhances a lot in energy utilizationefficiency according to energy consumption curve, energy security,and reliability integrating distributed and scalable sources.Instead of exploiting renewable energy itself, the key to dealwith the current energy source crisis is a highly efficient methodto the delivery and management of distributed renewable energysources at a large scale. Therefore, on the basis of nowadays informationintegration, the proposed EI emphasizes to make theenergy sources production, manufacture, storage, and transportinto an Internet-enabled period, to figure out the efficient way ofsharing and storage of distributed renewable energy sources, tolower the price of energy transportation consumption, to realizethat every household can be involved into energy transaction. If excess energy is produced, it can be sold to the grid and the consumer gets paid for it in peak load periods. In case there is a shortage of supply, the energy is purchased from the grid in order to manage the demand supply. These prosumers act as Distributed Renewable Energy Resources (DRERs) during energy deficient periods and as Distributed Energy Storage Devices (DESDs) during energy excess periods and thus provides better efficiency and grid stability.

As shown in Fig. 1, Energy internet is a combination of energy sector and Internet of Things (IoT) as described by its originator Jeremy Rifkin in his book “Third Industrial Revolution”. The energy internet, which is an internet of energy (IoE). and an integration of DRERs, DESDs, real time energy monitoring, information sharing, real time pricing and energy transactions. The EI revolution will present quantum leaps in terms of energy security and will aid to develop a cleaner, healthier and safe environment for energy exchanges.

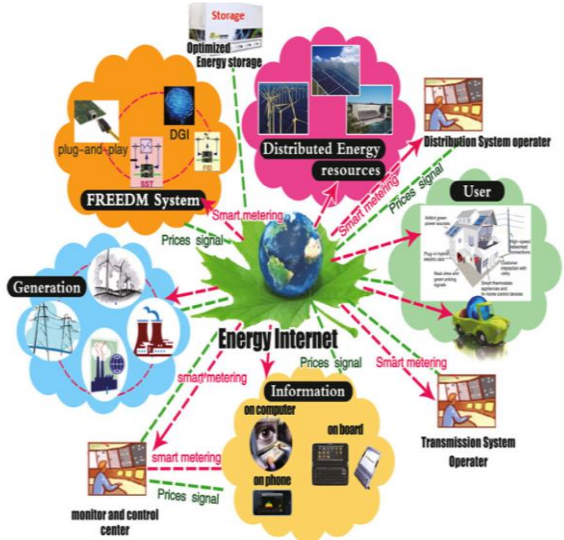

Fig. 1. Architecture of energy internet.

The energy router is the core of energy generation, distributionand storage. Different from the conventional electric devices, the energy routers are expected to be provided withthe following features. First, it could achieve a bidirectionalhigh-quality power conversion among different kindsof terminals. Second it should have equipped with plug-and-playinterfaces to support the seamless connection between endusers and electrical network. Third, it can achieve the optimalenergy management in the local grid or the whole EI. The EI revolution will present quantum leaps in terms of energy security and will aid to develop a cleaner, healthier and safe environment for energy exchanges.

Energy router enhance the power exchange in smart micrgrids from distributed sources to multiple loads providing increased efficiency and flexibility of the grid. The basic models of single energy routers are discussed below with their specific functionalities. It is having common DC bus, multiple input and output ports of AC/DC or DC/AC modules, energy storage devices and information controller. Energy storage devices are employed in energy router for small duration power balancing and avoid any power fluctuations in real time load management. Which increases the smoothness and quality of power supply preventing loss of any critical loads connected in network. In order to prevent the system damage and overheating the continuous monitoring and control of power rating mismatch at the input and output ports is carried out. Continuous update of network status regarding the power flow of lines connected with router and status of power available in DRERs is achieved with information controller. Information controller stores the data and update its status with the distribution system operator (DSO). Any two energy routers can exchange the power via one or more energy routers and from one or more transmission paths available. The research on ER architecture and design modelling leads to three different types of designs which are explained below. The comparison among the features of each of them is done in the following classification [9].This energy hub consists of multiple energy producers and consumers interconnected by energy hubs or energy interconnectors as shown in Fig.2. The hub interface directly or via-conversion of energy with producers, consumers, storage devices and transmission equipment to supply the consumer needs. It is aided with cogeneration and transmission to get the maximum efficiency out of hub system. For integrated transmission among several energy carriers each hub is powered with fuel cells, electrolyser, thermoelectric converters, power electronic converters and heat pumps etc. The hub has multiple types of energy inputs and on output side, the energy source can be CHP or any other depending upon demand of end consumer.

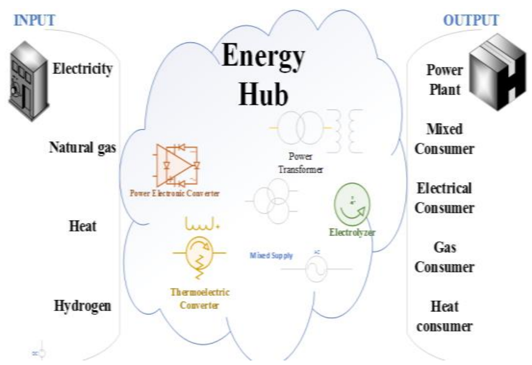

Fig. 2. Energy hub model

TheSolid State Transformer (SST) based energy router model is a common model used in various EI models. This model is a core component of energy internet in the distribution architecture presented in literature. Unlike energy hub, the SST based energy router considers different domains of grid i.e. generation, transmission, distribution, operation, servicing and trading along with user level functions such as distributed load attachment, detachment, status update and service isolation as shown in Fig.3. However, as compared to energy hub model, SST based energy router supports only electrical energy whereas the former also supports other forms of energy such as heat. But it is one of the efficient and advanced energy routers having the capability of fast synchronization with plug-and-play facility for prosumers. It can accommodate the large number of distributed energy resources and supports the bidirectional power flow making the flexible power grid efficient and reliable.

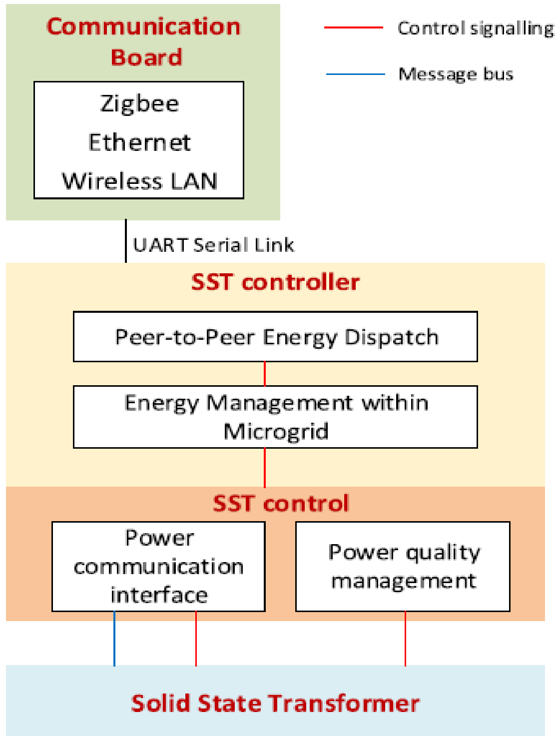

Fig. 3. SST based energy router

In PLC based energy router, Power Line Communication technique is used for information management and power transmission. Due to employment of PLC scheme, PLC based energy router is compact in size and saves additional communication network investment. These are then multiplexed over transmission line with time-division multiplexing (TDM) technique. Inorder to implement the information management and transmissionin the aging power grid, PLC emerges again. Thelow cost of PLC deployment is the most obvious advantagecompared to other wired communications [8]. The existing distributionetworks use transmission lines directly, greatlyreducing the investment on networks. Meanwhile, thepower line can form the most extensive networks and each
family can be easily involved in as shown in Fig.4. However, in order toachieve reliable long-distance communication with highcapacity in EI, PLC still has the following shortages: low
data transmission rates, limited bandwidth, signal attenuation,and high noise. When it applied into energy routers,the significant signal distortion and power loss cannot be
ignored. Since distribution system voltage dispatchingneeds to realize the communication between substation and
distribution feeder without high transmission rates, PLCtechnology becomes more challenging.

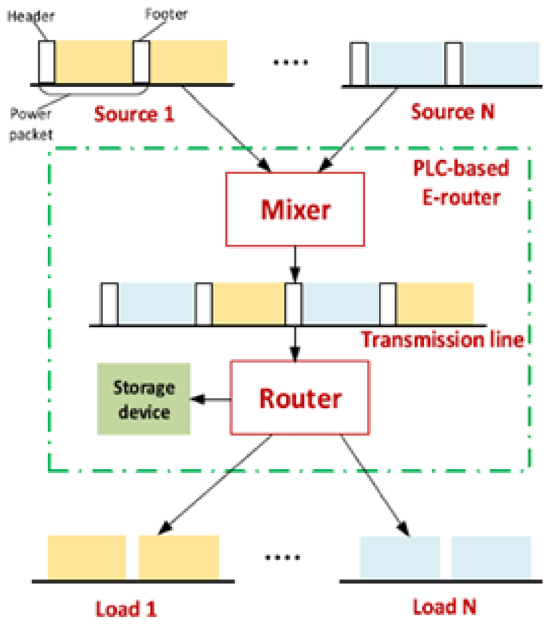

Fig. 4. PLC based energy router

BENEFITS AND CHALLENGES

The concept of energy internet results in various benefits which are discussed below.

a) End user benefits

Implementation of EI results in customer satisfaction because of economic savings in electricity bill, less maintenance and smart metering. Also, consumer can communicate directly with the power supply company which results in flexibility in utilizing power and can even sale the excess to act as one of the participants in country development [3].

b) Reliability

The reliability of the power system is improved by the frequent system monitoring in EI. The stability is increased due to the balancing of variable loads. The disturbances such as faults, unnecessary breakdowns are reduced and thus the reliability is improved [4].

c) Efficiency

EI consists of smart equipment systems which results in loss reduction. Faster information and communication, planning, energy telemetry technologies used in EI make the system efficient. Voltage and frequency fluctuations are reduced by using smart techniques. The load demand on the remote power plant is reduced. Transmission losses are reduced and this leads to increase in energy efficiency by introducing EI system [7].

d) Real time Pricing

The real-time demand is a variable parameter during off-load and peak load. Thus, to model service cost based upon customer's demand, a dynamic pricing strategy is required. This is one of the major challenges for implementation of EI system. Dynamic pricing can be contrasted with fixed pricing approach to setting the selling price for a service that does not change [7].

e) Standardization

Development of standards to regulate and control the energy internet on common grounds is required. Every field such as power generation, delivery and control have their own standards which are defined by international organizations. Implementing standards is a complex issue due to different vendors with their own legacies [7].

f) Stability Issues

The transmission system stability issue will become more complex due to energy internet with combination of various forms of energy exchange. The power system transfer stability and fault detection for smart-grid connected EI is yet to be developed [8].

III. IEC 61850 MODELLING

Smart grid is a kind of power system which incorporates the state of the art in communicationand information technology in order to achieve enhanced operational monitoring, control,intelligence, and connectivity. International standard IEC 61850, which is first presented byWorking Group 10 (WG10) of Technical Commission 57 in 2004, represents one the of the smartgrid automation pillars by introducing standardized communication principles and semanticdescription of controlled systems. As a result, IEC 61850 can effectively promote theinteroperability between different Intelligent Electronic Devices (IEDs) from various vendors in thesubstation automation of smart grid. With its outstanding performance in interoperability, opennessand expandability, IEC 61850 has gradually become a significant component in smart gridcommunication system.The first edition of IEC 61850 is a complex set consists of 14 different components which
provide detailed specifications, such as terms, device models and abstract communication serviceinterfaces, for communication networks and systems in substations. However, specific regulations
of the communication mode among different substations as well as that between substation andcontrol center are not illuminated clearly. In order to further elucidate technical standards andbroaden the application domains, since 2007, WG10 released the second edition of IEC 61850,namely IEC 61850 Ed2. The revised IEC 61850 supplemented the information modelling andcommunication mapping mechanism in clean energy and other fields as well as related peripheralspecifications. As shown in Fig.5, In this edition, its application area has been extended outwards substations, andall respects of power

utility automation are covered, promoting the application development basedon IEC 61850 in the research and construction of smart grids.

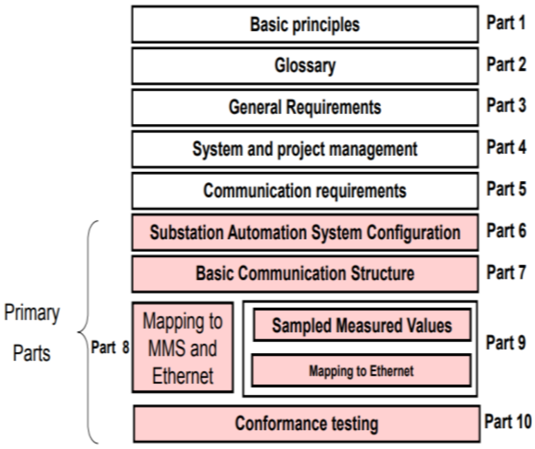

Fig.5.Standardized IEC 61850 structure.

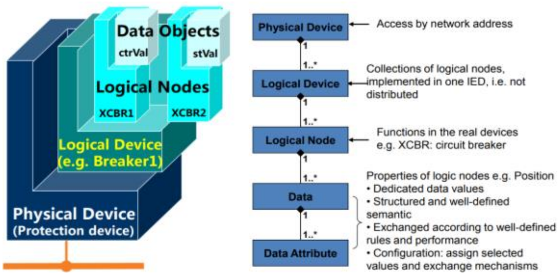

Fig. 6.Standardized IEC 61850 structure.

IV. GRAPTH THEORY CONSENSUS ALGORITHM

This Chapter details the algorithm based on which energy router routes the energy along the shortest path available with the minimum transmission losses caused and selects the best suitable source for suppling the power to the load. The synchronization process and control of ac link is explained. It accommodates the advanced isolation and protection devices which isolates the link involved in fault with minimum disturbance to the healthy system.The energy management automation is taken to the next level with the help of energy internet consensus algorithm which accommodates the load flow analysis even at the distribution level of the system. The information controller of each energy router will update its status of connected sources and loads to the DSO which will analyze the power generation, transmission and consumption in the network based on the algorithm provided for real time control and management of power flow. Each energy router will act as a agent of energy exchange in respect of consensus manager. Where we have a local controller, which reports constantly the status update to the central consensus manager. As shown in Fig. 7,the consensus manager will negotiate with the neighboring agents and calculates the consensus results and passes the decisions back to the local controllers for the implementation. These decisions can be related to the amount of power being sent to and being received in the next coming hours of the grid operation. Hence, in this manner the consensus algorithm will acts as prediction manager to make the smart decisions in advance.

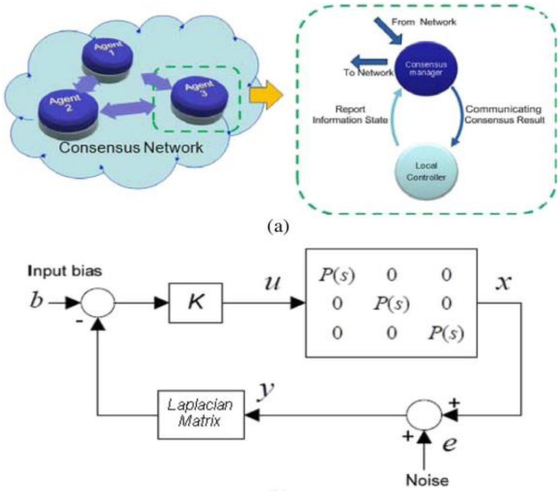

Fig.7. Consensus network

The local controller will then adjust its actions according to the decisions of consensus manager and reports back its new state the central controller.

V. FUTURE SCOPE

Future scope for Energy Internet and energy routing in Various future prospects of Energy Internet are detailed below.

1) We put forward several kinds of function requirements of EI, such as energy forecast, price adjustment model, interoperability capability, DGs, and stability evaluation, and summarized the challenges of promoting EI, which are complexity, efficiency, reliability, and security. The key goal of EI is to create new technology and new business models. This goal can realize the new industrial revolution. More and more traditional companies are eager to participate in the development of EI. It is obvious to observe the advantage from EI, but there are some huge challenges as well. Technologies must be planned well, so as to prevent the unnecessary loss in the security of electrical networks and communication networks. Our country should formulate the corresponding standard to encourage awide range of businesses to promote the healthy development in the EI industry.

3) Power optimization with the help of energy router can be explored. This can be achieved by optimizing the energy and information flow path in order to achieve desired optimal results.

4) Energy management solution in microgrids can be achieved with effective coordination among

energy routers. For this purpose, the IEDs of all power devices need to be equipped with standard firmware which accommodates the suitable EMS data functions.

5) Since the core concept of EI, integrates the Internet with the energy transactions, a robust security mechanism is extensively required.

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