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Design of Strategic Smart Grid Transformational Roadmap and Implementaional Framework-SWOT Analysis of Pakistan Case

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Abstract: The traditional multi-level hierarchical structured power grid is facing many systematic, operational, management and capacity challenges. Thus, strategic efforts are required from power enterprises to not only upgrade the existing grid infrastructure but move forward toward self-healing and resilient grid by integrating the diverse energy resources into the power systems through Information and Communication Technologies (ICT), smart sensing and instrumentation, and Distributed Renewable Energy (DRE) resources. To serve the purpose, the concept of new intelligent power grid known as Smart Grid (SG) was introduced. SG promises the direct involvement of all the stakeholders including service provider, grid operators and consumers making it a grid state aware network. However, SG is a new paradigm and its acceptance and implementation brings forth many folded challenges.

In this paper, we present the transformational road map and strategic framework of establishing the SG in Pakistan by making the SWOT (Strengths Weaknesses Opportunities Threats) analysis of existing power grid. The prospective requirements, multi folded constraints, adoptions barriers, technological requirements, design and technology standards, and deployment issues of Pakistan have been identified on the basis of the SWOT analysis in relationship to SG implementation. Various recommendations have been given for the up-gradation of existing electrical infrastructure to facilitate smart grid implementation including replacement of the electromechanical switches, smart instrumentation, advanced monitoring systems, meeting challenges in telecommunications services, and interoperability of information technologies etc. It is concluded that government support is obligatory to deploy SG concept in Pakistan along with the public-private partnership, private investment and more importantly the willingness of utility operators to accept and opt this intelligent grid. The presented framework will pave a path for future research work in SG domain in Pakistan so to move from traditional electricity supply system to the state-of-the art intelligent grid system.

Keywords: Smart grid, SWOT Analysis, Smart Metring Infrastructure, Distribution Automation, Demand Side Management.

1. INTRODUCTION

Energy is the prime mover for overall socioeconomic and sustainable development of any country (Halepoto *et al.,* 2014). The worldwide depleting energy reserves and increase in overall energy demand has raised concerns regarding energy security, efficiency and reliability. Electrification is broadly accepted as the greatest engineering achievement of the 20th century. The electric grid infrastructure is spine of daily life activities, social stability, economic growth, industrialization and etc. Traditional electric power grid has a multi-level hierarchical structure that constitutes a multi-state, multi-mode architecture which have served the utility industry for more than hundred years (Koc *et al.,* 2014). This grid was built for transferring the generated electrical energy by high-capacity, centrally placed power production units. This centrally interconnected network spans to large geographical areas and practically works as a single system that makes cost effective use of the generated power. However, centrally interconnected network increases the prospect of risk as any small disturbance may propagates and subsequently results in complete shutdown of the entire system. Also this centralized network faces many challenges especially meeting the demands that require immediate attention in growth, expansion and diversity into energy resources and sustainable policy measures. Meeting the requirements, traditional approach for extending infrastructure have been primarily in the form of installing and commissioning of the new power plants, transmission lines, substations, and driving equipment. However, the procedure for authorizing, locating, regularizing to extend the electrical infrastructure is nontrivial task which needs to be efficient and cost effective. Additionally, the existing grid is facing many systematic, operational, management and capacity challenges. Thus, major strategic efforts are required from power enterprises to integrate the diverse energy resources into the power systems through ICT, smart sensing and instrumentation to upgrade the existing infrastructure (Uqaili *et al.,* 2014).

To serve the purpose, SG signifies technological transformation from dumb electric infrastructure into intelligent grid system that relies on the dedicated information networks to enable information and communication between devices and applications

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(Naus *et al.,* 2014). SG promises the direct involvement of all the stakeholders including service provider, grid operators and consumers making it a grid state aware network. However, SG is a new paradigm and its acceptance and implementation brings forth many folded challenges (Farhangi, 2010).

In this work, to understand the functional gap between existing resources and prerequisite of SG, a SWOT analysis is performed for Pakistan prospect. The SWOT analysis is a preliminary decision-making support tool to methodically analyze the strategic conditions on the basis of internal strengths and weaknesses as well as external opportunities and threats by identifying the coordinating constraint factors (Halepoto *et al.,* 2015). If used correctly, SWOT analysis can provide a good basis for successful decision making and strategy formulation. With the help of SWOT analysis, strengths, possible weakness, prospect opportunities, and threats in form of benefits realization, technology adoption, technical issues, systematic challenges, financial investment etc. are outlined. Further to this, on the basis of SWOT analysis, a strategic process framework and transitional road map is proposed to deploy the SG technology in Pakistan.

The rest of paper proceeds as follows. In Section 2, case of SG as a driving force for sustainable developments is presented, followed by identification of issues and prospects of existing power grid on the basis of SWOT analysis in Section 3. In Section 4, a process framework is proposed as an integral part to strategize the SG development, followed by five phases SG transformational roadmap of Pakistan case on the basis of SWOT in Section 5. In section 6, we have concluded the work and discussed point to the future.

2. SMART GRID- DRIVING FORCE FOR SUSTAINABLE DEVELOPMENT

The digital era and over reliance on machinery and instrumentation requires uninterrupted electric power supply. The industrialization age and urbanization is also stressing the growth in power demand with reliable and distributed network, demanding to transform from unidirectional, centralized, hierarchical grid delivery systems to a bidirectional, distributed, instrumented, virtually networked and intelligent energy distribution grid system (Sahito *et al.,* 2015). The SG concept is gaining intensive interest from all over the world and is in practice already in many domains as eminently accepted as the future of the existing power grids. SG have been a strategic research area in the worldwide energy market; many power utilities, organization, institutions, universities and researchers have been studying SG to increase the reliability, efficiency and robustness of the grids to provide cheap and sustainable energy. SG concept is realized through the ICT with smart instrumentation platform that significantly relies on the design and development of dedicated information networks (Gungor *et al.,* 2011) which facilities the communication between devices and applications making direct involvement of all stakeholders including the generation; transmission, distribution as core backbones; electric market, service provider, grid operators and consumers. The generic conceptual model of the SG proposed by National Institute of Standards and Technology (NIST) is shown in **(Fig. 1).**

The SG provides an opportunity to move from a centrally produced network to distributively controlled network, meeting stochastic demands, and more consumer interactive network. Meanwhile the applications of distributed intelligence and integration of automatic control system assures that system behaviour is being monitored in real time by maintaining the quality of service and optimal resource management, control of power grid, anticipation of potential problems and self-healing, islanding and etc.

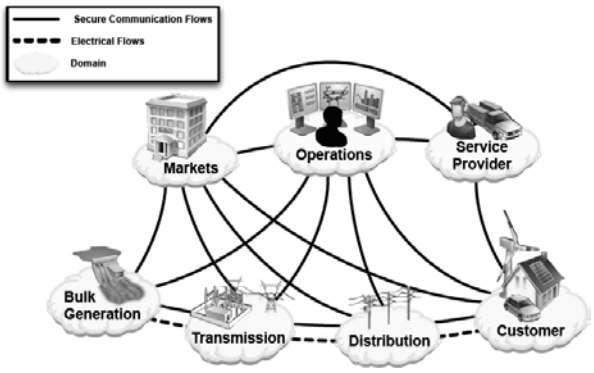


Fig.1.Smart Grid Conceptual Model proposed by NIST

The integrated features of SG are the strongly accepted as renaissance of world sustainable development by transforming the dumb electric utility from blind to state aware system with state of art business values. **(Fig.2)** shows the key driving factors of SG. The electricity demand is soaring continuously, stressing to meet the global demand, whereas the increasing dissemination of greenhouse gases and its impacts on climatically changes has raised the concerns about utility generation through these resources to meet the power demands. SG effectively limits the greenhouse gases and environmental impacts and thus maintaining the diversity in power generation with distributed energy resources. With technological advancement, the consumers are now probing for operational excellence making consumer satisfaction a challenging job for utility operators.

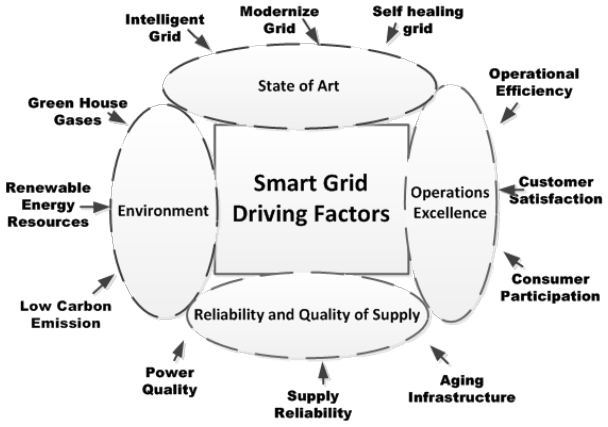


Fig.2.Smart Grid driving factors

SG offers an operational excellence by replacing dumb electric network with modernized grid using smart instrumentation and state of art technology leading a great satisfaction to consumers with real time system information. The deflecting reliability and frequent disruptions of power outage is distressing the global economy. The SG features of improved monitoring, advance automation and condition based management features offers significant improvement in the reliability of power supply. Despite all the benefits of SG, still its practical deployment is a nontrivial task due to different constraints and strategic challenges like technical, financial, geographical and political aspects (Marques *et al.,* 2014). It is also important to understand the power requirement that differs from country to country that builds the motivations for developing the smart grids in a broader perspective. Considering the devolving situation of Pakistan power sector and its impact on national economic growth, the implementation of SG in Pakistan is obligatory.

3. SWOT ANALYSIS OF PAKISTAN'S POWER GRID

Most of the existing electricity grids in developing countries especially in Pakistan are incapable of meeting the growing demands due to limited delivery system, high unit commitment cost, supply shortfalls, high technical and commercial losses, frequent peak load spikes, limited use of renewable energy, and high cost of power outages etc. Under these critical circumstances, maintaining the system reliability becomes a difficult task that can't be compromised at any instance. An unreliable system leans forwards the power grid under severe stress and if not responded immediately, it may result into complete shutdown, thus making unrecoverable financial loss. The ultimatum solution lies in the implementation of state aware SG. The SG implementation is a different prospective in different socio-economic setup but irrespective of regulatory structure, it is of worth to mention that the investment in SG technology will out-weight the costs, as evidences from some of the projects successfully deployed (Bossart, and Bean, 2015). The primary requirement for SG implementation is to systematic analysis of the existing power grid system, followed by a comprehensive feasibility study and process analysis. The feasibility study, point outs the in-depth understanding of system being practiced currently, its strengths, possible limitations, and tomorrow's objectives, strategic opportunities and plans to be executed by evaluating the strengths, weaknesses, opportunities and threats on the road to SG transformation. For this, a scenario based 'gap analysis' may be conducted to bridge the functional gaps by identifying the areas where improvements are required. The shortfalls especially technological requirements, financial resources, investment priorities and return of investment must be identified and analysed.

The SWOT analysis is a decision-making support tool to systematically and methodically analyze the strategic conditions on the basis of internal strengths and weaknesses as well as external opportunities and threats to formulate the implementable strategy by identifying the coordinating constraint factors. SWOT analysis highlights the relevant internal and external elements in prospective of positive and negative attributes (Halepoto, Sahito & Shoro, 2015) as shown in **(Fig.3)**.

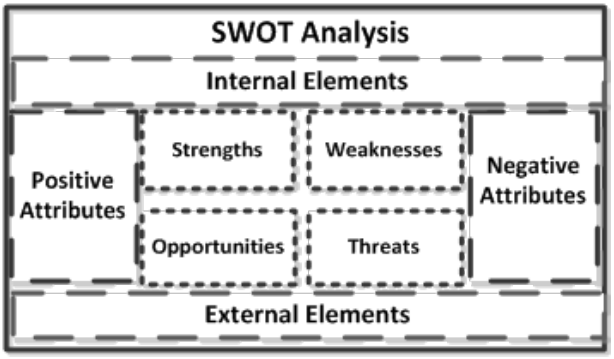


Fig.3. SWOT Analysis –Internal and External elements

(Table-1) present the detailed SWOT analysis considering the existing Pakistan's power grid scenario. The identified factors require the systematic design and strategic process framework to move forward towards intelligent grid. Although by considering the current power sector scenario of Pakistan, the concept of SG looks too much ambitious but by making the SWOT analysis of the existing infrastructure and bridging the functional gaps and following the strategic process frame work and transformational road, the dream of SG implementation in Pakistan can be realized slowly and gradually.

Table-1: Swot Analysis of Pakistan's Power Grid

Evaluation Parameter	Pakistan's Existing Power Grid
Strengths	Simplest hierarchal structure Simplified electrification process Long haul electric networks
Weaknesses	Inefficient power plants Aged transmission lines Insufficient installed capacity Unbalanced energy generation mix-up Fostering dependency on imported oil Uncontrolled circular debt Revenue bills inadequacy Lack of adequate planning Higher technical losses Theft and meter tempering Tariff subsidies
Opportunities	Strong potential to invest in research and development programs Upgradation of existing electric infrastructure Technology advancement & Innovation Deployment of bi-directional communication networks Automated Substation Infrastructure Installation of SCADA systems and Smart Instrumentation Installation of Smart Metering Infrastructure To raise the awareness in consumers about energy-efficiency and demand management
Threats	Lack of cost-effective generation and energy storage options Expensive power dispatching and unit commitment Infrastructure and technology immaturity System Tripping and Stability issues Frequent outages and Shutdowns Lack of Distribution Automation and Control Lack of consumers participation in DSM programs Environmental footprints System vulnerability to cyber attacks

4. PROPOSED SMART GRID STRATEGIC PROCESS FRAMEWORK

The process framework is an integral part of the system to set the future roadmap. The process framework is the integral part to develop the roadmap to implement any system network. The proposed SG strategic process framework is presented in **(Fig.4).** For the case of SG roadmap to transform from traditional electric utility network to intelligent grid network, the preliminary stage is the analyzing the current state of the electric utility, followed by a vision that must clarify how the smart grid is expected to transform the utility and what will be the utility business needs of future grid. For this a comprehensive feasibility study is required for the in-depth understanding of system being practiced currently, its possible limitations, tomorrow's objectives and strategy plans to be furnished. Then, a scenario based 'gap' analysis is conducted. From the gap analysis, the technological and system requirements are identified to bridge the gap, where every stockholder needs to play well defined role.

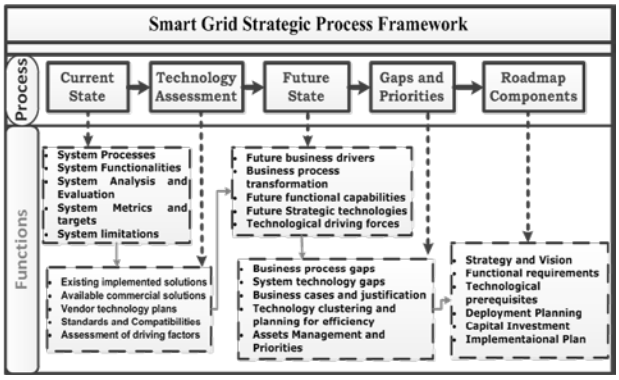


Fig.4. Smart Grid Strategic Process Framework

Once the technological and financial resources are identified, the investment priorities need to be set by analysing the return of investment. Based on feasibility study and gap analysis, the overlooked areas can be are identified, and then reforms must be initiated by replacing the old infrastructure with modern efficient system and component's, which will assure the existing infrastructure to be efficient enough to be acceptable as an international standards and regulatory frameworks. Finally, the roadmap is used to determine the steps that categorically realize the evolvement of the process framework from where the utility was intended to move on and where it is transforming. This is the most significant part of the process as it prioritizes the steps and clusters them into logical and efficient implementation activities.

5. SMART GRID TRANSFORMATIONAL ROADMAP: SWOT ANALYSIS OF PAKISTAN CASE

Pakistan's power sector has been facing an unprecedented energy crisis of its history which is consequently disrupting the national economic growth. Realizing the worst possible situation of power shortages and signifying it as one of the most serious adverse socio-economic growths, Government of Pakistan is determinant to make significant infrastructure reforms by reducing the technical and non-technical losses, reducing the power theft, meter tempering, bill recovery, etc. Though these initiatives must be appreciated but considering the limitation of existing dumb power grid infrastructure, the transformation towards SG is still obligatory. The proposed SG strategic process framework can cover the basic and technical aspects of SG from planning stages to final execution of plans, leading to SG deployment in Pakistan. While the strategic process framework may

seem somewhat traditional, the implementation is not. To implement the SG in Pakistan, five stages of strategize the process frame work has been identified as shown in **(Fig.5).** The SG process framework and transformational roadmap is the consequence of SWOT analysis carried out in Section 3.

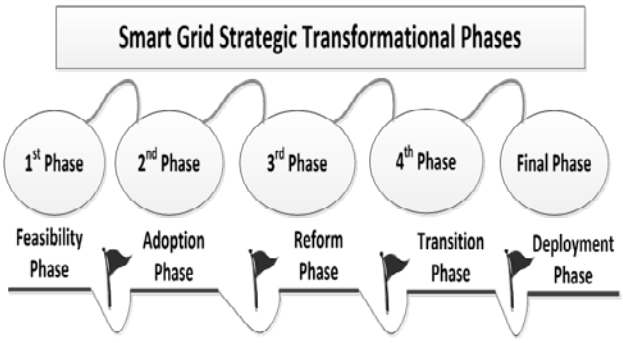


Fig.5. Proposed Five Phases of Smart grid Strategic Transformational Road Map for Pakistan

5.1. SWOT Analysis of SG Feasibility Phase

SG is the state of art of intelligent grid that greatly relies on the dedicated information networks that enables information and communication between devices and applications. The SG transformation is demanding task, as it requires in-depth understanding of existing electrical infrastructure and detailed information about SG transformational procedural process. To get started, a strong feasibility study with clarification of objectives and broader vision must be set to simplify the transformation process. This feasibility phase will clarify the basic business models subject to application requirements and strategic plans. Feasibly phase can set the roadmap and regulatory framework to assess the current standing and future requirements by scenario analysis. Intelligent SG have been already materialized and tested in several countries in order to optimize operation and management of the electrical grid (Yang *et al.*, 2015). The worldwide implemented projects of SG can be helpful for Pakistan to set the objectives and regulate the policies as per international standards. **(Table-2)** identifies the important SWOT factors during feasibility phase to strategize the SG transformation.

5.2. SWOT Analysis of SG Adoption Phase

On the path toward the SG, another important aspect is the understanding and realization of SG benefits. Based on SWOT analysis, the driving factors and prospectus challenges of SG can be analyzed. Involvement of all major stakeholders, feasibility study, technical and financial constraints, and clear understanding of process framework are key elements in adoption phase that can lead forward toward SG technology. All the stakeholders including government, policy regulators, utility operators, market investor's, consumer and society players will have to play their part in acceptance and adoption of this new technology. In initial stages, the utility operator mostly considers the return of investment as an integral barrier in acceptance and adoption of SG technology, although from the world wide deployed pilot projects it is evidenced that SG will outplay the initial capital investment. So for the larger scale benefits, Government of Pakistan must offer financial incentives to utility operators. For the utility operators, the SG technology can be viewed as intimidating the basic business model as they do not sell the electricity to consumer which directly replicates only the production costs; instead they sell the electricity in slab basis which does not reflect the real time generation cost. So for the utility operators this concept may not be as much as enthusiastic at least at initial stages. Hence, all driving forces must be convinced how this concept is beneficial for the socioeconomic development. Clarify of these factors and understanding should provide an opportunity to move in next phase. The identified SWOT factors for SG adoption phase are listed in **(Table-3).**

Table-2 SWOT Analysis of SG feasibility phase

Evaluation Parameter	SWOT Analysis of SG Feasibility Phase
Strengths	Already materialized by many countries & organizations Regulating the energy policy as per international standards
Weaknesses	Lack of Research & Development trends Lack of interest from main stakeholders Lack of Smart Grid working groups and task forces
Opportunities	Realization of power crisis at government level World-wide SG pilot project demonstrations Development of application based process frameworks
Threats	Lack of governmental incentives for market investment Uncertainty with utility operators about return of investment Vested interests and policies

5.3. SWOT Analysis of SG Reform Phase

Considering the limitations of traditional electricity infrastructure and its systematic issues, Pakistan need to take emergent steps regarding the up gradation of aged core components and should be replaced with smart instrumentation and advanced technology by defining the future targets. Once, the overlooked areas are identified, the reforms can be initiated by replacing the old infrastructure with modern efficient system and component's to make existing infrastructure efficient enough to be at acceptable level. Smart Metering Infrastructure (SMI) is a preliminary phase of SG (McHenry, 2013). It is a bridge between consumers and

utility operators, as consumer can have real time access and information about their energy consumption. This may lead a sense of understanding in consumers on choice energy usage and conservation plans by dynamically participating in demand response programs. The implementation of SMI will open the doors of DSM concept which is the complete package to have real time monitoring of utility services (Bae *et al.,* 2014). Active participation of consumer is an integral part of SG technology. With DSM, not only the utility operators but consumers can also influence the load shape to maintain the system stability by avoiding load spikes and by this they get financial incentives in billing services by adopting Time of Use (ToU) price concept. Development of SG is extraordinary difficult without the implementation of SMI and DSM. The key challenges in DSM implementation are smart metering, load forecasting, load control and optimization.

Table-3 SWOT Analysis of SG adoption phase

Evaluation Parameter	SWOT Analysis of SG Adoption Phase
Strengths	Potential to utilize the technological advancements Realization of consumer participation importance in DSM programs Government has placed substantial capital amount for infrastructure reforms
Weaknesses	Huge capital investment is required for system deployment Lack of collaborations between major stakeholders
Opportunities	Engagement of stakeholders in a participatory process to identify the gaps, priorities and standardization. Strong incentives to invest in Smart Grid field Opportunity for individual customers to access to their data in real time Strong potential of renewable energy resources
Threats	Lack of long term policies and regulations Infrastructure & technology adoptability

In Pakistan, electricity is charged on slab based regardless of the generation cost that results in unbalanced sale-purchase mechanism. This is economically unproductive as the price consumers pay do not reflect the true costs of production. On the other hand, spot time electricity pricing refers to a programme that reflects the real-time production costs so that customers may be charged on TOU. Further to this, power quality and lower power factor is the consumer driven issue which directly affects the system efficiency. The penalties of lower power quality and power factor may be imposed to improve the overall system efficiency.

Key challenges can be the installation and adoption of smart sensors and actuators; conversion from electromechanical to static metering; design of front and backend software's; high speed hardware; high speed data recording; super information storage system; fast data acquisitions and management; exchange of data; standardization in design of intelligent electronic devices (IEDs); Communication with central control unit like Supervisory Control and Data Acquisition systems (SCADA) and etc. Automation and control through SCADA based implementation plays vital role in providing quality and reliability in power services for a consumer. Fortunately, under US-AID energy support program from United State of America, different studies and survey have been conducted in Pakistan to analyze the prospective areas of power sectors where emergent reforms are required. One of the initiatives that have been implemented is the installation of smart meters at selected locations in first place. **(Table-4)** correspond the key SWOT factors concerned to SG reform phase.

Table-4 SWOT analysis of SG reform phase

Evaluation Parameter	SWOT Analysis of SG Reform Phase
Strengths	Installation of SCADA systems & Smart instrumentation Mature ICT solutions Pilot implementation of Smart Meters at different places Distributed power generation from renewable energy resources In process to upgrade the existing electric infrastructure
Weaknesses	Lack of Distribution Automation and Control Network Lack of consumers active participation in demand response programs
Opportunities	Penetration of intermittent power generation sources Increase in renewable energy portfolio Self-healing and resilient grid Construction of Ultra High Voltage power grid
Threats	Design standardization and data acquisition issues Flat monthly slab based bill charges

5.4. SWOT Analysis of SG Transition Phase

Fourth phase is the beginning and realization of SG as a transition phase from traditional electrical infrastructure to SG network, depending on ICT, smart instrumentation and standardized protocols specifically designed for SG. In this phase, various technologies and concepts should be taken into account for the implementation of SG concept. It includes telecommunication infrastructure, protocols and standards, smart metering system, home area networks, DSM, distribution generation resource, virtual power plants, and micro grids.

In the subsequent paragraphs we have described the prospects of these technologies and challenges that should be addressed while considering Transition

Phase. It is of no doubt that SG is the intelligent transformation towards smart communication and networks which must be equipped with standard protocols and regulatory framework. Fortunately, Pakistan is self-reliant in the vicinity of telecommunication resources; various international wireless operators are providing standard services since last fifteen years. However, SG development challenges in prospective of communication technologies can be of system reliability, security and availability of network without disturbance; collection and storage of data; high speed; design of architecture and monitoring system; physical and cyber security; plant and station security and secure access and control are the major challenges of telecommunication in smart grids.

Modernization of the grid is a next step once communication network is setup as per the requirement that requires automation ultimately. To optimise the performance of power distribution networks with automated control techniques Distribution Automation (DA) has major role to play in the development of SG by interacting with diverse integral applications of SG and enabling grid to be more efficient and reliable. Major challenges that should be considered for SG are complex distribution network; delay in communication; standard alone communication, signals and decisions; fast switching relays, grid automation and reconfiguration; educing human interaction; high speed fault locators and proper monitoring system. The SWOT factors related to SG transition phase are summarized in **(Table-5).**

5.5. SWOT Analysis of SG Deployment Phase

The Final phase is SG deployment phase based on planning and regulatory frameworks under national polices and reforms, which may be executed at pilot level initially. For deployment of SG, synergic synchronisation between generation, transmission and distribution with market, operations and service provider is obligatory. A way forward is to introduce gradual smartness into electricity infrastructure in steps of few months to few years. The deployment of SG will eventually require lots of standards, specifications and regulatory framework. For this case, IEEE has already taken the initiatives to identify these requirements and frame the rules and guidelines on how the SG should operate with interoperability between different technologies. For the Pakistan prospective of SG deployment, initially a university campus can be thought of an autonomous substation that can serve the purpose of a micro grid where all the protocols and standards can be implemented for testing purpose. The SWOT factors related to deployment phase of SG are listed in **(Table-6).**

Table-5 SWOT Analysis of SG transition phase

Evaluation Parameter	SWOT Analysis of SG Transition Phase
Strengths	Adequate telecommunication and networking infrastructure Potential to develop the decentralised infrastructure Access to clean and sustainable energy Minimizing the environmental footprints
Weaknesses	Smart grid pilot projects requires vendors and partners with appropriate experience and expertise Lack of collocation between academia and industries
Opportunities	Active involvement in SG research projects Efficient, Automatic modernized grid network Smart Appliances & Accessories Efficient integration of distributed & renewable energy resources Dynamic real-time decision and management
Threats	Pilot's projects have tendency to be more expensive High speed network hauls issues Telecommunication system reliability and access control

Table-6 SWOT Analysis of SG deployment phase

Evaluation Parameter	SWOT Analysis of SG Deployment Phase
Strengths	Use of proven models implemented by other countries and organizations
Weaknesses	High initial infrastructure and deployment cost Interoperability issues between different technologies and vendors
Opportunities	Collaboration with research institutions and non-governmental organisations to develop SG pilot systems Smart Islands & reclosing technology Development of Microgrid at smaller scale
Threats	Implementation complexities Lack of Regulatory Frameworks Standards and Interoperability issues Information security and shared data privacy issues Cyber security and big data handling issues

6. CONCLUSIONS

In this paper, we have discussed the prospect opportunities of implementing a SG in Pakistan which is mandatory for sustainable development of the country. In this perspective, a SWOT analysis is performed to highlight the challenges of existing electric grid and functional requirements of SG. As a matter of fact, the transition from conventional system to SG is not an easy task because implementation of SG involves integration of various technologies and system networks. In this work, a step by step process framework and transformational roadmap is proposed to setup SG technology in Pakistan by considering all the

major challenges including technical, communication, financial, infrastructure and etc.

It is concluded that the involvement and coordination of all the stakeholders including government, market driving factors, public-private partnership, utility operators and consumers is imperative. Only the coordinative efforts and strong initiatives will make this concept practicable so that some of the pilot projects may be started even at smaller scale initially to realize the dream which is necessity to come true. We believe that research and development institutes especially universities in collaboration with utility operators will carry the more research on SG and its deployment prospective challenges in first place at micro grid level which can be extended further on the basis of experience and financial support by government.

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