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# The Present Trends and Challenges in Renewable Energy Sources Connected to a Grid

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***Abstract***: ***Smart grids are alterations of the traditional power grids where the monitoring and control of the electricity system are faster and easier than before due to their automated self-healing and sensing processes. However, their primary target is two-way communication, which is only feasible if the decentralized generation of power will exist alongside the national grid. In that light, this report first gives a comprehensive description of smart grids and their history. Afterward, it examines the two major groups of challenges to the penetration of the technology; that is technical and regulatory, policy, and economic challenges. Case studies from the U.S., Canada, Korea, California, and Sweden are used to illustrate the discovered trends and challenges to renewable energy sources connected to grids and demonstrate possible solutions. The research design employed in the study is diagnostic since the problem, its history, and solutions are all reviewed in the report. The study's recommendation is policy interventions to solve both the regulatory and technical challenges to the proliferation of gridded renewables.***

***Keywords***: ***renewable energy, smart grids, power system.***

## I. INTRODUCTION

The global move towards secure, affordable, and sustainable supply of electricity is driving change in the production, transportation, and consumption of power. Within the last two decades, there has been a rash of some ‘’smart element” in electricity systems. That led to a consensus that smart grids will make way for efficiency, reliability, and decarburization in the electricity sector. Due to the term alone, smart grids have managed to garner significant support in state policy because of the theoretical advantages that their implementation might wield. By definition, Smart grids are power networks that facilitate power exchange and two-way communication between the consumers and producers of electricity, making use of information technology to ensure secure and safe energy distribution and manage demand [1]. Smart grids can support grid reliability with the infiltration of electric vehicles and distributed generation, and wield the capabilities of instantaneous regulation of electricity production, need, and storage.

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Nevertheless, the concept of smart grids is both vague and broad, allowing players to take a tactical stand, but not methodically support the development of a unifying idea for the smart grid [2]. Within the term's bias (no one would favor a dumb network), there is an assumption that trade-offs among affordability, security, and sustainability would be minimized with the move to smart grids [3]. However, not every investment adds to the affordability and sustainability goals from a broader social viewpoint. The points of conflict between various policy aims and the involved actors’ interests present a fascinating study point.

The smart grid’s functionalities are not concepts that were discovered recently. In a report dubbed “Homeostatic Control: The Utility/Customer Marketplace for Electric Power,” gave a description of these functions [4]. In their report, the three described homeostatic regulation as a means of upholding the internal balance between energy demand and supply with the employment of ICT and economic signaling. Even so, the phrase "smart grid" was devised in 2005. That year, the “Institute of Electrical and Electronics Engineers (IEEE)” issued a report titled "Toward a Smart Grid: Power Delivery for the 21st Century” [5]. In the publication, the authors likened the electric network to an $F_{15}$ aircraft that has self-healing abilities in case emergencies arise. In this wonderful metaphor, the aircraft can continue flying even with one wing broken because of fault automation and detection [6]. Just like in the plane's case, automation and detection were suggested to make the transmission operations of the grid better.

Technically, defining a grid as smart or not smart is not a straight forward endeavor. A majority of systems, particularly those at high voltages, have mechanisms “in place to sustain supply reliability with Supervisory Control and Data Acquisition Systems (SCADA)” [7]. Nonetheless, the management of distribution grids has traditionally been passive. Consequently, in general, smart grids describe new advances on the transmittal side. The smart grid elements that can symbolize these kinds of development include (a) setting up smart gadgets, and (b) real-time control of the operations of those devices.

Many experts often see the smart meters as a precondition for any smart grid. These modern meters’ record consumption data within short timeframes of about 15 minutes [8]. This information can be relayed to different players like the power generators who can use it to alter their consumption levels or patterns.

Besides, even the firm operating the distribution framework, the retailer, and the utility can use this data for purposes of billing and evaluating the given demand response. Other than the smart meter, the smart grid incorporates separate devices that offer the clients insight and give automatic responses to signals through systems such as in-home automation or in-home displays [9]. Distributed Energy Resources (DER) is one example of the different kinds of units that facilitate local production, storage, and alternative consumption. The units of distributed generation (DG) include Combined Heat Power (CHP) and solar photovoltaics (PV) [10]. On its part, storage of electricity in batteries can offer significant value considering the rise of self-use from power generation, decrease in generation costs across the system, decline in peak-consumption, and reduction in system-wide network congestion and losses. "Electric vehicles (EVs) can also" constitute smart grids [11]. For instance, they can store the generated electricity. This study reviews the prevailing trends of smart grid-connected renewable energy as well as the current challenges associated with the technology.

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## II. BACKGROUND OF STUDY

Increasing the generation of renewable energy is a vital component to attaining growth in the proportion of renewable energy relative to the worldwide mix of energy. Technically, a transition of that kind is possible but will entail having the old grid components upgraded, and fresh solutions innovated to house the unique nature of generating renewable energy [12]. To be specific, smart grids have the ability to incorporate the characteristics below:

- Distributed generation. These are smaller scale frameworks that are often privately owned and run, and represent a different and new model of business for electricity [13]. Often, traditional utilities find it hard to allow these systems to get connected to the grid following safety concerns, challenges in valuing and putting a price to their generation, and impacts on the stability and operation of the network [14].
- Variability. Specific types of renewable electricity like solar and wind depend on resources that keep fluctuating. Since the supply of electricity must always meet its demand, efforts are needed to make sure that electricity demand and power sources are available to handle the variability [15].
- High starting costs. The technologies used to generate renewable energy usually cost a lot initially but are cheaper to operate than the ones powered by fossil fuels [16]. Even though renewables might be cost-effective when the entire life cycle is considered, some systems of electricity – especially in developing nations – still lack enough capital to pump into renewables [17].

Smart grids can directly solve these three obstacles to the generation of renewable electricity. Besides, smart grids provide additional benefits, which can simplify the migration to clean power [18]. This chapter gives explanations of how smart grids technology facilitates renewables.

### A. *Variability in Smart Grids*

One of the main problems associated with running an electricity scheme is making sure that the demand for energy exactly meets the supply [19]. Storing electricity is difficult; therefore, operators of electricity systems have to regularly vary the output of their power plants to equal the demand. "However, according to the International Renewable Energy Agency (IRENA)," technologies for storing electricity are steadily getting better [20]. Many of the traditional power plants that run on fossil fuels will function at a set level of output. As a result, the operators of these systems can rely on them to generate a predictable and steady amount of power [21]. Moreover, natural gas and diesel-fueled electricity plants are usually structured to permit "continual fine-tuning of their power output" [22]. That makes the issue of having the supply of electricity to correspond with demand manageable.

However, some renewable energy forms – notably solar PV and wind – are reliant on a steadily fluctuating resource (sun and wind). If the clouds cover the sun or the wind slows, then these plants' output falls, leaving the operators to scramble to find alternative electricity sources [23]. When solar PV and wind generate a small portion of the total electricity, managing the fluctuations usually is straight forward [24]. However, when it is the variable resources that produce a bigger share of the total electricity, maintaining the reliability of the framework can become considerably challenging [25]. In some cases, renewables might constitute just a minor part of a scheme's overall electricity, but provide a significant fraction of power on a lesser scale of time or bigger geographic location [26]. For instance, although on average, wind supplied just 17% of Colorado's electricity, on one night, it generated 57% [27].

Smart grids can do a lot to alleviate that problem. Essentially, a smart grid allows for the integration renewables with a broad array of diverse sources of electricity [28]. For example, a set of industrial and commercial consumers of electricity and a PV system could all be linked together with the control and communication technologies of a smart grid.

If a cloud makes the output of the PV system to drop, then the services to the clients on interruptible rates are interrupted by the smart grid [29]. Once the cloud moves on, the services are restored. Likewise, "smart grids could integrate electric vehicles (EVS) with utility-scale wind turbines" to enable wind power to charge the batteries of the vehicles [30].

### B. *Distributed Generation in Smart Grids*

Distributed generation of renewables, particularly rooftop PV, is a renewable technology with a lot of promise.

The technologies of smart grids can significantly help in promoting more use distributed generation of renewables [31]. They can afford system operators continuous and real-time statistics on the manner in which the systems operate and allow total control over the framework [32]. That control and information can be utilized in many ways, including:

- Disconnecting or lowering the output of distributed generation, which is required to protect workers, maintain reliability, or match the load [33]
- Offering real-time data on the electrical output of distributed generation [34]
- Providing support to the distribution system through practices like tighter voltage control [35]

Operators of utility systems might not be comfortable with the generation of electricity that they cannot control or monitor. Smart grids can offer this control and monitoring, thus inspire utilities to contemplate distributed generation of renewables as an option to the customary utility-scale electricity plants [36]. Distributed generation has the ability to impact the distribution systems in many areas, including administrative costs and voltage regulation [37]. Detailed information on the performance and output of renewables like that collected by smart grids can help operators of utility systems to put a precise figure on the distributed renewables' value [38]. In addition, the data can assist the utility in establishing the rightful amount to offer the operators or owners of the distributed renewable for the output of their system.

### C. *Better Consumer Control, Choice, and Information*

Smart meters, one component of smart grids, enable the consumer and utility to have two-way communication [39]. That makes several innovations possible. Some of them include:

- Facilitating real-time valuing
- Directly linking price pointers of electricity to smart gadgets [40]
- Offering detailed client information on patterns of electricity consumption [41]
- Accommodating different products of electricity like scheduling a plug-in electric vehicle to use only wind power to charge [42]

The innovations above can support green power by giving the consumers facts that enable them to use power only when the renewables are the source [43]. That can work only when the loads are deferrable as is the case with EV charging and dishwashers.

### D. *Improved Control and Monitoring of Distribution and Transmission Systems*

Smart grid technology enables the generation of polished records from the Transmission and Distribution (T&D) networks. This data can be used to lower costs and improve reliability. For instance:

- If a distribution line's voltage turns out to be on the lower side, then the output from the distributed generation framework on that specific line can be boosted [44].
- If a component of the distribution apparatus was working contrary to specifications, the issue could be solved before it caused a blackout [45].
- If electricity theft takes place in a nation's electricity system, it could be identified, and further theft stopped [46].

These capabilities can then help the renewables by enabling them to attain fetes like matching the distributed generation's output to the needs of the T&D system [47]. The distributed renewables could offer voltage support while the smart grid with better T&D system control and monitoring could make certain that the two frameworks operate hand in hand.

### E. *Incorporation of New Capital*

There are many alternatives to old-fashioned utility-scale electricity plants. They include:

- Supply-side alternatives like distributed generation
- Consumption-side options like demand-side management
- Stowage alternatives like thermal storage, batteries, and EVs [48]

The technologies of smart grids can facilitate optimal use of these alternative know-hows. As a result, smart grids can help to avoid the necessity for big power plants [49]. Further, as discussed earlier, these options are amenable to direct investment from the private sector and can assist in addressing capital constraints and utility underinvestment [50]. This simplified integration can help both the generation of smaller distributed and utility-scale renewables. New and flexible resources like distributed storage and DSM enable the incorporation of advanced levels of variable capital like wind turbines in the systems [51].

## III. METHODOLOGY

To fully understand how smart, robust, and flexible grids are enabling the generation of renewable energy around the globe, one has to assess the nature of the challenges that have recently arisen in integrating RE to networks. This study will group these challenges into two major categories:

1. Technical challenges. Ensuring the power system remains reliable as variability and uncertainty increase [52].
2. Policy, regulatory, and economic challenges. Effectively running the cost of integrating RE and its supporting grid investments, formulating policies to get optimum value out of RE, and making sure that the relevant incentives are set to encourage the appropriate investments on grids [53].

This study investigates and gives a summary of developing issues and solutions in the areas mentioned above and explores some of the top solutions that could be instrumental in addressing these challenges. This report is too brief to explore all the possible solutions; therefore, it only uses selected case studies to show the practicability of some emerging solutions to the challenges of gridded RE.

Both the two challenge subgroups are augmented by the increasing democratization of power supply [54]. To be specific, changing consumer preferences, policy innovations, and cost reductions are driving improved investment and participation in power system and variable RE operations for every type of end user [55]. Consumers are increasingly getting the motivation and ability "to deploy distributed generation behind the meter" [56]. That represents a distinct change from the customary organization of power systems where electricity was predominantly supplied by nationwide centralized generators. This research will use examples from specific regions around the globe to prove that this trend is a real thing in the market now, and discuss how it helps to solve some of the challenges associated with renewables connected to smart grids. In addition, the report will highlight ways in which distributed energy could contribute to the fiscal and technical setbacks discussed in the next section of the paper. In brief, besides reviewing existing literature to list the various challenges and trends surrounding gridded renewables, the report will employ case studies to explain these emerging trends and problems, and suggest possible solutions.

This study is a mixed method one since it entails collecting, integrating, and analyzing both qualitative and quantitative research. For instance, in the case studies, some sections will consist of information gotten from interviews by other bodies, and those obtained from surveys and experiments by other scholars. The research design is mainly diagnostic as the study does not only state the problems and trends, but also aims to establish the causes of the issues, diagnose them, state proven solutions, and suggest other possible solutions [57].

## IV. RESULTS AND DISCUSSION

### A. *Technical Challenges*

The research identified two critical technical challenges associated with greater penetration of renewable energy generation. They are: 1) managing uncertainty and variability during the system's continuous balancing, and 2) balancing demand and supply during surplus and scarcity situations [58].

*1) Managing uncertainty and variability during the system's continuous balancing*

Variable sources of renewable energy are both more variable and more uncertain than typical generators. Wind farms offer a helpful illustration of that uncertainty [59]. Specifically, when the farm might reliably generate electricity for 40% of the year's total number of hours, it is difficult to make a prediction on when the generation will take place [60]. The figure 1, illustrates the hourly power production of one farm in thirty successive days. A rooftop installation of solar offers a significant demonstration of variability. That is true since transient occurrences like the passage of clouds can rapidly reduce output. The figure 2, illustrates how scattering solar PV across large geographic locations tends to lower aggregate variability. In general, the output of solar PV changes more rapidly on a minute-to-minute basis than that of wind, but has less uncertainty [63]. However, with both solar and wind power, the ability of generation and system operators to predict levels of generation is becoming better [64].

*2) Balancing demand and supply during surplus and scarcity situations*

Supply of solar and wind may not even be close to the need [65]. That introduces challenges at the level of the bulk system of power, and if the generation of distributed PV is significant, at the level of the local network of distribution [66]. The reverse flow of energy that can take place in the middle of the day from regions with vast quantities of distributed PV is an excellent illustration of the distribution system problem [67].

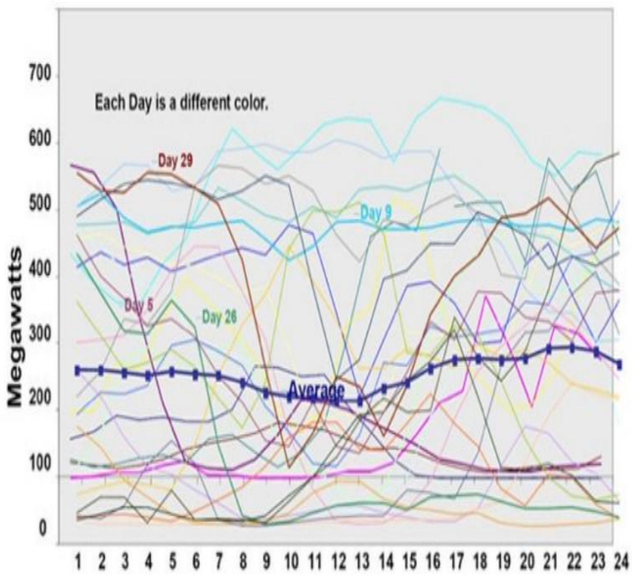


**Fig 1: Output of Tehachapi Wind Farm in 30 successive days**

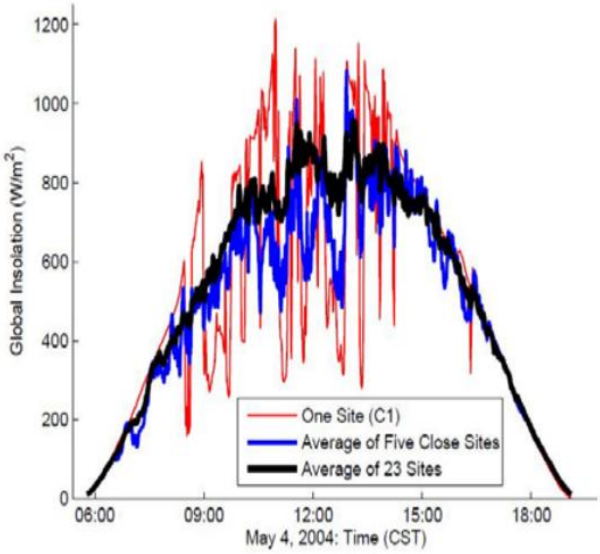


**Fig 2: One-Minute worldwide insolation from a single site on a slightly cloudy day, the aggregate of 23sites, and the aggregate of 5 sites that are close to each other**

When many people are at work away from their homes, the residential demand for electricity reduces significantly. Therefore, more of the produced power "feeds back up through the transformer to the medium-voltage network" [68]. Traditionally, the systems of distribution have not had to anticipate this scenario since a majority of the generation has been from large-scale schemes situated on the transmission grids, with electricity moving predictably in one direction to the systems of lower voltage [69]. Wind during the night demonstrates the demand-supply issue on the large-scale energy framework. When demand for power during the night is too low, and the wind has high strength, there will not be enough demand to make use of all that power [70]. Conventional producers may also not be eager or able to downscale their production more to accommodate the extra wind power. In such a case, limited flexibility in the power system could lead to curtailed wind energy [71]. Problems associated with high demand during episodes of low production of RE are not as technically demanding as those from the scenario explained above [72]. They are typically economic issues linked to market responses selected to remunerate demand response or reserve capacity activities [73]. Below are some of the emerging solutions from smart grids to address the continual system balancing:

- Smart inverters. Inverters can give some control to the system operators, and automatically offer some degree of grid support [74].
- Integrated storage. Enough storage can assist with smoothing temporary variations in the output of renewable energy as well as tackling the mismatches between demand and supply [75].
- Better forecasting. Advance computer prototypes and extensive instrumentation enables operators of power systems to better estimate and handle RE uncertainty and variability [76].
- Demand response. Intelligent appliances coupled with smart meters, and industry-scale loads can make the contributions of the demand-side to balancing possible [77].
- Real-time management and system awareness. Control and instrumentation equipment across distribution and transmission networks allow the operators of systems to get real-time awareness of the conditions of the system and the ability to manage the behavior of the grid [78].

**B.** *Regulatory, Policy, and Economic Challenges*

Besides technical challenges, institutional ones also come up with rising proportions of variable renewable energy [79]. Broadly, these are analogous to the exclusive economics of green energy, which lead to various regulatory and policy issues [80]. This study identified two particular challenges: 1) Capital-intensive upgrades to grids, and 2) Uncertain project cash flows and costs [81].

1) *Capital-intensive upgrades to grids*

Grid upgrades might be needed to accommodate solar and wind power [82]. For instance, if high quality solar and wind resources occur at places distant from where the need is, new lines of transmission or upgrades to the old ones may be needed [83]. At the level of distribution, rooftop PV might speed up the fatigue of the distribution elements like low-voltage transformers, bringing closer the need to upgrade the grids [84]. Minimizing the upgrade costs while keeping the system reliable translates to improved value for renewable energy investments.

2) *Uncertain renewable energy project cash flows and costs*

Costs of upgrade allocated to renewable energy projects and curtailment of energy when the entire production of RE cannot be integrated into the electricity system are two issues that have traditionally had negative impacts on the economics of RE projects [85]. Solutions of smart grids to these problems are emerging. Both glitches can cause a project's cash flow to move further away from the expectations [86]. In instances where subsidies and policy measures insulate investors from the above risks, risks and costs may be socialized [87]. That may be done to improve the investment atmosphere of RE. Therefore, cost-effective ways of minimizing grid upgrades or new transmission and lowering curtailment can capture greater value from sources of renewable energy, maximize system value, improve the feasibility of single RE initiatives, and enhance the general investment atmosphere [88]. Below are some of the emerging solutions of smart grids to the regulatory, policy, and economic issues of variable renewable energy:

- Demand response. Facilitated by intelligent loads and smart meters, solutions based on the response from customer demand can help to accommodate excess RE production, lowering the need to upgrade the distribution channels [89].
- Grid-scale storage. Bulk storage of different types can assist in lowering the need for extra transmission capacity.
- Dynamic line grading. Instantaneous information concerning the capacity of transmission lines can enable operators of grids to rip more value from present lines, lowering the requirement for expensive upgrades [90].
- Behind-the-meter storage. Client storage solutions are capable of absorbing the extra PV generated, making distribution upgrades less necessary [91].
- Better forecasting. Forecasting at the system level can assist system operators in running their grids with more flexibility, allowing for the acceptance of more production [92].
- Advanced power controls and smart inverters. Smart inverters, coupled with other mechanisms of power control, can lower the need for substantial grid distribution and transmission upgrades; hence, pulling down costs that might otherwise be socialized or imposed on RE projects [93].
- Advance systems of energy management. Such systems that offer instantaneous, high-resolution discernibility, and power systems control can enable operators of grids to defer the excessive capital expenditures [94].

**C.** *Worldwide Case Studies*

The case studies below from Austria, Korea, Canada, Sweden, and the United States highlight specific smart grid practices and technologies that can be employed to support the economic and technical incorporation of variable RE to grids better. Specifically, the examples explore dynamic line grading, system management and energy storage, smart inverters and regulations, system awareness (visualization), and voltage controls. The selection is not a comprehensive one; therefore, other examples may exist. The presentation of this list is to spur the inclusion of more cases over time.

- *Smart Grid Pilots in Austria's Salzburg Region*

Austria's Salzburg region has launched pilot projects to test voltage regulation on distribution channels, among other things [95]. One of the projects situated in a town named Lungau, a rural region with great potential for solar, wind, and hydro power, used an advanced system of energy management that led to a 20% rise in the capacity of the distribution network on the thirty-kilowatt lines [96]. That rise in capacity of the grid, and the ability to control voltage more accurately has enabled the deployment of more RE while avoiding the necessity to undertake costly upgrades [97]. Experts estimate that this pilot tactic could save up to 2.2 million liters of fossil fuel as a critical source of energy and lower emission of $CO_2$ by 5,500 tons every year [98].

Another pilot program was seen at a hydropower plant called Turrach. The plant had initially been determined to require a 14-kilometer-long cable to distribute its power to the network []. After the voltage controls had been implemented, the line's required length reduced to about 50 meters, resulting in savings of 2.3 million US dollars [99]. Other benefits that these pilot programs have brought include increased renewable energy share, improved supply security, and lower emissions [100].

- *Dynamic Line Rating in Sweden's Gotland Wind Farm*

The 48.MW wind farm on Sweden's Öland Island gives an excellent example of how dynamic line grading can be used by individual power companies to increase the capacity of the lines. Specifically, the farm increased its capacity by sixty percent closer to the actual limits of operation [101]. Between 2009 and 2014, Öland saw substantial additions of wind power connected to grids [102]. A static rating of the lines was used to establish that investments in new transmission lines would be required to accommodate electricity from the envisioned Karehamn wind energy production farm. The investments would have taken up approximately US$9 to 16 million [103]. In contrast, when dynamic rating of the lines was done, the cost fell to less than a tenth of the initial amount; that is about US$ 750,000 [104]. Therefore, the second rating option was chosen for test implementation [105].

**Fig 3: Windfarm in the Öland Island**

Before these trials, the transmission line providing service to the farm was said to have the capacity to handle approximately 30 MW of extra electricity [107]. Using regularly updated quantities and observation of the line's ambient atmospheric temperatures, power transfer, and temperature made it possible to increase the capacity of the line to 48 MW [108]. If the line gets overloaded for whatever reason, the wind farm gets a message to cut its electricity output.

However, inappropriate utilization of dynamic ratings of lines could increase the danger of line failure or even line losses following increased line temperature [109]. Running the lines with increased loss rates could have negative impacts on the grid company's revenue cap [110]. The regulators who set the cap may give grid firms with minimal network losses and few interruptions during delivery higher rates [111]. It is also worth stating that presently, the grid companies cannot split the accrued savings from utilization of dynamic line grading with the clients or wind generators [112]. Nonetheless, considering the substantial cost savings, there is need to further roll out the line rating system and explore the policy incentives to increase the allocation of savings to customers.

- *California's Smart Inverters' Rule 21*

The California Public Universities Commission (CPUC) advances the distribution of smart inverters on the distributed PV models to lower system effects of rising PV deployment [113]. The commission's Rule 21 describes the state's metering, operating, and interconnection needs for generators linked with the distribution network [114]. The rule was updated in 2014 to allow for smart inverters to be interconnected [115]. These inverters can offer frequency and voltage event ride-through, volt-VAR control, high-frequency reduction of power, ramp-rate control, and grid monitoring [116, 117]. These advantages are expected to facilitate higher PV deployment while lowering system effects and the likely need for an upgrade of grids.

"California is the first state in the U.S. to" permit advanced inverters after several nations in Europe [118]. Initially, some inverters with disabled smart functions were retailing in the US since the smart capabilities had not been allowed yet [119]. The regulation is founded on policies crafted "by the Smart Inverter Working Group, a partnership" between the California Energy Commission and CPUC staff, together with IEEE and other stakeholders and organizations concerned with standards [120]. It is not applicable to the back-up systems of power or inverters that are already in the market [121]. Even so, inverters usually have to be replaced each 7-9 years throughout the 20+ year's lifespan of PV systems [117]. As a result, the inverters that have already been sold and have the smart capabilities only need those turned on. The new ones will likely be installed in the coming years as replacements for the older ones.

*Korea's Smart Grid Power Self-Sufficiency Framework in Gapa Island*

Korea offers a fascinating example in growing Gapa Island to be a model of energy self-sufficiency for renewable energy and smart grid deployment. The region has been developing from the experience of a close by Island called Jeju [122]. Jeju Island is also famous for its progressive work on the smart grids and "the Carbon Free Island by 2030 project" [123]. Gapa Island is 8.5 square kilometers big and was inhabited by 281 residents in 2012 [124]. Systems of Solar PV and wind generation of 111 kW and 500 kW were erected in the island to replace the 450- kW fossil fuel generator [125]. The systems for RE generation have then been supplemented by a 1-megawatt Lithium-ion battery, an advanced system for energy management, and a framework for power conditioning to assist in managing uncertainty and RE variability [126]. The storage devices serve to provide support to the grid's flexibility and offer initial start-up energy to the wind turbines [127]. Moreover, the automated system of power management, which keeps track of electricity on an instantaneous basis, assists in optimizing grid operations [128]. The figure 4, further describes this project:

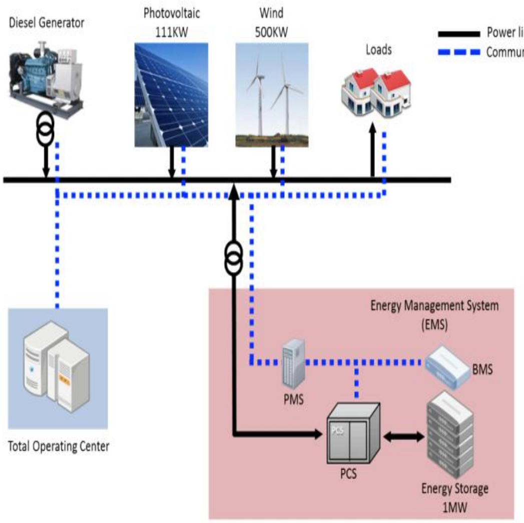


**Fig 4: Illustration of the Smart Grid Model in Gapa Island**

The mix of cutting-edge energy management, renewables, and energy storage has made the Island of Gapa a carbon-free power system [130]. The merits of the scheme are estimated to be US$415, 000 through evaded costs of fuel and over 750, 000 kilograms of reduced $CO_2$ emissions every year [131]. Founded on this proven prototype, which produces power from renewables as well as storage and systems of power management, Korea intends to launch the concept of a self-sufficient grid on other tiny islands that have usually relied on the unstable power supply from fossil fuels [132].

- *"SmartMaps" in Ontario, Canada*

Through the city's Smart Grid Fund (SGF) initiative, Ontario is funding the commercialization and demonstration of facilitating technologies that enable better planning of distribution networks, and more reliable operation of systems with growing variable RE proportions [133]. The SmartMap control and distribution monitoring system by Essex Energy Corporation (EEC) is one vital example [134]. The platform offers utilities a tool for geographic analysis of medium-voltage systems of distribution, obtaining data "from smart meters, wholesale meter points, and other sensors to" come up with a complicated simulation of a distribution system [135]. It then makes use of actual measured load meter and voltage data to give a realistic image of the system of distribution from the substation where the distribution is done to the individual meters [136]. The geographical user interface enables the operators of utilities to view essential data about any single feeder line such as reactive and real power, losses, current, and percentage loading [137]. Having these crucial data enables utilities to better schedule and run grids with increasing distributed generation. Other benefits that can be expected from the SmartMap platform include automated client alerts and faster restoration in case of outages [138].

Through SGF's support, EEC and Utilismart, its partner in data management, came up with, and integrated the SmartMap into all the powerline operations of ESSEX between 2012 and 2014 [139]. Following repeated trials and refinement, the platform (SmartMap) gathers, reports, and permits action on critical requirements for renewable energy such as:

- Utilization of five-minute and one-hour data to point out the maximum, median, and minimum system conditions [140]
- Precise simulation of suggested future states of systems
- Automated response to the dispatch requests from generators of the province-wide operators of systems [141]
- Identification of fault current and loading capacities down to single feeders [142]
- Observation of secondary levels of voltage on every transformer in increments of 15 minutes [143]

The figure 5, illustrates what operators of utilities view when making use of the SmartMap to see the performance of individual feeders. By using SmartMap, Essex, through its powerlines, has managed to integrate 14 projects of renewable energy, representing a capacity of 550 kilowatts, with total discernibility into the operations of facilities as tiny as 10 kilowatts or less [139].

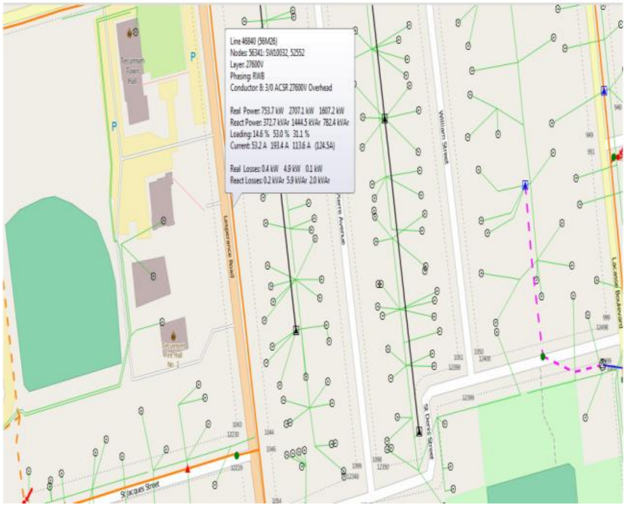

**Fig 5: Analysis of Load Flow on SmartMap**

- *"Smart" in America: Supply Reliability*

In the United States, policy attention to smart grids grew because of the regular power interruptions of 2005 [145]. That interest drove several innovations in the power sector [146]. In December of 2007, the smart grid concept was established in the nation's legislation. The smart grid got named as the primary pillar of the Energy Independence and Security Act 2007 [147]. The modernized network would possess a range of elements. It would have the self-healing capabilities discussed earlier in the report, which were intended to motivate the consumer's participation to provide electricity of quality fit for the needs of the 21st Century [148]. The motivation was also viewed as a way of resisting attacks, optimizing assets, enabling markets, accommodating all storage and generation alternatives, and operating in an economically efficient manner [149]. For these reasons, the Recovery or Stimulus Act of 2009 offered funding to the tune of 4.5 billion U.S. dollars to have the power grids modernized [150].

Thirty of the U.S's biggest utilities have wholly installed smart meters for their customers [151]. Texas and California lead with the smart meter penetration [152]. Some utilities have even allowed for the likelihood of alternative programs of pricing or including bigger smart grid visibility with in-home displays and systems of energy management in Wisconsin and New York [153]. Unlike the European one, the American electricity industry mostly follows the integrated utility framework structure, and municipality utilities contract for a majority of the residential consumers [154]. Other than in Texas, retail choice is quite uncommon in the US [155]. Consequently, smart meter penetration is conducted in many states via centralized rollouts [156]. That is probably a result of the high concentration of integrated utilities with monopoly positions to do so [157]. Nevertheless, several states give customers the choice of opting out of the smart meters [158]. For the clients who take this option, "an initial and monthly opt-out fees are charged" [159]. Even so, the number of customers who use this alternative is moderately low [160].

## V. CONCLUSION

Energy planners and system operators must overcome many challenges when incorporating high variable RE penetrations. These setbacks can be grouped as either regulatory, policy, and economic, or technical. Solutions to at least four of these challenges are coming up, and will be essential to observe in the near future. They are:

- Balancing demand and supply during generation surplus and scarcity scenarios (technical)
- Avoiding or deferring capital-intensive upgrades to grids (regulatory, policy, and economic)
- Enhancing the rate of returns on renewable energy projects to better the investment atmosphere (regulatory, policy, and economic)
- Managing uncertainty and variability during the system's continuous balancing (technical)

Luckily, a variety of practical solutions and potential technology to address these challenges already exist. Some of them are smart inverters, large-scale and distributed storage, dynamic line grading, improved forecasting, instantaneous system awareness, and demand response. New progressive protocols for energy management in the distribution and transmission interfaces are also capable of supporting flexible incorporation of variable renewables.

As the case studies evaluated in the report demonstrate, smart grids and the technologies that come with them can enhance the utilization of present infrastructure, improve the grid's flexible operations and their cost, and meet the costs of large-scale investments. Technologies of smart grids, through these measures, assist policymakers and system operators to affordably achieve energy deployment objectives, ensure the system runs in a reliable manner, and reduce the emission of greenhouse gases.

To improve the effectiveness and speed of the move towards smarter grids that facilitate the integration of increased shares of renewable energy, policymakers and regulators will have to merge the domains of institutional arrangements, technologies, and operational practices. Effective electricity systems regulation and policy will progressively work at this vital intersection. In favor of effective regulation and policy, all the relevant stakeholders should continue to gather and monitor data and trends on the effects of smart grid initiatives, share the knowledge with decision-makers and practitioners, and release targeted assessments on essential topics.

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