Centralized and Decentralized Generated Power Systems - A Comparison Approach

Future Grid Initiative White Paper

Power Systems Engineering Research Center

Empowering Minds to Engineer
the Future Electric Energy System

Centralized and Distributed Generated Power Systems - A Comparison Approach

Prepared for the Project
"The Future Grid to Enable Sustainable Energy Systems"
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White Paper Team

James A. Momoh
Howard University

Sakis Meliopoulos
Georgia Institute of Technology

Robert Saint
National Rural Electric Cooperative Association

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Information about this white paper

For information about this white paper contact:

James A. Momoh,
Professor of Electrical and Computer Engineering and Director, Center for Energy Systems and Controls.
Howard University
Lewis K. Downing Building
Suite 1105
Washington D.C. 20059
jmomoh@howard.edu, 202-806-5350

Power Systems Engineering Research Center

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For additional information, contact:

Power Systems Engineering Research Center
Arizona State University
577 Engineering Research Center
Tempe, Arizona 85287-5706
Phone: 480-965-1643
Fax: 480-965-0745

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Executive Summary

The objective of the paper is to identify the strengths and weaknesses associated with CG and DG infrastructure for the future electric grid system. These are many reasons for considering the extent for which a planning and operation decision should be based. This will involve the development of indices for an economical scale study of DG relative to CG, and consider which is the most cost-effective to accommodate new markets. In order to assess the robustness of DG and CG under different load conditions, different indices for measuring the combination of CG/DG with respect to its capability and resilience to handle unforeseen events. This will involve development of new tools for stability measure and reliability as constraints.

The second aim of the paper is to evaluate the environmental impact of the structure and its ability to diminish radiation, decrease emissions, and reduce environmental effects. This again will require new sustainability indices and predictive algorithm for proper measuring the trade-off between CG and DG.

Based on the analysis and drawbacks and gaps in existing tools, new computational tools will be recommended as part of the research agenda to development of a DG-based network for the future electric grid. The paper also plans to provide a national roadmap to guide towards identifying the right path forward in terms of which combination of DG resources and CG would make sense.

The roadmap includes the determination of costs and trades off between CG and DG with respect to control costs, life cycle analysis, and protection and maintenance; introduction of resilience sustainability metric into power systems planning and operation which will help to evaluate stability margin, demand response, reliability issues of the system under resilience; development of new curriculum and education to provide human capacity training; and to develop better and faster algorithms which include adaptive predictive model and state estimation for better management and planning.

This version of the white paper will be revised. Your feedback on the white paper will be welcomed. Send your comments to James Momoh at jmomoh@howard.edu.

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1. Abstract

The aim of this paper is to evaluate the relative benefits and weaknesses of centralized generation (CG) and distributed generation (DG) in the future electric grid interface. The CG has been in dominant use in the legacy system, serving large consumption of power but with variety of problems including its reliability, sustainability and resiliency challenges in the long run. The DG on the other hand is smaller in designs and power generation, basically designed with renewable energy resources (RER) like wind and solar.

To embark on development of grid flexibility for the future, research effort is needed to evaluate the potentials of available options amidst the increasing power demand. The sustainability of the grid is equally important for consideration in order to justify the performance of centralized and distributed generations. As this paper proffers criteria for analysis of DG and CG, it takes into consideration the reliability and resiliency of either grid architecture as well as the possibility to combine the systems the systems for optimal performance.

2. Proposed Objectives and Approach

The objective of this paper is to identify the strengths and weaknesses associated with Centralized Generations (CG) and Distributed Generations (DG) infrastructure for the future electric grid system.

The criteria for analysis will include:

i. To what extent are economies of scale still relevant for CG/DG?
ii. Which is the most cost-effective combination of DG and CG infrastructure?
iii. To what extent does DG or CG improve system resilience to unforeseen events?
iv. What is the most attractive combination of DG and CG infrastructures to maximize system resilience due to unforeseen events?
v. To what extent does DG or CG improve sustainability i.e. decrease emissions and diminish other environmental impacts?
vi. What is the most attractive combination of DG and CG infrastructures to maximize system sustainability?

The following summarizes the approaches to the prior posed questions:

i. In consideration of the economies of scale involved for the CG and DG system, combination of both CG and DG would better prove to attain a better scale.
ii. Provided that consistent electricity and heat loads are available, proper DG penetration in CG could attain the lowest cost technology.
iii. Since the resilience of a power grid is dependent on power consumption, a DG system can be said to be of better resilience than a CG system.
iv. To eliminate emission, the mixture of DG and CG is pertinent to be deployed.
v. Sustainability could be achieved by elimination of emission. Wind, solar, and biomass making up the DG can also go a long way to improve sustainability. However, the limitation of DG during extreme events could also be limiting. The role of CG, if elimination of emission is possible, is considerable. Combination of the CG and DG therefore is open for discussion.

Also, to be incorporated in the decision support tool for analysis and determination of optimal mix of DG and CG, the following tools are proposed **[43,44,45]:**

i. Decision support tools - AHP, game theory, and sustainability measure.
ii. Optimization methods **[43]** based on goal programming with stochastic programming under uncertainty constraints, where resilience, reliability and power quality are constraints.

This white paper also plans to provide a national roadmap to guide towards identifying the right path forward in terms of which combination of DG resources and CG would make sense.

3. Criteria for CG/DG Comparison

The criteria for CG/DG comparison presented here will involve economical scale study of DG relative to CG, and consider which the most cost-effective combination to accommodate new markets is.

Another criterion for CG/DG comparison is to evaluate the resiliency of the combined infrastructure.

Sustainability impact of either or both DG/CG as it relates to diminish radiation, decrease emissions, and reduce environmental effects.

With these criteria, we provide a national roadmap to guide towards identifying the right path forward in terms of which combination of DG resources and CG would make sense.

4. Building a Flexible Future Grid

In an attempt to build a feasible future grid that will meet the growing demand of the population worldwide. Urgent resources that are cost effective, environmental friendly and guarantee sustainability as well as resilient to attacks by unforeseen forces are needed. The infrastructure of the future grid will determine CG/DG or combination is of interest.

To provide working guide, institutional arrangement of the presentation provides criteria for evaluating the options available. These options are:

- Economic of scale
- Sustainability
- Resiliency

5. Introduction of DG and CG Technology in the Future Electric Grid

The limited generation in the power sector has continually been exacerbated by uncontrolled load growth, power demand, limitations in transmission lines and technology and manpower needed to achieve the development of a sustainable, secured and economically viable society and infrastructure. The growth in the developed and developing country has created an energy divide in terms of wealth which is reflected in major disparities of energy consumption per capital. A universal global electrification challenge to meet the world population growth to attain its current per capital electricity consumption will require massive increase in electricity generation capacity.

Distributed generation (DG) is not a new concept. A small number of cooperative consumers have been using DG for decades. Over the last 10 years, the DG market has been somewhat turbulent. In the late 1990s, the creation of competitive retail electric markets, new regulations like net metering, and the development of new DG technologies sparked broader interest in distributed generation. Recently however, higher natural gas prices have slowed the implementation of DG in many areas.

In some cases, properly planned and operated DG can provide consumers and society with a wide variety of benefits, including economic savings, improved environmental performance, and greater reliability. Some cooperatives and other utilities have acted to bring the benefits of DG to their systems and are funding research to develop new technologies.

Nevertheless, the interconnection of DG with the electric grid continues to pose genuine safety and reliability risks. Moreover, because DG could replace or reduce the demand for traditional utility service, DG could also pose an economic risk to some incumbent utilities and their consumers without appropriate rate structures or other cost recovery mechanisms.

This has created a conflict between industry stakeholders and other interest groups. On the one hand, proponents of DG are telling decision makers that utilities and regulators continue to impose technical and economic barriers to the development, installation, and interconnection of DG facilities with the electric grid. They are asking regulators and legislators to act to remove those barriers so that consumers can benefit from DG.

On the other hand, many utilities have insisted that if decision makers adopted the DG proponents' recommendations, it would significantly degrade the safety and stability of electric systems and would require utilities and their residential and small commercial consumers to subsidize uneconomic technology investments by others.

In fact, the truth probably lies somewhere in between. Decision makers should address the legitimate concerns of DG proponents to help attain the potential benefits of DG. But, decision makers must first address a number of real safety, reliability, and economic issues. To accomplish that goal, decision makers should look carefully at different applications of different DG technologies. Separate rules can and should apply to each. The electrical grid is very complex and there are too many variations between the different applications of different DG technologies for any one rule to be universally applicable.

Almost every participant in discussions about DG defines the term "distributed generation" differently. And, unfortunately, participants in discussions about DG seldom make their definition of the term clear at the outset, making it difficult to evaluate competing proposals.

At one end, DG could include only small-scale, environmentally friendly technologies – such as photovoltaics (PV), fuel cells, small wind turbines, or more conventional technologies like micro turbines or reciprocating engines fueled by renewable fuels such as landfill gas – that are installed on and designed primarily to serve a single end-user's site. At the other end, DG could encompass any generation built near to a consumers' load regardless of size or energy source. The latter definition could include diesel-fired generators with significant emissions and large cogeneration facilities capable of exporting hundreds of megawatts of electricity to the grid. Other definitions of DG include some or all of the following:

- Any qualifying facilities under the Public Utility Regulatory Policies Act of 1978 (PURPA);
- Any generation interconnected with distribution facilities
- Commercial emergency and standby diesel generators installed, for example, in hospitals and hotels;
- Residential standby generators sold at hardware stores;
- Generators installed by a utility at a substation for voltage support or other reliability purposes;
- Any on-site generation with less than "X" kW or MW of capacity. "X" ranges everywhere from 10 kW to 50 MW;
- Generation facilities located at or near a load center;
- Demand side management (DSM), energy efficiency, and other tools for reducing energy usage on the consumers' side of the meter. The alternative to this definition would be to abandon the term distributed generation altogether and use instead "distributed resources" (DR) or "distributed energy resources." (DER)

Why all of these definitions? As discussed below, many decision makers believe that DG is beneficial and are likely to adopt regulations or legislation that removes barriers to or subsidizes the development and installation of DG. Depending on the definition of DG that the decision makers adopt, and the different applications of DG that the decision makers address, different industry participants, or different interest groups will share in the benefits of the new regulatory programs. No industry or interest group wants to be left out.

For the purpose of this paper, it is not necessary to propose yet another competing definition. Instead, the paper will use the term "DG" generically to refer to any or all of the above concepts except DSM. For that reason, the paper will try not to make any categorical statements about DG generally, unless they truly can be said to apply regardless of the reader's definition.

Central generation which provide bulk power now is produced by central station power plants most of them using large fossil fired combination of nuclear boilers to produce steam that drives the turbine generators. These plants are so large that they require large infrastructures which are costly to manage. Their limitations in terms of efficiency and environmental impact as well as stability to sustain them have given rise to renewable energy resources options for researchers and policy makers.

Renewable energy resources which would lead to sustainable electricity supply system given these resources could be harnessed to power distributed generation and reduced incurred power consumption cost. We face a massive challenge and must address the renewable energy depletion. These have lots of advantages including its non-depleting ability, indigenous not dependency on importation, non-polluting with some emission produced during manufacturing and end of life disposal, diverse and complementary in their time dependency.

A centralized generated grid system has its merit and demerits, so also a distributed generated grid system. This white paper therefore aims at enumerating both positive and negative sides of either grid as well as addressing the challenges posed by the grids. This is in a bid to come to a definitive best option that enhances the reliability, resiliency and sustainability of the current grid architectures. Of course other power grid architectures exist but we will focus on the options for centralized generated system or distributed generated power system grid network. Challenges and benefits inherent in a distributed generation system if first determined. Thereafter, the rationale for a more dependable generation systems-DG or CG-is evaluated based on some sets of criteria classified as reliability, resilience and sustainability.

6. DG and CG Technologies

The widespread use of natural gas for distributed generation systems, restrictions on new transmission lines for a centralized generation systems with different technologies for control scheme of DG has resulted in the reconsideration of widespread use of DG.

The possible negative impacts of DG on reliability can be computed using performance tools such as voltage Var and fault analysis studies. The impacts of DG failure and loss of natural gas supply can be catastrophic when compared to CG. The study of DG system on different network topology such as radial and non-radial and the selection of appropriate relay protection scheme may contribute to further knowledge so as to determine the extent for which CG and DG should be encouraged in the system.

A review of the cost implication arising from installation of DG and CG in same coverage regions for the states of New York and Florida was carried out by [9]. Using a static optimization model to minimize overall investment and operating costs that would meet the varying seasonal power and heat of the two states. This optimization approach makes use of investments in energy and the regime of operation. Results indicate that for electricity production alone, DG technologies are quite expensive compared to CG systems. Approximately, this optimization model indicates that 23% and 26% increased cost for DG installation would be incurred for the states of Florida and New York respectively.

For optimal use of DG, the waste heat can be used for cogeneration. This approach of DG usage will increase the efficiency of the DG units that leads to more economic benefits that will result from the transmission losses avoided.

DG has beneficial application in this sector and so when compared to CG; it has more economies of scale and resilience to the power network. Transportation, communication and communication infrastructure are vital to the security and economic survival of the country. Reliance on CG will affect the travel and mobility and information transfer during emergency. The supporting infrastructure can be made useless if there is no power supply. The role of DG at this time cannot be underestimated. The use of DG will minimize the disruption to essential services and hence mitigate disaster and down time of essential services.

Defense and industrial base and commercial facilities: These sectors are also vulnerable since they use extensively electricity, so reliance on CG will have immediate effects on large number of people and suffering or negative impact which could also affect security and safety of people and facility. The technology to sustain such facility is proven to be DG but how sufficient it will be is a matter of further study. These economic impacts, when properly analyzed using advanced system thinking, could be used to verify that DG and CG or their combination will provide viable means of reducing vulnerability and hence resilience of the future power networks. With DG, a resilient grid can avert many types of losses such as economic, material information, loss of human life, health and safety and communication.

6.1 Limitations of DG Systems

If truly a DG system need be implement, impediments issues has to be considered that may be based on network expansion. The most common impediments that affect DG ownership or operation on the network includes the revenue on the part of CG and stand by charges, retail natural gas rates for whole sales application, exit fees and sell back rates. The impact of these rates depend on assumed locational marginal pricing, type of technology chosen, the size of generator, charges for utility studies and other payback periods for supporting the cost of service of DG, land use charges and maintenance cost.

The other non-related impediments that may affect DG installation include: interconnection charges, application and study fees, insurance, reliability requirements and other charges for application processes which could be time consuming.

To effectively determine the implication of DG as compared to CG in support of the resilience network, cost benefit analysis of each system and their combination need be studied. Such studies includes indices for resilience as a measure of vulnerability, congestion studies, stability impact and cost of operation and planning needed to determine the optimization mix of the two power grid systems.

Table 1: Challenges and Benefits for DG Technologies [7]

Technology	**Characteristics**			
	Thermal Efficiency	**Capacity**	**Challenges**	**Advantages**
Coal	30-40%	200-1000MW	Air pollution, high water usage, transmission losses	Cheap fuel, favorable subsidies
Biomass	40%	20-50MW	Air pollution, low fuel energy density	Widely available fuel
Wind Turbine	N/A	1kW-5MW	Intermittency	Free fuel, declining production costs
Solar PV	7-17%	1W-10kW	Intermittency, low capacity, high cost	Free fuel, compactness, easy integration
Natural Gas	25-30%	200-1000MW	Transmission losses, carbon emissions and other GHGs, expensive fuel cost	Burns more efficiently than coal or biomass

6.2 Technical and Economic Issues Facing Distributed and Centralized Generations

Generally some distributed generation systems are geographically distributed and can be located near to the region of power consumers thus reducing transmission and distribution losses, robust term because of the very large numbers of individual generators and statistical robustness of such a collection compared **[7]** to centralized generation. This is a simple manufacturing technology when compared to CG. However, the RER still have their limitations or disadvantages which are:

- The cost of electricity reform some of which are higher than the ones form CG (this include the so called hidden cost)
- They are not in general be dispatched except biomass

- Their distributed nature may require restructuring of the electricity supply infrastructure.
- Evolution of the electricity networks will be found in future distribution networks where automatic network reconfiguration schemes aimed at facilitating high penetration of DG while reducing system down time due to faults. This can be found in transmission and sub-transmission active network in high voltages. In a situation where a distributed generation (DG) system is embedded in the system, there will still be a number of technical implications in the following areas,
- Fault levels will increase when the DG is installed: This of course will economize the size of DG.
- In network security, the size will be limited since a DG has to comply with set standards rather than to simply meet supply security at the pre-reconnection point which will require more controls options for better security though at higher budgeted cost.
- Voltage levels one feature of radial type system is that they supply a number of distributed consumers economics suggest that h they taper along their length and hence DG at such location will increase local voltage level.
- Network stability issues under fault condition the system dynamics may cause instability depending on the characteristic of DG. If this occurs, appropriate control system has to be included at a cost to overcome the instabilities.

Most power grid systems main concerns are the reliability of the grid, the resiliency and sustainability. Depending on country or region, a power grid network could be centralized and decentralized. These two grid architectures are the most common for a power grid network. When a renewable energy options is considered as alternative energy supply options to the grid, either grid architectures is then referred to as a distributed generated system.

In a centralized generated (CG) power system network, transmission of power from the centralized system is carried over long distances before making the generated power available to consumers via distribution networks. At the generating end, power could be generated with different sources-hydropower, nuclear power, thermal power etc. In regions where a centralized generated system is quite far from users, need arises for such centralized systems to be decentralized. Obviously, this act reduces transmission of power losses via copper losses and heat losses.

A distributed generated (DG) system, on the other hand, supplies users power via renewable energy sources incorporated into a power grid system. Such renewable energy options include solar, photovoltaic, wind etc. This distributed generated system is installed closer to energy consumers than a centralized generated system. Thus, the DG system need not have transmission or a distribution grid network. Considering this layout architectures for both a CG and DG, let us now look at the best options of enhancing the reliability, resiliency and sustainability of the power grid if either or both a CG and DG will have best means making our objective optimal.
Some specific reasons for DG interconnection to the power grid include:

- Electric system reliability increase
- Urgent power demands supply
- Peak power reduction
- Power quality improvements

- Infrastructure Resilience improvement
- Land use effects reduction
- Vulnerability reduction

The vast majority of electric power generated by DG is harnessed directly to consumers without necessarily being transmitted or distributed via the power grid. Such DGs supplying consumers' power are termed standalone while those that connected to the power grid are referred to as grid-connected. This clearly shows that energy reliability could be enhanced with DG.

Though DG have quite more benefits as enumerated, proper interconnection of it to the power grid is necessary to forestall undesirable consequences to electric system operations. Use of proper interconnection and control devices can be done to ensure more dependency on local system conditions.

Researchers have proposed how to handle challenges including encouraging new standards for probabilistic and random load patterns. Such standards will reduce costs in interconnection and penalties imposed on embedded generation. Extensive use of power electronics and control devices will be needed to aid the integration of RER and facilitate interconnection. In addition extensive use of communication and signal processing tools will be needed for real time allocation work.

The use of islanding strategy will favor RER installations since the power system network will increase reliability but will require several cost increase of controls. Dynamic loads schedule under RER will increase opportunity to balance loads by proper frequency regulations and hence leads to innovative work in local control for demand side management which has not been properly addressed in research. Another technology solution to RER and DG deployment is the use of storage technologies such as batteries, super-caps, high speed flywheels and regenerative fuel cells.

The idea of self-sufficient energy efficient homes (smart homes or the evolvement of micro grid is another by-product of the increased development of DG micro grid, smart grid and virtual power stations. This is called a cluster of distributed generation installation which is collectively run by a central control entity. The purpose of this is to minimize the random and probabilistic nature of resources making up RER.

7. Economies of Scale of DG

With the widespread of increasing power demand, an increasing need for better economies of scale becomes apparent **[2]**. Most power plants are built due to a number of economic, health & safety, logistic, environmental, geographical and geological factors. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water flow. Power plants are often considered to be too far away for their waste heat to be used for heating buildings. Low pollution is a crucial advantage of combined cycle plants that burn natural gas. The low pollution permits the plants to be near enough to a city to be used for district heating and cooling.

In localized generation for distributed generation is another approach, the amount of energy lost in transmitting electricity is reduced because the electricity is generated very near where it is used, sometimes even in the same building. This also reduces the size and number of power lines that need be constructed. Typical distributed power sources in a Feed-in Tariff (FIT) scheme **[6]** have low maintenance, low pollution and high efficiencies. In the past, these traits require dedicated operating engineers and large complex plants to reduce pollution. However, modern embedded systems can provide these traits with automated operation and renewables, such as sunlight, wind and geothermal. This reduces the size of power plant that can yield profit.

7.1 Economies of Scale in Power Demands

As power demands increase, the ability of the power grid to enhance power reliability becomes indispensable. To ensure power system resiliency, sustainability and reliability, the present grid has diversified the technologies of power production. This technology has necessitated the demand for growth in the number of distributed generations. Same could be said about the centralized generations. However, due to the higher installed capacity of most CG, it becomes more expensive increasing the number of CG operating in a region of power demand. Hence, as power demands increase it costs less installing a DG to meet the increased power compared to CG. Recall also that the transmission of power cost in CG makes it highly non-economical when there is a new power production facility to be installed. A DG on the other hand has no need for a transmission network thereby eliminating losses in transmission. It then becomes apparent by installing new power capacity plants; a DG has better **[2]** economies of scale than a CG.

7.2 DG Penetrations

Estimating the worldwide share of distributed generation can lead to significant divergence in results due to the differences in the definitions used. The differences introduction can yield significant adjustments in the estimate of the total share of distributed generations. The inclusion or exclusion of large cogeneration facilities can significantly affect the results. For instance, the total share of distributed generation is of 2.5% [8] in California if cogeneration capacities larger than 20MW are excluded. If included, the share goes up to 17% of the total net peak demand (Rawson and Sugar, 2007). The bone of contention here is whether this large cogeneration capacities often connected to the transmission grid can be considered as distributed generation. The impact on the result is even more significant as the capacities of such facilities tend to be high.

A survey conducted by WADE in 2006 led to an estimated 25% share of distributed generation (WADE, 2006). The definition used by WADE does not take into account project size, the technology used or whether or not the facility is connected to the distribution grid. It thus includes large cogeneration facilities. The International Energy Agency's model (2003) estimates that distributed generation will account for between 20 and 25% of additional capacities to be built up to 2030 in the reference scenario and 30 to 35% in the alternative scenario. This will add up to approximately 30 to 35% and 40 to 45% of power generation investments over the period 2001 - 2030. The strong incentive to support distributed generation will be driven, among others, by the size of investment in transmission network to be avoided. It is estimated at $130 billion (IEA, 2003).

Two final impacts of DG incorporation into the grid are natural gas and emissions of CO_2, SO_2 and NO_2. But widespread penetration of DG shows that these emissions are reduced drastically for renewable energy resources when comparison is made with respect to coal.

Traditionally, generated power sources produced by non-utilities are mostly used in emergency situations and power systems standby. These distributed generations, though have minimize impact with the utilities power. At present, the hardware to implement distributed generations interconnection to the grid has increased the utilization of DG output in meeting various energy needs thereby offering nonutility-generated power sources, such as emergency and standby power systems. As distributed generation (DG) hardware becomes reliable and economically feasible, an increasing trend to the interconnection of several DG units with other interconnect those DG units with existing utilities to meet various energy needs and offer more service possibilities to customers.

8. Cost Implication for CG and DG

With the technologies involved for centralized generation and distributed generation, it becomes essential to compare the costs that could be incurred in a typical design layout of both CG and DG. Since distributed generation will continue to be a potential source of viable energy that enhances uninterruptible power, expanding the role of DG in the power grid of the future could totally be based on whether the **[1,6]** costs of DG is lower than DG.

For capturing small niche market of power demands, by producing power directly at the site of usage, power by distributed generations would be more valuable at or very near the retail price of generated electricity since it displaces utility-provided power. A small power generation project like the DG is also less likely to have negative impacts with land uses. This goes a long way to install DGs more than CGs.

Given same region of power to be supplied, table 1 depicts the cost involved in using either centralized generation system or distributed generation system. Provided that consistent electricity and heat loads are available, DG is the lowest cost technology. By restricting the technologies available to the model, optimal system solutions using DG can be compared to an energy system using conventional *electricity-only* and *heat-only* technologies. Will DG provide economic savings for an entire system? Table 2 provides the rationale for the economic savings.

Table 2: CG and DG Cost Implication

<table>
<tr><th>Component Cost</th><th>Centralized Generation (CG)</th><th>Distributed Generation (DG)</th><th>Distributed Generation (DG)</th></tr>
<tr><td>Cost of Capital</td><td>Lower Cost per unit</td><td>Higher cost per unit

Saved cost of system design due to reduced capacity
Saved cost of system design due to use of waste heat in cogeneration</td><td rowspan="7">With consideration to either CG or DG serving same power demands, it becomes pertinent that combined power system leads to optimal cost.

Capital cost which is higher for DG compared to CG for same power output production goes a long way to the implementations of more DG in a grid based networks.

This approach would therefore lead to a reduced cost for the power grid system with the combined CG and DG.</td></tr>
<tr><td>Fixed Operation and Maintenance Cost</td><td>Higher</td><td>Lower</td></tr>
<tr><td>Variable Operation and Maintenance Cost</td><td>Lower</td><td>Higher</td></tr>
<tr><td>Fuel</td><td>Same as DG</td><td>Same as CG</td></tr>
<tr><td>Transmission</td><td>High voltage transmission is mandatory

Far higher unit cost compared to DG</td><td>Only distribution required

Unit Cost is far lower than CG</td></tr>
<tr><td>Expense for unserved energy</td><td>High</td><td>Low</td></tr>
</table>

8.1 Economic Pricing Benefits for CG and DG Systems

Another approach to value DG over CG is to determine the benefit **[1]** marginal price of DG over CG to the customer and to the utility to determine the value of reliability. This is an area of research worth pursuing. This effort will also allow us to compute the outage cost to determine the value of DG to improve reliability of the network. Locational marginal pricing [1] that addresses the need for transmission congestion clearly defines that a need arises to limit power flows in a transmission system. This is essential so that resulting stability and voltage are kept within acceptable limits.

In a situation where an incremental load has a cost associated with it such that the bid price of the next unit in an economic order, then the lowest associated cost generator will not be sufficient to supply loads increment at some locations. Since a generator pays nodal prices and load pays the nodal prices, then the congestion charge is associated with difference between generator and load nodal prices. This price is rather low with a DG system compared to a CG system. Hence, a DG system supplying power in same region as a CG has lower congestion charge implying that the DG network is prone to power system stability as against the CG system.

9. Resilience of CG and DG System

Resilience is the ability of a system to respond and recover from an event. In other word, it is the response of the system to recover from a catastrophic event like hurricane, earthquake etc. The resilience prevalent in either a CG or DG system is the property associated with the system such that increased or decreased load demand is appropriately compensated with increased or decreased supplied power. Resilience required in a CG is therefore not the same as that necessary for a DG. This is because the load demand required for a CG is higher than a DG. In compensating this higher load demand for a CG, recall that that the installed capacity for the CG is greater than DG.

Moreover, faults in a power system network are inevitable. Faults in systems are mainly not as disastrous when compared with the aftermaths of some indispensable natural disasters like hurricane, earthquake, tornado etc. In consideration of these intermittent power failures in a power grid, what means is there that can be employed in reducing the aftermath effect and duration of such faults in either a CG, DG or both systems? Recall that a CG system has several power consumers when compared to a DG system. This then imply that, the availability of supplied power is largely dependent on the resilience of the CG than a DG system. Since the resilience of a power grid is dependent on power consumption (ceteris paribus), hence a DG system can be said to be of better resilience than a CG system.

Today's energy availability to users is largely dependent on the resiliency of the power grid supplying the need of the consumers. The study of economics has proved that provision need be taken into consideration should power demand exceed power generated. And, in a particular region under consideration, required energy consumption increases with population. Therefore, a need arises to have a power grid expansion options during the installation of either a DG or CG systems.

We could argue that the unit commitment approach to power system planning and operation is the solution to this challenge. But then, recall that the unit commitment only takes into consideration the optimization of generated or supplied power to consumers. Both DG and CG systems could be optimized to meet the everyday need of power consumers. However, in the advent of population increase, a need arises to increase the capacity of either the CG or DG to commensurate with power consumption.

Given the fact that losses is prevalent in a CG system and cost of installation is rather on the high side, a more better option to cater for the need of ever increasing power demand would be the DG systems. A decentralized option for CG could very well be an option but expense involved in the setting up of a DG with nature replenish-able renewable energy makes the DG more preferable. It should be noted that resiliency expands on vulnerability and may be viewed as the qualities CG or DG system to return to its fail-safe state at the shortest time possible.

9.1 Measures of Resilience in CG/DG

Resilience metric defined as

$$R(x,u) = \int_t^n [\sum_{i=1}^{n} c_i f_i(x,u)]dt$$

This could be used as assessment of the resiliency **[4]** of DG or CG systems where $f_i(.)$ is the routine task, such as power supply and transmission transactions, and/or communication services, with weight coefficient c_i as an associated cost at a given time scale; x and u are the state and control variables, respectively.

Since DG is more resilient than CG, therefore a higher metric of resiliency is understandable in a grid with CG and DG networks.
Resiliency in DG systems is high due to self-healing capability as compare to CG. Faults cases in CG have less severe impacts on the grid since they serve smaller regions that CG. In extreme cases of natural disasters like hurricane, tornado etc. leading to faults in the grid, a CG based network would highly be affected with less effect on DG.

9.2 Enhancing the Reliability of Power Grid through DG

As CG or DG systems continue to grow in size and capabilities, the current state of the art in power system reliability is being pushed to its limit. While power engineers try as much as possible to ensure that there is constant power availability to users, considerations of some natural disasters like earthquake, hurricane, tornado, snowflakes continually mitigate the **[5]** availability of continued power being supplied to these consumers. The question to be addressed now is: will either DG/CG or both power grid architecture would best improve the reliability of power consumption.

A centralized generated system has a central location of power being generated before the generated power is transmitted, distributed and therefore made available to consumers. Clearly, power generated at the central station cannot be same as the total sum of power supplied to consumers.

A distributed generated system on the other hand has its location closer to power users. This architecture there needs not a transmission network. Hence, losses inherent in DG architecture are far less than CG system.

Centralized generated (CG) system, though has high cost of installation and maintenance, but its usage is mainly from a central location. When compared to several installations and maintenance of a DG system, clearly a CG could be considered less expensive. Consider a region of about 70, 000sq km with CG system and same region with DG. It is definitely less expensive to supply power to users with the CG though losses in the CG architecture would be greater than DG system comprising up to about 30 dispersed evenly to meet the demands of power consumptions.
In consideration of the economies of scale involved for the CG and DG system, combination of both CG and DG would better prove to attain a better scale. In regards to this, consideration should be given to densely populated regions. Either the CG system is installed closer to such densely populated region to minimize losses or a DG is installed at such location to minimize same effect. This combination therefore will further ensure less installed capacity for either a DG or a CG system thereby optimizing the cost implication involved in their set up. In determining the reliability of a DG, measures of index is necessary to have accurate understanding of extent of the reliability.

9.3 Measures of Reliability

Some measures of reliability **[8,20]** are defined as:
EUE - Measure of transmission system capability to continuously serve all loads at all delivery points while satisfying all planning criteria. It is requires the following information for its computation:

- Frequency of each contingency (outage/year)
- Duration of each contingency (hr/outage)
- Unserved MW load for each contingency

EUE = sum of all the probabilistic weighted unserved MW for each contingency.
Where:

$$EUE = \frac{\sum_{i=1}^{N} \sum_{y=1}^{Y} \sum_{d=1}^{D} \sum_{h=1}^{H} E_h}{N_h}$$

EUE = Expected Unserved Energy (MW-hours/hour)
N = the number of Monte Carlo simulations for the period, which is typically one year using hourly level of granularity
Y = number of years in the study
D = number of days in each year that are simulated
H = number of hours in each day that are simulated
$\mathbf{E_h}$ = the amount of unserved energy for this hour (in megawatt-hours)
$\mathbf{N_h}$ = the total number of hours simulated in the Monte Carlo study.

Loss of Load Probability (LOLP) in units of *percent*, measures the probability that at least one shortfall event will occur over the time period being evaluated.
Where:

$$LOLP = \frac{\sum_{i=1}^{N} S_e}{N}$$

LOLP = Loss of Load Probability (%)
$\mathbf{S_e}$ = Simulation in which at least one significant event occurs.
N = the number of a Monte Carlo simulations for the period, which is typically one year.

Table 3: Resiliency Effects in CG and DG

	Factors	**DG**	**CG**	**Recommendations**
1	Reliability	Low reliability but has power output limitation	High with more output power	Combined DG and CG with more DG in the grid
2	Stability	Good stability	Better stability	Combined DG and CG with more CG in the grid
3	Faults in the grid	Less severe impact	Severe impact	Combined DG and CG with more DG in the grid
4	Extreme unforeseen events	Less impact	High impact	Combined DG and CG with more DG in the grid

10. Sustainability of a CG and DG System

Sustainability of a power system network **[11]** is the capacity of the power grid to withstand load requirement and yet meet the power consumers need. Previous evaluations of CG and DG shows that more installation capacity is required for a CG than a DG since the CG has more power demand on it than a DG (obviously not group of DG). But considering the cost of installation and ease of resource availability, DG systems could very well serve as better option to meet the increasing needs of consumers. Sustainability means the capability of critical infrastructures to persist functions or services in a longer term.

The use of DG has gained significance attention in a liberalized electricity markets and it is expected to make a particular contribution to climate protection. This section of the paper investigates the advantages and disadvantages of DG according to the overall concept of sustainable electric power development.

The energy system lies at the core of sustainability just as energy satisfaction can assist increase resource efficiency; minimize unwanted wastes thereby reducing the adverse environmental impacts of energy production. Sustainability in a DG system would thereby aim at addressing the following:

- Energy consumption reduction
- Reduction of sources of energy waste
- Minimization of energy production pollution
- Minimization of life-cycle costs of renewable energy resources
- Sustainability in CG and DG Systems
- The following four scenarios can be used as comparison basis for the sustainability requirements from co-optimizing CG and DG. These can be stated as:
- Environmental protection such as it concerns climate change and conservation resources. How each of this will contribute to electric power system sustainability will be compared.
- Health and safety in environment: This is an aggregate comparison to be undertaken depending on the location and type of technology use for DG.
- Security of Supply: here we need to look at the medium to long term availability or the diversity of fuel options from producing the power ; consideration of low cost of availability reduction nor loss of grid or plant and also adaptability of DG to f different fuel and resources.
- Economic impact inters of job creation, increase in production of services, innovation, flexibility and increase knowledge.

These factors can be used as criteria in selecting the mixture of DG and CG integration for developing sustainable electric supply chain.

Renewable energy resources usable for a DG system could have some element of pollution if consideration is not given to the location of the installed DG. For example, consider a DG using wind energy as a renewable energy located in downtown region. Clearly, noise pollution is inevitable in such region of DG installation. Therefore, better alternative renewable energy supply should be taken into consideration in such cases like this. We could employ solar energy as an alternative option of renewable energy resources in a location that is downtown while simultaneously having an energy storage option available should there be unfavorable weather conditions e.g. winter seasons.

On a local basis there are opportunities for electric utilities to use DG to reduce peak loads, to provide ancillary services such as reactive power and voltage support, and to improve power quality. Using DG to meet these local system needs can add up to improvements in overall electric system sustainability. Table 3 below compares some factors in CG that could be used in assessing the stability of DG systems.
The sustainability metric could be defined as:

$$T(S_r) = P(S_r)(f(S_r))^{-1} = [\sum_{j\epsilon S_r}^{n} P_j]\, [\sum_{j\epsilon S_r}^{n} P_j \sum_{j\notin S_r}^{n} \lambda_{jr}]^{-1}$$

could be used to measure the level of sustainability of either a DG or CG networks where contingency *j* at certain load level is characterized with probability *pj* and transition rate λ_{jr} is from and to other system states *j, r*. There are several and important drivers that aims at mitigating fossil fuel dependency thereby substituting these fuels for more sustainable sources of energy. One of the important drivers includes:

Environmental Concerns: Pollution and climate change effects are major concerns when it comes to a preferred power production technology. The centralized generation systems are aptly dependent on all forms of input energy that include the fossil fuels, among others. But most fossil fuels serve as combustion processes input since the products include pollutants: aerosols, nitrogen oxides and sulphur oxides. These pollutants are by far the major contributors to global warming as a result of the greenhouse gas emissions.

Table 4: Sustainability Factors in CG and DG

	Factors	DG	CG	Recommendations
1	Emissions	Low but has power output limitation	High with more output power	Combined DG and CG with more DG in the grid
2	Power Quality	Good power quality	Better power quality	Combined DG and CG with more CG in the grid
3	Quality of service	Better quality of service	Less quality of service	Combined DG and CG with more DG in the grid

Table 5: Sustainability Effects in CG and DG

Centralized Generation	Distributed Generation
High losses and transmission failure	Lower capital costs
Recycle of heat failure	High efficiency
Low reliability of power and quality	Higher reliability and quality
Vulnerable	Reduced vulnerability
Pollution	Reduced pollution

10.1 Global Trends and Best Practices in Sustainable Development

Current options include harnessing primary energy through decentralized and distributed generation, which allows for reduction on fossil fuel dependence and greenhouse emission control; subsidizing renewable energy resource (RER) through regional incentives and cash grants (stimulus) to offset costs for limited time; mandating RER-only in appropriate locations; and diversity of energy through the introduction of nuclear and clean coal over oil.

Globally, micro grid power markets are moving towards smart grid and embracing new generation capabilities and technologies. Such technologies include DG, DSM, and smart meters, and RER. In addition to new technology, the global best practices include enabling technology for security by preparing for external infrastructure attacks or realizable threats through cyber security, interoperability, and preventative maintenance.

10.2 Sustainability and Development through DG

Sustainable energy has two key components: renewable energy and energy efficiency. DG encompass any generation built near to a consumers' load regardless of size or energy source. These include diesel-fired generators with significant emissions and large cogeneration facilities capable of exporting hundreds of megawatts of electricity to the grid.

10.3 Power Quality

In simple terms, power quality is the measure of voltage quality at the end user. If the voltage is proportionate with the generated voltage by a constant ratio, then the power quality is said to be better. However, if the end users voltage fluctuates constantly while the generated voltage remains constant, the power quality for such a system is very poor and a need thus arises for the assessment of such power quality. Power quality in a power grid network needs proper assessment as reliability of the grid is also based on the level of power quality in the grid.

Favorably, the DG networks supplies power consumer's electricity over a small region of operation. Such power qualities to be addressed include: voltage sag, voltage swells, switching surges and harmonics.

The inclusion of power quality study to assessing the role of DG and CG based on fundamental criteria that include: steady state voltage rise, voltage fluctuation, voltage dip, generator start-up and static voltage stability could be embarked on as selection of best power grid topology that minimizes cost of incorporation of DG, CG or both systems.

Recall that CG networks are over long distances as compared to DG networks. It therefore follows that a CG network system is more prone to voltage fluctuations, voltage dip and instability when compared to a low ranger DG systems. This, however, does not limit power quality challenges to a CG system.

DG networks are excellent power grid networks that can be used to address a grid power quality challenges by the incorporation of storage systems (flywheel, super-capacitors etc.) and equipment usable as power conditioner.

10.3.1 Enhancing Power Quality through DG

DG Grounding Issue: A grid-connected DG, whether directly or through a transformer, should provide an effective ground to prevent un-faulted phases from over-voltage during a single-phase to ground fault.
DG can reduce power losses and defer utility investment for network enforcing; on the other hand, the DG interacts with the power quality (PQ) of the distribution network.
DG can introduce several disturbances causing a reduction of PQ levels, such as:

- Transients, due to large current changes during connection or disconnection of the generators.
- Voltage fluctuations, due to cyclic variations in the generator output powers;
- Long-duration voltage variations, due to generator active and reactive power variations;
- Unbalances, due to single-phase generators.

10.3.2 Some Indices for Measuring Power Quality

Table 6: Some Power Quality Indices [8,11,42]

Index	Definition	Main applications
Total harmonic distortion (THD)	$\left(\sqrt{\sum_{i=2}^{\infty} I_i}\right) / I_1$	General purpose; standards
IT product	$\sqrt{\sum_{i=1}^{\infty} w_i^2 I_i^2}$	Audio circuit interference; shunt capacitor stress
Crest factor	V_{peak} / V_{rms}	Dielectric stress
Unbalance factor	$\lvert V_- \rvert / \lvert V_+ \rvert$	Three phase circuit balance

10.4 Concerns for Deployment of DG for Sustainability

10.4.1 Safety

DG imposes a widely recognized risk to public safety that must be and can easily be addressed in any interconnection requirements. On most distribution systems today, generation flows only one way. Even most distribution systems with two way flows are still fairly simple compared to the interconnected transmission system, and the distribution utility will generally know which way power is flowing. Thus, if a line goes down, the utility will know whether the line is energized and can respond safely. Consumer ownership and operation of generation can change that. Consumer-owned generation could unexpectedly energize a line that the utility believes is cold, with the possibility of injuring or killing a utility worker or a citizen or starting a fire.

Many other interconnection provisions exist to ensure the DG is safely interconnected with the grid system. Unfortunately, the cost of ensuring safety sometimes makes this issue more controversial. Some organizations oppose any utility requirement for small residential generators to have utility-accessible disconnect switches. Paying an electrician to run the wires for such a switch can add costs to the interconnection. The absence of such a switch, however, can impose an unnecessary and unreasonable risk to the life and health of utility employees engaged in system maintenance.

10.4.2 Controls in Achieving Higher Sustainability in the Grid

The electric grid is a complicated "machine" that does not work by itself. If a utility is to provide reliable power, it must have adequate generation, transmission, and distribution capacity and must be able to control the voltage and the frequency of the system. If the utility fails by a small margin – even momentarily – voltage or frequency sags and spikes could ruin expensive computer and manufacturing equipment. If the system goes far off balance, it could experience serious failures: transformers and control systems could burn out, lines could sag into trees and start fires, and neighborhoods could black-out.

Thus, operator has to keep generation and demand exactly balanced at all times; has to provide adequate "voltage support" on the lines; has to keep sufficient distribution capacity on all lines to move the power being used; and has to build and maintain sufficient generation, transmission, and distribution capacity to respond to contingencies, including the failure of lines or generators or the sudden addition or loss of large loads.

Moreover, that control process is location sensitive. Where generation and voltage support have to be located depends on the location of load and the design of the distribution system. That means that load, generation, and distribution facilities all have to be planned together. It also means that the addition or removal of a large load or generation source can require the construction of new distribution facilities; the re-engineering of existing distribution facilities; and/or the re-dispatching of existing generation facilities. The problem is further complicated because no two systems have the same structure or geography. One rule for responding to changes in system architecture may not work for any two systems or even for any two changes on the same system.

Further every connected load affects and is affected by the system. If an industrial customer that generates its own power drops load without simultaneously dropping generation, it could create a surge that damages utility control equipment as well as any connected electronic equipment operating in the surrounding neighborhood. If the industrial customer instead loses its generator without simultaneously dropping load, it could create destructive voltage sag.

New generation sources can also change the direction and volume of power flows on the system, possibly causing some wires to be underutilized while overloading others. Those changes may require the distribution company to reinforce its system, build new lines, or install new control equipment.

New generation could also force the system operator to re-dispatch the rest of the generation on the system. That is, it could require the operator to ramp down lower cost base-load plants and run more expensive peaking plants in order to maintain system reliability.

Obviously, the potential for system harm varies widely according to the type and size of the generator installed whether the generator is intended to be isolated or operated in parallel with the system, or whether the generator is intended either to meet only a fraction of the consumer's load or to export significant amounts of power.

Most of the reliability risks discussed here can be addressed with the proper equipment on the grid and customer sides of the meter. The complexity and cost of such equipment varies widely depending on the size, application, location, and technology of the DG facility, the voltage at which it connects, and the size and architecture of the system to which it connects.

10.4.3 Interconnection Agreements

As discussed in detail elsewhere in this paper, properly planned and coordinated additions of distributed generation can allow a system to postpone expansion of distribution or central station generation plants, provide reliability benefits, and save consumers money. But those benefits can only be achieved when the newly installed generation is planned in coordination with the utility responsible for serving that territory. Because of the nature of the electric grid, the addition of generation to a system is neither simple, nor without cost and risks.

10.4.4 Environmental Concerns

At present, environmental policies or concerns are probably the major driving force for the demand for distributed generation in Europe. Environmental regulations force players in the electricity market to look for cleaner energy- and cost-efficient solutions. Here, distributed generation can also play a role, as it allows optimizing the energy consumption of firms that have a large demand for both heat and electricity. Combined generation of heat and electricity

10.5 The Role of DG in Global Energy Challenges

Currently, the world faces a global crisis in energy. The main issues global energy challenges involve generation, transmission, distribution, and demand-side management. DG has the capability to help resolve these issues.

For example, the development of micro grid and pricing strategies, utilization of research and development in renewable energy resources, upgrades and maintenance of current systems, optimal scheduling, and the development of efficient controls could help issues with generation.

In the area of transmission, DG could allow for sustainability through research and development in the implementation of high-voltage systems (super grid), reduction of congestion, development of pricing and efficiency strategies, upgrade and maintenance of systems, implementation of performance studies, and modernization.
For challenges in distribution, DG could resolve issues by increasing reliability and efficiency, decreasing losses, optimizing and implementing intelligence and automation controls, developing pricing strategies, and upgrade and maintenance of systems.

For the challenge of demand-side management, DG could assist in the development of pricing strategies, upgrade and maintenance of systems, provision of incentives, and implementation of automation.

11. Standards and Controls

Analytic evaluation of the consequences for DG systems could lead to quite a number of complex set of social consequences. Wind energy being harnessed for DG for instance has been reported to be of immense noise pollution to surrounding environs, most especially if it is situated in close proximity to consumers. Environmental consequences as a result of land use, waste heat are also some consequences to the benefits in DG.

In addressing these side-effects of DG, the Institute of Electrical and Electronic Engineers (IEEE) in 1999 started devising a universal interconnection standard for a distributed generation. This was necessitated given the fact that major barriers or challenges posed by DG was as a result of inappropriate interconnection between the DG and a power system network. By the winter of 1999, IEEE came up with the standards for DG **[14]** and termed it IEEE P1547. Its purpose is to set up a uniform standard for distributed generation of 10MW or lesser. These standardized requirements are relevant to the performance, operation, testing, safety, and maintenance of the interconnection.

12. Roadmap: A National Research Agenda for Development of the Infrastructure for the Future Electric Grid

Distributed generations can be depicted as attractive energy resource solutions whether in the near future or long-term when the energy supply and capacity challenges becomes critical. There are numerous benefits in the distributed generations. Some of such benefits reiterated include: increased power supply efficiency, reduced line losses, greenhouse gas emissions reduction, decreased distribution and transmission infrastructural spending. With all these benefits coupled with enhanced security, stability and flexibility of the distributed generation, it thus becomes vital to evaluate the roadmap for distributed generations.

Identification of the Roadmap: A National Research Agenda for Development of the Infrastructure for the Future Electric Grid will include:

- Determination of costs and trades off between CG and DG with respect to control costs, life cycle analysis, and protection and maintenance
- Introduction of resilience sustainability metric into power systems planning and operation which will help to evaluate stability margin, demand response, reliability issues of the system under resilience.
- Determination of value added CG and DG incentives for renewable energy storage, plug-in cars, ramping, and price response, and demand management in the grid.
- Better use of new tools like phasor measurements, time of day pricing, and other intelligent infrastructure for system support
- Develop better and faster algorithms which include adaptive predictive model and state estimation for better management and planning.
- Development of new curriculum and education to provide human capacity training.

13. Research Topics to Aid National Roadmap Agenda

1. Impact studies and analysis, which include reliability, stability, and network congestion.
2. Mitigation of market power.
3. The economic incentives to owners of clean DG technologies and the reduced health risks to society.
4. Reduced Security Risk to Grid.
5. Voltage Support to Electric Grid.
6. Land Use Effects: The value of reducing "foot-print" or space needed by generation, transmission and distribution infrastructures.
7. System Losses.
8. Combined Heat and Power/Efficiency Improvement.
9. Consumer Control.
10. Ancillary Services. The value of providing spinning reserve, regulation, or other ancillary services with respect to the cost-benefit analysis study.

Table 7: National Research Agenda for Development of the Infrastructure for the Future Electric Grid

Roadmap	Factors	Combined CG and DG	Suggested Period of Roadmap
Research	Cost	Combined CG and DG will determine costs and trades off between CG and DG with respect to control costs, life cycle analysis, and protection and maintenance.	Short term
		Mixture of CG and DG will determine incentives for renewable energy storage, plug-in cars, ramping, and price response, and demand management in the grid	
		Better use of new tools like phasor measurements, time of day pricing, and other intelligent infrastructure for system support is attained with mixed CG and DG.	
	Economic of Scale	The economic incentives to owners of clean DG technologies combined with CG leads to reduced health risks to society.	Short term
	Service Enhancement		
	Computational tools	Develop better and faster algorithms which include decision support tools, adaptive predictive model and state estimation for better management and planning.	Medium term
Resilience	Reliability	Appropriate resilient metric applied to the power systems planning and operation would help to evaluate stability margin, demand response, reliability issues of the system under resilience for a more robust CG and DG.	Short term
	Stability		
	Quality of Service		
Sustainability	Emissions	To eliminate emission, the mixture of DG and CG is pertinent to be deployed.	Long term
	Environmental Impact	Land Use Effects - The value of reducing space needed by generation, transmission and distribution infrastructures is promoted leading to reduced security risk to the grid for the CG and DG.	Short and Long term
	Power Quality	DG can reduce power losses and defer utility investment for network enforcing better than CG; on the other hand, the DG interacts with the power quality (PQ) of the distribution network.	Long term
Institutional Arrangement		Land use in CG and DG comprises the institutional arrangement. This is aiming at addressing economic of scale, cost resiliency and sustainability benefits in combined CG and DG would better lead to institutional arrangement.	Short, medium and long term
Human Capacity Building		This work is aimed at developing new curriculum and education to provide human capacity training.	Short, medium and long term

14. Conclusion

A centralized generation system has its merits over a distributed generation system. So also, distributed generated system has its own merits over a centralized generation system. In a bid to optimizing the power system operation and planning of the current grid, it therefore becomes pertinent to address what system operation would best be deployed to optimized the power system performance. Distributed generation would continue to be an effective energy solution under certain conditions and for certain types of customers, particularly those with needs for emergency power, uninterruptible power, and combined heat and power.

Foregoing issues addressed in the sections on reliability, resiliency and sustainability of CG and DG system shows that both systems have strengths and weakness over the other. It is therefore important that in power system planning operation, a combination of both systems would best achieve optimal performance of the current power grid.

Depending on the size of region where power need be utilized, a CG is advisable to be deployed in a smaller region for power utilization while it is simultaneous located far away from densely populated settlement. Where such region under consideration has prevalent natural disasters like earthquake, hurricane, tornado, then a DG system should be incorporated into the grid architecture. This will further boost the power supply available in advent of power outages as a result of faults in the CG system caused by unforeseeable natural occurrences.

For a larger region requiring power consumption, both a CG and DG system is better employed. In situation where consumers are located long distances from the CG, a DG can be implemented such that it reduces the power demand burden on the CG system while simultaneously reducing losses inherent in the long distance transmission and distribution network systems.

Appropriate standards could also be employed in the determination of best and optimal combination of a DG networks with a CG in situations where neither is discouraged to be deployed. In cases where only a DG network is being deployed, a control standard scheme need be developed so that the DG grid has incorporated enhanced-reliability, better power quality assessment, sustainability and system resiliency.

This presentation has also been reviewed based on different technology, options for serving power demands. In the future, flexible grid DG based on renewable energy has proven to be of interest to utility, government and independent power producers (IPP) due to its affordability and flexibility to penetrate the grid’s networks.

CG continues to be attractive due to its availability for large power production and some areas. The challenge remains to what extent can we co-optimize CG integration in the future grid? This presentation addresses this question. It also summarizes the various viewpoints in terms of economic of scale or index for comparing DG and CG that will justify and develop a policy that will promote economic of scale, optimal cost, resiliency, and sustainability

The issue of resiliency is caused by unforeseen events which have been discussed to value CG and DG. This purpose is to optimize the coordination of CG and DG that will provide a resilient source of power in the future grid. The resilient aspect of this presentation also concerns the issue of reliability and power quality of DG and CG. The next attribute for comparison involves the development of DG or CG based sustainability. Issues of DG to provide cleaner environment and reduce emissions are discussed. The disadvantages of DG resources are also compared with CG in the presentation.

Therefore, based on the analysis in the presentation challenges arise to provide opportunity for research and development and this has helped to shape or direct a national roadmap for development of a combined DG and CG based networks.

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