Submission by the

Alternative Technology Association

to

Infrastructure Australia

on the

‘Network Benefits of Embedded Generation’

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By Email to: mail@infrastructureaustralia.gov.au

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Executive Summary

ATA welcomes the opportunity to submit to *Infrastructure Australia*, to identify relevant infrastructure projects requiring funding and progression in order to increase Australia's productivity, diversify Australia's economic capabilities, build on Australia's global competitive advantages and reduce our greenhouse gas emissions.

ATA is a not-for-profit organisation established in 1980 to empower our community to develop and share sustainable solutions for the way we live and to promote the uptake of sustainable technologies in order to protect our environment. The organisation provides service to over 4,500 members, who are actively promoting sustainability in their own homes by using good building design and implementing water conservation and renewable energy technologies.

ATA advocates in both the government and industry arena for ease of access and continual improvement of these technologies, as well as the production and promotion of information and products needed to change the way we live. As Australia's peak member-based organisation representing early-adopters of renewable energy systems, ATA is in a unique position to highlight the needs and potential of the small-scale renewable energy market.

Electricity Network Benefits of Embedded Generation in Australia

This submission relates to the current infrastructure needs of small and large scale embedded energy within Australia's changing electricity market. Embedded energy is electricity generation systems that sit within the existing electricity grid, such as small-scale solar PV or larger scale co-generation (CHP).

As part of its commitment to addressing the challenge of climate change, the federal government currently has a number of policy initiatives that seek to increase the uptake of renewable energy within Australia's electricity grid. For embedded renewable energy systems, these include photovoltaic (PV) rebates and renewable energy certificates allocated under the Mandatory Renewable Energy Target (MRET). These programs have had varying success in attempting to facilitate this uptake.

Our view is that the most effective mechanism for unlocking the potential of both embedded renewable technologies in Australia and properly valuing their network benefits (including economic, social and environmental benefits) is that of a feed-in tariff. Feed-in tariffs have demonstrated significant success internationally and have recently been implemented (with varying scheme designs) in some Australian states. Indeed the current federal government expressed interest in the establishment of a nationally consistent feed-in tariff and a Parliamentary Senate Inquiry is currently being held into this issue.

However, the full network benefits of embedded generation have not yet been properly costed or quantified. A comprehensive infrastructure study into the potential economic, social and environmental benefits would justify the implementation of a comprehensive policy mechanism that will drive small and large scale renewable energy uptake and make a significant positive difference to Australia's energy market reform process.

1. The CPRS and Complementary Measures

The introduction of the government's Carbon Pollution Reduction Scheme (CPRS) will be an essential part of Australia's response to the climate change. It alone however will be insufficient to accelerate the uptake of many important renewable energy technologies that will be critical in addressing greenhouse gas reduction.

As such, the CPRS alone won't facilitate the full reduction in greenhouse gas emissions that could potentially be achieved if additional complementary schemes are in place. Additional policy measures and incentives are necessary to overcome the remaining financial (the CPRS will only provide a small financial incentive), institutional, technical and regulatory barriers that remain.

Indeed, as the recently released *Garnaut Climate Change Review Issues Paper* stated:

> *"Establishing a carbon price alone will be an incomplete approach to mitigating climate change; additional measures will be required" (Garnaut Climate Change Review Issues Paper 4, page 2).*

One of the most successful policy mechanisms internationally in increasing the uptake of both small and large-scale renewable energy technologies has been a feed-in tariff.

2. The Case for Embedded Generation and Feed-in Tariffs

The introduction of a mandated feed-in tariff for the production and supply of electricity from small and large scale embedded renewable energy is the most appropriate mechanism for valuing the full benefit of embedded generation within the electricity market. A feed-in tariff provides a means for capturing the true economic value and many related benefits of such technologies.

Simply put, a feed-in tariff is a premium tariff paid for electricity fed back into the electricity grid from a designated source of electricity generation, typically renewable energy. At present, feed-in tariffs for renewable energy exist in over 40 countries, states or provinces internationally. The scope and implementation of these laws varies across jurisdictions, however all involve the payment of an increase rate for electricity from renewable energy sources in recognition of the range of benefits from this form of generation.

Small and large scale embedded generation is disadvantaged in Australia through market failure which fails to take into account the true value and many benefits to the electricity network that arise from the adoption of renewable energy technologies embedded within the electricity grid.

2.1 Economic Value to the Grid Network

At present, Australia's electricity generation infrastructure is heavily weighted towards fossil fuels, which accounts for 93% of all electricity generated, with 77% coming from coal alone. Further, fossil fuel generation comes from a relatively few generation facilities, owned by a small number of increasingly foreign-owned companies.

This lack of supply diversity exposes Australia's energy industry to significant risk of potential price spikes and / or supply limitations in the future. As such, it is prudent to invest significantly in lower risk generation sources such as solar and wind to ensure security of supply. A feed-in tariff is a proven mechanism for promoting technology deployment to enhance generation diversity.

Embedded generation technologies have a true value to the market higher than is currently able to be captured. For example, peak output of solar PV systems correspond closely with times of peak demand – sunny summer afternoons, typically times of high air-conditioner use.

At these times, the wholesale electricity price frequently rises well above the average National Electricity Market (NEM) price of $35/MWh, reaching the hundreds, even thousands of dollars per MWh. This pushes the overall average price higher, and hence increases the cost of power to all consumers.

By generating electricity at these times of peak demand, solar PV effectively acts as a form of consumption abatement, reducing the demand on remote electricity generators and thus lowering the peak wholesale price of electricity.

Further, by generating electricity close to the point of consumption, embedded generation technologies avoid the need for expensive transmission and distribution network augmentation. It has been calculated that Australian network services providers are committed to spending in the order of $24 billion dollars over the next 5 years on upgrades to networks in order to meet growing peak demand.

A feed-in tariff offers an opportunity to reward embedded generation for its contribution to avoiding this network augmentation, and the associated cost which is ultimately borne by consumers through electricity prices. This is particularly the case with solar PV, as the peak production of electricity corresponds closely with times of peak demand; the very times at which the network infrastructure is stretched to its limit.

2.2 Other Values of Embedded Generation

2.2.1 Societal Value

When considering an incentive for embedded generation, it is important to also consider the economy-wide benefits of the development of the manufacturing, distribution and installation industries in Australia. For example, solar PV generates at least 30 jobs per installed MW – more than three times that for coal-fired electricity[1].

Not only are jobs created immediately, but the development of a high-tech embedded generation industry in Australia with enormous export potential would negate the present trend of locally developed innovations, intellectual property and industry exports heading off-shore in search of markets.

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[1] Navigant Consulting, Inc., Survey of Predicted and Actual Renewable Energy Job Creation Presented at 'POWER-GEN Renewable Energy and Fuels 2007' conference, March 7, 2007

Further, the expansion of the embedded generation industry locally will lead to economies of scale and reduced real costs, eventually enabling these technologies to reach parity in the Australian market without the need for financial incentives.

2.2.2 Environmental Value

While debate continues about the economic cost of climate change, the IPCC Fourth Assessment Report and the recently released Garnaut Review make a strong case for the need to internalise the cost of greenhouse gas pollution. Infrastructure Australia has a clear commitment to supporting projects that will make a material contribution to reducing Australia's greenhouse gas emissions, as stated in Discussion Paper 1.

Embedded generation such as small scale solar PV and larger scale cogeneration are zero or low emission technologies and have obvious significant environmental benefits. In addition, emissions of sulphur dioxide (SO_2) and nitrous oxides (NO_x) have a significant environmental, social and associated economic cost, and as such are subject to emissions reduction legislation, emissions trading and taxation in many countries internationally.

A study by the European Commission places the cost of SO_2 and NO_x emissions from electricity supply at roughly $25/MWh for black coal and up to $50/MWh for brown coal fired generation[2]. When added to a price for the emission of greenhouse gases, such as carbon dioxide and methane, the economic case for solar PV and other renewable energy technologies is further enhanced.

Feed-in tariffs offer a mechanism to economically value the reduced emissions from these technologies and appropriately reward technologies which avoid environmental pollutants in the generation of electricity.

2.3 The German Experience

The most widely recognised, comprehensive and successful instance of feed-in tariffs internationally would be those introduced and modified in Germany over the past 16 years.

In 1991 the German government introduced the Electricity Feed Act, legally regulating the feed-in to the grid of electricity generated from renewable resources. This act required utilities to purchase electricity generated from renewable resources at set rates.

This scheme was expanded and enhanced with the adoption of the Renewable Energy Sources Act of 2000, which has been responsible for the dramatic growth in Germany's renewable energy market and the solar photovoltaic industry in particular. In the five years from 2000, the quantity of electricity fed into the grid from eligible sources has more than doubled, with a seven-fold increase in installed solar photovoltaic (PV) capacity to over 1,500 MW by the end of 2005. By comparison, at the same time Australia in the order of 7MW of grid-connected solar PV, or less than 0.5% of Germany's capacity.

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[2] Rabl, A & Spadaro, J (2005), Externalities of Energy: Extension of accounting framework and Policy Applications, ExternE, European Commission

3. Research into the Network Benefits of Embedded Generation

Given the significant potential of embedded generation, driven by a nationally consistent, comprehensively designed feed-in tariff, and given its close alignment with the greenhouse, economic and productivity goals identified by Infrastructure Australia, there is a strong need to undertake a thorough piece of research into quantifying the network benefits of increasing the level of embedded generation within the existing electricity grid.

Similar such studies have been undertaken internationally and have proven extremely useful in establishing the justification for the introduction of feed-in tariffs. Two such studies are attached to this submission in **Appendix A**. While these studies are useful for a general comparison with the Australian context, the specific costed network benefits will be different for each region and each electricity grid.

We therefore submit to Infrastructure Australia that the funding of a formal study into the Network Benefits of Embedded Generation would be of significant benefit in increasing the efficiency, reliability and productivity of Australia's electricity grid whilst achieving sound environmental objectives.

4. Further Contact

We once again thank Infrastructure Australia for the opportunity to highlight such an important infrastructure project within the context of Australia's electricity market.

This submission is supported by the **Moreland Energy Foundation Ltd** (MEFL), an independent not-for-profit organisation established by the Moreland City Council to help reduce greenhouse gas emissions across the municipality. MEFL have conducted significant research in the area of large scale renewable embedded generation and strongly support the need for quantitative research into the network benefits of this technology.

Feel free to contact the undersigned should you have any questions regarding the content of this submission. We would be more than happy to meet with representatives of Infrastructure Australia to further discuss details of how this project might be progressed.

Yours sincerely,

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Appendix A

~ Research into Network Benefits of Embedded Generation ~

Manuscript submitted to Electricity Journal 6/2/2006

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UNDERSTANDING THE BENEFITS OF DISPERSED GRID-CONNECTED PHOTOVOLTAICS: FROM AVOIDING THE NEXT MAJOR OUTAGE TO TAMING WHOLESALE POWER MARKETS

Abstract:

Over the past two decades the operation of the U.S. electric grid has become increasingly complex as it has been called upon to accommodate growth in total electricity consumption of 75%, accompanied by an increase in non-coincident peak demand in excess of 65%. At the same time, the electric industry is in the midst of an historic restructuring to promote non-discriminatory, open access to the nation's electricity super highway to facilitate greater competition in the provision of electrical energy. This article investigates the role that dispersed, grid-connected photovoltaic (PV) can play in helping to build an electric grid for the 21st Century. The article describes how a better characterization of the solar resource based upon satellite remote sensing has facilitated an improved understanding of the role that grid-connected PV installations could serve to enhance electric grid reliability. Evidence is presented that PV installed in dispersed applications could serve to prevent and/or hasten recovery from major power outages and serve to mitigate extreme price spikes in wholesale energy markets. Dispersed, grid-connected PV system's contribution to the electric industry should be understood in the context of both grid support and as a provider of electricity during the hours of peak demand.

I. Introduction

Electrical energy plays a central role in delivering a level of wealth and affluence that Americans have come to expect. A proliferation of electrical appliances over the past century has made life for millions of Americans more comfortable and convenient. Over the past two decades, the operation of the U.S. electric grid has become increasingly complex as it has been called upon to accommodate growth in total electricity consumption of 75%, accompanied by an increase in non-coincident peak demand in excess of 65%.[1]

Accompanying this growth in electricity consumption and peak demand has been an ongoing process of creating an industry structure to accommodate robust wholesale competition, beginning first with the 1978 Public Utility Regulatory Policies Act (PURPA). Since PURPA, the Federal Energy Regulatory Commission (FERC) has continued the march toward a competitive electric power sector through its historic Order 888, effectively requiring the unbundling of generation from transmission, and more recently with its Order 2000 to foster independent, non-discriminatory operation of the electric grid.

In recent years, several studies highlighted the concern that investment in the nation's electric grid has been inadequate to accommodate increasing energy flows, resulting from an increase in electricity use and greater wholesale market activity. The U.S. Department of Energy's 2002 National Transmission Grid Study called attention to these issues. The report concludes that:

> There is growing evidence that the U.S. transmission system is in urgent need of modernization. The system has become congested because growth in electricity demand and investment in new generation facilities has not been matched by investment in new transmission facilities. Transmission problems have been compounded by the incomplete transition to fair and efficient competitive wholesale electricity markets. Because the existing transmission system was not designed to meet present demand, daily transmission constraints "bottlenecks" increase electricity costs to consumers and increases the risks of blackouts.

It has also been argued that the competitive model, which has usurped the regulated franchise model of electricity production and delivery, creates a disconnect between economic and reliability interests.[2] One remedy being pursued, which appeared as one of the recommendations in the U.S.-Canada Power System Outage Task Force's final report on the August 2003 blackout, is to move toward mandatory reliability standards.[3] Section 215 of the Energy Policy Act of 2005 codified this recommendation into law and calls for a nationwide Electric Reliability Organization and a much greater role for the FERC in assuring reliable operation of the grid.[4] The FERC is now placed in the interesting position of both championing electric utility competition, and the associated economic efficiencies, and a more robust and enforceable reliability regime for the nation's electric grid.

While a variety of investments will be required to address the deficiencies of the nation's electric grid, greater use of dispersed solar photovoltaics (PV) systems should be included in the portfolio of solutions. This paper present empirical evidence that dispersed, grid-connected PV can serve a number of valuable functions when deployed at the distribution level. In fact, PV has unique characteristics that could address the two potentially competing goals now under the purview of the FERC—effective wholesale competition and a reliable electric grid. The article begins with a description of modern solar resource assessment techniques and how they can be used to better understand PV's contribution as a grid-connected resource.

II. Understanding the Solar Resource

At some point, everyone has experienced the awesome potential of the solar resource, whether basking in the sun on a pristine sandy beach or opening the door of a vehicle that had been parked directly in the sun's path. Traditionally, the solar resource has been understood in diurnal patterns of average solar radiation striking the earth's surface. The U.S. Department of Energy's National Renewable Energy Laboratory maintains the National Solar Radiation Database, which contains hourly values of the three most common measurements of solar radiation (global horizontal, direct normal, and diffuse horizontal) over a period of time adequate to establish means and extremes (30-year period, 1961-1990), and at a sufficient number of locations to represent regional solar radiation climates.[5] While solar resource data in this form is extremely valuable for predicting the average annual output of a solar energy installation, it is less valuable when attempting to understand PV's contribution to meeting electrical demand or providing grid support services. In these cases, time and location specific resource data becomes critical to understanding PV's potential.

In the early 1990s new resource assessment techniques were developed using satellite-derived cloud cover data. Through well tested algorithms cloud cover data from geostationary weather satellites are utilized to estimate the ground-level solar resource at a particular location at any given time. The technique has been rigorously validated using actual ground-level measurements.[6] Furthermore, the availability of satellite-derived solar resource data frees researchers from the limitations of average solar resource data, and allows detailed analyses of PV's potential contribution as a grid-connected resource.

Prior to the mid-1990s, there was not much interest in PV for grid-connected applications, given that PV was viewed primarily as a power source for remote applications far from an electric grid. With the introduction of net metering rules in various states and the development of inverters for grid-tied applications, interest in grid-connected PV grew. Today, due to these changes and burgeoning government incentive programs, grid-connected solar is the fastest growing market for PV technology.[7] As a result, it has become increasingly important to gain a rigorous understanding of the contribution that grid-connected solar can provide to the nation's electric grid—satellite-derived solar resource data makes this possible.

III. The Capacity Value of Grid Connected PV

As anyone connected to the electric industry readily understands, peak demand for power occurs in regions with significant air-conditioning load during periods of hot, steamy weather. For example, the 2004 peak load of the New England Independent System Operator's network of just over 24,000 MW occurred on August 30th.[8] Similarly, the PJM Interconnection experienced their 2005 peak demand of 135,001 MW in the late afternoon of July 26th.[9] Coincidently, the solar resource tends to be quite good on days when peak demand for power is being driven by electrical demands for space cooling. Although the sun will likely be shining on days when peak demand occurs, how confident can grid operators be that a PV generator will be providing power when it is most desperately needed?

Electric power analysts have devised methods to quantify the capacity value that a generator can be expected to contribute to the overall network. While many approaches have been used, the Effective Load Carrying Capability (ELCC) is well-grounded in reliability theory and practice and can be applied to all generators.[10] While admittedly the ELCC approach require large datasets, it is viewed as the most rigorous approach that can readily distinguish capacity contributions among different generator types.[11] Prior to the development of satellite-derived solar resource assessment techniques, PV ELLC calculations were limited to those locations with multiple years worth of ground-level solar resource data.

Thus, one of the first applications of satellite-derived solar resource data was to calculate ELCCs for utility service territories across the country. Statistical derivations of ELCC for PV generators were derived using system load data for several utilities across the country. Energy output from hypothetical PV generators was simulated using time-coincident solar resource data for each of the utility service territories studied. Earlier ELCC results for PV were derived from late 1980 and early 1990 utility load profiles and simulated PV generator output.[12]

At low PV penetration rates—2% and less—PV's ELLC were calculated to be as high as 70% for regions along the eastern seaboard.[13] Figure 1 provides an ELCC contour map for the U.S. based on this early PV ELLC analysis. Recent updates to PV's ELCC using more current load data (2002 and 2003), high resolution satellite data, and a more accurate satellite model to simulate site- and time-specific PV output support the overall regional trends identified in the earlier work.[14] The updated PV ELCC study found a significant increase in PV's ELCC values in western and northern regions of the U.S., and a modest decrease in PV's ELLC values in the central and eastern portions of the U.S. In sum, the capacity value of PV has been well established. The logic underlying this empirical finding is quite simple—the principal cause of the demand peaks, solar gain, is also the direct source of PV generation.

(Figure 1 about here.)

It is clear from recent trends that future PV deployment will likely continue in a distributed fashion. PV's modular, easily sited characteristics make it a perfect technology to deploy within the distribution network, preferably as close to loads as possible such as the millions of square feet available on buildings and other man-made structures. While the ELCC method to assess a generator's capacity value is typically applied to large-scale, central station generators like wind and fossil fuel-fired thermal plants, it is equally valuable in assessing the capacity value of PV even though it is deployed as a distributed technology. This attribute becomes particularly attractive in load pocket, capacity constrained areas, where it is not possible to easily increase local generation capacity or bring in additional power lines.

Given that PV will be connected primarily through existing meters, some may argue that it may be appropriate to evaluate its deployment in the demand-side management or demand response contexts.[15] To understand its potential in these contexts it is useful to look at a slightly different method of analysis from the ELCC approach, referred to as minimum buffer energy storage (MBES). MBES is a metric used to quantify the minimum amount of reserve energy (from storage and/or load control) necessary to guarantee a peak load reduction equal to value of the installed PV system's rated capacity. An analysis of Sacramento Municipal Utility District's load and solar resource profile suggests that a firm 2% peak load of the utility's 2,700 MW peak load requirement could be met with 54 MW of solar (southwest-facing at 30 degrees tilt) and 19 MWh of energy storage and/or load control.[16] This stands in contrast to 110 MWh of storage and/or load control to accomplish the same goal without PV.

Misconceptions that there is insufficient physical space to site PV arrays for solar to satisfy a significant portion of our energy requirements persist. However, based on existing solar PV technology, less then one half of one percent of the land area in the U.S. would be required to accommodate a sufficient amount of PV to produce all the electrical energy consumed in the U.S. This amounts to approximately 25,000 km^2 of PV panels to produce a total of 4 trillion kWh of electricity—roughly equivalent to the total electrical energy consumed each year in the U.S. Although the ELCC for PV declines as the amount installed increases, this does not preclude PV from providing a significant portion of our electrical energy needs. ELCC remains significant at load penetrations of up to 20-25% for large portions of the US . At higher penetration rates, energy storage and/or active load control would be required to maintain high ELCC values for PV as for other intermittent sources such as wind. Putting the intermittency issues aside, it is clear that there is sufficient physical space on building rooftops and other structures to accommodate amounts of PV that could provide a large portion of our total demand for electrical energy.[17]

IV. Can Solar Help Avoid the Next Major Outage?

Like a large thermal power plant, PV can deliver firm capacity to an interconnected power network. Beyond this, the distributed nature of PV provides additional grid support benefits that are becoming increasingly important for reliability purposes; reliability, after all, is fundamentally about keeping the lights on!

When the power grid fails significant disruptions are imposed on individuals and businesses alike, in addition to significantly increased risks to human safety as critical infrastructure becomes disabled. Experience has shown that most major power outages occur during times when the grid is under stress due to heat-wave driven peak load situations. Over the past several years, satellite-derived solar resource data has been utilized to retroactively demonstrate that dispersed PV systems injecting solar electricity on the grid may have avoided the major heat-wave driven power outages that have occurred.[18, 19] These studies have demonstrated that dispersed PV systems would have been operating near their peak output during the hours leading up to, and after, the outage.

The most severe outage in recent history, and the one foremost on the industry's mind, was the power outage that took place on August 14th 2003. This event serves to demonstrate how modest amounts of dispersed PV could serve to prevent, and/or hasten recover from, a major heat-wave driven outage.

(Figure 2 about here.)

On the afternoon of August 14, 2003 loads throughout the U.S. Northeast, though not at record levels were high, driven by air-conditioning demand. The region was experiencing large power transfers (of more than 5 gigawatts) from south central states to the north. Much of that power transited through Ohio on its way to the major load centers in Detroit, Cleveland, and Toronto. A series of precursor events took place near Cleveland eventually leading to a cascade of plant and transmission facility failures. The U.S.-Canada Power System Outage Task Force identified three main causes: (1) inadequate situational awareness from the local utility; (2) inadequate tree trimming; and (3) inadequate diagnostic support from reliability coordinators. The Task Force also concluded that the outage was preventable and that better, enforceable controls and regulations should avert future similar contingencies.

Above and beyond the "official" causes identified by the Task Force, analysis of the events clearly suggests that, had regional power transfers to meet localized energy demand not been as high, the probability of each contingency—even unattended—leading to the next and finally into cascade would have been much lower. Conditions on August 14, 2003, although not extreme, represented a textbook example of high regional air-conditioning demand creating high power transfers and stress on the grid. Therefore, it was no coincidence that the solar resource was plentiful. The question becomes, how much PV-generated power would have been sufficient to prevent the blackout? There are two ways to answer this important question.

First, enough PV was needed to provide sufficient localized voltage support, power and reactive power to avoid precursor events. The first contingency involved the failure of a power plant near Cleveland due to exceeding its reactive-power-generation limit. High demand from air-conditioning compressors increases the need for reactive power or megavars—a service that power plants can deliver in addition to megawatts. It has been argued that the there should be increasing attention given to the issue of reactive power management, as the need for this service has increased over the past several decades.[20]

Thus, displacing even a small fraction of the cooling load that was creating the demand for reactive power would have been sufficient to keep the Cleveland power plant operational. This fact suggests that at most, a few tens of megawatts of PV deployed locally would have been enough. Further, the failure of transmission lines that occurred in the hours following the Cleveland power plant trip and before the cascading outage, may have been avoided by reducing power flows by at most a few tens of megawatts. It is reasonable to argue that, had these dominos not fallen, the cascade would not have occurred.

A second way to quantify the amount of dispersed PV needed to avoid the August 14th, 2003 outage is to look at the need to minimize regional power transfers via local generation. Prior to the precursor events, the north-south power flow was of the order of 5,000 MW. Had local dispersed generation been available near Detroit, Cleveland, and Toronto, it would have reduced these transfers, and inadvertent power line trips would have been inconsequential. A power-transfer reduction of as little as 10 percent (500 MW) likely would have kept the precursor events from feeding into each other.

Both approaches suggest that the availability of, at most, a few hundred megawatts of PV generation located in and around each major concerned metro area would have provided insurance against the contingencies of August 14th, 2003.

The accumulated evidence showing that the highest grid-stress conditions are directly caused by solar gain suggests that the deployment of a dispersed, grid-connected PV resource will contribute to strengthening the reliability of the U.S. power grid. Not only could a dispersed PV resource lower the probability of a massive grid failure by injecting power at peak demand times, but it could also provide insurance against outages should they nevertheless occur (e.g., for reasons other than stress induced by high demand, such as severe weather or terrorism). Properly designed, customer-sited PV installations that include emergency storage/backup at a modest additional cost could provide enough emergency power to keep critical loads at businesses and residences going almost indefinitely during an outage. The outage-preventive attributes of PV may even be enhanced when systems are designed with outage recovery in mind, by making part of the storage/backup reserve available to grid operators for emergency load management.[21]

V Solar and Peak Power Prices

In a number of regions throughout the U.S., wholesale power markets have been functioning for several years. The California energy debacle aside, it has been asserted that wholesale competition has delivered billions of dollars in savings to electricity consumers.[22] At the same time, however, power markets have exhibited considerable volatility in the form of dramatic price spikes during periods of peak demand. Most every wholesale power market has at one point experienced sharp spikes in the price of electricity. Many believe that price responsive load is a key strategy for keeping wholesale electricity prices in check.[23] As such, the subject of price responsive load (also referred to as demand response) has gained much attention in recent years.

While demand response requires an active engagement of loads in responding to high energy prices and/or emergency supply shortfalls, distributed PV offers a passive approach once the initial installation is completed. As established earlier in the discussion of PV’s ELCC value, solar PV output is well correlated with peak power demands. By extension, given that price spikes tend to occur during supply shortages caused by high demand, PV output tends to correlate with peak power prices. Again using satellite-derived resource data, the empirical relationship between PV output and peak power prices has been well established.[25, 25]

Table 1 provides data on the number of days during the summer of 2002 when electricity prices in the PJM Interconnect and the New York ISO wholesale power markets spiked to 20¢/kWh and above. The table also presents the average daily PV availability statistic that corresponds with the peak price events. The PV availability (percent value) statistic represents the fraction of what a PV system would produce if the sky was ideally clear.

Solar resource data was obtained for each day and location during these peak price events to determine a PV availability factor.

Two different PV availability measures have been calculated. The daily PV availability represents how a PV system would have performed throughout the entire day when the peak price event occurred. A daily PV availability rating of 0.70 indicates that a south facing appropriately angled PV array would be produce 70 percent of its ideal output, or rated output, during the day when power prices spiked upward. The second measure, peak time PV availability, measures a PV system's performance during the exact time of day that the peak power price event occurred. In this case, a 0.70 peak time PV availability measure would indicate that the PV system was performing at 70% of its ideal output during the hour(s) when power prices spiked. Both measures of PV availability were calculated based on the summer 2002 peak price events in the NYISO and PJM wholesale power markets.

Table 1
PV & Peak Price Events Summer 2002
(Number of Days with Peak Price Events / Average Daily PV Availability)

	May	**June**	**July**	**Aug.**	**Sept.**
PJM	9 / 0.74	2 / 0.79	6 / 0.88	10 / 0.83	4 / 0.78
NY-ISO	3 / 0.86	3 / 0.81	9 / 0.81	12 / 0.78	5 / 0.71

In New York, the average daily PV availability statistic for all peak price days in the summer of 2002 was 0.79. Thus, on average, in the NYISO control area, distributed PV systems would be operating at roughly 80 percent of their ideal output during the days when power prices spike in the wholesale market. The average peak time PV availability statistic was 0.55 for New York. Turning to the PJM Interconnect, the average daily PV availabilities for all peak power days during the summer of 2002 was 0.81, and 0.72 for the average peak time PV availability. These empirical results suggest that distributed PV output would be high during days when peak price events occur. By extension, PV could play a role in addressing price volatility in wholesale energy markets.

How much PV would be needed to have a positive downward effect on power prices in wholesale energy markets? There is no exact method to determine this. However, it seems reasonable that as little as 1 – 3 percent of peak load coming from PV could serve to restrain most of the peak price events. Again, this would result in several 100 MW connected throughout New York given its summer peak load of slightly over 30,000 MW.

VI. Creating a Solar-Friendly Policy Environment

Many predict that the next several decades will challenge society on several fronts, one of those being in the provision of environmentally sensitive, reliable, low-cost electrical energy. Advocates for addressing global climate change call for a rapid shift away from carbon based primary fuels. Although PV may not be the least costly resource to displace fossil fuel use for power production, it is clearly a climate friendly technology. This coupled with the other contributions solar could provide to the electric grid discussed in this article suggests that promoting greater investment in solar PV is a wise policy objective.

The contributions that PV can make to a more robust reliable electric network are shared broadly and not easily captured, in a financial sense, by any one single actor. Thus, like many states have initiated, general provisions that encourage private investment in solar PV should be aggressively pursued. This paper provides strong evidence that a significant public good is derived from greater use of dispersed solar PV.

Clearly, the state of California through its California Solar Initiative has identified solar as a key resource for the State. The goal of the $2.9 billion 10-year program is to increase the installed capacity of PV to 3,000 MW by the year 2017.[26] Similar, aggressive initiatives should be adopted by other states and perhaps supplemented by stronger initiatives at the federal level to stimulate greater investment in solar PV. As stated earlier, outage mitigation should be kept in mind to promote deployment of solar PV in such a way that it would have the greatest impact on system reliability. The FERC could commission a study, in the context of its new role ensuring a reliable electric grid, which provides technical guidelines for future PV deployment that take into account outage mitigation. These guidelines could be tied to more favorable federal tax credits or other mechanisms to encourage greater investment in solar PV.

Solar technology is a mature technology, and is poised to make a significant contribution to a more robust and reliable electric grid. From avoiding the next major power outage to taming wholesale power markets—the sun is rising on a new era for the solar electric industry!

Endnotes:

1. ISO/RTO Council. (November 2005). The value of independent regional grid operators. White paper prepared by the ISO/RTO Council..

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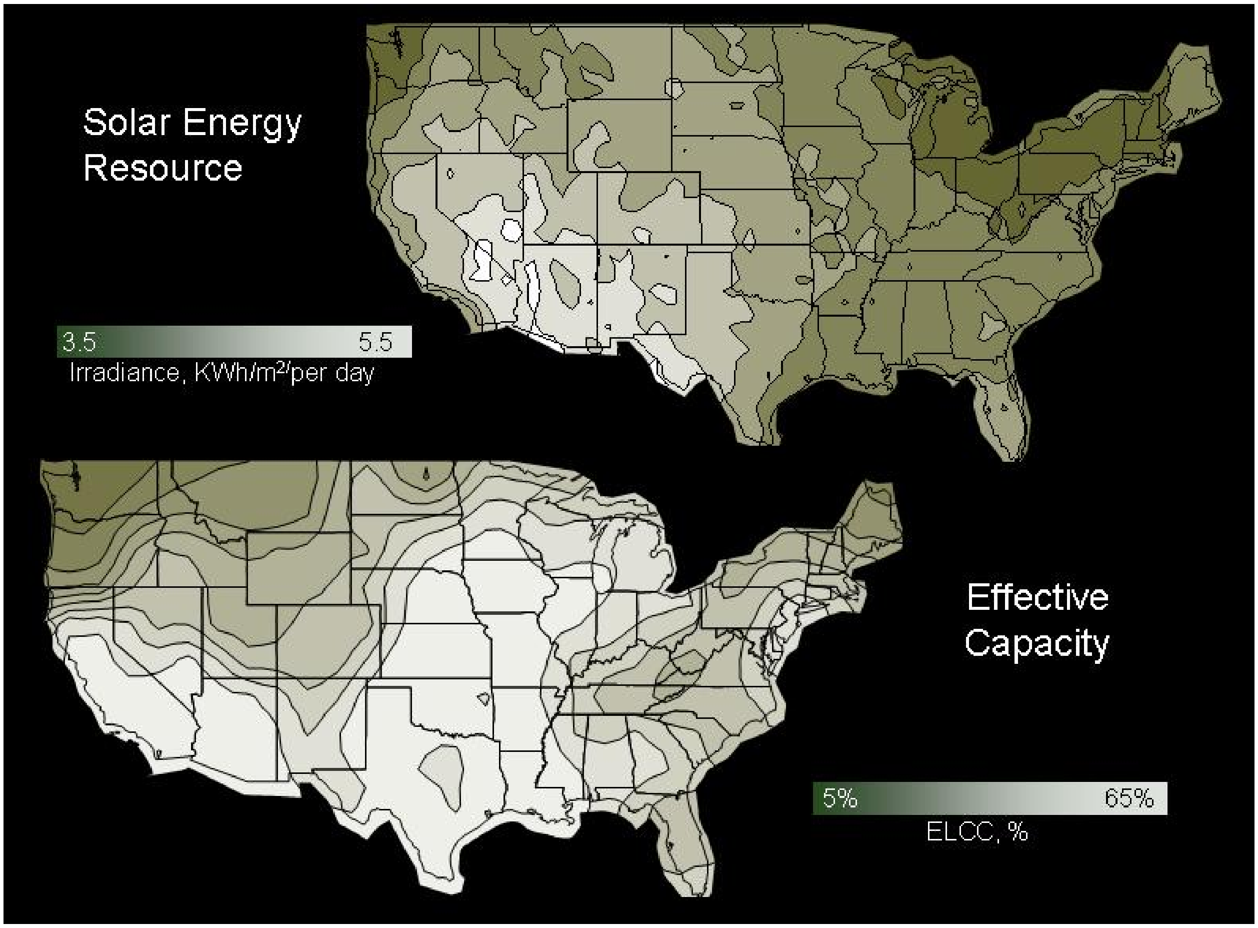

Figure 1: Solar Irradiance and Effective Capacity
Possible caption: Locations with relatively low average irradiance values may still have high PV capacity values.

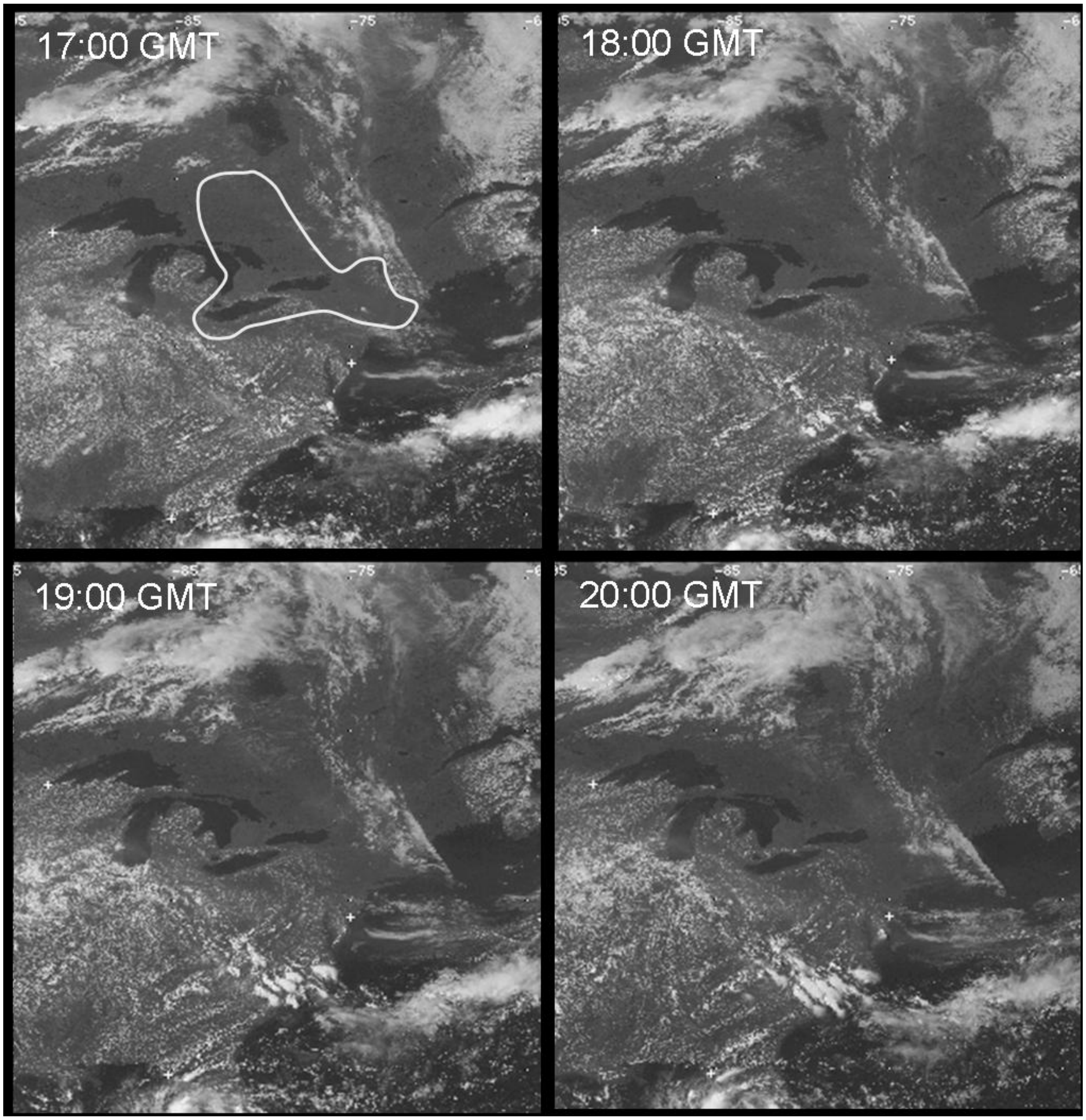

Figure 2: Satellite Photograph of Area Affected by the Summer 2003 Power Outage
Possible caption: These satellite images demonstrate that the area affected by the August 2003 power outage had clear skies, thus dispersed PV would have been performing near its peak rated output, thus possibly preventing the outage.

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VOLTAGE STABILITY ANALYSIS OF GRID CONNECTED EMBEDDED GENERATORS

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Abstract

The increasing costs and stringent environmental regulations are making the construction of large power stations to meet rising energy demands economically unfeasible. Hence, Embedded Generation (EG) is predicted to play a prominent role in the electric power systems of the future. The term "embedded generation" refers to electricity generation connected at distribution level rather than transmission level. The insertion of EGs presents a new set of conditions to distribution networks. The aim of this paper is to conduct a voltage stability analysis using an iterative power system simulation package, PowerWorld^{TM} Simulator, to evaluate the impact of strategically placed EG on distribution systems with respect to the critical voltage variations and collapse margins. This paper concludes with the discussion of EGs' excellent options for system reactive power compensation and voltage stability.

1. INTRODUCTION

In the last decade, environmental issues and concerns have increasingly come to the forefront. One area that attracts greatest environmental concern is energy use. Energy conservation policies in several countries encourage the use of renewable energy or so called "green energy" sources such as wind, hydro, solar and biomass. In Australia, for example, a mandatory renewable energy target has been imposed. The Renewable Energy (Electricity) Act 2000 requires the generation of 9500 GWh of extra renewable electricity per year by 2010 [1].

To date, 6% of Australia's total energy use comes from renewable energy sources. As of January 2002, there are 270 operating renewable energy power stations in Australia with biomass being the largest source of renewable energy [1]. In the electricity sector, current use of renewable energy contributes approximately 10.7%, most of which is generated from large-scale Hydro electricity schemes [1].

Embedded generation (EG) has the potential to promote the extensive use of renewable sources. The term "embedded generation" refers to electricity generation connected at distribution level rather than transmission level [2]. EG can reduce the effect of losses while providing reactive power and contingency reserves to the network. It can also reduce the need for new transmission and distribution facilities consequently reducing overall infrastructure costs.

For more than 50 years, modern electrical power systems have conventionally transmitted power from HV to LV and are generally designed to operate without any electricity generation on the distribution system or customer loads [3]. The introduction of EGs can significantly impact the flow of power and voltage conditions at consumers and utility equipment. The impacts may either manifest themselves positively or negatively depending on the distribution operating characteristics and the EG itself.

To gain lucrative benefits, EG sources must be reliable, dispatchable, of the proper size and at the proper locations. Since many EGs will not be utility owned or will be of variable energy sources such as wind and solar, there is no guarantee that the above-mentioned conditions will be satisfied [2].

This paper commences with an overview of renewable energy and the important role of EG to promote the greater use of renewable sources. This is followed by a comprehensive description of the adopted methodology and the test systems used for the analysis. The results from the performed studies and simulations are discussed in detail. Finally, the paper will conclude with the summary of findings and provide relevant recommendations for future development in this area of research.

2. BACKGROUND

2.1 Objective

The objective of this study was to conduct a power system analysis using an iterative power system simulation package, PowerWorld^{TM} Simulator, to evaluate the impact of strategically placed EG on distribution systems with respect to the critical voltage variations and collapse margins.

2.2 Generation Technologies

Various technologies are used for generating electricity from other forms of energy. These generation technologies can be group as follows:

a) Rotating machine coupled to Synchronous AC Generators.
b) Rotating machines coupled to Induction Generators.
c) DC current sources coupled to Electronic Inverter Systems.

The type of generation technology adopted determines the behaviour of EG in a distribution system. The major difference between the synchronous generator and the induction generator is that the induction generator can only operate on the circular locus and so there is always be a defined relationship between real power (P) and reactive power (Q). Hence, the independent control of Power Factor in an induction generator is not possible [2]. This independent control of P and Q make synchronous generators attractive for embedded generation schemes. Electronic Inverter Systems, however, introduce power quality problems into the system [4].

2.3 Voltage Stability

A system experiences a state of voltage instability when there is a progressive or uncontrollable drop in voltage magnitude after a disturbance, increase in load demand or change in operating condition [5]. The main factor, which causes these unacceptable voltage profiles, is the inability of the distribution system to meet the demand for reactive power.

Under normal operating conditions, the bus voltage magnitude (V) increases as Q injected at the same bus is increased. However, when V of any one of the system's buses decreases with the increase in Q for that same bus, the system is said to be unstable [5].

Although the voltage instability is a localised problem, its impact on the system can be wide spread as it depends on the relationship between transmitted P, injected Q and receiving end V. These relationships play an important role in the stability analysis and can be displayed graphically.

2.3.1 PV Curves

When considering voltage stability, the relationship between transmitted P and receiving end V is of interest. The voltage stability analysis process involves the transfer of P from one region of a system to another, and monitoring the effects to the system voltages, V. This type of analysis is commonly referred to as a PV study [5].

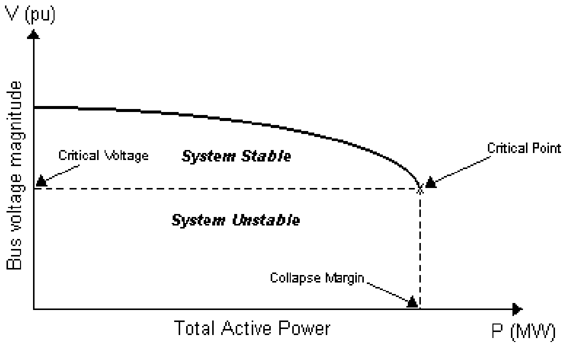

Fig. 1. Typical Power-Voltage (PV) characteristic curve

The Figure 1 shows a typical PV curve. It represents the variation in voltage at a particular bus as a function of the total active power supplied to loads or sinking areas. It can be seen that at the "knee" of the PV curve, the voltage drops rapidly when there is an increase in the load demand. Load-flow solutions do not converge beyond this point, which indicates that the system has become unstable. This point is called the Critical point. Hence, the curve can be used to determine the system's critical operating voltage and collapse margin. Generally, operating points above the critical point signifies a stable system. If the operating points are below the critical point, the system is diagnosed to be in an unstable condition [5].

2.3.2 QV Curves

Voltage stability depends on how the variations in Q and P affect the voltages at the load buses. The influence of reactive power characteristics of devices at the receiving end (loads or compensating devices) is more apparent in a QV relationship. It shows the sensitivity and variation of bus voltages with respect to reactive power injections or absorptions [5]. Figure 2 shows a typical QV curve, which is usually generated by a series of load-flow solutions. Figure 2 shows a voltage stability limit at the point where the derivative *dQ/dV* is zero. This point also defines the minimum reactive power requirement for a stable operation [5].

An increase in Q will result an increase in voltage during normal operating conditions. Hence, if the operating point is on the right side of the curve, the system is said to be stable. Conversely, operating points in the left side of the graph are deemed to be unstable.

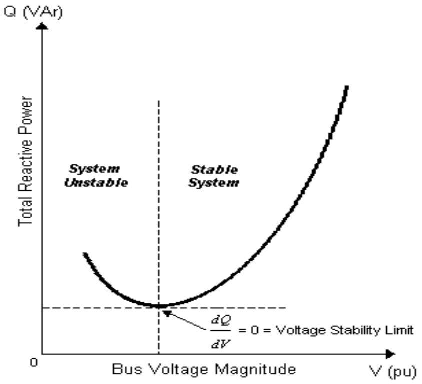

Fig. 2. Typical Reactive Power-Voltage (QV) characteristic Curve

2.4 Impacts of EG

Connecting a generation scheme to a distribution network will affect the operation and performance of the network depending on the scheme and rating of the generator itself [6]. The impacts are as follows:

2.4.1 Power Flows

The significant penetration of embedded generation reverses the power flow and the network is no longer a passive circuit supplying loads. It becomes an active system with power flows and voltages determined by the generation as well as the loads [7]. In these cases, the generator exports excessive power to all the loads on the system to which it is connected. The surplus power is transferred into a higher voltage system.

2.4.2 Network Losses

EG will have an impact on losses in a network. The strategic placement of EG on the network can reduce losses normally seen by the system while improper placement may actually increase the network losses [8]. Proper placement can also free available capacity for transmission of power and reduce equipment stress. Siting of EGs to minimise losses is like siting capacitor banks for loss reduction. The only difference is that EG will impact both real power and reactive power flow, whereas capacitors only impact the reactive power flow. A small penetration of a strategically placed EG with an output of just 10-20% of the feeder demand can have a significant loss reduction benefit for the system [8].

2.4.3 Steady Sate Voltage Variations

For networks where X>>R, the bus voltage magnitude increases as reactive power at the same bus is increased. If an adjacent load absorbs the output from an embedded generator, then the impact on the distribution network voltage is likely to be advantageous. However, if it is necessary to transmit the power through the network then steady-state voltage variations may adversely become excessive [9].

3. APPROACH AND METHODOLOGY

The system study was evaluated through a series of scenarios comprising of different system loads, operating modes of EGs, interconnection schemes and location of EGs.

3.1 Simulation Software

The PowerWorld^{TM} Simulator (Simulator) package Ver 8.0 is able to perform Load Flow simulations using Newton-Raphson power flow algorithm and is capable of analysing multiple sources on the distribution system, predicting the network voltages, voltage stability and losses. This makes it suitable to study the behaviour of a system with EG

Simulator's voltage stability assessment tool, PV-QV, can be used to analyse the voltage characteristics of a system. The PVQV tool allows the user to monitor any system parameter while automatically increasing a user-defined transfer. It can solve multiple load flow solutions in order to generate PV curves for a particular transfer or a QV curve at a given bus [10].

3.2 Test Systems

Many studies have been conducted on EG connected to 11kV networks and have published several results. However, very little studies have been conducted on the reticulation regions. This paper will present the impact of EGs when interconnected in the reticulation regions.

The three distribution systems were chosen to study the impact of EGs. The 5 Bus system was adopted from IEE Power and Energy Series 31. It was used to demonstrate the effects of EG and to understand the concept of embedded generation. The IEEE 13 Bus system, rated at 4.16kV, is very small and yet displays some very interesting characteristics. Lastly, the IEEE 37 Bus system, rated at 4.80kV, is a three-wire delta system, which was modelled from an actual feeder located in California [11].

3.3 Locating EGs

The impact of feeder losses of EGs can be analysed with the rule of thumb, "2/3 Rule" often used in capacitor placement studies in distribution systems. The rule states that, *"For a feeder with a uniform KVAr load, the best capacitor size is 2/3 of the KVAr load, located 2/3 of the distance out the feeder*."[12]. Figure 3 illustrates the effect of the 2/3 Rule on the power flow and the reduction in losses.

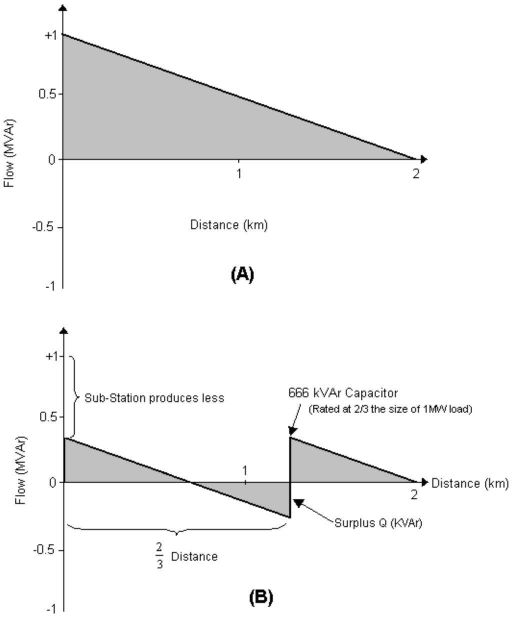

Fig. 3. Graphical display of the 2/3 Capacitor Rule [12].

As shown in (B) of Figure 3, the substation produces less Q as the capacitor produces the required Q as opposed to (A). Hence, from the sub-station point of view, there is reduction in power loss. This is due to the fact that power loss is proportional to the amount of power produced for given impedance of a transmission line.

Similarly, the same graphical and rule-of-thumb depiction can be applied to EGs and its impact will be similar to that of a capacitor. However, it must be noted that the 2/3 Rule is only an approximate, which provides a useful guide to the placement of EGs [12].

3.4 Implementation of Feeders

As described above, the location of the EG depends on the feeder's length. A feeder will be located in the Load Concentration Zone (LCZ) supplied from the transmission grid. The feeder will be modelled as a transmission line, which is connected from the transmission grid to the selected loads, within the LCZ. This arrangement was chosen based on the size of the loads connected in a particular region of the LCZ. The aim is to group the large loads into a feeder so that the penetration of the EG could show significant effects. Two feeders were chosen to compare the effects of EG network losses according to the 2/3 Rule. It is important to note that this implementation only applies to the IEEE 13 Bus and IEEE 37 Bus systems.

Feeder 1 from the IEEE 13 Bus system is from Bus 650 to Bus 652. The feeder is 1.55km long. Feeder 2 is from Bus 650 to Bus 675. The feeder is 1.37km long. Feeder 1 from the IEEE 37 Bus system is from Bus 799 to Bus 741. The feeder is 2.43km long. Feeder 2 is from Bus 799 to Bus 728. The feeder is 1.48km long. See Figure 4 and 5.

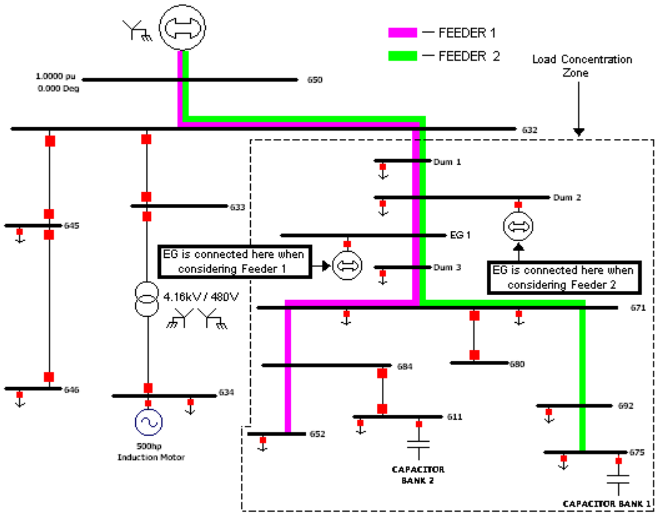

Fig. 4. Feeder implementation of IEEE 13 Bus System

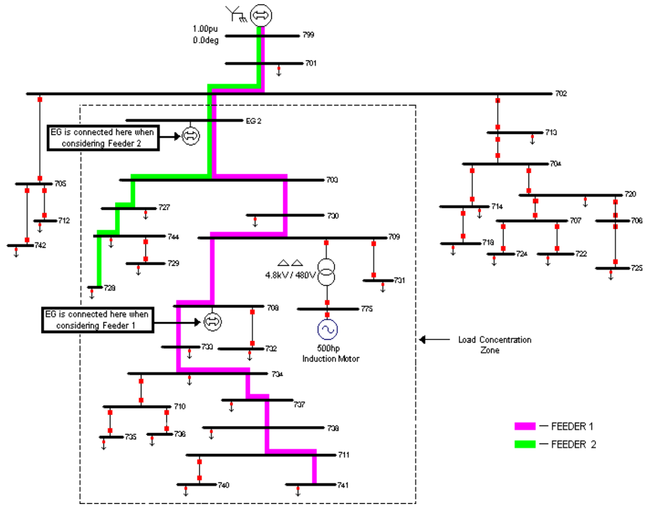

Fig. 5. Feeder implementation of IEEE 37 Bus System

3.5 EG input Parameters

Tables 1 lists the EG's input parameters. The 2/3 Rule applies only to the IEEE 13 Bus System and IEEE 37 Bus System.

Test Sys	Loca-tion	Base MVA	Unity Power Factor		0.95 Lagging Power factor		0.95 Leading Power Factor	
			P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
FEEDER 1								
IEE 5 Bus	Bus D	100	20.0	0.00	20.0	6.60	20.0	-6.60
IEEE 13 Bus	Bus EG1	10	3.51	0.00	3.51	1.15	3.51	-1.15
IEEE 37 Bus	Bus 708	10	1.15	0.00	1.15	0.38	1.15	-0.38
FEEDER 2								
IEE 5 Bus	-	100	-	-	-	-	-	-
IEEE 13 Bus	Bus Dum 2	10	5.64	0.00	5.64	1.85	5.64	-1.85
IEEE 37 Bus	Bus EG2	10	4.26	0.00	4.26	1.40	4.26	-1.40

Table 1. EG input parameters

4. RESULTS AND DISCUSSIONS

The results presented are system specific and are accompanied by discussions of the observations made.

4.1 IEE 5 Bus System

Bus D was selected for evaluation as it a critical bus prone to voltage instability. Figure D shows the PV curve for the system when the EG is operated at different conditions; it represents the variation in voltage at Bus D as a function of total active power load.

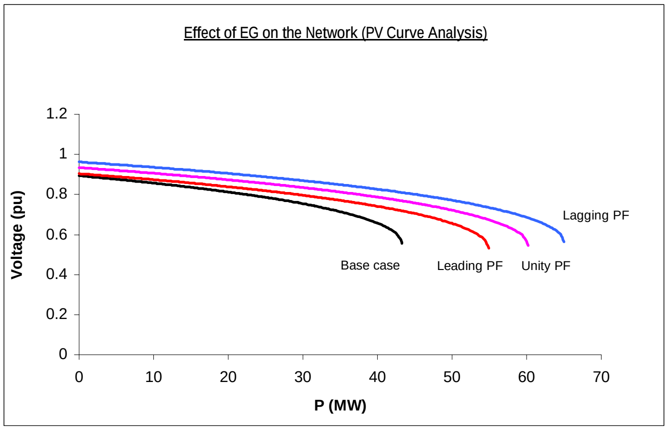

Fig. 6. PV Curve Analysis of IEE 5 System.

Operating Condition	*Critical Voltage (pu)*	*Collapse MW*
Base Case	0.556	43.3
Unity PF	0.546	60.2
0.95 Lagging PF	0.565	65.0
0.95 Leading PF	0.533	54.9

Table 2. PV Curve Result summary for IEE 5 Bus System

It can be seen that the EG has improved the system's collapse margin particularly when the EG is operated at Lagging PF. The Collapse Margin in improved by 50.12%. This means that the system becomes less vulnerable to voltage collapse by 50.12%.

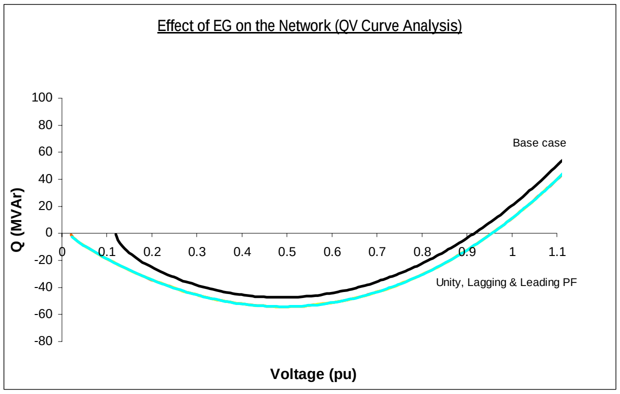

Fig.7. QV Curve Analysis of IEE 5 System

Operating Condition	*Critical Voltage (pu)*	*Minimum MVAr*
Base Case	0.4941	47.4
Unity PF	0.4944	54.2
0.95 Lagging PF	0.5026	54.2
0.95 Leading PF	0.4044	54.2

Table 3. QV Curve Result summary for IEE 5 Bus System

It can be seen that the EG has improved the system's stability limit regardless of its operation mode. The Stability Margin is improved by 14.35%. This means that the minimum reactive power requirement for stable operation has been lowered by 14.35%. It must be noted that the smaller the margin, the closer the system is in operating near the Critical Operating Point.

4.2 IEEE 13 Bus System

As mentioned in Section III, the 2/3 rule and the simulation parameters were applied to system. Like the IEE 5 Bus system, the EG was found to improve the system's voltage stability. Bus 684 was selected for evaluation due to its location within the Load Concentration Zone and is supplied by a heavily loaded Bus 671.

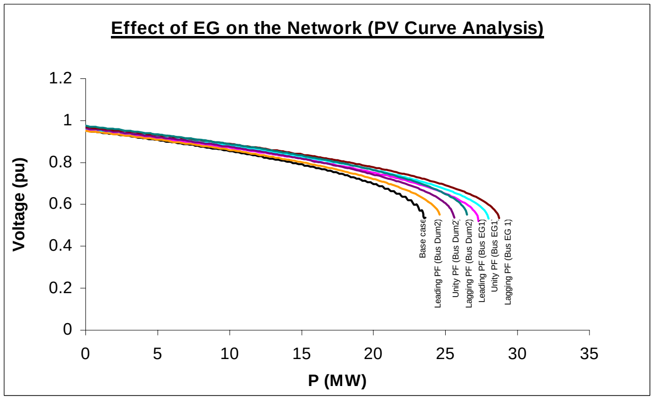

Fig.8. PV Curve Analysis of IEEE 13 System

Operating	*EG at Bus EG1*		*EG at Bus Dum 2*	
	Critical Voltage (pu)	*Collapse MW*	*Critical Voltage (pu)*	*Collapse MW*
Base Case (No EG)	0.537	23.6	-	-
Unity PF	0.532	28.0	0.537	25.6
0.95 Lagging PF	0.550	28.6	0.555	28.6
0.95 Leading PF	0.547	24.6	0.550	24.6

Table 4. PV Curve Result summary for IEEE 13 Bus System

It can be seen that the EG has improved the system's collapse margin particularly when the EG is connected at Bus Dum2 and operated at Lagging PF. The Collapse Margin in improved by 21.19%. This means that the system becomes less vulnerable to voltage collapse by 21.19%.

Figure 9 shows the QV curves when the EG is connected at different locations and operated at various modes.

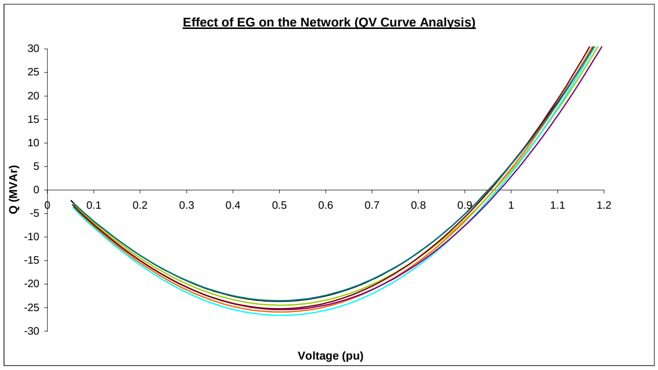

Fig.9. QV Curve Analysis of IEEE 13 Bus System

Operating Condition	*EG at Bus EG1*		*EG at Bus Dum 2*	
	Critical Voltage (pu)	*Minimum MVAr*	*Critical Voltage (pu)*	*Minimum MVAr*
Base Case (No EG)	0.5009	23.7	-	-
Unity PF	0.4121	25.9	0.5034	24.5
0.95 Lagging PF	0.4998	26.7	0.4948	25.4
0.95 Leading PF	0.5043	25.2	0.5115	23.5

Table 5. QV Curve Result summary for IEEE 13 Bus System

Hence, it can be seen that the EG has improved the system's stability limit when it is connected at Bus EG1 and operated at Unity PF. The Stability Margin in improved by 9.92%. This means that the minimum reactive power requirement for stable operation has been lowered by 9.92%.

4.3 IEEE 37 Bus System

The 2/3 Rule was applied to perform the system study. However, it must be noted that the system's load profile was modified to make the system "unhealthy". The spot loads were increased by a factor of five (500%) to create the "unhealthy" effect. The aim of this was to analyse the EG's ability to enhance the system stability margin under the unhealthy condition.

Bus 709 was selected for evaluation, due to its heavy loading and location within the LCZ. The tables below show the summary of results.

Operating Condition	*EG at Bus 708*		*EG at Bus EG2*	
	Critical Voltage (pu)	*Collapse MW*	*Critical Voltage (pu)*	*Collapse MW*
Base Case (No EG)	0.652	47.0	-	-
Unity PF	0.677	47.4	0.534	136.99
0.95 Lagging PF	0.677	47.4	0.540	136.99
0.95 Leading PF	0.682	47.0	0.539	135.70

Table 6. PV Curve Result summary for IEEE 37 Bus System

The system becomes less vulnerable to voltage collapse by 191.47% particularly when the EG is connected at Bus EG2 and operated at Lagging PF. This situation, however, is not likely to be implemented; as such a penetration into the Distribution system will cause the Utility to loose control of the Grid. The aim an EG is to complement a distribution network, not to control it.

Operating Condition	*EG at Bus 708*		*EG at Bus EG2*	
	Critical Voltage (pu)	*Minimum MVAr*	*Critical Voltage (pu)*	*Minimum MVAr*
Base Case (No EG)	0.9582	0	-	-
Unity PF	0.9631	0	0.9682	0
0.95 Lagging PF	0.9641	0	0.9699	0
0.95 Leading PF	0.9621	0	0.9665	0

Table 7. QV Curve Result summary for IEEE 37 Bus System

Table 7 indicated that the system was in a critical operating point due to its unhealthy condition. Bus 709 is already heavily loaded and the QV curves show that the system has a very small stability margin, which led to failure of the power flow convergence at the stability limit. The EG operated at various modes and connected at different locations the system's voltage collapse margin could not be enhanced. Hence, it proves that the EG cannot dramatically improve the system's stability limit when the system is in unhealthy condition. EG unit can only support the network.

5. CONCLUSIONS

This paper established some significant findings. The system analysis was conducted successfully and the results obtained are according to expectations. The system study demonstrated that the EG can have significant impacts on distribution system.

The significant finding of this thesis is the EG's ability to improve the voltage collapse margin. The IEEE 13 Bus system for example, had its collapse margin increased by 21.19%. This indicates that the system becomes less vulnerable to a collapse when subjected to a disturbance. The study showed that the strategically placed EG was able to increase the stability margin by increasing the stability limit threshold. However, this does not apply to all systems as the system loads play a major role in this aspect. From the IEEE 37 Bus system, it was discovered that the EG does have the capability to enhance the characteristics of an unhealthy system. The EG unit was able to give minimal improvements as the system itself was heavily loaded. Therefore, the EG cannot be applied in these situations as it is meant to support a network rather than control it.

In summary, EGs operated at appropriate modes can offer excellent options for system reactive power compensation; voltage support and collapse margin enhancement provided it is of the proper capacity and at the proper location.

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