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Distributed Generation: Impacts and Cost Analysis

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Abstract - This paper presents the reason for the current interest in distributed generation and the challenges that are faced while increasing its share in the electricity generation mix. Under the present centralized generation paradigm, electricity is mainly produced in bulk amount at large generating stations, wheeled though the transmission and distribution grids to the end consumers. However, the recent quest for energy efficiency and reliability and reduction of greenhouse gas emissions led to explore possibilities to alter the existing generation paradigm and increase its overall performance with the implementation of distributed generation.

Keywords - *Distributed generation, grid, solar PV cells, voltage regulation, reliability, renewable energy sources, and cost effectiveness.*

I. INTRODUCTION

Distributed generation (DG), defined as generation located at or near the load centers, is being recognized as an environment friendly, reliable, and secure source of power that not only has minimal negative social impacts but also serves to promote social welfare. The technologies for DG are based on reciprocating engines, photovoltaic, fuel cells, combustion gas turbines, micro turbines and wind turbines. The technologies are also called alternate energy systems as they provide alternative ways to the traditional electricity sources i.e. oil, gas, coal, water etc. and can also be used to enhance the performance of existing electrical power system. DGs are becoming increasingly popular due to their low emission, low noise levels and high efficiency. One of the main advantages of DG is its close proximity to the consumer loads. DG can play important role in improving the reliability of the grid, reducing the transmission losses, provide better voltage support and improve the power quality. The major obstacle for the distributed generation has been the high cost. However, the costs have decreased significantly over the past 20 years. The distributed generation also reduces green house gas emission addressing pollutant concerns by providing clean and efficient energy. Distributed generation is the key to meet growing power demand, provide benefits to consumer by improving the quality of life, relieves utility to supply additional loads and opens the opportunities for power trading in competitive environment.

II. DISTRIBUTED GENERATION TECHNOLOGY

Commercial energy technologies include:

- IC engines
- Gas turbines
- Micro turbines
- Energy storage technologies

Renewable energy technologies include:

- Fuel cells
- Solar photovoltaic
- Wind & Wave Energy
- Hydro electric energy

III. IMPACTS OF DISTRIBUTED GENERATION

Interconnecting a DG to the distribution feeder may have significant effects on the system such as power flow, voltage regulation, reliability etc. A DG installation changes traditional characteristics of the distribution system. Most of the distribution systems are designed such that the power flows in one direction. The installation of a DG introduces another source in the system. When the DG power is more than the downstream load, it sends power upstream reversing the direction of power flow and at some point between the DG and substation; the real power flow is zero due to back flow of power from DG. The rules are defined for power flow reversal, optimal DG placement for reduction of losses and the impacts of DG on over-current protection. The rules for modeling DG interaction and its zero point analysis have been reported in the literatures so far. The 1547 series of IEEE standards for interconnecting distributed resources to the power system is a set of standards consisting of 6 parts [2]. The standards provide criteria and requirement for interconnecting distributed resources to the power system. The IEEE 1547.1 defines the requirement for interconnecting equipment that connects the DG to the electric power system is presented [3]. The IEEE 1547.2 provides technical details and application to understand the IEEE standard is presented [4]. The IEEE 1547.3 guide addresses engineering concerns for design, operation and integration of DG island systems [5]. The IEEE 1547.6 standard focuses on criteria, test and requirements for interconnection distribution secondary network of area electric power system (Area EPS) with Local EPS having Distributed Resource generation [6]. The impacts of installing DG on voltage, losses and reliability indices of a residential distribution network are studied based on various criteria.

A. Losses

Installation of DG impacts the losses and overall power factor of the total system. The reduction of transmission losses with DG using power summation method have been reported [7]. The loss analysis at various penetration levels of DG and distributing were presented [8].

B. Reliability

Distribution system reliability is an important factor in system's planning and operation. The reliability indices such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Frequency Index (CAIFI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Energy Not Supplied (ENS) etc presented by the IEEE guide are used to evaluate reliability of the system. The methods of data collection to calculate the reliability indices of system is crucial [9]. It takes into account the power consumption pattern, selection of relevant index, outage data collection and actual consumer perceptions and hence would contribute towards improving the reliability. The results showed that SAIDI, SAIFI, CAIDI and ASAI were the mostly used indices [10]. However, a general Distribution Reliability (DISREL) program can used to validate the impact of distributed generation on system performance improvement and its reliability [11]. It shows that DG is a cost-effective solution that could benefit both utility and customers. The modeling techniques for DG, and its application to a radial network using commercial software tools that shows improvement in the reliability indices [12]. The analytical approach to calculate the reliability of the system that included some intrinsic attributes of the DG and the distribution system including DG failure, component failure, change in load demand etc [21]. Many factors were considered for the reliability indices calculation in the proposed technique The location for the placement of DGs is of key importance. In [14], the authors studied the effects of DG on system reliability on an Iranian Distribution system. The positive impacts included faster restoration and reduced voltage sags while the negative impacts could be sympathetic tripping, increased fuse blowing etc. A few papers had presented validation models for calculating reliability indices . In [17], the basic data for reliability assessment of distribution system was presented. The paper also contained basic results of continuity studies for a range of sensitivity analysis and alternate configurations. The impact of installing DG as backup at various locations on the distribution circuit is also explored in this research.

C. Voltage Impacts

The DG installation can impact the overall voltage profile of the system. Inclusion of DG can improve feeder voltage of distribution networks in areas where voltage dip or blackouts are of concern for utilities. The DG has a greater impact on electric losses, voltage profile, flicker, harmonics, short circuit levels, islanding and reliability. The optimal location of DG allocation is an important aspect. wer system were analyzed. The paper also addresses DG impacts on short circuit levels and the islanding operation of DG. The approach makes use of controlling DGs reactive power based on its real power to satisfy system voltage requirements. The DG is installed at the lowest voltage location and distributing it across several locations to explore the impacts. Also, the implication of installing DG on one phase and its impact on the other phases has been investigated.

IV. COST ANALYSIS

A. The Levelized Cost of Energy

The Levelized Cost of Energy (LCOE) is the most transparent metric used to measure electric power generating costs, and is widely used as a tool to compare the generation costs from differing sources. The LCOE is a measure of the marginal cost (the cost of producing one extra unit) of electricity, over an extended period, and is sometimes referred to as Long Run Marginal Cost or LRMC. The LCOE is representative of the electricity price that would equalize cash flows (inflows and outflows) over the economic life time of an energy generating asset. It is the average electricity price needed for a *Net Present Value (NPV)* of zero when performing a discounted cash flow (DCF) analysis. With the average electricity price equal to the LCOE, an investor would breakeven and so receive a return equal to the discount rate on the investment.

$$\sum_{t=0}^{n} \frac{Revenue}{(1+r)t} = \sum_{t=0}^{n} \frac{\text{Costs}}{(1+\text{r})\text{t}}$$

Where:

n = Project lifetime (yrs).

t = Year in which sale or cost is incurred.

r = Discount rate (%)

By definition this is the point at which the *Net Present Value* (summation of the *Present Values, PV,* of the cash flows) for a project is zero:

$$\text{NPV} = \sum_{t=0}^{n} PV = 0$$

Where :

$$\text{PV} = \frac{EBIT(1-T)+ DEP-CAPEX}{(1+r)t}$$

EBIT = Earnings Before Interest

Tax DEP = Depreciation

CAPEX = Capital Expenditure

T = Corporate Tax rate (%)

B. *Global Assumptions*

Tax: The corporate tax rate is assumed to be 30% for the purposes of all cash-flow analysis.

Depreciation : The electric utility industry typically uses the *straight-line* method, which was used in this analysis. For a 25 year lifetime, the annual depreciation is 4%, and for a 30 year lifetime, the annual depreciation is 3.33%.

Exchange Rate : In line with the Mid Year Economic Financial Outlook approach, the exchange rate is assumed to remain around the levels seen at the time the forecasts were prepared3. As of March 01 2011, a US$ exchange rate was $0.985 used, and an EU€ exchange rate of $0.70 was used.

C. *Construction Period and Economic Lifetime*

The construction period and economic lifetime can have a considerable affect on the levelized cost of generation. This is particularly important for protracted construction periods (lead times). The economic and lifetimes and construction periods used are presented in Table 1, and are based on the AEMO dataset. The IEA reports wind construction periods of 1 year (unlike AEMO), and the effects of this are explored.

TABLE 1. Construction Periods and Economic Lifetimes

Technology	Construction Period	Economic Lifetime
Wind	2year	30years
Solar PV	1year	30years
Solar Thermal	2year	30years

D. *The Capacity Factor*

In the case of renewable energy generators the assumed capacity factor of a facility has a significant impact on the LCOE. For renewable energy generators, the capacity factor is generally dependant on the quality of the renewable resource. In the interests of a consistent approach, constant capacity factors were used for each technology type. These capacities were based on reasonable resource qualities for Australian conditions, summarized below in Table 2, as used in the EPRI study.

TABLE 2. Capacity Factors

Technology	Resource Quality	Capacity Factor
Wind	6.8m/s	30%
Solar PV	2445 KWh/m2/yr	20%
Solar Thermal	2400 KWh/m2/yr	Varried by plant storage configuration

V. RENEWABLE ENERGY TECHNOLOGY COST REVIEW

This paper has undertaken a review of current and future costs of three forms of renewable energy technology, comparing data from a range of international and Australian-specific studies, taking care to compare data on the same basis of financial assumptions (discount rates) and resource quality. The purpose was to compare both the current costs, along with the rate of decrease, and the reason for differences between the studies. The Australian-specific datasets are the ‘Australian Energy Generation Technology Costs’ report by EPRI, and the 2010 dataset used by the Australian Energy Market Operator (AEMO), largely based on the EPRI data with a review from ACIL Tasman. The assessment reviewed technical and economic parameters of wind, photovoltaic and solar thermal energy generation technologies, considering technology specific learning rates and cost reduction potentials. It includes a detailed exploration of the factors contributing to the learning rates and cost reductions. Common financial assumptions (in particular discounting rates) are used, to provide a common basis of comparisons and analysis. These parameters were utilized in Levelized Cost of Energy (LCOE) calculations to develop cost outlooks, and compare the outlooks to other projections. Where relevant, LCOE is calculated from capital & operating cost data at a common renewable resource level, and includes the revenue generated from the sale of Renewable Energy Certificates, priced under a simplified assumption at an unchanging $50/MWh. However, especially in the case of the solar technologies (both PV and thermal), the rate of cost reduction expected from the global analyses is faster than that in the AEMO dataset. In both cases, AEMO costs in 2030 were higher than, and outside the range of, the 2020 costs from the international analyses. The renewable technologies of PV and wind have historically shown that a large proportion of cost reductions have come from the learning's and economies of scale associated with large-scale global deployment, and not just improvements in technical efficiency. With this in mind, when considering scenarios for new energy technology development and deployment, especially in the context of shifting away from greenhouse gas emitting energy sources, initial higher costs of renewable energy should not be considered a barrier to deployment. Rather, the focus should be on whether learning curves can give confidence that the technology is able to achieve desirable cost reductions within an acceptable timeframe, and how much the rate of deployment is expected to change the rate of cost reduction. The key findings of this assessment are summarized below for each of the three technologies.

A. Photovoltaic

The installed capacity of photovoltaic has grown at rate of 40% over the last decade. As the industry has grown PV module prices declined along a well established learning curve, which has seen cost reductions of 22% for each doubling of cumulative capacity, over the last few decades. An excursion from this historical rate occurred due to supply bottlenecks and market dynamics from 2003 to the end of 2008. The learning curve has since returned towards the historic, and the global installation capacity increased to 10 Gigawatt-peak (GWp)/annum in 2010. The International Energy Agency (IEA) and the EPIA expect further cost reduction with increased production capacities, improved supply chains and economies of scale. China has experienced a 20-fold increase in production capacity in four years, increased expansion of global production capacities for key components (including modules and inverters) and is continuing to exert downwards pressure on prices.

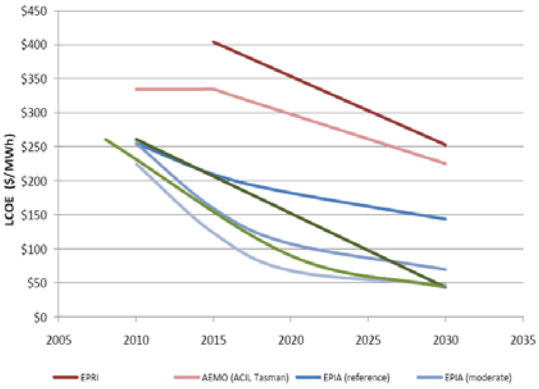

Fig. 1: Solar photovoltaic cost projections (Direct Normal Irradiation = 2445 kWh/m2/yr)

B. Wind

Wind energy generation has expanded rapidly in the previous decade 2000-2010, with installed capacity growing at 28% and doubling every 3 years. Wind capital costs have tracked along a learning curve as this capacity has grown, and the expectation of all of the studies reviewed is for the trend to continue as the expansion of the wind industry continues. Key commodity constraints and supply chain bottle necks have hampered cost reductions in the past few years. The IEA and the Global Wind Energy Council (GWEC) expect that modest cost reductions will continue, due to economies of scale (as a result of continuing industry expansion, especially Chinese manufacturing), alongside stronger supply chains and technological improvements. The major technical cost reduction opportunities include increasing turbine size, hub height, and the elimination gearbox losses via the use of direct drive turbines.

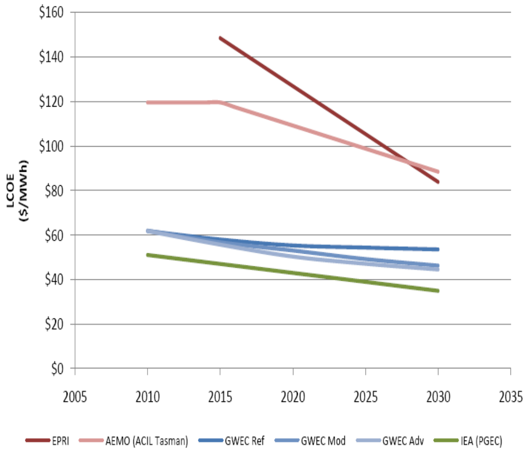

Fig. 2 : Wind power cost projection

C. Concentrating Solar Thermal

For concentrating solar thermal (CST, or also known as CSP – concentrating solar power) technology, which is less mature than wind and solar PV, a range of sources indicate that there is significant cost reduction potential, from known technical improvements, economies of scale and industry learnings from continued deployment, similar to the observed learning rates of wind and PV.

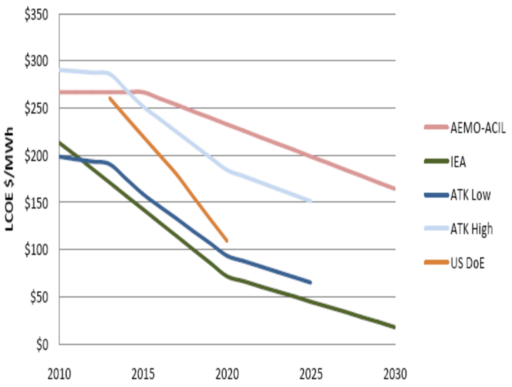

Fig. 3 : CST cost projections, at Direct Normal Irradiation of 2400 kWh/m2/yr.

VI. CONCLUSION

It has been concluded that distributed generation has a number of advantages over conventional central power generation, and is most suitable for tapping small power resources scattered over a large area, yet it still can-not replace the grid. Grid based central power system is still preferred for most of the cases except in situations when the cost of installation of transmission system is too high. Thus an ideal power system, which has the benefits of DG as well as grid, can be formulated by accommodating these DGs into the grid along with central power units so that surplus power generated at DGs can be easily sent to regions, which have a deficit. In the Indian context, distributed generation through small, mini, micro and pico-hydel projects do hold the solution to power crisis. Moreover distributed generation also aids in promoting economic development and social welfare. Moreover community distribution projects by ensuring greater participation of people helps to create a civic conscience in the society.

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