A COMPETITIVE MARKET INTEGRATION MODEL FOR DISTRIBUTED GENERATION

EE622 Term Paper Presentation

Prepared for

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Agenda

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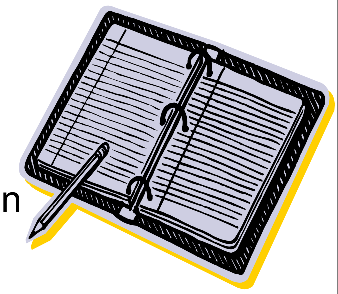

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Introduction

- High penetration of distributed generation (DG) resources into the distribution networks is increasingly observed worldwide.
- DG is suited for the integration of renewable energy sources. Unfortunately, the additional integration of distributed generation has some negative consequences
  - for the organization of the electricity market
  - other technical obstacles, such as dispatchability and reliability issues associated with the integration of DG systems using renewable energy.
- Following slides discuss issues related to DG and presents a proposed mechanism for the competitive market integration of DG in a pool-based electrical system

Definition of DG

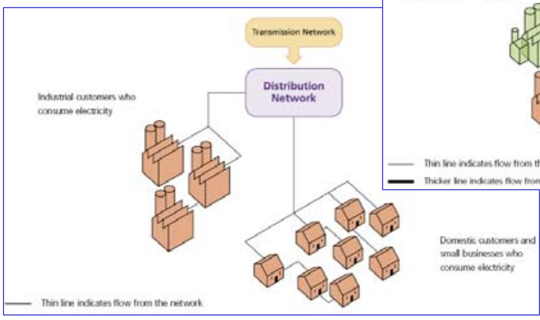
- Due to variations in government regulations, different definitions for DC are used:
  - In the English and Welsh, DG is mainly used for power units with less than 100 MW capacity.
  - In Australia, DG is often defined as power generation with a capacity of less than 30MW.
- For our purpose, DG may be defined as

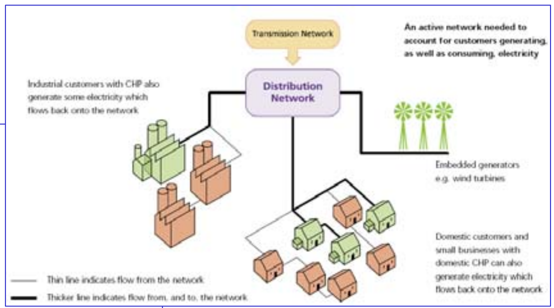
"Distributed generation, sometimes called embedded generation, is electricity generation, which is connected to the distribution network rather than the high voltage transmission network. It is typically smaller generation such as renewable generation, including small hydro, wind and solar power and smaller Combined Heat and Power".

Definition of DG

- The Figures below illustrate the differences between a conventional distribution network and a distribution network with DG

Without DG





With DG

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Types/Applications of DG

- DG technologies may be categorized as
  - Renewable
    - solar, photovoltaic or thermal
    - wind
    - geothermal
    - ocean
  - Nonrenewable
    - internal combustion engine, ice
    - combined cycle
    - combustion turbine
    - microturbines
    - fuel cell
- DG should not to be confused with renewable generation.

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Evolution of DG Systems

- Since the beginning of the 20th century, the backbone of the electric power industry structure has been large utilities operating within well-defined geographical territories and within local market monopolies
- Traditionally, these utilities own the generation, transmission, and distribution facilities

Evolution of DG Systems

Installed generation capacities (GW) worldwide at the end of the 20th century

Region	Thermal	Hydro	Nuclear	Other/Renewable	Total
North America	642	176	109	18	954
Central and South America	64	112	2	3	181
Western Europe	353	142	128	10	633
Eastern Europe and Former USSR	298	80	48	0	426
Middle East	94	4	0	0	98
Africa	73	20	2	0	95
Asia and Oceania	651	160	69	4	884
Total	2175	694	358	35	3262
Percentage	66.6	21.3	11.0	1.1	100

Evolution of DG Systems

The range of capabilities for the various DG technologies at the end of the 20th century

Technology	Typical Capability Ranges	Utility Interface
Solar, photovoltaic	A few W to several hundred kW	DC to AC converter
Wind	A few hundred W to a few MW	Asynchronous Generator
Geothermal	A few hundred kW to a few MW	Synchronous Generator
Ocean	A few hundred kW to a few MW	4-quadr. synch. machine
ICE	A few hundred kW to tens of MW	Synch. generator or AC to AC converter
Combined Cycle	A few tens of MW to several hundred MW	Synchronous Generator
Combustion turbine	A few MW to hundreds of MW	Synchronous Generator
Microturbines	A few tens of kW to a few MW	AC to AC converter
Fuel cells	A few tens of kW to a few tens of MW	DC to AC converter

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Evolution of DG Systems

- The installed wind power capacity in 2005 reached 59.1 GW at the global level, with 18.4 GW in Germany, 10 GW in Spain, and 9.1 GW in the USA.
- A study by EPRI indicates that by 2010, 25 % of the new generation will be distributed. Also, a study by the Natural Gas Foundation concluded that this figure could be as high as 30 %.
- The evolution of DG systems in each country highly depends on
  - The cost of traditional technologies (diesel engines, coal fired, combined cycle, hydraulic, and nuclear power plants)
  - Market design concepts (pool, power exchange or physical bilateral-based systems).

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Evolution of DG Systems

- A key aspect explaining this fast evolution is the development of promotion programs, subsidies, and compensation mechanisms.
- Future applications of DGs are expected to include
  - Power firming
  - Pool support
  - Total energy systems power quality
  - Peak shaving
  - Others
- DG technology will continue to improve and the costs of DG should reduce in the future as a result of increased demand, improved technology, and better manufacturing practices.

Issues of DG Integration

- The following four key strategic issues relating to DG shall be taken into account by any distribution company
  - How much DG will appear in the distribution network?
  - What effect will the DG have on the technical performance of the network?
  - What effect will the DG have on the financial performance of the utility?
  - What changes in technical design or commercial practice will be effective within a distribution utility DG strategy?

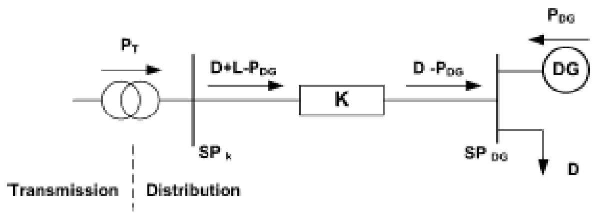
Issues of DG Integration

- Other key issues that must be addressed are:
  - Power Quality
  - Reactive Power Coordination
  - Reliability and Reserve Margin
  - Reliability and Network Redundancy
  - Safety
  - Accountability
  - Standards

Proposed Market Integration Model

- Energy Market
  - A mechanism to establish an energy price for the DG injection could be based on an extended model incorporating the DisCo network into the spot price computation. In this approach, a spot price at the distribution level (SP_{DG}) can be calculated for the specific injection point of the DG.
  - The DG sells energy at SP_{DG}, while the DisCo supplier buys the same amount of energy at the same price.
  - To develop a methodology for estimating SP_{DG}, a simplified network scheme with a DG injecting power at the distribution level is used, as shown in the next slide.

Proposed Market Integration Model



- The DisCo purchases energy from the wholesale system (P_T) and from the DG (P_{DG}). Without the proposed methodology, this second purchase is done via an over-the-counter (OTC) market, where the DisCo buys energy from DG under a bilateral agreement.

Proposed Market Integration Model

- The energy supply cost (EC) of the DisCo is calculated as

$$EC = P_T \, . \, SP_k + EC_{DG} \qquad (1)$$

where

P_T active power injection from the transmission system;
SP_k spot price of the wholesale market;
EC_{DG} is the OTC payment from DisCo to DG.

Proposed Market Integration Model

- The payment is formalized by incorporating the injection point of the DG as an energy exchange point in the wholesale market.
- The exchange point is the core of the interface mechanism, where the price for the DG energy is computed based on an estimation of the spot price at the injection point of the DG (SP_{DG}).
- SP_{DG} is calculated by using a penalty factor pf_{DG}, which accounts for the effect of DG energy injections on the DisCo network ohmic losses.
- Under this interface concept, the energy cost for supplying the DisCo is given by

$$EC = P_T + P_{DG} \cdot SP_{DG}$$

$$EC = (D + L) \cdot SP_k + P_{DG} \cdot SP_k \, (pf_{DG} - 1) \qquad (2)$$

where

- D: total net active power demand in the DisCo;
- L: total ohmic losses in the DisCo network;
- P_{DG}: active power generated by the DG units inside the DisCo.

Proposed Market Integration Model

- The DisCo losses, L, can be estimated with the following expression

$$L = K.\left(\sum_{k=1}^{N_{DG}} P_{DG}^{k}\right)^2 = K.(D - P_{DG})^2 \qquad (3)$$

- The K factor approximates an equivalent resistance of the distribution network at medium voltage level. This factor can be estimated using the average values of the involved variables at the same voltage level, based on measurements or validated information used in tariff processes. Consequently, a set of different K factors should be used, considering diverse load and supply conditions. Thus, a specific factor can be calculated as

$$K \approx \frac{\overline{L}}{(\overline{D} - \overline{P}_{DG})^2} \qquad (4)$$

Proposed Market Integration Model

- The estimation of the SP at the DG busbar, for a specific selected K factor, involves the construction of the penalty factor (pf_{DG}) as follows

$$P_T + P_{DG} = D + K \cdot (D - P_{DG})^2 \qquad (5)$$

P_T and P_{DG} are known values, measured and registered by the market/system operator, for example, in hourly steps.

- From (5) and (3), L can be calculated as a function of P_T, P_{DG} and K. This can be achieved by solving the quadratic equation for the auxiliary variable $x = D - P_{DG}$ in (5) and replacing the result in (3).
- Using (6), the associated penalty factor pf_{DG} is calculated as shown in (7)

$$L = \frac{1}{2.K}(1 + 2.K.P_T - \sqrt{1 + 4.K.P_T}) \qquad (6)$$

$$pf_{DG} = \frac{1}{1 - \frac{\partial L}{\partial P_T}} = \sqrt{1 + 4.K.P_T} \qquad (7)$$

Proposed Market Integration Model

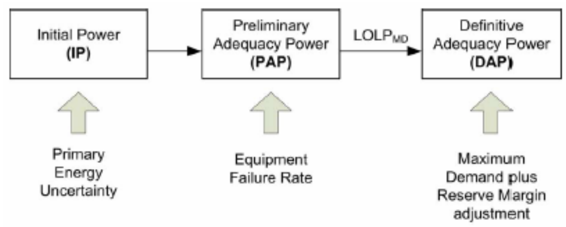
- The resulting pf_{DG} for each period can be used to calculate the SP_{DG} using the SP_k defined at the wholesale level.
- For a specific DGi, the spot price at the injection point SP_{DGi} is

$$SP_{DGi} = SP_k \cdot pf_{DG} \qquad (8)$$

- From (7), in the normal case where $P_T > 0$, SP_{DGi} is greater than SP_k, reflecting the effect of DG injection on the system ohmic loss reduction.
- For the counterflow ($P_T < 0$), $SP_{DGi} < SP_k$.
- The calculated DG spot prices imply price signals for optimum operation at both system and local levels .

Proposed Market Integration Model

- Capacity Payments
  - In pool-based markets, different schemes for capacity payment (CP) were developed.
  - The recognition of a CP for a DG must be consistent with the CP procedure applied to conventional generation units.
  - The Figure below shows the general framework for capacity recognition and payment



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Proposed Market Integration Model

- Energy Price Stabilization Mechanism
  - Usually, financial entities evaluate DG project as a high-risk venture. To deal with this issue, the proposed market integration model incorporates an energy price stabilization mechanism.
  - The proposed energy price stabilization mechanism is formulated as a time-based average of the locational SP over a fixed time frame. This average price is known as the energy nodal price

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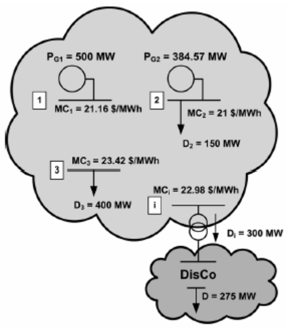
Application Example

- Without DG
  - A small interconnected power system containing 2 generators (in busbars 1 and 2), 2 generic loads (in busbars 2 and 3), and a DisCo connected to busbar ***i***
  - The system load is 850 MW and the marginal generator is generator 2 located at busbar 2
  - The following bilateral contracts are in place:
    - Generator 1 supplies demand D2
    - Generator 2 supplies demand D3
    - Generator 2 supplies demand Di



Application Example

- Without DG
  - The energy balance at the wholesale market level for each generator is equal to the generator sales minus the load purchases

$$EBG_k = ES_k - \sum_{j \in k} EP_{kj} \qquad (9)$$

where EBG_k is the energy balance for generator k, ES_k are the sales of generator k at its injection point, and EP_{kj} is the energy purchase of generator k at the delivery point j

  - The system marginal income (MI) is defined as the difference between the total sales and total purchases in the system. Under non-congestion operation, the MI reflects the existence of ohmic losses in the system

Application Example

- Without DG
  - **Energy balance for generator 1**
    EBG_1 = 500 * 21.16 – 400 * 23.42 = $1212
  - **Energy balance for generator 2**
    EBG_2 = 384.57 * 21 – 150 * 22.89 = $ - 1968
  - **Marginal income**
    MI = $756
  - **Total system losses without considering the DisCo**
    Losses = 34.57 MW
    (4.07% of system demand at wholesale level).

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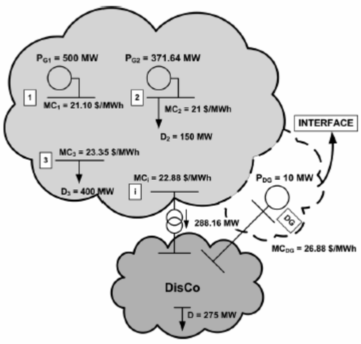
Application Example

- With DG
  - DG units with a total capacity of 10 MW are integrated inside the DisCo
  - The demand D_i is reduced to 288.16 MW, while the net DisCo demand at the distribution level remains at 275 MW
  - The DG and its injection point are considered as part of the wholesale market
  - Most busbar spot prices experience changes as compared with the case without DG
  - G2 varies its dispatch to 371.64 MW, which represents a decrease in generation of 2.93MW from the wholesale market point of view
  - The K factor for the DisCo is calculated as follows



$$K \approx \frac{\overline{L}}{(\overline{D}-\overline{P}_{DG})^2} \approx \frac{23.16}{(275-10)^2} \approx 3.3X\,10^{-4}$$

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Application Example

- With DG
  - Once K factor is estimated, DG penalty factor is calculated, pf_{DG} = 1.175. Thus, the spot price at the DG injection point, is $SP_{DG} = SP_i \cdot pf_{DG}$ = 26.88 $/MWh.
  - **Energy balance for generator 1**
    EPG_1 = 500 * 21.10 – 40 * 23.35 = $1210
  - **Energy balance for generator 2**
    EPG_2 = 371.64 * 21 – 150 * 21 – 288.16 * 22.88 – 10 * 26.88 = $ - 2207
  - **Energy balance for DG**
    EP_{DG} = 10 * 26.88 = $269
  - **Marginal income**
    MI = $729
  - **Total system losses without considering the DisCo**
    Losses = 33.48 MW
    (3.99% of system demand at wholesale level).

Application Example

Comparison between the energy balances before and after the DG incorporation

Agent	Energy Balance without DG	Energy Balance with DG
G1	1212	1210
G2	-1968	- 2207
DG	----	269
MI	753	729

Conclusion and Further Work

- The use of DG can be a significant benefit to the competitive wholesale marketplace.
- DG can provide the price response needed.
- This response will only be seen if the high wholesale price values can be reflected to customers with DG.
- The methodology proposed in this report is focused on OTC markets embedded in a pool-based wholesale market structure. Nevertheless, its main concepts can be extended to markets based on physical bilateral contracts and power exchanges (PBC/PE), similar to those in North America and Europe.
- Future work in this field will be focused on the evaluation of calculation alternatives of penalty factors at the distribution level and the development of specific market interfaces for other market structures.

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Thank you