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Term Paper

# A COMPETITIVE MARKET INTEGRATION MODEL FOR DISTRIBUTED GENERATION

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# 1. INTRODUCTION

High penetration of distributed generation (DG) resources into the distribution networks is increasingly observed worldwide. The evolution of this penetration in each country depends on the cost of traditional technologies, market design, and promotion programs and subsidies. Nevertheless, with the acceleration of this trend, higher levels of penetration will be achieved and, in turn, a competitive market integration of DG will be needed for an adequate development of the power sector [1].

Distributed generation 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 in addition to some other technical obstacles, such as dispatchability and reliability issues associated with the integration of DG systems using renewable energy [2, 3].

This report discusses issues related to DG and presents the details of a proposed for the competitive market integration of DG in a pool-based electrical system.

# 2. WHAT IS DISTRIBUTED GENERATION (DG)?

Due to variations in government regulations, different definitions for DC are used in different countries, for example [4]:

- DG in Sweden is often defined as generation with up to 1,500 kW. But under Swedish law, a wind farm with one hundred 1,500 kW wind turbines is still considered DG, as the rating of each wind energy unit, and not the total wind farm rating, is relevant for the Swedish law.
- In the English and Welsh power market, the term 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.
- In New Zealand, DG is often considered generation of up to 5 MW.

For the purpose of this report, distributed generation may be defined as [4]:

> ***"Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter".***

Alternatively, DG may be defined as [5]:

> ***"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".***

Figures 1 and 2 below illustrate the differences between a conventional distribution network and a distribution network with DG [5].

## 3. TYPES AND APPLICATIONS OF DG

DG technologies may be categorized as renewable and nonrenewable. Renewable technologies include [6]:

- solar, photovoltaic or thermal
- wind
- geothermal
- ocean.

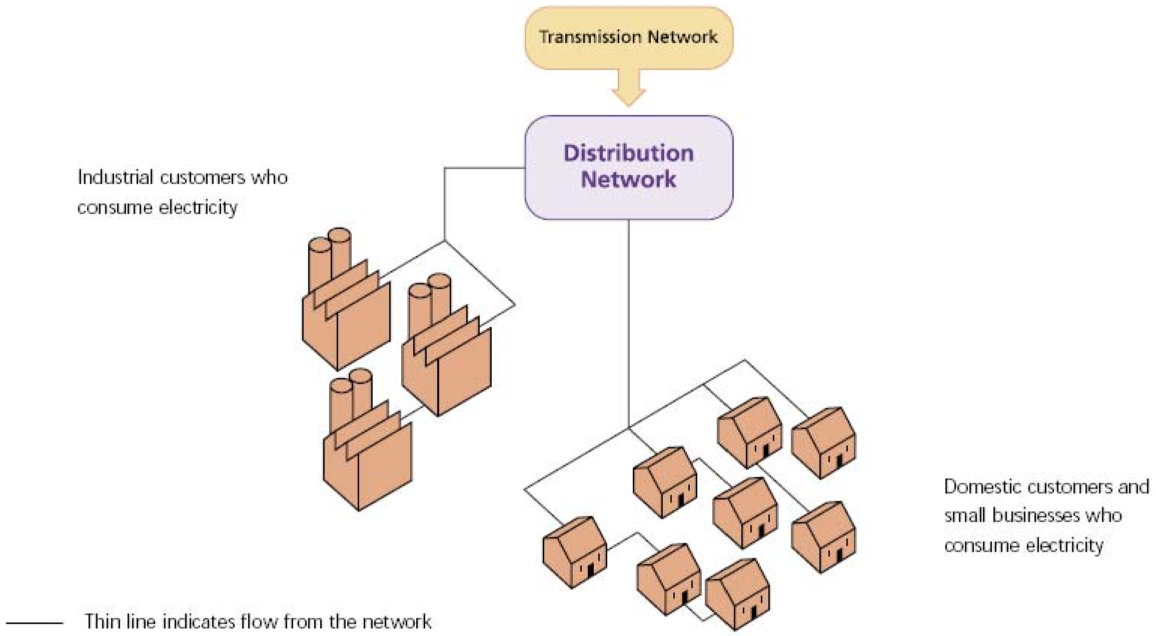


Figure 1: Conventional Distribution Network

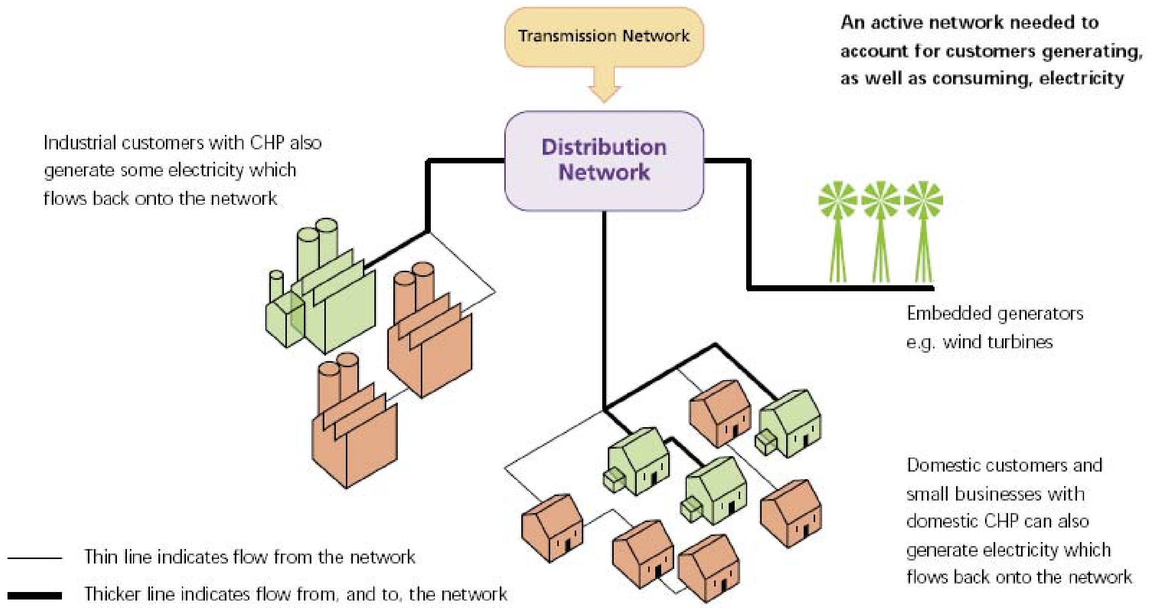


Figure 1: Distribution Network with Distributed Generation

Nonrenewable technologies include [6]:

- internal combustion engine, ice
- combined cycle
- combustion turbine
- microturbines
- fuel cell.

Distributed generation should not to be confused with renewable generation. Distributed generation technologies may be renewable or not; in fact, some distributed generation technologies could, if fully deployed, significantly contribute to present air pollution problems [6].

Presently, there are three major application groups feasible for utility operated DG's. First, it can avoid or defer distribution upgrades. Second, they can avoid or defer substation upgrades. Third, they can avoid and defer major transmission upgrades [7].

# 4. EVOLUTION OF DG SYSTEMS

## 4.1 Present Power Production Situation

Since the beginning of the twentieth century, the backbone of the electric power industry structure has been large utilities operating within well-defined geographical territories and within local market monopolies under the scrutiny of various regulatory bodies. Traditionally, these utilities own the generation, transmission, and distribution facilities within their assigned service territories; they finance the construction of these facilities and then incorporate the related capital costs in their rate structure which is subsequently approved by the relevant regulatory bodies [6].

Table 1 shows the installed capacities on a worldwide basis at the end of the twentieth century and Table 2 details the range of capabilities for the various technologies generally falling under the DG category. The electric power network interface which plays a major role when considering the network operation aspects related to dispersed generation is also listed in Table 2 [6].

Table 1: Worldwide Installed Capacity (GW) be 1 January 2000

| 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 |

Table 2: DG Capabilities and System Interfaces

| 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 |

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 [1].

Recently, DG is attracting a lot of attention and might become more important in the future power generation system. For example, a study by the Electric Power Research Institute (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 % [4].

DG presently contributes about 3% of new generation capacity. It is estimated that in the next few years distributed generation will make about 6% of the newly installed generation capacity. DGs can not only compete for regional electricity market, as they are at present, but also have potential to export its energy to other networks [3]. It is expected that the DG share of worldwide annual capacity additions would be 40% by 2008 [1].

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) and market design concepts (pool, power exchange or physical bilateral-based systems). A key aspect explaining this fast evolution is the development of promotion programs, subsidies, and compensation mechanisms [1].

In the meantime, the power industry is experiencing major restructuring from a traditional vertically-integrated structure to a horizontally-operated and competitive wholesale market. Accordingly, the average cost based electricity price is transforming into marginal cost or locational marginal pricing (LMP) based scheme. Power deregulation has led to open transmission and DG systems; the latter has made a strong impact on power system operation [3].

Growing DG technologies and improvements are providing cheaper generation to customers of choice. Regulatory incentives and evolving environmental requirements will enhance the use of DGs. DG will become a more common arbitrage tool between local fuel (mostly natural gas) and electricity retail prices [7].

Future applications of DGs are expected to include [7]:

- 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 [7].

In recent years, wholesale power markets have shown extreme price swings and this illustrates that much of the marketplace is functioning on market-based rather than cost-based rates. DG controlled and dispatch for wholesale supply can show added benefits above that of conventional central station units. DG can provide local reliability for distribution outages, heat or steam for process use, reduced losses, reduced distribution loads and power inside of transmission constraints. Thus, customers can retain the benefits of their on-site DG and this DG can also be reflected as regional supply [8].

DG's strategic value derives from flexibility. DG can be sized appropriately to match the needs of specific customers. They can operate flexibly to capture the hour-to-hour variation in energy prices. They can be sited almost anywhere to capture the market value at key locations [7].

### 4.2 Issues/Difficulties Associated with DG Integration

DG technologies are most often connected to existing electric power delivery systems at the distribution level. One of their significant benefits is that they are modular enough to be conveniently integrated within electric distribution systems, thereby relieving some of the necessity to invest in transmission system expansion. However, significant penetration within existing electric distribution systems is not without a new set of problems [6]. The following four key strategic issues relating to DG shall be taken into account by any distribution company [9]:

1. How much distributed generation will appear in the distribution network?
2. What effect will the distributed generation have on the technical performance of the network?
3. What effect will the distributed generation have on the financial performance of the utility?
4. What changes in technical design or commercial practice will be effective within a distribution utility distributed generation strategy?

Other key issues that must be addressed are detailed below [6].

### 4.2.1 Power Quality

Several of the DG technologies rely on some form of power electronic device in conjunction with the distribution network interface, be it AC-to-AC or DC-to-DC converters. All of these devices inject currents that are not perfectly sinusoidal. The resulting harmonic distortion, if not properly contained and filtered, can bring serious operational difficulties to the loads connected on the same distribution system [6].

### 4.2.2 Reactive Power Coordination

DG, implemented at the distribution level, i.e. close to the load, can bring significant relief to the reactive coordination by providing close proximity reactive power support at the distribution level, provided the proper network interface technology is used and that proper system configuration has taken place. However, wind generation actually contributes to worsen the reactive coordination problem. Most wind generators feature asynchronous induction generators that are ideally suited to the variable speed characteristics of wind machines but that must rely on the network to which they are connected for reactive power support [6].

### 4.2.3 Reliability and Reserve Margin

Several DG technologies are such that their production levels depend on Mother Nature (wind and solar) or are such that their availability is subject to the operational priorities of their owners. Under a highly DG ownership scenario, assignment of reserve margin maintenance increasingly will become a problem unless a market-driven solution is put forward [6].

### 4.2.4 Reliability and Network Redundancy

Most electric distribution systems feature a radial network configuration as opposed to the meshed structure adopted at transmission levels. As a result, network redundancy becomes an issue when significant DG is connected directly to distribution system, since single line outages could completely curtail the availability of generation facilities [6].

### 4.2.5 Safety

Distribution system protection schemes typically are designed to rapidly isolate faults occurring either at load locations or on the line itself. The assumption is that, if the distribution line is disconnected somewhere between the fault and the feeding substation, then repair work can safely proceed. Clearly, if DG is connected on the same distribution feeder, then significantly more sophisticated protective relaying schemes must be designed and implemented to properly protect not only the personnel working on the lines but also the loads connected to them [6].

### 4.2.6 Accountability

A daunting problem is looming over the “brave new electric utility industry” in its restructured configuration: Who will the customer call when the lights go out? The local “wire company” might arguably answer, “my wires are just fine, thank you.” The existence of local transmission company may not even be known by the end-user. The power producer might arguably respond, “please refer your inquiry to your local wire company, with which we have a service contract.” The resolution of this all-important question is still very much open for debate [6].

### 4.2.7 Standards

Many utilities have very structured standards that make it difficult and expensive to interconnect DG units [8]. The approval of IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems represents a major milestone in the development of DG [10].

# 5. PROPOSED MARKET INTEGRATION MODEL

To design a proper market integration model for DG, it is necessary to consider its participation in the energy and capacity exchanges among the power producers (PPs) as an equivalent power producer (EPP) in the wholesale market [1].

## 5.1 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, by using an economic dispatch model with network constraints, a spot price at the distribution level ($SP_{DG}$) can be calculated for the specific injection point of the DG. Nevertheless, the implementation of such a methodology is not practical, mainly because of the size of the network and the difficulties in accessing the necessary data set from the DisCos [1].

A methodology to overcome these difficulties is proposed in this report, which is based on approximations of the system modeling [1].

The computation of a $SP_{DG}$ implies the incorporation of a new delivery and injection point into the wholesale market. Consequently, the DG sells energy at $SP_{DG}$, while the DisCo supplier buys the same amount of energy at the same price [1].

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 Figure 3 [1].

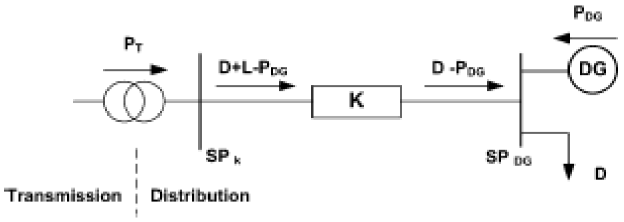


Figure 3: Simplified Model to Estimate the Spot Price at the DG Busbar

In Figure 3, 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. Thus, as illustrated in Figure 3, the energy supply cost (EC) of the DisCo is given by two terms, as follows [1]:

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

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.

The proposed methodology formalizes the payment 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 ($SP_{DG}$). The calculation of $SP_{DG}$ is achieved by using a penalty factor $pf_{DG}$, which accounts for the effect of DG energy injections on the DisCo network ohmic losses.

Consequently, under this interface concept, the energy cost for supplying the DisCo is given by [1]

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

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.

Under the interface concept, the DG busbar is directly incorporated into the wholesale market. This approach allows the formal integration of DG into the wholesale market. Also, when the interface is compared with the traditional OTC-based market, DG injections and the penalty factor ($pf_{DG}$) are the only additional information required.

The proposed interface concept can be extended to any distribution system with multiple DG injections and multiple busbars connected to the transmission system. In this general case, the energy balance in the DisCo system can be calculated from [1]

$$\sum_{i=1}^{N_T} P_T^i + \sum_{k=1}^{N_{DG}} P_{DG}^k = P_T + P_{DG} = D + L \qquad (3)$$

where

- $N_T$ total number of energy delivery points of the distribution system from the transmission system;
- $N_{DG}$ total number of DGs in the distribution system.

The DisCo losses, L, can be estimated with the following expression [1]:

$$L = K.\left(\sum_{k=1}^{N_{DG}} P_{DG}^k\right)^2 = K.(D - P_{DG})^2 \qquad (4)$$

The K factor used in (4) (see Figure 3) approximates an equivalent resistance of the distribution network at medium voltage level. This factor can be estimated using the average values $\left(\overline{L}, \overline{D}, \overline{P}_{DG}\right)$ 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 [1]

$$K \approx \frac{\overline{L}}{(\overline{D} - \overline{P}_{DG})^2} \qquad (5)$$

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: replacing (4) in (3), yields

$$P_T + P_{DG} = D + K \cdot (D - P_{DG})^2 \qquad (6)$$

$P_T$ and $P_{DG}$ are known values, measured and registered by the market/system operator, for example, in hourly steps. From (6) and (4), 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 (6) and replacing the result in (4). Using (7), the associated penalty factor $pf_{DG}$ is calculated as shown in (8)

$$L = \frac{1}{2.K}(1 + 2.K.P_T - \sqrt{1 + 4.K.P_T}) \qquad (7)$$

$$pf_{DG} = \frac{1}{1 - \frac{\partial L}{\partial P_T}} = \sqrt{1 + 4.K.P_T} \qquad (8)$$

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

$$SP_{DGi} = SP_k \cdot pf_{DG} \qquad (9)$$

The proposed market integration interface behaves in accordance with a marginal cost pricing scheme, representing a compromise between accuracy and operability in a real system. From (8), it can be observed that, 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. On the other hand, for the counterflow ($P_T < 0$), as expected, $SP_{DGi} < SP_k$ . Moreover, the calculated DG spot prices imply price signals for optimum operation at both system and local levels [1].

### 5.2 Capacity Payments

In pool-based markets, a wide range of different schemes for capacity payment (CP) was developed. The recognition of a CP for a DG must be consistent with the CP procedure applied to conventional generation units. Figure 4 shows the general framework for capacity recognition and payment [1].

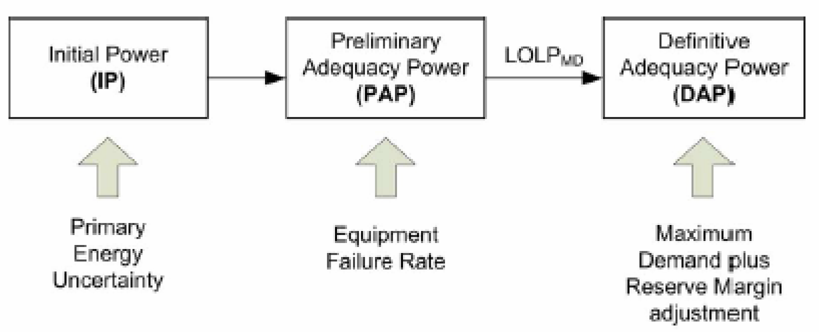


Figure 4: Procedure for Power Recognition

The capacity recognition of a generation unit, valued at the power price (investment cost of a peak load unit), corresponds to the contribution to the system adequacy of each generation unit in three main steps. In the first step, an initial power (IP) is determined based on the primary energy uncertainty associated with a generation technology. In the second step, the IP is penalized by considering the equipment failure rate and its effects on the system operation under peak load conditions. The resulting preliminary adequacy power (PAP) corresponds to the expected power injection of each unit for different operation conditions. In the last step, the definitive adequacy power (DAP) of a unit is determined by the adjustment of the total system

PAP with the system peak load, including a reserve margin defined by the regulator. Some specific implementation aspects for DG are briefly discussed below [1].

### 5.2.1 Initial Power Calculation

The DG IP does not differ from its installed capacity for power plants with full availability of primary energy. However, this is not the case of DG based on renewable resources such as wind, sun radiation, and water. As mentioned before, for DG units operating in a system with high hydro regulation capability, the uncertainty of primary energy is modeled in the same way as conventional plants, such as run of river hydro units. Thus, IP is determined as the average power injection, considering the historical scarcity of the associated natural resource [1].

### 5.2.2 Preliminary Adequacy Power Calculation

The calculation of a DG PAP requires an estimation of the generation equipment failure rate, which could be obtained using the following criteria [1].

- The forced outage rate (FOR) is calculated by the ISO every 2 years in accordance with the DG operational statistics.
- International statistics or failure rates guaranteed by the equipment manufacturer are used when the operational information is not available.
- In the case of DG arrays connected to the grid through one connection point, an equivalent state distribution model based on each individual FOR must be calculated.

### 5.2.3 Applicable Power Price

The power price applicable to a specific DG depends on its location in the system. Power prices for the distribution level busbars $PP_D$, where DG units are connected usually, must be calculated using power penalty factors **ppf** applied to the power price of the nearest transmission level busbar. This procedure is illustrated in Figure 5 [1].

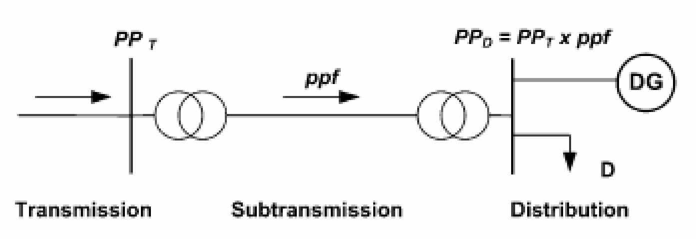


Figure 5: Power Price Formulation to DG Located in Distribution Networks

### 5.3 Energy Price Stabilization Mechanism

To promote the entry of a new generation of investors into the market, it is necessary to reduce the risk perception of the projects. Usually, financial entities evaluate this kind of project as a high-risk venture. To deal with this issue, the proposed market integration model incorporates an energy price stabilization mechanism [1].

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 [1].

## 6. APPLICATION EXAMPLE

In this section, an illustrative example to analyze the DG insertion scheme on the wholesale market is presented. In Figure 6, a small interconnected power system containing two generators (in busbars 1 and 2), two generic loads (in busbars 2 and 3), and a DisCo connected to busbar ***i*** is presented. The system load is 850 MW and the marginal generator is generator 2 located at busbar 2 [1].

In this system, the following bilateral contracts are in place:

- Generator 1 supplies demand $D_2$.
- Generator 2 supplies demand $D_3$.
- Generator 2 supplies demand $D_i$.

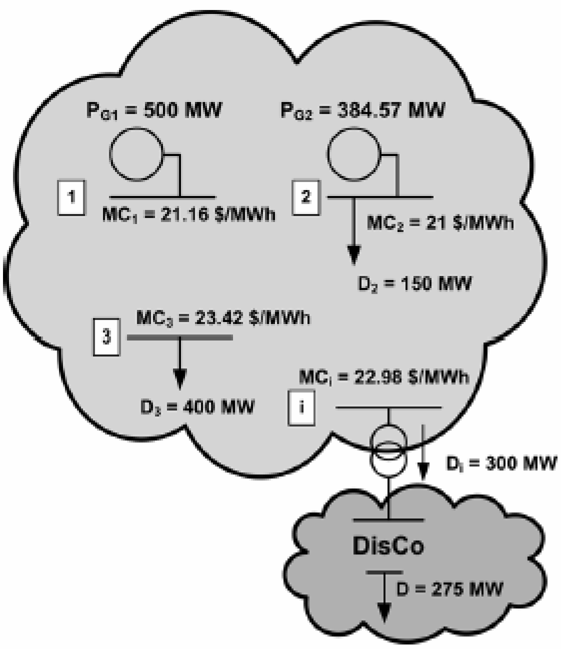


Figure 6: Illustrative Example - Case without DG

The energy balance at the wholesale market level for each generator is equal to the generator sales minus the load purchases. The energy sale price corresponds to the spot price at the injection points. On the other hand, the purchases are realized at spot price at the delivery points. In formal terms

$$EBG_k = ES_k - \sum_{j \in k} EP_{kj} \tag{10}$$

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 [1]. Additionally, 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 [1].

### 6.1 Case Without DG

The case where there is no DG in the DisCo's grid is shown in Figure 6, where $SP_k$ stands for spot price at busbar k in $/MWh. The energy balance for each generator during a period of 1 h is as follows [1]:

**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).

## 6.2 Case With DG

In this example, the effects of market integration of new DG units with a total capacity of 10 MW inside the DisCo are analyzed. The analysis can be extended directly to more than one DG unit. Thus, the demand Di is reduced to 288.16 MW, while the net DisCo demand at the distribution level remains at 275 MW (Figure 7).

In the proposed market interface, the DG and its injection point are considered as part of the wholesale market (expansion with dashed lines in Figure 7). It is also shown that most busbar spot prices experience changes as compared with those in Figure 6 (case without DG). Also, G2 varies its dispatch to 371.64 MW, which represents a decrease in generation of 2.93MW from the wholesale market point of view [1].

Considering the DisCo as a one-node system with a general loss function, for this scenario, the K factor for the DisCo is calculated as follows [1]

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

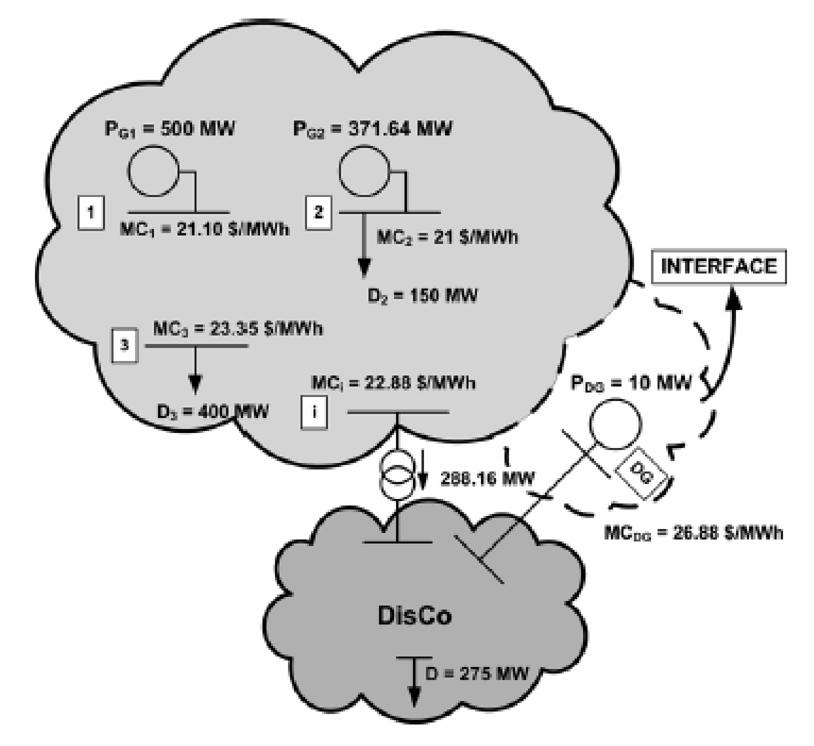


Figure 7: Illustrative Example - Case with DG

Once the K factor is estimated, the DG penalty factor is calculated, obtaining $pf_{DG}$ = 1.175. Thus, the spot price at the DG injection point, is

$$SP_{DG} = SP_i \,.\, pf_{DG} = 22.88 * 1.175 = 26.88 \text{ \$/MWh.}$$

With $SP_{DG}$, it is possible to perform the following new energy balance for all generators [1].

**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).

A comparison between the energy balances before and after the DG incorporation is shown in Table 3 [1].

Table 3: DG Energy Balance Comparison

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

The impacts produced on the different participants are as follows [1]:

- A minimum effect in the balance of generator G1.
- An increase in the negative balance of generator G2. This result is mainly because of the reduction of G2 power sales in the system. In fact, the costs of supplying the DisCo decreased from $6894.00 to $6862.90.
- A decrease in the system MI reflecting a reduction in system losses.
- A surplus condition for the DG (without contracts) with its injection of 10 MW valued at spot price.

It is important to note that the DG can be easily integrated to the wholesale market. The only required information to perform the DG integration is its injections and the associated penalty factor ($pf_{DG}$). This makes possible the treatment of the DG as an EPP [1].

### 6.3 Multiple DisCo Feeding Busbars

In most cases, DisCos are supplied through multiple busbars. For instance, in Figure 8, three different busbars feeding the DisCo example under analysis are shown.

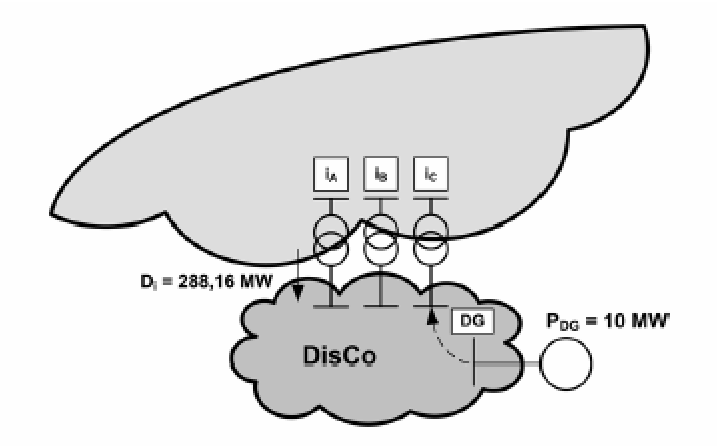


Figure 8: Multiple Supply Busbars

In this example, busbar $\boldsymbol{i}$ has been broken down into three busbars ($\boldsymbol{i}_A$, $\boldsymbol{i}_B$ and $\boldsymbol{i}_C$). As these busbars belong to the transmission system, each one of them has a different spot price; there is a need to find a criterion to select the appropriate busbar for the DG under study. The proposed criterion to identify $SP_{ik}$ for a specific DG is based on the minimal electrical distance under normal feeder operation of the DisCo network. It is important to note that the proposed methodology refers each $DG_i$ to a unique $SP_k$ at the wholesale level [1].

## 7. CONCLUSION AND FUTURE WORK

The use of DG can be a significant benefit to the competitive wholesale marketplace which is prone to wide price swings due to limited supply and other factors. DG can provide the price response needed - that of appearing to reduce load at high price signals. This response will only be seen if the high wholesale price values can be reflected to customers with DG. Sharing the benefits and revenues of these high wholesale prices with DG will reduce the peak and volatility of prices and will provide a more balanced response than today's current supply only option [8].

The methodology proposed in this report is focused on OTC markets embedded in a pool-based wholesale market structure. Nevertheless, based on the previous analysis, 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 [1].

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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