Price Definitions in Energy Contracts with Investor Owned Generation

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Abstract—Nowadays IPP’s power plant construction is encouraged by the current deregulatory climate, and the financing technique employed to implement these projects is often the project financing formula. This means that an investor consortium, usually foreigner, plan, build, operate the power plant, and sell the generated electricity to the host utility. The sale price is determined from the expected IPP’s production cost, enhanced of the expected welfare obtainable by selling electricity. This paper proposes a methodology for linking the uncertainty of the future production cost with the price of the electricity generated by an IPP. This is a stochastic approach to the sale price definition problem, while usually a deterministic procedure is used.

I. INTRODUCTION

In recent years, political and regulatory changes promoted competition in electricity industry, at different levels. In 1996, important deregulation policies have been adopted in US and EU. The Federal Energy Regulatory Commission (FERC) encouraged the open market system in US by creating a competitive environment where generation and transmission services are bought and sold under demand and supply market conditions. In Europe, the Directive 96/92/EC of the European Parliament and of the Council established common rules for the generation, transmission and distribution of electricity. It lays down the rules relating to the organisation and functioning of the electricity sector, access to the market, the criteria and procedures applicable to calls for tender and the granting of authorisations and the operation of electric power systems.

In developed countries, the reason for the market liberalisation was the increasing evidences that private sector generally performs better in terms of construction costs and times, operation and customer service: independent power producers (IPPs) can construct and operate relatively small plants at unit costs comparable with larger generators.

In emerging nations, the prospect of a large-scale private participation in the generation sector involved the entry of entrepreneurial capital as an investment option in electricity generation. In particular, in these countries, the difficulty to raise the large investments required to meet a strong and sustained demand growth, forced the Governments to provide increasing opportunities for foreign investment, either directly in power production and use, or indirect as portfolio investment in utility bonds and shares. In this context, the globalisation of financial markets and innovative financing techniques are offering more infrastructure financing options, especially for emerging nations, where vast power project development opportunities contrast with a reduced capital availability. Because of their relatively large size and long payback periods, power projects are implemented using a financing technique known as project finance. A project financing scheme involves the judgment of the power investment only on the basis of the future cash flow, which should be high enough to cover, with a safety margin, operating costs, debt servicing and an adequate return on investment [1]-[3]. Moreover, the implementation of the power project can be arranged using the build operate and transfer (BOT) option or the build, operate and own (BOO) option. In a BOT arrangement, a private power development consortium raises the finance and builds a power station whose output is purchased by an electric power utility in the host nation. At the end of a period, known as the franchise period, typically 15-20 years, the ownership of the plant is transferred to the host utility or government, usually for a token payment. The B.O.O. arrangement differs from this in that ownership of the plant is retained in perpetuity by the private developer [6].

To meet the growing demand for power and because of the limited domestic financing, the Albania’s Republic opened the power sector for private and foreign investment. The innovative financing methods were needed to mobilize the required funds during 2007 for construction of more than 35 small and medium electric power stations. Implementation of power projects under BOO/BOT scheme was one of the important options being considered by the Government.

In this paper, the incorporation of investor owned generation within the operational ambit of the host utility is established through a number of contracts covering a wide range of issues from capital financing, foreign currency remittances where relevant, and energy purchasing and pricing. The arrangement between the investor and the host...
utility to which this energy is delivered include agreements about how much energy is to be delivered, at what cost, when and what penalties are to be imposed in the event of breach of contract. A breach occurs if either the supplier fails to provide a previously agreed quantum of power, or if the host declines to accept it.

There are two types of agreement depending by the penalty imposed to host: the Take-and-Pay (T.A.P.) contract and the Take-or-Pay (T.O.P.) contract. In T.O.P. contract the host utility pays only the requested energy, and if this quantity is less than the quantum of power previously agreed, host shall pay a penalty on difference. In T.O.P. contract, the host utility pays all the agreed quantum of power, even if the energy really token is less than it.

Setting the penalty imposed on IPP is not easy, because if a supplier fails to provide power it can cause various kinds of damages.

To define the sale price it needs to know the IPP’s expected production costs, on which there is a significant uncertainty degree due, for examples, to uncertainty of future fuel prices, or to government policy.

In the developed countries it is possible to forecast the expected production costs with a little uncertainty degree, while in the underdeveloped ones the degree of uncertainty is greater.

Usually the sale price definition procedure is a deterministic procedure, in which the uncertainties don’t affect directly the sale price, but imply higher values of the wished financial-remunerative index, that involves a higher electricity prices.

This paper propose a stochastic approach for linking the degree of future uncertainty, the expected production costs of investor plant and the expected production costs of host utility, with the electricity prices and penalty charges which are stipulated in the energy contract between the two parties.

It needs to be emphasised that this mathematical approach is based on the economic concept of a rational participant, so the sale price will be less than host’s production cost for a plant that host will build employing a corporate financing technique;

Below it will be obtained the stochastic sale price of electric energy by the IPP and host’s point of view, getting minimum and maximum price level respectively.

II. THE BEHAVIOURAL MODELS

Any business venture has its risks, and independent power generation is no different. However, what is peculiar in the power generation, particularly in emerging nations, is the lack of clarity as to what the specific risks are. Moreover, these risks are usually perceived by both the investor and host. Investor perceptions mainly include: non-recourse financing, construction phase risks, no-take risk, fuel supply and price risks, plant reliability, inflation and force majeure and political risks. Host perceptions cover: failure to deliver, failure to maintain the plant, dispatch inflexibility, etc. [4], [5].

Most of the previous mentioned risks reflect on the negotiation process of the purchase price agreement between the investor and the host utility. In this Section, the different reasoning adopted by the investor and by the host utility in defining the energy price is investigated by developing appropriate behavioral models. Under specified conditions, this leads, respectively, to the definition of the minimum sale price favorable for the investor and to the concept of maximum purchase price acceptable by the host utility.

A. The investor model: minimum sale price

Let us suppose that \( \bar{c}_V \) and \( \bar{c}_V \) are the fixed and the variable operating costs (c$/kWh) of the investor power plant and indicate by \( \pi_i \) (c$/kWh) the penalty to be paid by the host utility to the host utility if the investor declines to deliver the unit energy. It is easy to verify that the investor will find advantage to deliver energy if

\[
\bar{c}_V \leq p_i + \pi_i \]

where \( \bar{p}_i \) is a specified value of the power purchase price.

Now, let us indicate by \( C_V \) and \( C_V \) the random variables which represent, respectively, the fixed operating cost and the variable operating cost of the investor power plant. Under these assumptions, the equation (1) can be written, in terms of stochastic variables, by considering the probability that \( C_V \leq p_i + \pi_i \), that is

\[
P(C_V \leq p_i + \pi_i) = Q_i(p_i + \pi_i) \]

(2)

where \( p_i \) is the generic value of the stochastic variable \( P_i \) representing the selling price expected by the investor and \( Q_i(.) \) is the cumulative distribution function of \( C_V \) in particular

\[
Q_i(p_i + \pi_i) = \int_{0}^{p_i + \pi_i} q_i(c_v)dc_v
\]

(3)

where \( q_i(c_v) \) is the probability density function of \( C_V \). It should be noted that the function \( q_i(c_v) \) must be equal to zero for any \( c_v \leq 0 \). The equation (3) gives the probability that IPP delivers energy to the host. At the same time, the probability
that the investor finds not favourable to deliver energy is given by

$$C_i(C_F, C_V) = C_F + C_V \text{ if } C_V \leq p_i + \pi_{ih},$$

or

$$C_i(C_F, C_V) = C_F \text{ if } C_V > p_i + \pi_{ih}. \hspace{1cm} (5)$$

Analogously, the penalty payments to the host can be expressed by the function of random variable

$$\Pi_{ih}(C_V) = 0 \text{ if } C_V \leq p_i + \pi_{ih} \hspace{1cm} (6)$$

or

$$\Pi_{ih}(C_V) = \pi_{ih} \text{ if } C_V > p_i + \pi_{ih}. \hspace{1cm} (7)$$

In this paper, the following expression is adopted to define stochastically the selling price $P_i$ for the electrical energy produced by the IPP power plant:

$$P_i = C_i + \Pi_{ih} \hspace{1cm} (8)$$

The equation (8) provides the strategy adopted by the investor in defining the pricing mechanism. Since we assume that the penalty to be paid by the investor to the host is fixed, for a given value of $\pi_{ih}$, the selling price is a function of the two unrelated random variables $C_F$ and $C_V$. By adopting the above defined pricing mechanism, it is assumed that the investor charges the actually incurred production costs and makes an adjustment to recover the penalties.

It is supposed that $C_F$ and $C_V$ have a normal distribution with mean values $\mu_{C_F}$ and $\mu_{C_V}$, and standard deviations $\sigma_{C_F}$ and $\sigma_{C_V}$, respectively. Under these assumptions, it can be shown that the expected value $\mu_{P_i}$ of $P_i$ can be evaluated using the following expression:

$$\mu_{P_i} = \mu_{C_F} + \int_{-\infty}^{\infty} c_V q(c_V) dc_V + \pi_{ih} \left[1 - Q_h(\mu_{P_i} + \pi_{ih})\right] \hspace{1cm} (9)$$

The equation (9) provides the mean value of the minimum, acceptable selling price, in the investor strategy, capable of covering: the fixed production costs, the expected incurred variable costs and the risk of paying the penalty $\pi_{ih}$.

Moreover, since the right side of (9) is an implicit function of $\mu_{P_i}$, an iterative procedure is required to evaluate $\mu_{P_i}$.

In Fig.1 it is presented the minimum sale prices $p_i$ for different values of penalty $\pi_{ih}$ and $\sigma_{C_V}$, fixed $\mu_{C_F}=2\text{cent$/kWh}, \mu_{C_V}=8\text{cent$/kWh}, r=1\text{cent$/kWh}$.

B. Host utility strategy

In this section the behavioral model of the host utility in assessing, stochastically, the acceptable value of the energy purchase-price is developed. Let us indicate by $C_h$ the random variable representing the production cost estimated by the host utility to produce the energy quantum using the same investor technology and building on one’s own the plant.

Moreover let $P_h$ be the random variable representing the purchase price considered acceptable by the host and indicate by $\pi_{hi}$ the penalty paid by the host to the investor if the host declines to take energy. Then, the host will find commercially rational to take energy from the investor owned plant if the purchase price is less costly than the sum of the estimated production cost and the payment of any penalties that may arise. In this case, the following equation is satisfied:

$$P_h \leq C_h + \pi_{hi} \hspace{1cm} (10)$$

where $p_h$ is the generic value of $P_h$ and the probability that the host buys energy from the investor owned plant is given by

$$P(C_h \geq p_h - \pi_{hi}) = 1 - Q_h(p_h - \pi_{hi}) \hspace{1cm} (11)$$

where $Q_h(\cdot)$ is the cumulative distribution function of $C_h$; in particular

$$Q_h(p_h - \pi_{hi}) = \int_{-\infty}^{p_h-\pi_{hi}} q_h(c_h) dc_h \hspace{1cm} (12)$$

where $q_h(c_h)$ being the probability density function of $C_h$.

It should be observed that the function $q_h(c_h)$ must be equal to zero for any $c_h \leq 0$.

Consequently, given the function $q_h(c_h)$ and a stipulated penalty $\pi_{ih}$, a commercially rational choice for the host is to adopt a stochastic definition for the purchase price given by the following expression:
\[ P_t = C_h - \Pi_{hi} \]  \hspace{1cm} (13)  

where \( \Pi_{hi} \) is a penalty function equal to zero if (10) is satisfied or equal to \( \pi_{hi} \) when \( C_h < p_h - \pi_{hi} \).

Under the previous assumptions, the price threshold under which the host will find suitable to take energy from the investor plant can be obtained by evaluating the mean value \( \mu_{C_h} \) of the penalty payment \( \Pi_{hi} \). By assuming that \( C_h \) has a normal distribution with mean value \( \mu_{C_h} \) and standard deviation \( \sigma_{C_h} \), it can be shown that

\[ \mu_{p_h} = \mu_{C_h} - \pi_{hi} Q_{C_h} (\mu_{p_h} - \pi_{hi}) \]  \hspace{1cm} (14)

The equation (14) gives the purchase price as the difference between the expected value of the estimated host production cost and the risk of the penalty payment to the investor.

Similarly to the case of \( \mu_{p_h} \), the right side of (14) is an implicit function of \( \mu_{C_h} \), then an iterative procedure is required to evaluate the mean value of the purchase price, in the host model. The maximum sale prices \( p_h \) for different values of penalty \( \pi_{hi} \) and \( \sigma_{C_h} \), fixed \( \mu_{C_h} = 12\text{cent$/kWh} \) it is presented in Fig. 2.

![Figure 2. Maximum sale prices \( p_h \) for different values of penalty \( \pi_{hi} \) and \( \sigma_{C_h} \).](image)

III. OPTIMAL SALE PRICE DEFINITION

When host utility purchases electricity from IPP, there is convenience in this operation, therefore the consequently gain can be calculated.

A. Welfare obtainable by host purchasing IPP’s electricity

In the deterministic case welfare it will be:

\[ G = c_h - p \]  \hspace{1cm} (15)

where \( p \) is the stipulated sale price.

In the stochastic case, there is a probability of host default, therefore can be defined a function, called “sustained cost”, as follows:

\[ \tilde{C}_h = \begin{cases} C_h + \pi_{hi} & \text{if } C_h \leq p - \pi_{hi} \\ p & \text{if } C_h > p - \pi_{hi} \end{cases} \]  \hspace{1cm} (16)

In the stochastic case the gain will be the mean value of the random variable \( C_h - \tilde{C}_h \):

\[ g = \mu_{C_h} - p + (p - \pi_{hi}) Q_{C_h} (p - \pi_{hi}) - \int_0^{p - \pi_{hi}} c_h q_{C_h} (c_h) dc_h \]  \hspace{1cm} (17)

The equation (9) developed above links the minimum sale price to penalty \( \pi_{hi} \).

It is useful to join the minimum sale price with the penalty \( \pi_{hi} \), so that become possible to compare this one directly with the maximum sale price, given the penalty level \( \pi_{hi} \).

To achieve this aim, we can suppose that the penalty \( \pi_{hi} \) is equal to the existing gap between the agreed sale price \( p \) and the electricity cost \( C_h \).

The gap above mentioned is the welfare \( g \) that can be realised by host purchasing electricity from IPP’s plant rather than producing this quantity itself or buying this quantity from other plants (15).

In general we can suppose that:

\[ \pi_{hi} = k \cdot g \]  \hspace{1cm} (18)

where \( k \) is a coefficient in interval \([0,1]\)

Ultimately it is possible to define the penalty \( \pi_{hi} \) as follow:

\[ \pi_{hi} = k \cdot \left[ \mu_{C_h} - p + (p - \pi_{hi}) Q_{C_h} (p - \pi_{hi}) - \int_0^{p - \pi_{hi}} c_h q_{C_h} (c_h) dc_h \right] \]  \hspace{1cm} (19)

Joining (19) and (9), we can obtain the relation we had looking for.

The price value \( p \) in (19) need be replaced with the minimum sale price \( p_i \) because we are studying the sale price by IPP’s point of view.

\[ p_i = r + \mu_{c_i} + \int_0^{(1-k)} c_i q_{C_h} (c_i) dc_i + k \cdot \left[ \mu_{C_h} - p_i + (p_i - \pi_{hi}) Q_{C_h} (p_i - \pi_{hi}) - \int_0^{p_i - \pi_{hi}} c_i q_{C_h} (c_i) dc_i \right] \\
\times \left[ l - Q_{C_h} (p_i (1-k)) + k \cdot \left[ \mu_{C_h} + (p_i - \pi_{hi}) Q_{C_h} (p_i - \pi_{hi}) - \int_0^{p_i - \pi_{hi}} c_i q_{C_h} (c_i) dc_i \right] \right] \]  \hspace{1cm} (20)

The relation developed above is a implicit relation, which can be solved implementing an iterative procedure.

Now it is possible to compare directly the maximum and the minimum sale price in order to establish the allowed range.
of sale prices, given the penalty values imposed to host, the uncertainty degrees, and the esteemed values of host and IPP’s production cost.

IV. ILLUSTRATIVE EXAMPLE

A host entity whose \( \mu_1 = 11.5 \) cent$/kWh and an IPP whose \( \mu_2 = 10 \) cent$/kWh is examined here. Since the host plant will be realised implementing a corporate financing technique and IPP’s plant will be realised implementing a project financing formula, it is reasonable suppose that the overall host’s production costs is greater than the IPP’s.

We will consider two different uncertainty degree: the greater may be possible in the less development countries, while the least may be possible in the most development countries. The two cases are represented in the Fig.3 and Fig.4 and illustrates the application of the stochastic approach presented in this paper.

The uncertainty degrees (mean quadratic differences) needs to be linked to the mean value of the production costs, in order to avoid inconsistency in the probability distribution: it is important to note that in this problem \( Q(\sigma) \) needs to be equal 0 if \( \sigma \leq 0 \), and to be a continuous function. To this aim we need to remember that in a normal distribution: Probability \( \{ \mu - 3\sigma < \sigma < \mu + 3\sigma \} = 99.73\% \).

We will consider two different uncertainty degree: the greater may be possible in the less development countries, while the least may be possible in the most development countries.

If the power plant is to be realised in a less industrialised country, in which can be estimate the uncertainty degree equal to 2.5cent$/kWh for host and 1.5cent$/kWh for IPP’s plant, relating to mean values as reported in Fig.3 and considering a penalty level as 4cent$/kWh, the admissible range for sale price is 10.76cent$/kWh < \( p < 11.31 \) cent$/kWh.

V. CONCLUSIONS

In this paper, the incorporation of investor owned generation within the operational ambit of the host utility is proposed. A stochastic approach to define the acceptable value of the energy purchase-price is developed.

Proposed methodology takes into account the penalty values imposed to host, the uncertainty degrees, and the esteemed values of host, the uncertainty degrees of the production costs and IPP’s production cost.

The allowed range of sale prices, it is possible to establish, comparing directly the maximum and the minimum sale prices. The proposed methodology has been successfully applied to an illustrative example.

REFERENCES