# Integrated Model of Fuel Supply with Take-or-pay Contracts for Short-term Electric Generation Scheduling

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*Abstract*-- **The need for short-term generation scheduling with take-or-pay fuel supply contracts is of increased importance for the new restructured electricity industry. This paper presents an integrated multiperiod supply-chain model which includes different types of transportation networks for fuel supply. The model also considers the impact of reliable fuel supply networks on system reliability. Numerical examples are provided.**

***Index Terms***--. Transportation networks, take-or-pay contracts, integrated model.

## I. NOMENCLATURE

The following nomenclature will be used throughout the present work:

| | |
|---|---|
| $u$ | Number of generating units |
| $f$ | Generators with fuel restrictions |
| $N$ | Nodes of power system |
| $T$ | Number of periods of study |
| $I$ | Number of lines of coal transportation |
| $J$ | Number of lines of natural gas transportation |
| $C_{u,t}$ | Cost per MBtu of unity *u* in period *t* |
| $Pg_{u,t}$ | Generated power by the unit *u* in period *t* |
| $tc_i$ | Amount of coal transported by the line *i* |
| $tg_j$ | Amount of natural gas transported by the line *j* |
| $\phi c_i$ | Shipping costs of fuel in the line *i* |
| $\phi g_j$ | Shipping costs of fuel in the line *j* |
| $P_{D,t}$ | Power demand in period *t* |
| $q_{u,t}$ | Fuel consumption of the unit *u* in period *t* |
| $P_k$ | Power transmitted by the line *k* |
| $Fs_u$ | Final storage of fuel in the unit *u* |
| $Cf_u$ | Contributions of fuel for the unit *u* |
| $Is_u$ | Initial storage of fuel in the unit *u* |
| $FC_{u,t}$ | Fuel consumption in the unit *u* in period *t* |
| $TAC$ | Total amount of transported coal |
| $TAG$ | Total amount of transported natural gas |

## II. INTRODUCTION

THE integration of fuel supply in the electricity sector has increased largely as a consequence of the expanded installation of natural gas (NG) fired power plants and also the need for more robust and reliable systems. A few statistics tell the story: in 2002, the US extracted 1,093.8 million tons of coal of which 89.2% was used to produce electricity [1]; in 2005, more than 26% of total NG consumed in Latin America was used to produce electricity. Five countries, Argentina, Brazil, Chile, Colombia and Venezuela, account for 94% of NG used for power generation [2].

A large number of models that integrate NG supply with the electric power system have been reported in the literature. For example, the economic efficiencies of the integrated energy system, comprising the fuel networks and the electric power system are studied in [1]. The framework proposed by the authors is driven by fixed electricity demands that must be satisfied at the minimum overall operating costs, subject to meeting engineering and environmental constraints. The structure and objectives of this study [1] determine a medium-term operational time scale. Although the model proposed is suitable to be applied to shorter or longer periods within an operational time frame, a one-year time horizon best reflects the cyclical pattern followed by the energy flows that are mainly driven by externally imposed seasonal variations.

In [3] an integrated optimal electricity and NG expansion planning model is proposed. The problem is formulated as a mixed-integer linear multistage optimization model where the objective function is to minimize the integrated gas-electricity system generation investment and operational costs subject to hydro and thermal power plant, electricity and NG interconnection, and gas well reserve and capacity constraints. The link between both systems is the NG-fired power plants that are connected directly to NG pipelines. The approach presented in [4] proposes to solve the OPF problem in a distributed way based on the concept of "energy hubs", where each hub, also referred to as a control area, is controlled by its respective control agent. The objective function is to minimize the total energy costs of all sources and/or imports from other systems. The costs are modeled as quadratic functions of the consumed fuels. The OPF variables comprise the state variables of the electricity and NG system and the hub.

In [6] the authors show that a long-term perspective on fuel diversity is a resource-planning problem, where load

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factors are introduced into the mean-variance analysis for long-term electricity generation. The optimization model is described in terms of per energy unit (MWh) thus allowing load factor terms to be explicit in the mean-variance computations. The model runs with varying input assumptions such as variance of fuel prices that provide numerical results and mean-variance efficient frontiers that find the model to behave intuitively and tend to validate the method. Other studies like [7] describe various indices for measuring fuel diversity, such as the Shannon-Wiener Index, Herfindahl-Hirschman Index and the Laspeyres Index.

A methodology for pricing flexible NG supply contracts to determine their “value” according to the risk profile of the buyer is proposed in [8]. The authors describe the experiments carried out by the Brazilian gas authorities to assess the impacts of the creation of a flexible gas market. The approach adopted constructs a “willingness-to-contract” (demand) curve for each consumer that indicates the desired volume to be purchased for each contract price offer. After calculating the curves for all consumers, a single-product auction can be easily simulated. Another study developed in Brazil [9] proposes a model that considers a set of NG power plants supplied by a gas pipeline system. The objective function is to minimize the costs of power generation, NG production and/or acquisition and transmission. System requirements, such as electric load demand, power generation limits, NG flow pressure limits at pipeline network and take-or-pay (T-O-P) contracts are represented in the formulation. In [10], the authors develop an integrated, interdependent model of the US national electric energy system (NEES) that includes coal, gas, hydro and electricity. Another model that integrates both optimal flows on the grid and the pipeline network for NG is reported in [11].

Under the new scheme of competition in the electricity sector, it is necessary to re-evaluate the T-O-P fuel contracts in order to reduce risk, but it is even more important to ensure the availability of fuel. In this paper, a multi-period supply chain model, fuel supply networks and generation and transmission of electricity is present for short-term scheduling with T-O-P contracts under a centralized decision-making scheme. It can also be used as a tool for power system planning in a market environment, integrating fuel transport networks.

The paper is organized as follows: Section III describes the components of the integrated energy system, the importance of fuel diversification in a model of integration and the contracts in the electricity sector. Section IV illustrates a mathematical model. A numerical example with two cases is provided in Section V. Conclusions are presented in Section VI.

## III. INTEGRATION OF FUEL SUPPLY AND POWER GENERATION

The ability to supply electric power demand depends not only on the subsystems of generation, transmission and distribution, but also on the subsystems needed to transport the raw energy used to produce electricity. These raw energy forms include coal, NG and oil. Currently, most of the models in the literature focus only on integrating the NG transportation system with the electricity sector [2]-[5], [8], [9], [11], [12]. Some studies include simplified models that integrate other fuel transportation networks such as railroads, pipeline, roads and rivers with the electricity industry.

The different activities of today’s energy supply chain are organized via markets as shown in Fig. 1.

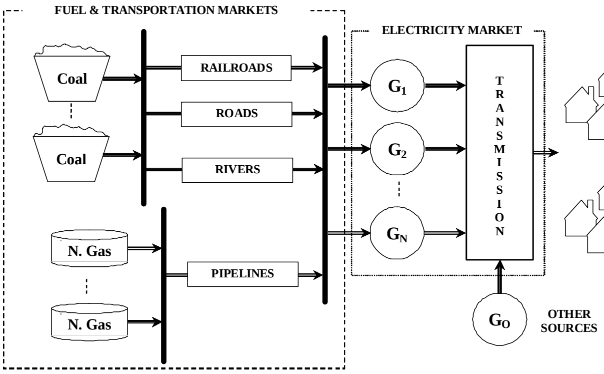

Fig. 1 – The integrated energy system

The model used in this paper includes transportation networks. We stress the importance of these networks because of the situation in Brazil in January 2004. Brazil generates about 85 percent of its energy from hydroelectric; due to drought in the north, the ONS operator ordered the dispatch of a 1,200 MW natural gas plant in the region, yet only one third (400 MW) was actually made available because of restrictions on NG production and transportation [12].

### A. *Importance of Fuel Diversity*

Power system operations must be planned based using different models that balance reductions in both cost and risk. Risk in supply of fuel is an important factor for electricity producers which require reliable sources of supply; for instance, managing two different types of fuel brings significant decreases in risk for a generator. In addition, fuel diversity can benefit the environment by avoiding $CO_2$ emissions; these alternatives include wind, mini hydro, hydrogen-based generation and biofuels.

### B. *Contracts in the Electricity Sector*

Nowadays, generation companies (GENCOs) must contract for fuel in the most strategic ways that permit them to participate in the electricity market without incurring any negative profits. Thus GENCOs must build a portfolio of contracts for fuel purchases [13]. Portfolio-building requires consideration of all potential fuel contracts and their characteristics, transportation contracts, storage/consumption commodity and other services (uncertainty in inputs).

Controlling fuel cost, then, becomes the essential input variable. The costs must be controlled in order not to decrease revenues over time, and flexible with regard to fuel input markets and power sale output markets. Finally, the portfolio of fuel types allows GENCOs to add more flexibility in generation.

Currently various financial arrangements exist, such as futures contracts which fix the prices of an asset in advance and facilitate the entry of domestic/foreign investors. Another type of arrangement are options (put and call) contracts designed to limit losses in the transaction of a given asset.

A sales contract is a legal agreement between two parties in which one party agrees to deliver a product or service to another, specifying certain conditions, and receiving in return a certain amount of money, product or service. In the electricity sector, sales contracts help to establish commercial relations between the various participants [14]. A T-O-P contract is a financial arrangement whereby one party agrees to "take" (or not to use) a minimum amount for a period of time, and the other party agrees to "pay" a minimum charge.

## IV. MATHEMATICAL MODEL

The basic short-term generation scheduling problem with *m* generators under a T-O-P contract and fuel transportation networks in a multi-period framework is described mathematically as:

$$Min\,Cost = \sum_{n=1}^{u}\sum_{t=1}^{T} C_{u,t}(Pg_{u,t}) + \sum_{i=1}^{I} tc_i \cdot \phi c_i + \sum_{j=1}^{J} tg_j \cdot \phi g_j \qquad (1)$$

The objective function is to minimize total costs of generating electricity and total cost of transshipping fuels, coal and NG.

$$\sum_{n=1}^{u} Pg_{u,t} = P_{D,t}; \qquad t = 1,...,T \qquad (2)$$

$$\sum_{n=1}^{f}\ \sum_{t=1}^{T} q_{n,t}(Pg_{n,t}) - q_{TOT} = 0 \qquad (3)$$

Constraint (2) requires that the total amount of electricity generated satisfy the demand at each period. Constraint (3) requires that the total amount of fuel under the T-O-P contract is consumed by the GENCO.

$$Pg_u^{Min} \le Pg_u \le Pg_u^{Max} \qquad (4)$$

$$P_{i,j}^{k} \le P_{i,j}^{k\,Max}; \qquad \forall i,j \in N \qquad (5)$$

$$tc_i \le tc_i^{Max}; \qquad \forall i \in I \qquad (6)$$

$$tg_j \le tg_j^{Max}; \qquad \forall j \in J \qquad (7)$$

Constraint (4) represents the operative bounds of generation units. Constraints (5)-(7) are only upper bounds of electric and fuel transportation networks (road, railroad, rivers and pipelines).

$$Fs_u \ge Cf_u + Is_u - \sum_{t=1}^{T} FC_{u,t} \qquad (8)$$

Constraints (8) require that the initial storage plus the amount of fuel shipped minus the amount of fuel required to generate $Pg$ units of electricity is at most the final fuel storage.

$$\sum_{i=1}^{I} tc_i = TAC \qquad (9)$$

$$\sum_{j=1}^{J} tg_j = TAG \qquad (10)$$

Constraints (9) and (10) represent the balance between transport fuel and fuel consumed by the generating plants.

## V. NUMERICAL EXAMPLE

This section presents two numerical examples of the model described above. For the purposes of calculation we use a five-node electric system [15], to which we add fuel transportation networks as shown in Fig. 2.

The optimization problem developed in the previous section is solved using MINOS solver of General Algebraic Modeling System (GAMS) [18].

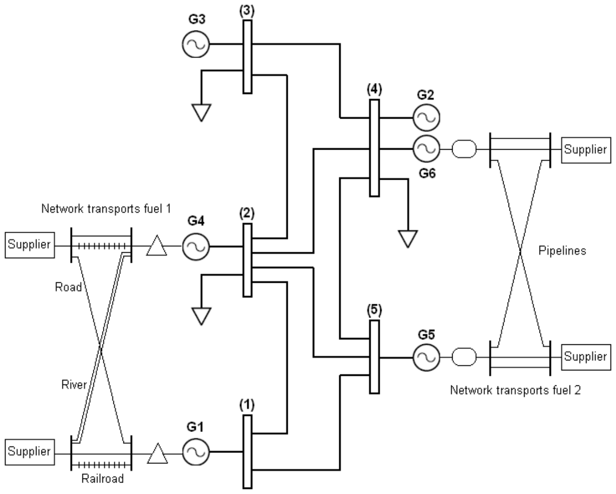

Fig. 2. 5-nodes short-term generation scheduling with unit 1 T-O-P contract

Fig. 2 shows the electrical system, to which we add 2 fuel transportation networks, one transported NG through pipelines, and the other coal transported through railroads, roads and river. Generator 1 (G1) must use or pay for consuming a specified amount of coal specified in the T-O-P contract, and generator 2 (G2) must consume 11,000 m³ of water.

Data for the generating units are shown in Table I.

TABLE I
GENERATOR'S COST DATA AND OPERATIVE LIMITS

| Unit | Input / Output curve (MBtu/hr) | $P_{Gi}^{\min}$ (MW) | $P_{Gi}^{\max}$ (MW) | Fuel |
|---|---|---|---|---|
| 1 | $225.0 + 8.47Pg_1 + 0.0025Pg_1^2$ | 50 | 350 | Coal |
| 2 | $250.0 + 4.40Pg_2 + 0.0045Pg_2^2$ | 10 | 150 | Water[1] |
| 3 | $400.0 + 5.00Pg_3 + 0.0025Pg_3^2$ | 50 | 450 | Oil |
| 4 | $350.0 + 6.40Pg_4 + 0.0065Pg_4^2$ | 50 | 450 | Coal |
| 5 | $729.0 + 6.20Pg_5 + 0.0081Pg_5^2$ | 50 | 350 | Natural Gas |
| 6 | $550.0 + 5.80Pg_6 + 0.0035Pg_6^2$ | 40 | 250 | Natural Gas |

[1] input / output parameters in (cubic meters / hr)

Tables II and III show the expected prices of fuel and thermal equivalence, respectively [16].

TABLE II
EXPECTED FUEL PRICES

| Fuel | Price |
|---|---|
| Natural Gas | 0.2800 $\$/m^3$ |
| Oil | 80.000 $\$/barrel$ |
| Coal | 58.590 $\$/ton$ |
| Water | 0.0028 $\$/m^3$ |

TABLE III
THERMAL EQUIVALENCE

| Fuel | Thermal Equivalence |
|---|---|
| Natural Gas | 27.49208 $m^3/MBtu$ |
| Oil | 0.194175 $barrel/MBtu$ |
| Coal | 0.054054 $ton/MBtu$ |

The fuel prices are randomly assigned, and the price of water is taken from reference [17].

The characteristics of the fuel transportation networks are given in tables IV and V.

TABLE IV
COAL NETWORK DATA

| Element | Cost unit transported ($) | Transport capacity (tons) |
|---|---|---|
| 1 | 8 | 5,000 |
| 2 | 10 | 4,000 |
| 3 | 9 | 3,000 |
| 4 | 7 | 4,000 |
| 5 | 13 | 2,000 |
| 6 | 13 | 4,000 |

TABLE V
NG PIPELINES DATA

| Element | Cost unit transported ($) | transport capacity ( $m^3$ ) |
|---|---|---|
| 1 | 0.00014 | 1,500,000 |
| 2 | 0.00012 | 1,500,000 |
| 3 | 0.00013 | 1,000,000 |
| 4 | 0.00015 | 1,000,000 |
| 5 | 0.00053 | 1,500,000 |
| 6 | 0.00053 | 1,500,000 |

Table VI shows the power system transmission line limits and Table VII shows the expected hourly demand during a day.

TABLE VI
POWER SYSTEM TRANMISSION LINES CAPACITY DADA

| Element | transmission capacity (MW) |
|---|---|
| 1-2 | 90.00 |
| 1-3 | 360.00 |
| 2-3 | 360.00 |
| 2-4 | 360.00 |
| 2-5 | 360.00 |
| 3-4 | 360.00 |
| 4-5 | 360.00 |

TABLE I
NODAL HOURLY DEMAND

| Periods (hrs) | Node 2 (MW) | Node 3 (MW) | Node 4 (MW) |
|---|---|---|---|
| period-1 | 200 | 300 | 100 |
| period-2 | 210 | 310 | 100 |
| period-3 | 220 | 320 | 110 |
| period-4 | 230 | 350 | 140 |
| period-5 | 270 | 400 | 230 |
| period-6 | 400 | 500 | 300 |
| period-7 | 395 | 490 | 295 |
| period-8 | 390 | 470 | 290 |
| period-9 | 385 | 465 | 290 |
| period-10 | 385 | 460 | 285 |
| period-11 | 375 | 455 | 280 |
| period-12 | 370 | 450 | 280 |
| period-13 | 360 | 420 | 270 |
| period-14 | 360 | 430 | 270 |
| period-15 | 380 | 460 | 290 |
| period-16 | 450 | 610 | 350 |
| period-17 | 550 | 680 | 430 |
| period-18 | 570 | 700 | 440 |
| period-19 | 560 | 710 | 430 |
| period-20 | 530 | 670 | 400 |
| period-21 | 430 | 470 | 330 |
| period-22 | 380 | 370 | 290 |
| period-23 | 230 | 350 | 140 |
| period-24 | 200 | 300 | 100 |

Two cases are reported where different coal T-O-P contracts for G1 are considered.

### A. *Case A*

In this case the T-O-P fuel contract for G1 is 930 tons of coal.

The results of fuel quantity transported as well as active transportation are presented in Tables VIII and IX.

TABLE VIII
COAL’S NETWORK: CASE A

| **Coal Network** | **Quantity transported (tons)** |
|---|---|
| 1 | 930.0 |
| 2 | 1813.8 |
| 4 | 4000.0 |

TABLE IX
NATURAL GAS PIPELINES: CASE A

| **Natural gas pipelines** | **Quantity transported** ( $m^3$ ) |
|---|---|
| 1 | 261454.78 |
| 2 | 1500000.00 |
| 6 | 1252226.74 |

The total operating cost of $1,707,465.70 includes generation production and transportation, neglecting the cost of storage. They meet the restrictions of the fuel contract in G1 and water consumption in G2. Penalties on coal lines 4 and NG line 2 are over the horizon simulation.

Fig. 3 shows the active lines associated with the transportation networks.

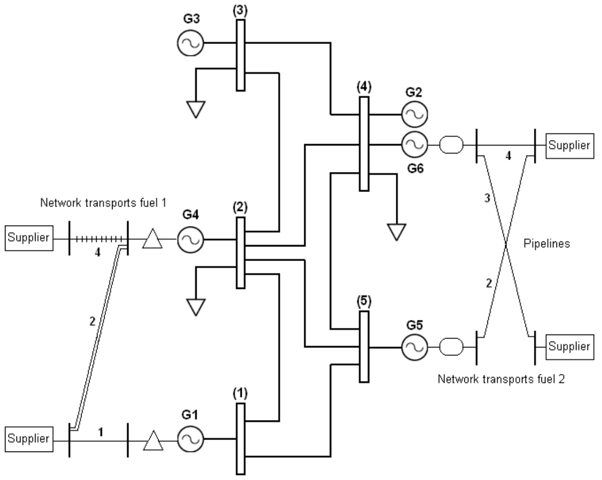

Fig. 3. 5-nodes short-term generation scheduling with G1 under T-O-P contract: case A

Table X contains the power generating output per period. The last row shows the total amount of power produced.

Table X shows that G1, G4 and G6 operate at their limits most of the time (lower for unit 1 and upper for units 4 and 6). The fact that G1 operates at minimum does not mean that it is more expensive to run, but merely that the contract constraint prevents it from generating a larger amount. G4 and G6 prove to be cheaper than G3 according to the optimization model. In addition, G2 has limited its production of energy consumption of 11,000 m³, which the algorithm proves is more economical overall.

TABLE X
EXPECTED S OF EXPECTED GENCOS’ GENERATING ACTIVE POWERS: CASE A

| Period (hrs) | G-1 (MW) | G-2 (MW) | G-3 (MW) | G-4 (MW) | G-5 (MW) | G-6 (MW) |
|---|---|---|---|---|---|---|
| 1 | 50.00 | 10.00 | 50.00 | 400.00 | 50.00 | 40.00 |
| 2 | 50.00 | 10.00 | 50.00 | 420.00 | 50.00 | 40.00 |
| 3 | 50.00 | 10.00 | 50.00 | 449.99 | 50.00 | 40.01 |
| 4 | 50.00 | 10.00 | 50.00 | 450.00 | 50.00 | 110.00 |
| 5 | 50.00 | 10.00 | 50.00 | 450.00 | 90.00 | 250.00 |
| 6 | 50.00 | 37.27 | 108.88 | 450.00 | 303.85 | 250.00 |
| 7 | 50.00 | 32.74 | 99.34 | 450.00 | 297.93 | 250.00 |
| 8 | 50.00 | 25.94 | 85.02 | 450.00 | 289.05 | 250.00 |
| 9 | 50.00 | 23.68 | 80.24 | 450.00 | 286.09 | 250.00 |
| 10 | 50.00 | 21.41 | 75.47 | 450.00 | 283.12 | 250.00 |
| 11 | 50.00 | 16.88 | 65.91 | 450.00 | 277.21 | 250.00 |
| 12 | 50.00 | 14.61 | 61.14 | 450.00 | 274.25 | 250.00 |
| 13 | 50.00 | 10.00 | 50.00 | 450.00 | 240.00 | 250.00 |
| 14 | 50.00 | 10.00 | 50.00 | 450.00 | 250.00 | 250.00 |
| 15 | 50.00 | 21.41 | 75.47 | 450.00 | 283.12 | 250.00 |
| 16 | 50.00 | 89.99 | 220.01 | 450.00 | 350.00 | 250.00 |
| 17 | 87.81 | 150.00 | 372.19 | 450.00 | 350.00 | 250.00 |
| 18 | 116.06 | 150.00 | 393.94 | 450.00 | 350.00 | 250.00 |
| 19 | 110.41 | 150.00 | 389.59 | 450.00 | 350.00 | 250.00 |
| 20 | 54.00 | 149.85 | 346.15 | 450.00 | 350.00 | 250.00 |
| 21 | 50.00 | 44.08 | 123.25 | 450.00 | 312.68 | 250.00 |
| 22 | 50.00 | 10.00 | 50.00 | 450.00 | 230.00 | 250.00 |
| 23 | 50.00 | 10.00 | 50.00 | 450.00 | 50.00 | 110.00 |
| 24 | 50.00 | 10.00 | 50.00 | 400.00 | 50.00 | 40.00 |
| Total | **1368.2** | **1027.8** | **2996.6** | **10669.9** | **5467.3** | **4880.0** |

## *B. Case B*

In this case the T-O-P fuel contract for unit 1 is 970 tons of coal.

Total operating cost is $1,701,497.76. The network fuel topology, shown in Figure 4, changes with respect to case A. Transported amounts of fuels are shown in Tables XI and XII.

TABLE XI
COAL’S NETWORK: CASE B

| **Coal Network** | **Quantity transported (tons)** |
|---|---|
| 1 | 970.0 |
| 2 | 1813.8 |
| 4 | 4000.0 |

TABLE XII
NATURAL GAS PIPELINES: CASE B

| **Natural gas pipelines** | **Quantity transported** ( $m^3$ ) |
|---|---|
| 1 | 261437.99 |
| 2 | 750380.28 |
| 3 | 20022.70 |
| 4 | 499948.96 |
| 5 | 749636.51 |
| 6 | 732255.09 |

Due to the increase in the fuel contract, some generating units are re-dispatched. Consequently, the gas flows are switched, such that all existing pipelines are active in this case (see Fig. 4). However, G5 and G6 do not change their generation outputs as shown in Table XIII.

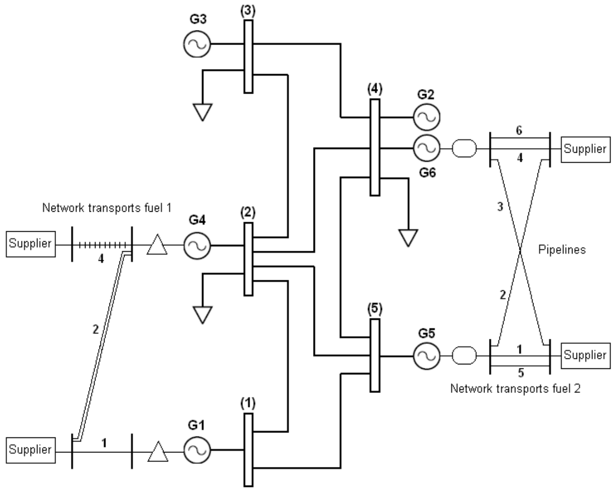

Fig. 4. 5-nodes short-term generation scheduling with G1 under T-O-P contract: case B

With these changes the global optimization cost is reduced by \$5967.94. Nonetheless, the cost of shipping NG has increased slightly, from \$880.28 in case A to \$989.64 in case B. Even when the costs are increased the power system reliability will increase from the raw supply side. Thus, T-O-P allows for efficient power system operations.

TABLE XIII
EXPECTED S OF EXPECTED GENCOS' GENERATING ACTIVE POWERS: CASE B

| Period (hrs) | G-1 (MW) | G-2 (MW) | G-3 (MW) | G-4 (MW) | G-5 (MW) | G-6 (MW) |
|---|---|---|---|---|---|---|
| 1 | 50.00 | 10.00 | 50.00 | 400.00 | 50.00 | 40.00 |
| 2 | 50.00 | 10.00 | 50.00 | 420.00 | 50.00 | 40.00 |
| 3 | 50.00 | 10.00 | 50.00 | 449.99 | 50.00 | 40.01 |
| 4 | 50.00 | 10.00 | 50.00 | 450.00 | 50.00 | 110.00 |
| 5 | 50.00 | 10.00 | 50.00 | 450.00 | 90.00 | 250.00 |
| 6 | 50.00 | 38.06 | 108.11 | 450.00 | 303.83 | 250.00 |
| 7 | 50.00 | 33.51 | 98.53 | 450.00 | 297.97 | 250.00 |
| 8 | 50.00 | 26.71 | 84.24 | 450.00 | 289.05 | 250.00 |
| 9 | 50.00 | 24.44 | 79.47 | 450.00 | 286.09 | 250.00 |
| 10 | 50.00 | 22.17 | 74.70 | 450.00 | 283.13 | 250.00 |
| 11 | 50.00 | 17.64 | 65.15 | 450.00 | 277.21 | 250.00 |
| 12 | 50.00 | 15.37 | 60.38 | 450.00 | 274.26 | 250.00 |
| 13 | 50.00 | 10.00 | 50.00 | 450.00 | 240.00 | 250.00 |
| 14 | 50.00 | 10.00 | 50.00 | 450.00 | 250.00 | 250.00 |
| 15 | 50.00 | 22.19 | 74.73 | 450.00 | 283.08 | 250.00 |
| 16 | 50.00 | 90.86 | 219.14 | 450.00 | 350.00 | 250.00 |
| 17 | 107.46 | 150.00 | 352.54 | 450.00 | 350.00 | 250.00 |
| 18 | 136.02 | 150.00 | 373.99 | 450.00 | 350.00 | 250.00 |
| 19 | 130.30 | 150.00 | 369.70 | 450.00 | 350.00 | 250.00 |
| 20 | 76.95 | 143.41 | 329.64 | 450.00 | 350.00 | 250.00 |
| 21 | 50.00 | 44.88 | 122.44 | 450.00 | 312.69 | 250.00 |
| 22 | 50.00 | 10.00 | 50.00 | 450.00 | 230.00 | 250.00 |
| 23 | 50.00 | 10.00 | 50.00 | 450.00 | 50.00 | 110.00 |
| 24 | 50.00 | 10.00 | 50.00 | 400.00 | 50.00 | 40.00 |
| Total | **1450.7** | **1029.2** | **2912.7** | **10669.9** | **5467.3** | **4880.0** |

By comparing Table X and Table XIII we can observe that G1-G3 have increased their total power produced during the all day as a result of the change in the T-O-P fuel contract.

## VI. CONCLUSIONS

Diversification of fuel supply allows greater certainty in electricity generation. While the management of T-O-P fuel contracts brings certainty in energy prices, if a generator does not select the proper amount of fuel in the contract, it will most likely incur higher costs of energy production that reduce overall revenues in today's highly competitive marketplace.

Increasing the amount of the fuel contract causes a decrease in the objective function. The maximum increase in the amount of the contract may occur in the maximum capacity of the generator, the transmission capacity of the power system or limits on the coal transportation network. To reduce the impact of such fluctuations, and to prevent another scenario such as occurred in Brazil, it is advisable for GENCOs to have in place additional financial contracts. It is appropriate to take payments for capacity in transmission systems for fuel, since this, too, will increase power system reliability.

## VII. ACKNOWLEDGEMENT

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