ELECTRICITY SUPPLY INDUSTRY

Electricity plays a vital role in our society. In the United States alone, retail electricity sales reached $200 billion in 1994. The electricity industry performs three primary functions—generation, transmission, and distribution. Some utilities are engage in all three functions, whereas others specialize in one or two functions.

Generation is the process of producing electricity. In 1994 US electric utilities produced 2.9 trillion kWh of electricity. It was produced using 56% steam-driven generators fueled by coal, 3% steam-driven generators fueled by oil, 9% steam-driven generators fueled by natural gas, 9% renewable resource generators, 1% gas turbine or internal combustion generators, and 22% nuclear generators. In addition, renewable energy resources represent primarily hydroelectric, biomass, geothermal, solar thermal, photovoltaic, wind, and ocean.

Transmission is the process of conducting the flow of electricity at high voltages from the points of generation to the locations of electricity consumption such as residential, industrial parks, and commercial centers. The transmission system consists of transmission lines, substations, voltage transformers, and circuit breakers. Electricity transmission involves fixed costs associated with obtaining rights of way.

Distribution is divided into two functions—delivery and retail sales. Delivery of electricity is the process of transforming high-voltage electricity to lower voltages and then physically delivering it to households, industrial facilities, and commercial establishments. Retail sales of electricity is the process of marketing electricity to customers. Physical distribution of electricity involves large fixed costs for capital amenable to competition. There are different types of generating companies with their own generating capacity and share of final sales; some are owned by investors, whereas the others are publicly owned, rural electric cooperatives, and federally owned utilities.

The US electricity industry began as an unregulated private enterprise in 1882. Then in 1907 the states began to regulate electric utilities. In 1935 the Public Utilities Holding Company Act (PUHCA) transformed the multistate and complex holding companies into simple corporate structure subject to regulation by state authorities. PUHCA granted the Securities and Exchange Comission (SEC) broad power to confine acquisition of assets to geographically defined areas and to functions related to utility operations. PUCHA also has a responsibility for controlling the utilities' corporate structures. The use of atomic energy to produce electricity started in 1950. At that time, privately owned utilities were fully under the control of state public utility commissions, the SEC, and the Federal Public Commission (FPC).

In 1950 average electricity rates fell from 3¢/kWh to 2.5¢/kWh for residential customers, and demand for electricity grew at twice the annual rate as the national economy. In 1965 the system suffered the great Northeast blackout. The utility industry responded by forming the North American Electric Reliability Council (NERC) charged with keeping electricity service reliable. In 1992 the Energy Policy Act started to widen access to the transmission grid. In 1994 California proposed to allow competition at retail level by 2003. In 1996 the Federal Energy Regulatory Council (FERC) issued Order 888, which specified conditions under which all utilities must provide such access to the US transmission system.

ENERGY SOURCES

Nonrenewable Energy Sources

Nonrenewable energy sources are coal, oil, natural gas, and nuclear energy. In 1990 oil provided about 41% of the world's energy derived from nonrenewable sources; coal provided about 29%; natural gas, 23%; and nuclear energy, 6%.

1. Oil is the world's most widely used fuel; the total usable energy contained in the world's oil reserves is about one sixth of the coal reserve.
2. Coal is the world's most abundant nonrenewable energy source. Coal is the least expensive of fossil fuels and is widely burned for domestic and industrial heat and electric power generation. Coal was the industrial world's main energy source until the early 1960s, when the availability of inexpensive oil and the growing use of liquid fuels for transportation made oil the dominant fuel. During the 1970s, the rapid increases in the price of oil brought about a modest worldwide return to coal for heating and electric power generation. However, oil has remained the leading energy source.
3. Natural gas is not as abundant as coal. The energy content of the world's natural gas reserves is comparable to that of oil. Methane, which is the major constitute of natural gas, burns easily and can be untreated as an industrial or domestic heating fuel. However, when compared to oil, methane has a few significant disadvantages, which have tended to limit its use.
4. Nuclear energy is produced by nuclear power plants through a process known as nuclear fission. Here a free-moving atomic particle called a neutron collides with the nucleus of an atom and causes it to split apart. During fission, a portion of the split atom's mass is converted into energy. Nuclear fission produces additional free neutrons, which can split other atoms in a chain reaction.

Renewable Energy Sources

Hydropower. Hydropower converts the energy in flowing water into electricity. The quantity of electricity generated is determined by the volume of water flow and the amount of head, the height from turbines in the power plant to the wa-

J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*.

ter surface created by the dam. The greater the flow and head, the more electricity is produced. With a capacity of more than 92,000 MW (enough electricity to meet the energy needs of 28 million households), the United States is the world's leading hydropower producer. Hydropower supplies 49% of all renewable energy used in the United States.

Biomass Energy. Biomass energy (the energy contained in plants and organic matter) is one of the most promising renewable energy technologies. Instead of conventional fuels, the technology uses biomass fuels (agricultural residues, or crops grown specifically for energy production) to power electric generators. Today, biomass energy account for nearly 45% of renewable energy used in the United States. Biomass is used to meet a variety of energy needs, including generating electricity, heating homes, fueling vehicles, and providing process heat for industrial facilities.

In the last few decades, biomass power has become the second largest renewable source of electricity after hydropower. Hydropower and biomass plants provide baseload power to utilities. Biomass power plants are fully dispatchable (i.e., they operate on demand whenever electricity is required). About 350 biomass power plants with a combined rated capacity of 7000 MW feed electricity into the nation's power lines, whereas another 650 enterprises generate electricity with biomass for their own use as cogenerators. National Renewable Energy Laboratory (NREL) research has helped lower the cost of ethanol fuel from these sources to $1.22/gal. The target of current researches is 70¢/gal.

Photovoltaic (PV) Systems. Most commonly known as solar cells, PV systems convert light energy into electricity. PV systems are already an important part of our lives. They are a popular means of powering small calculators and wrist watches. More complicated PV systems provide electricity for pumping water, powering communications equipment, and even lighting our homes and running our appliances. In a surprising and increasing number of cases, PV power is the cheapest form of electricity for performing many tasks. Costs have dropped from 90¢/kWh in 1980 to 22¢/kWh in the late 1990s. Photovoltaics are cost competitive in rural and remote areas around the world. The National Photovoltaics Center at NREL is leading federal efforts to improve performance and lower costs (1–10).

Wind Power. Wind energy projects provide cost-effective and reliable energy in the United States and abroad. The US wind industry currently generates about 3.5×10^9 kWh of electricity each year, which is enough to meet the annual electricity needs of 1 million people. Wind energy installations are going up across the country as generating companies realize the benefits of adding clean, low-cost, reliable wind energy to their resource portfolios.

Solar Thermal Systems. Solar thermal electric (STE) technologies, which include parabolic troughs, power towers, and dish/engine systems, convert sunlight into electricity efficiently and with minimum effect on the environment. These technologies generate high temperatures by using mirrors to concentrate the sun's energy up to 5000 times its normal intensity. This heat is then used to generate electricity for a variety of market applications, ranging from remote power needs as small as a few kilowatts up to grid-connected applications of 200 MW or more. Solar-thermal electricity provides electricity for grid-connected applications at the lowest price available today, and it has the potential for further, significant cost reductions. Although not currently competitive for utility applications in the United States, the cost of electricity from STE can be competitive in international and domestic niche applications, where the price of energy is higher. The goal for advanced STE technologies is to be below 5¢/kWh.

The United States annually uses more than 7.1×10^{13} Btu of solar energy (1.0×10^6 Btu equals 90 lb coal or 8 gal gasoline). The residential and commercial sectors use 6.0×10^{13} Btu, the industrial sector uses 1.1×10^{13} Btu, and utilities use 5.0×10^{11} Btus.

Geothermal Energy. Geothermal energy is the heat contained below the Earth's crust. This heat is brought to the surface as steam or hot water—created when water flows through heated, permeable rock—and used directly for space heating in homes and buildings or converted to electricity. Most of the country's geothermal resources are located in the western United States.

Currently, US geothermal power plants have a total generating capacity of 2700 MW, enough electricity to power the homes of more than 3.5 million people. The power plants produce electricity at 5¢/kWh to 7.5¢/kWh. The Geysers Power Plant in northern California, the world's largest geothermal power plant, generates more than 1700 MW of electrical power, 7% of the total electricity Pacific Gas and Electric Company (PG&E) supplies to California.

Ocean Thermal Energy. Ocean thermal energy conversion (OTEC) is an energy technology that converts solar radiation to electric power. OTEC systems use the ocean's natural thermal gradient—the fact that the ocean's layers of water have different temperatures—to drive a power producing cycle. OTEC systems can produce a significant amount of power as long as the temperature between the warm surface water and the cold deep water differs by about 20°C (36°F). The oceans are thus a vast renewable resource, with the potential to help us produce 10^{13} W of electric power. The economics of energy production have delayed the financing of OTEC plants. However, OTEC is very promising as an alternative energy resource for tropical island communities that rely primarily on imported fuel.

Energy Storage

Energy may be stored in a variety of forms, including thermal, electrical, mechanical, and chemical energy. Storage systems are a valuable addition to renewable energy facilities whose output is variable and sometimes difficult to predict. Adequate storage can help ensure that the intermittent output from solar and wind facilities is available when it is needed. For example, batteries have been used to provide energy storage for small photovoltaic arrays and wind turbines that have been installed at thousands of locations worldwide during the past 10 years. Energy storage can provide benefits to utilities by bridging the gap between energy supply and demand and thereby using their generating capacity more efficiently. Rather than cycling units on and off as demand fluctuates, utilities can operate more of their units during the day, storing surplus energy produced during hours of low demand and later using it when the demand increases. More details will be demonstrated in the next sections by an application to battery storage (33–35).

SHORT-TERM THERMAL GENERATION SCHEDULING

In the electric power system, the load will be higher during the day and early evening and lower during the late evening and early morning. Also, the load is lower during weekend days than during weekdays. The problem in the electric power system is that we would like enough committed (turned on) units to supply the load while generation and operation costs are minimized.

An available option is to apply augmented Lagrangian relaxation (11,12) to solve the thermal unit commitment problem. The production cost is calculated as the product of the unit's heat rate (MBtu/h) and fuel cost ($/MBtu) with an approximated cost function as a quadratic equation. The optimization problem has the following constraints.

1. According to system real power balance equation, generation should be equal to the load.
2. System spinning reserve should be sufficient to make up for a generation unit failure, and it should be spread around the system to avoid transmission limitations.
3. The transmission line capacity has limits.
4. There is a total emission limit.
5. Thermal unit limitations are represented by the following constraints:
   a. Minimum up time—Once the unit is on-line, it should not be turned off immediately.
   b. Minimum down time—Once the unit is decommited, there is a minimum time before it can be recommitted.
   c. Crew constraints—The number of units that can be started up is limited by the number of crew members available.
   d. Ramp rate limits—There are limits on the rate of change in power generation of each unit.
   e. Fuel constraints—Some units can burn only a limited amount of fuel in a given time, whereas other units must burn a specified amount of fuel in a given time.
   f. Minimum and maximum power generation for each unit (21,24).

Short-Term Generation Scheduling in a Thermal-Photovoltaic Grid with Battery Storage

We present an efficient approach to short-term generation scheduling for an integrated thermal and photovoltaic–battery generation. The proposed model incorporates battery storage for peak load shaving. Several constraints including battery capacity, minimum up/down time and ramp rates for thermal units, as well as natural photovoltaic capacity are considered in the proposed model. A case study composed of 26 thermal units and a PV–battery plant is presented to test the efficiency of the method (13–15).

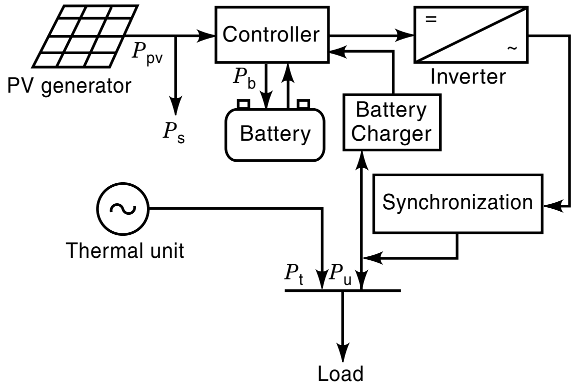

Figure 1. PV-utility grid with battery storage.

Problem Formulation. The PV utility uses the energy generated by PV plants to minimize the cost of operating thermal units. Figure 1 presents an example of a PV-utility system; the PV system may be spread out over a large geographical area with the battery in a centralized location.

The intermittent nature of a PV system adds a significant variance to the thermal generation of a power system. For secure operation, utilities have traditionally planned for normal load fluctuations and sudden loss of the largest generating unit. For the most part, penetration of PV performs well up to about a certain percentage (i.e., 5% of the scheduled load at a time) (2). In certain generation dispatches, this penetration can increase, depending on the available thermal units and their ability to perform regulatory duty. This ability varies based on the season and will be different for each utility. For maintenance reasons, the battery is charged at fixed power for a few hours at particular time to avoid sulfation.

Results and Discussion. The effect of a PV system and battery on thermal generation can be seen in Fig. 2. Using a PV system without a battery reduces thermal unit generation during hours 5 to 21, which in turn reduces the production cost. The most severe condition created by PV generation without battery results from the change in PV generator output when radiation decreases but the load increase (hours 17 to 19). This appears to thermal units as a large, sudden load change. These large load changes may not be tolerated by the thermal PV system because additional thermal unit commitment is limited by ramp rate and minimum up/down time of thermal units.

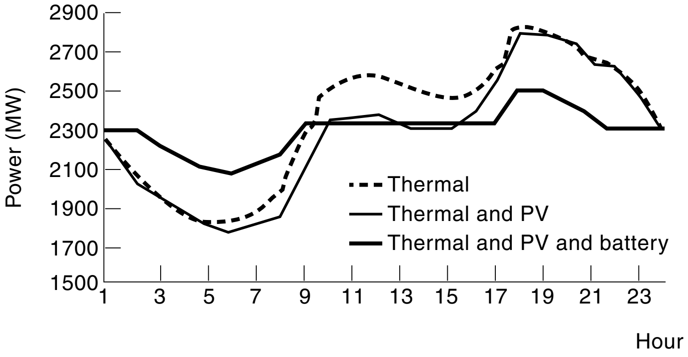

Figure 2. Thermal unit generation.

Table 1. Production Costs

No.	Case	Cost ($/day)	Battery Consumption (MWh/day)
1	Thermal only	749,541	—
2	Thermal & battery	742,931	388
3	Thermal & PV	709,808	—
4	Thermal & PV & battery	696,124	344

In Fig. 2, the type of battery used in PV-utility plants provides the flexibility to schedule thermal units as follows:

1. To avoid commitment of expensive thermal units during peak load hours, which in turn reduces the fuel cost.
2. To avoid base generation, such as nuclear plant, to be shut down in low load hours.
3. To avoid frequent start-up and shutdown of thermal units which in turn reduces the start up cost.

The production cost savings resulting from the use of a battery and a PV system are seen in Table 1. We test four different cases. In the first case, load is supplied by thermal units only. In the second case, we add battery to the system for the load peak shaving. In the third case, load is supplied by a PV system and thermal units without battery. In case four, we add a battery to PV-thermal generation. From Table 1, we see that PV and battery (case 4) can save fuel costs by as much as $53,417/day over case 1. We also see that even when there is no PV energy (case 2) the battery provides a saving of $6,610/day over case 1 in the total daily production cost. The battery consumption represents additional energy needed for charging the battery. For our cases, this consumption is not significant as compared to the benefits of shaved peak load.

Figure 3 shows the penetration of PV plant. The white bar is the PV power flow to the utility when we do not consider the battery. The dark bar represents the case where we use a PV system and a battery. The battery is designed to save fuel costs by serving the peak load in the evening (a high fuel-cost load) with stored energy and then charging at light load periods after midnight (a lower cost load). At hours 1 to 9, the injected power is negative as the battery is charged for peak shaving (23–25).

RESTRUCTURING THE ELECTRICITY INDUSTRY

Restructuring the electricity industry will introduce additional competition, which may lead to lower rates and expanded forms of service. The electricity industry is divided into three sections—power generation, long-distance transmission, and local distribution. Many proposals to deregulate electricity generation and expand competitive electric power markets are currently under consideration by state and federal regulators. There is wide disagreement on whether the authority to expand competition and to be responsible for the effects of expanded competition should lie with states or the federal government.

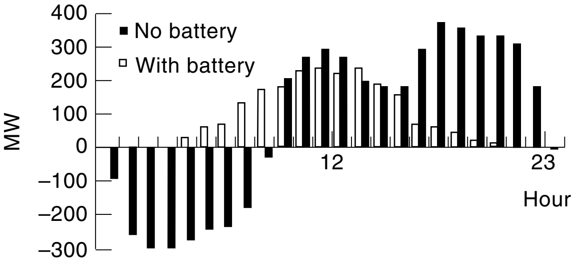

Figure 3. Penetration to the utility from PV plant.

Components of a Deregulated System

In the deregulated environment, there are mainly three players—GENCOs (generating companies), DISCOs (distribution companies) and TRANSCOs (transmission providers). The GENCOs are the companies that own the generation and sell the power. DISCOs are typically companies that buy power from GENCOs and sell it to customers in their area. TRANSCOs are companies that own and operate the transmission networks. GENCOs and DISCOs enter into negotiations to finalize the power deals. After a deal is finalized, one of the parties must book the transmission capacity so that the power can be "shipped" from the delivery point to the receipt point. This process of reserving transmission capacity is done through the Internet. This brings in another entity into the picture—the OASIS (Open Access Same-time Information System). The OASIS provides the Web interface for checking out the available transfer capacities between two buses and to reserve transmission capacity.

There is an additional entity, which acts as the go-between for a GENCO and a DISCO. It negotiates a lower price from the various GENCOs, consolidates the power, and sells it at a higher price to a DISCO. Conversely, it can combine small demands of various DISCOs and, after consolidating, buy in bulk from a GENCO.

Because all the deals are market-based, there is an entity known as the ISO (Independent System Operator) in charge of the operations of the grid. The ISO takes care of deals that are finalized and can, in fact, be allowed to go through the system without having any abnormal effects on the grid (17–22).

Competition and Market Structures

Advances in technology are making competition an increasingly attractive alternative to traditional regulation of the electricity. A second motivation for change is dissatisfaction with the current way regulation sets electricity prices. There are two types of competition in the electricity industry. Expanded wholesale competition opens the market so that generators can sell power to local distributors and other wholesalers. The second type is the retail competition, where generators can supply power to customers directly or via marketers.

There are two types of market structures—the bilateral contracting and the PoolCo market structures. The difference between the two can be found in the activities performed by the system operators. Several factors affect the choice of bilateral contracting or PoolCo market structures or a combination of the two.

California Market Structure

The investor-owned electric utility industry in California will be restructured to allow for wholesale and retail competition in 1998. Under the plan, an ISO will operate, as a single control area, the transmission systems that at present are owned and operated by the three largest utilities in the state—Pacific Gas & Electric Co., Southern California Edison Co. and San Diego Gas & Electric Co.

The ISO will be responsible for ensuring that schedules for using the transmission system are feasible, operating the transmission system in real time, and settling financially with parties who use the transmission system. It will guarantee open access to the transmission grid so that no particular group of market participants—wholesale or retail—is favored.

A separate power exchange (PX) will serves as a daily spot market for electricity with publicly posted prices. That is, an auction will be held daily in which bids will be taken for each hour of the next daily operation. The PX and ISO will work together not only to provide competitive generation markets but also to safeguard the reliable operation of the transmission network. Market participants will compete in day-ahead and hour-ahead physical energy and ancillary service market. Generation, load, and out-of state interchange can participate by making bids to the PX. In addition, market players are free to arrange bilateral trades through scheduling coordinators. The next-day market consists of 24 individual hourly markets. Load and generation bids are evaluated each hour, based on bid price. Responsibility for unit commitment (scheduling) resides with those who bid generation and not with the PX.

The PX serves to match generation with load and to provide the resultant balanced energy schedules to the ISO. The ISO then evaluates the feasibility of the proposed schedules from a transmission network security standpoint. For the purposes of transmission management, the California network is divided into multiple zones. The ISO identifies the constraining interzonal transmission facilities and allocates their usage to the highest value users. The users of the constraining facilities then pay for the (redispatch) cost of congestion management, as determined by ISO.

Generation resources participate in redispatch process for congestion management by making energy adjustment bids. The ISO selects from among these bids, when required, based on their cost-effectiveness. Minor congestion within a zone is resolved by slight redispatch, with associated costs borne by all schedules within the zone by means of a zonal uplift charge.

In addition to energy in the next-hour and next-day markets, essential ancillary services are bid. These include frequency regulation, reactive support and spinning, nonspinning, and replacement reserves. Black start capability is contracted on an annual basis. The ISO manages real-time energy imbalance by dispatching a supplemental energy source, which bids into the next-hour market. The power exchange and scheduling coordinators communicate with the ISO using Internet-based communications protocols. The ISO also communicates with generators and dispatchable loads using dedicated real-time communications links.

The California model collectively implements the nondiscriminatory open access requirements without the need for any OASIS and transmission providers.

A new approach for unit commitment with game theory in a deregulated power marketplace may be used by GENCOs to schedule generating units. They will take into account the availability and capability of transmission lines given by TRANSCO to ISO. This approach is demonstrated in the next section (16–22).

GENERATION SCHEDULING FOR ELECTRICITY PRICING IN A DEREGULATED POWER MARKET

The unit commitment problem is to determine which units in a GENCO should be on-line at a given hour in the deregulated power marketplace. In a deregulated power marketplace, the modified load is not equal to the local load. It can be higher or lower depending on the market price. If the spot price in the marketplace is high, then the modified load in a GENCO is high and vice versa. There must be some methodology to determine the modified load for GENCOs so that they can commit their units to maximize their profits. The chance to trade power depends on the bid provided by each GENCO for each committed generator. The modified load is calculated so that the GENCO's profit is maximized. Then unit commitment is applied using the modified load. Profits are maximized by optimal transaction analysis via the game theory.

Game Theory Concept

Game theory is an interdisciplinary approach to the study of human behavior in which the outcomes depend on the interactive strategies of two or more participants (players) who have opposed motives. There are two types of games—the zero-sum game and the non-zero-sum game. The participants are assumed to be the GENCOs.

In the zero-sum game, any profits made by a player are equal to the other players' losses. It is called "zero-sum" because, no matter what is done by any player, the total profit in the PoolCo is zero. The zero-sum game is a noncooperative game.

In the non-zero-sum game, any profit made by a player is not necessarily equal to the other players' losses, and the total profit in the PoolCo is nonzero. This game represents the actual situation in the deregulated power marketplace. There are two types of non-zero-sum games—the cooperative game and the noncooperative game (see Refs. 2, 14, and 16 for more details). Some of the games are considered with complete information, whereas others are played with incomplete information. In a game with complete information, players (GENCOs) have full information about the generation cost functions of others. In a game with incomplete information, players (GENCOs) have partial information on opponents' generation cost functions. The incomplete information game is considered by modeling the player's unknown characteristics as the player's type. The type of a player embodies any information that is not common to all players (e.g., the player's payoff function, beliefs about other player's payoff functions, beliefs about what other players believe his beliefs are, fuel prices, and availability of transmission lines). The incomplete information game is transferred to a complete information game by assigning a basic joint probability distribution to unknown variables.

The non-zero-sum game represents the actual situation in the deregulated power marketplace (27–29).

Optimal Transaction Analysis with Game Theory

We assume that every PoolCo's participant (GENCO) performs its own resource scheduling and provides the ISO with

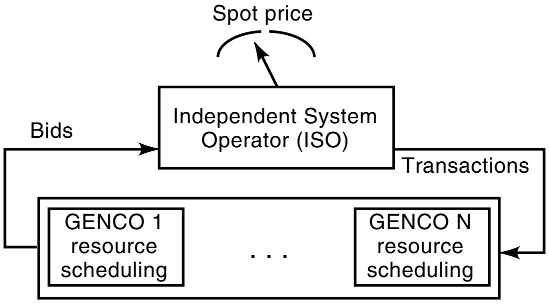

Figure 4. The marketplace structure (PoolCo).

a bid for supplying the load. The ISO analyzes the bids and defines transactions among participants by looking for the minimum price that satisfies the load in the PoolCo (spot price). The mechanism adopted for the deregulated power marketplace is shown in Fig. 4. For a defined market spot price, each GENCO maximizes its own profit. The optimization is constrained by generation limits in the generators, power balance at each bus, and power flow limits.

GENCOs can maximize their profits by changing the bidding strategy. Trading electric power with other GENCOs depends on strategies in the game. GENCOs play the game using different strategies to maximize their own profits. The participants' cost functions are considered confidential. ISO receives bids and tries to supply the load. If the load is higher than the power offered by participants, the spot price will increase; otherwise, it will decrease. If the spot price defined by ISO is lower than the participant's bid, then the participant will import power. Otherwise, the participant will export power if the spot price is higher than the participant's bid. The modified load for any GENCO is equal to its total generation.

Before transactions are defined, each GENCO supplies its local load by applying a unit commitment to its units. Then, each GENCO offers prices at each hour in the time horizon to the Pool. We assume each player is a GENCO that can either sell or buy power and that bids are interpreted by the ISO as incremental price curves where transactions are defined in order to minimize total expenditures. Profits are computed as the difference between the total expenditure before and after transactions.

The slope of the bid curve is modified for each unit to get the maximum profit. A GENCO can change its strategies as the others can do the same. So, a game theoretical approach is applied to analyze these strategies with the corresponding profits for each GENCO. A new strategy is introduced by changing bid slopes (26–29).

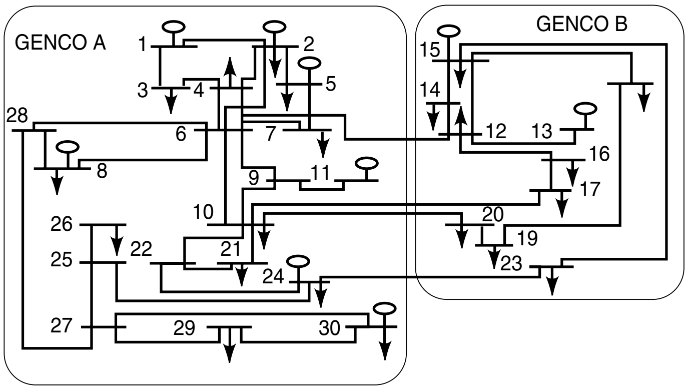

Figure 5. IEEE-30 bus system topology.

Case Study

We apply the proposed method to the modified IEEE-30 bus system. This system is made of 9 generating units, 20 loads, 30 buses, and 41 transmission lines (30). A study period of 24 hours of winter weekends, weeks 44 to 52, is considered. The system topology is shown in Fig. 5, where tie lines are drawn with thicker lines. For simplicity, the system is divided into two GENCOs; GENCO A and GENCO B. The reserve is 5% of the load. The generation cost is expressed by quadratic equation.

Consider the GENCOs before applying the game theory and optimal transactions. The unit commitment based on the original local loads is shown in Table 2, and the bid parameters are calculated. Now, GENCO A plays the game against GENCO B using their bids. GENCO's objective is to maximize its profits by modifying the slope of the bid curve for each generator. While modifying the bid for each generator, the sell or buy option is checked by comparing profits at each hour in the time horizon. After calculating the modified load at each hour, we apply unit commitment. The results are shown in Table 3 where units that are shown in italics change status.

From the results, at hour 18, GENCO B's dominant strategy is to bid high. The dominant optimal strategy for GENCO A at hour 18 is to bid high. For GENCO A, the modified load at hour 18 is 239.3 MW where the local load is 227.2 MW. The unit commitment cost in GENCO A is increased from $67,224.80 to $77,301.00 after applying the game theory.

Table 2. Unit Commitment Before Playing the Game

GENCO	Generator at Bus No.	Hour (1–24)																							
GENCO A	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GENCO B	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 3. Unit Commitment After Playing the Game

GENCO	Generator at Bus No.	Hour (1–24)																							
GENCO A	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	*1*	*1*	*1*	*1*	0	0	0	*1*	*1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	*1*
	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GENCO B	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

However, the profit at each hour is increased from \$0/h to \$4.05181/h at hour 18, which is the major issue in the deregulated power marketplace.

REMARKS

Electricity use pervades all facets of our daily life. The electric power industry is shifting from a scenario in which the operation schedule is fully regulated to a new competitive and deregulated scenario.

The short-term generation problem is to determine the hour at which thermal units of an electric power utility should either be taken off-line or be put on-line. In order to produce a scheduling procedure that is practical, it is essential that numerous and complex constraints are incorporated into the solution method.

Renewable resources are energy sources that do not use exhaustible resources as fuels. Federal and state policies have boosted the use of renewable resources in electricity generation.

There are some uncertainties in the electricity market. The game theory is introduced to model these uncertainties to identify the strategies to be adopted by GENCOs for electricity pricing (31–35).

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