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Challenges and Trends of Restructuring Power Systems due to Deregulation

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Abstract: - The deregulation of power systems creates new demands for their operation. In this paper, taking into account electricity market models, we analyze in detail the technical considerations needed and we provide the main trends for the power system restructuring focusing on the design of Local and Wide Area controls supported by suitable information systems. The British model is described as a characteristic example of the new market requirements.

Key-Words: - Deregulation, Power System restructuring, Power System Control and Stability.

1 Introduction

The deregulation of power systems and the restructuring of energy utilities into new competitive markets create some new conditions in the system operation. Under these circumstances, the solutions of the new problems lead to new challenges in the design of the integrated system. Large vertically integrated utilities providing power at regulated rates are being restructured to incorporate competitive companies selling unbundled power. Consumers were supposed to benefit from lower rates expected as a result of serious bulk power markets. Unfortunately, in some cases, larger electricity bills and poor power quality in terms of blackouts and brownouts have been experienced [1].

In the case of deregulated electricity market, data transmission and control at the system level will become much more important in the future, as generating companies may have clients dispersed over a geographically diverse area. They produce electricity using the standard central station type of facilities and the energy is transported at the high voltage transmission level. This may require development of new centralized control strategies to avoid bottlenecks due to congestion in the event of a lack of transmission capacity. To maintain successful and reliable system operation, it offers additional challenge of the coordination of controls between the various independent bodies, each having different objectives and goals.

The recent incidents of a number of major blackouts in various parts of North America and Europe raise another problem that will draw significant attention. They have already resulted in rethinking and in some cases slowed the march towards deregulation. Measures such as wide area control employing GPS technology may be required to gain more up-to-date knowledge of the state of the system so that predictive measures can be taken to minimize the area to be affected adversely in case of major disturbances [2, 3, 4].

In this paper, a number of new developments and trends due to the restructuring of the power system are discussed. Particularly, wherever deregulation has been implemented, market forces are affecting the normal operation of the power system; the nature of certain traditional functions, such as generation scheduling, economic dispatch, unit commitment, etc. is being affected significantly. Therefore instead of performing these functions through optimal load flow, etc., the system operator will have to manage the network according to market requirements, dictated by supply contracts, bids for available generation and the location of the load. The system operation function will change to that of managing the transmission network. Instead of the power flowing over the network according to the laws of nature, the power flow will have to be managed by incorporating new controls based on power electronics. A number of new control strategies based on advanced control methodologies and high power control devises (such as advanced PSS and FACTS) are proposed to be applied in order to control the flow of active and reactive power and maintain phase and voltage stability [1,4].

2 The new operating conditions

In order to apply deregulation policies to the electricity market, significant changes should be made to the way the market operates. These changes are collectively known as restructuring. Restructuring refers to reorganizing electric companies from vertically integrated monopolies into separate generation, transmission and distribution companies. This is intended to promote competition between generators and to open transmission and distribution systems [5].

The essential aspects of restructuring are wholesale and retail access. Wholesale access is the ability of generators to access transmission systems and to compete in for wholesale markets including distribution companies and independent markets. On the other hand, retail access refers to the ability of marketers to obtain access to distribution systems in order to sell electricity to end customers. Conversely, end consumers will be able to choose a marketer to buy electricity from. The prerequisite for retail access is wholesale access.

The implementation of restructuring requires the utilization of new strategies and techniques in a number of electricity market sectors, ranging from generation, transmission and distribution up to pricing policies.

3 Trends and Challenges of Restructuring System

Before looking at technical considerations, necessary for applying restructure, we shall consider the different market models available.

3.1 Electricity Market models

In principle, the electricity market resembles any other industry where goods are manufactured and transported to the customers. The customer has contracted to purchase a certain amount of goods at the agreed price. For efficiency reasons, intermediaries exist, who purchase and resell goods and arrange delivery to diverse locations. In the electricity market, there is just one good and the amount produced must equal the consumption on a second-by-second basis. If for example, the load exceeds production, the frequency will start to drop and this may result in a brown out or eventually in black out. From the market view point, there must be a continuous connection between generators and consumers and various intermediaries (co-ordinators, market brokers) act to facilitate the energy transfer.

We must note that within a power system a generator cannot physically direct its output to a particular load (contracted customer). A generator can control the mechanical energy provided to its plant by varying fuel consumption. Power is transferred from generation at point A to generation at point B by increasing the power output of generation at B and reducing by the same amount the power output of the generation at point A.

Several electricity market models have been proposed, each representing a step in the transition from the monopoly to a fully competitive market. These models have been proposed or implemented in various US states, UK and elsewhere in Europe. The main models identified are the following [6]:

Model 1. Monopoly at all levels (generation, transmission, distribution). In this model there are no competing generators or retailers and there is no choice for any customer. The price policy is enforced by the government.

Model 2. Purchasing Agency. In this model, a single buyer can purchase electricity from competing generators. The buyer can then transfer the electricity over the transmission and distribution system (which both operate in monopoly state) and sell to customers of all sizes at agreed prices. This model introduces competition at the generation level.

Model 3. Wholesale competition. In this case, generators become completely degenerated and competitive. The many independent generators compete to sell power to distribution companies. The Independent System Operator (ISO) is responsible for the reliable operation of the market and for coordination for auxiliary services, control and transmission. ISO also controls the dispatch of power through an energy pool. Distribution companies are free to purchase electricity from the generator of their choice. The distribution companies however maintain their monopoly to the final customers of all sizes. Under wholesale model, each electric utility that owns transmission facilities is required to provide the same services to all interested parties, at the same terms that provide transmission to itself. A distribution company that wishes to purchase energy can make two kinds of contracts: Purchase the power from the pool, or deal directly with a generating company.

The main features of the wholesale model are:

- Generation is separated from the transmission and distribution business.
- The ISO is responsible for the reliability of the grid and the proper dispatch of power. ISO also coordinates ancillary services, transmission services and sets the rules for participants.
- Distribution companies purchase electricity from the wholesale market and sell it to end customers along with other services.

Distribution companies provide load forecasts to ISO, who uses them to schedule daily power dispatch.

There are two pricing options available: bilateral through which parties deal directly with each other and the pool market where distribution companies purchase at a price set by ISO who takes into account the operating costs of the generators needed to cover the demand.

The wholesale model is very similar to the model implemented in UK and Wales after the privatization. It has been as well applied in many diverse markets ranging from California to Ukraine and India.

Model 4. In this case, all customers have access to competing generators, either directly or through a retailer of their choice. The prerequisite for retail competition is the full separation of generation, transmission and distribution. Customers of all sizes can choose to purchase through the pool or through short-term or long-term bilateral constraints.

3.2 Technical considerations

The deregulation of the electricity market creates new needs for the control and information structure. This is mainly due to the following reasons:

- In a deregulated environment the generators have to compete for contracts and have no assurance for keeping a given market share. Since generators enter and exit the grid according to their contracts, we must expect a continuously changing profile of power generators. This could seriously affect voltage at critical points in the system.
- The large number of participants in the market with different scopes and conflicting interests make an imperative need the access to different sets of real-time and historical data. In order to prevent market power phenomena, it could be necessary to apply restricted access policies.
- The increased number of transactions between buyers and sellers creates more needs for recording large sets of data.
- The large number of small size units (e.g. wind units) expected to integrate with traditional generation plants.

Next, we shall identify some technologies traditionally used for power control and that have to be upgraded in the new environment, divided in local and wide area controls [1,2,3].

3.2.1 Local controls

We can define local controls as those their inputs and outputs are within the same area and consequently no information infrastructure is needed. In most of the cases the input is analog (voltage, current, frequency) and the output represents on/off states (like circuit breakers).

Protection. This is the fastest and the most localized control. In many cases, it can be a microprocessor based circuit breaker. Beyond protection against excessive currents, it can guard against voltage and frequency deviations and instability. The algorithms implemented can be quite sophisticated.

Governor Control. The governor guards against rotor speed and frequency deviations. Due to requirements for high response speed and low dead band, the mechanical governor is replaced by electrohydraulic governing.

Voltage control. The excitation of the generator is controlled to maintain a constant output voltage. A widely accepted solution is the adoption of tap-changing transformers. Supplementary excitation controls known as Power System Stabilizers (PSS) which are used to enhance power system stability have to be redesigned in order to operate over a wider range of conditions, while withstanding parameter uncertainties and disturbances.

Power flow control. For some time ago, the power flow on a ac line was controlled by phase-shifting transformers. The speed of this control was rather slow. Nowadays, fast controllers based on power electronics (FACTS) have been developed for ac lines.

In a restructured system, the goal would be to obtain the desired performance for the system, by applying relatively simple local control laws. Agent-based control could be very helpful in a decentralized control environment, since it has helped to improve algorithms for solving computationally complex problems that arise in power system control. These problems are known as NP-complete and are defined as the problems for which no polynomial-time algorithm exists. Algorithms for solving such problems are one of the most perplexing open research problems in computer science [4].

The nature of the power grid suggests that local adaptive controls like intelligent agents should be combined with robust control techniques, in order to make sure that unforeseen interactions and side effects of the local controllers will not result in difficult to predict destabilization of the whole grid.

A potentially fruitful approach is the passivity based control. In passivity design, instead of assuming that a mathematical model captures all the details of the underlying system, we try to modify the dynamics of the system in a way that in any deviation from the nominal point, energy damping (analogous to friction of mechanical systems) drives the system in the nominal equilibrium point. An advantage of passivity techniques is that the action of multiple controllers is additive and enforcing and there is no possibility to destabilize the system due to undesirable interactions. This is a very desired feature, especially in a deregulated environment, where the expansion of power systems results in oscillatory behaviour [4].

Another technique for robust control is, instead of using a constant-parameter controller, the introduction of adaptive controllers based on analytical and Artificial Intelligence methods. Such a controller that can be mainly used for PSS design is able to adapt its action to the changing underlying parameters and significantly increase the stability margins of the system [1, 7].

When one producer sends electricity over the grid, the current flows along all paths available. The current that flows along each line, depends on the line impedance (which in turn depends on line length and design parameters). Changing the power flows over the system to reduce the loading on the critical line after a contingency occurs increases the power transfer that can be achieved. Technologies, developed as a part of Flexible AC Transmission Systems, (FACTS), use power electronics switches to provide finer and faster control and change the way power flows divide over the grid under normal operation or under transmission contingencies. A FACT device can decrease the load on an overloaded line and increase the load on alternative paths with available capacity. This would allow for increased transfer capability in existing transmission and distribution systems. The integration of FACTS in the power system will help to improve voltage quality and grid stability while simultaneously facilitates the deregulation objectives [1, 2, 4].

3.2.2 Wide area controls

This control scheme includes:

Frequency control. When an increase in load occurs at the system, the mechanical speed and consequently the frequency of interconnected generators will fall, since the increased energy required by the grid will be drawn from the kinetic energy stored in the rotors. The governor control is applied to cope with such situations. In order to maintain system frequency and schedules between areas, AGC (Automatic Generation Control) is used as a secondary loop to control generators. The role of AGC is to respond to Area Control Errors (ACE) computed for each area. A negative ACE means that the area does not produce enough power to meet the load. The AGC runs typically on a periodic cycle of 10 sec. and on each cycle each plant receives a signal to adapt its output as determined by the principles of economic dispatch [8].

Regional Voltage Control. It is analogous to AGC. This scheme monitors voltage at key buses and then schedules voltage over a wider area to maintain the key bus voltage. The set points are then sent to the local voltage controllers.

To apply these control schemes, a communication infrastructure is needed in order to acquire input signals and to apply control.

To coordinate the above scheme a SCADA/EMS typically is employed. A usual SCADA consists of four levels. At level 0 there is the power system with transmission lines, transformers etc. At level 1 substation (local) controls exist. These might be relays and compensator controls related to level 0. At level 1 voltage and current measurements are performed and the results are send up to the next level (area concentrators). Usually, level 1 consists of electronic units called Remote Terminal Units (RTUs). At level 2 (area) human machine interface and data concentrators exist, enabling control to apply. SCADA resides at level 3. SCADA communicates with level 1, collects and presents them to the user in the form of a mimic diagram or on a screen. The EMS part process SCADA data. By collecting noisy voltage and current measurements in a redundant fashion the state of the system can be estimated. The state estimation is defined as the process of obtaining reliable data for control and recording purposes, out of a set of data telemetered from network measurements points. Usually, estimation is applied to steady state, while transient phenomena are ignored. The measurements used for estimation are taken within a short interval (usually below 10s). Data acquired through state estimation (e.g. load flows) are used to update user screens.

We shall now consider how the above adapt to the deregulated case. We start by considering the role of the ISO.

ISO. The role of the ISO is to apply load following control while preserving the reliability of the grid. Generation scheduling, ancillary services and real time control are the main means to achieve his objectives.

A. Generation Scheduling. There are two methods of generation scheduling in deregulated environment:

1. The generation schedule is performed by generating companies while ISO retains responsibility for ancillary services and

system reliability (this model was implemented in various US states and in UK and Wales after 2001).

2. ISO dispatches generators based on a merit-order procedure (this practice was followed, between others, in UK and Wales from 1990 to 2001).

In the first case, ISO does not interfere with generator dispatching decisions. However, generation schedules are reviewed by the ISO, who checks whether they conform to load and reliability demands. Energy schedules are modified and approved on an hourly basis. This happens in order to cope with differences between actual and forecast load due to unpredictable failures.

B. Ancillary services. ISO purchases through competitive bidding ancillary services from generators. These include:

- Spinning reserve. Part loaded unsynchronized generators are held to compensate for any fast frequency deviation. Classified into primary (<10s) and secondary (<30 min).
- Standing reserves. Unsynchronized fast-start (<5 min) plants. Usually gas turbines.
- Reactive power for voltage control.
- Black start. A generator can start without external power supply. Usually a diesel generator is used to provide excitation.

C. Real time control. For real time load following to be applied, ISO must monitor the outputs (status, active & reactive outputs, voltages) of each one generator every few seconds. The existing RTUs in the plants, after deregulation should be made available to ISO.

Furthermore, emerging technologies facilitate the implementation of deregulation schemes. These technologies are mainly based on both: advanced measurement technologies which may include Global Positioning System (GPS) and SCADA/EMS systems [9] that are integrated to Optimal Power Flow (OPF) software and Security Constrained Optimal Dispatch (SCOD) operation.

4 Restructuring threats

While the above suggest certain technologies than can help to cope with the increased and variant requirements of the deregulated market, there are potential threats that can jeopardize the effectiveness of the process:

- Market power. Market power problems in electricity market are much more complicated than in markets for other commodities (natural gas, crude oil etc). This is mainly due to the inefficient electricity storage. Relevant technologies such as hydroelectric pump storage, batteries or even flywheels are quite inefficient. Furthermore, there is the need to balance demand and supply on a second-by-second basis. A shortfall or surplus could jeopardize the stability of the entire grid. A result of this situation, is that almost no end customer can observe or response to real time prices.
- Reliability. Traditionally, electric generating utilities operated with high reserve margins. In a restructured environment, safety margins tend to be lower and (keeping other influencing factors constant) the probability of power outages is higher, although costs are lower.
- Average and Marginal costs. In the traditional electricity market, prices are set by average cost pricing. In a restructured market there is competition between generators, prices are based on market forces. Buyers and sellers have to find ways to settle prices. One way is to negotiate bilateral arrangements between a generator and a buyer. Another arrangement is the formation of a power pool where buyers and sellers interact to establish the market price.

The specific model that each country implements, is expected to apply strategies that will minimize these threats. Characteristic examples of different implementations are the models followed by UK and Wales and California [5, 10, 11, 12].

The British model

In April, 1990 the British power market experienced a fundamental restructure. The generation side was broken up into two private companies. Eventually, the restructure of the British market ended up with three generating companies, a transmission company and twelve Regional Electric Companies (REC). Remaining issues like least-cost dispatch and grid reliability were assigned to a completely new institution, the Electric Pool of England and Wales. In UK and Wales the central piece of restructuring was a spot market known as the pool.

The pool is operated by the National Grid Company (NGC). The pool operates as a day-ahead market for electricity. Every day, each generator offers to supply power from each one of its generating plants for half-hour intervals during the next day at company selected prices. NGC, using a 24-hour ahead demand forecast produces a schedule to meet the demand over the next day in the cheapest way possible. To achieve this, the bids of generators are sorted in merit order (least-cost) using the SUPERGOAL computer algorithm. The pool dispatches generators in order (from the cheapest to most expensive) until the demand for each half-hour is met. The System Marginal Price (SMP) is the cost of the most expensive plant needed for each half-hour. All generating units that will be dispatched, receives the SMP regardless of their offer price.

The bids made by generators consist of five elements: a startup price (the price of just starting-up the unit), a no-load price (pounds per hour for keeping plant warm) and three incremental prices for power actually generated (pounds per MWh).

However, in 1997 the regulator and government judged that the pool has to be replaced by the New Electricity Trading Arrangements (NETA). NETA is a complete change of direction. It is based on self-dispatch rather than central dispatch and no official price is used as a reference. Another change in NETA is the introduction of Balancing Market (BM). Generators and retail suppliers that do not forecast their supply or demand with acceptable accuracy, are forced to pay a cost. The cost could be signifigantly high and a small generator has a power outage in a period with high BM price, could find himself out of business. This will be a serious problem for wind and photovoltaic generators that cannot make exact power production predictions.

The example of the British model makes clear that the restructured system must be supported by a new control and information system. Although certain modifications of the existing information and control system are continuously applied, major issues still remain open [13].

5 Conclusion

It is clear that deregulation certainly affects the normal operation of a power system in accordance to market requirements. From the technical point of view this leads to new control and data transmission management, in order to ensure voltage and phase stability and desired power production and flow through the grid. The basic trends for the design of such integrated control and information systems are discussed in this paper. Advanced control techniques such as nonlinear adaptive, fuzzy methods etc., combined with high performance power electronics devises are needed. Furthermore, a more extensive information system has to be implemented.

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