Power System Restructuring: A review of the progress in various parts of the world

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Abstract— Globally, the electrical power supply industry has been and is still undergoing change in the mode of operation from Vertically Integrated Utilities (VIUs) to liberalized power markets, with unbundling of the generation, transmission and distribution functions. These reforms have been driven by various internal and external factors. The internal drivers for electrical industry liberalization vary depending on the level of development of a country.
In mature economies, restructuring has been propelled by the need to provide electricity at lower prices and to offer customers a greater choice in the retail market. In developing countries, the power industry needs to meet the fast growing electrical energy demand induced by blooming economies. The overall expected outcomes are improved efficiency, improved service reliability and introduction of reflective pricing, hence, a reduction in the price-cost gap of electrical energy. These benefits are expected to stimulate economic development.
This paper reviews the drivers of the reforms; the proposed standard model of implementing the reforms; merits and demerits of the various options which chart the evolution of the Electricity Supply Industry (ESI) from a regulated monopoly to full competition. In addition it discusses the various fully restructured power markets in the world; the reforms, so far, in Sub-Saharan Africa, South Asia and Latin America; their impacts and lessons learned.

Keywords— *Vertically Integrated Utilities, Liberalized Power Markets, Restructuring, Electricity Supply Industry, Standard Reforms Model, Regulated monopoly, Power markets.*

I. INTRODUCTION

Adequate, reliable and competitively priced electricity is essential for modernization, domestic growth and international competitiveness [1]. Reliable electrical power supply has become increasingly important since industrial, commercial and domestic consumers are relying on electronic devices to perform a wide range of tasks. In addition, a reliable power supply facilitates the provision of modern basic services such as healthcare and communication [2].
Historically, the ESI has been a monolithic structure with a single entity owning generation, transmission and distribution infrastructure in addition to performing all system operations. In many countries, especially developing countries, the electric utility was owned by the state or local government while in other countries, such as in the United States of America, it was an investor-owned monopoly. The VIUs were a natural monopoly since only the national or local electric utility was permitted to produce, transmit, distribute and sell electric power within its service territory. The governments guaranteed regulated rates that would provide the electric utilities with a profit margin above their operating cost. At most times, this was replaced by economic arrangements such as government ownership and subsidies. This operation structure was inadequate in providing incentives for innovation since the utilities had little motivation to use new ideas and technologies to lower costs under a regulated rate of return framework. Lack of competition also gave the utilities little incentive to improve standard of service to the power consumers [3].

II. DRIVERS OF REFORMS IN THE ESI

Since Chile pioneered a radical restructuring and privatization in 1982, the shift towards liberalized power markets has been a global phenomenon [1]. The reforms have been driven by new requirements for the energy industry such as reducing electrical energy cost, improving operational efficiency and maintaining sustainable long-term development of the power system infrastructure. Liberalization will enable to satisfy these requirements by creating a competitive environment for electricity trading. A competitive power industry will provide rewards to risk takers and encourage the use of new technologies. This shall drive electricity price closer to the marginal cost of generation, generating companies will optimize their production cost and consumers could get a cheaper electrical energy cost with a choice of the supplier, resulting in improvement of social welfare [3] [4].
Specific reasons for adoption of Electrical Supply Industry (ESI) restructuring vary depending in the level of economic development of a country. In developing countries, inadequate public sector financial resources to meet growing demand; institutional inefficiency; burden of energy subsidies; low service quality; high energy losses and capacity shortage needed to be addressed. In the mature industrial economies, the pressure for change grew with; the emergence of excess

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capacity, disillusionment with expensive and capital-intensive generation projects precipitated by the oil crisis of the 1970s, and a need offer customers a great choice in the retail market [5].

Other factors that have contributed to the restructuring are technology advances; political faith on the forces of market, competition and privatization; the rise of environmentalism; the shortage of public resources for investment in developing countries; and pressures from international donor agencies. Moreover, advances in gas turbine technology has resulted in more efficient small turbines and generators which could match the efficiency of very large units. This has led to a change in generation economies of scale [3].

III. Options for Restructuring Electricity Markets

An ideal fully restructured power industry should have competitive generation and retail markets along with the regulated transmission and distribution networks. A general representation of the restructuring process is as illustrated in *Fig.1* [6].

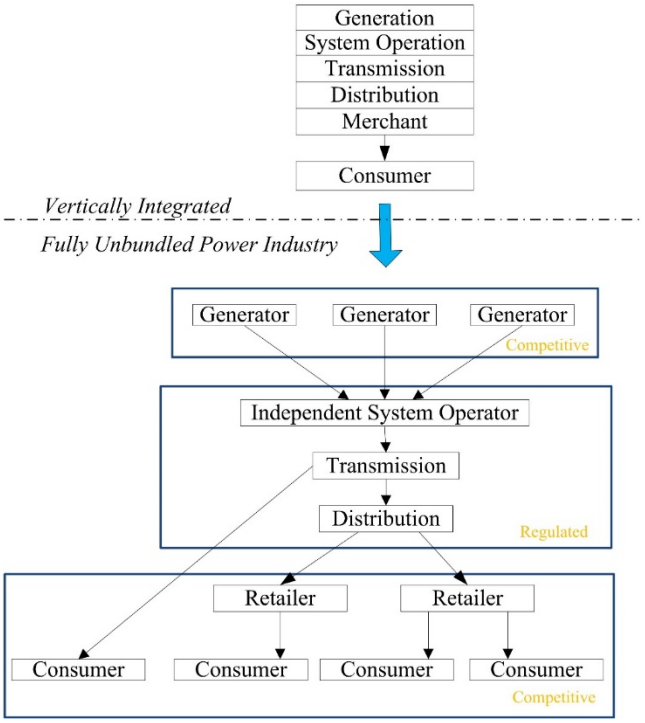

Fig.1: Evolution of the electrical power industry [6].

There are four models, as proposed by Hunt and Shuttleworth, which chart the evolution of the ESI from a regulated monopoly to full competition [7];

Model 1: monopoly at all levels. This model corresponds to the traditional monopoly utility structure. There is no competition at the power generation level and the consumer has no choice in selecting the supplier. A single company has the monopoly of producing electricity and delivering it over the transmission and distribution networks to final consumers.

Model 2: purchasing agency/single buyer. This is the first possible step towards introduction of competition in the ESI. The model allows a single buyer to choose from a number of generators to encourage competition in generation. This model is perceived to be a reasonable second-best solution in countries where Model 3 would not work [8]. It could take two forms as illustrated in *Fig. 2*. In *Fig. 2(a)*, there are IPPs connected to the network and sell their output to the vertical utility, which acts as a purchasing agent. A further evolution of this model is as illustrated in *Fig. 2(b)* whereby the utility no longer owns any generation capacity and purchases all its energy from IPPs. There is also a disaggregation of distribution and retail activities. DISCOs purchase the energy consumed by their customers from the wholesale purchasing agency.

The rates set by the purchasing agency must be regulated to avoid it exercising market power. This model does not discover a cost-reflective price in the same way that retail competition does. However, it has the advantage of introducing some competition between generators without the expense of setting up a competitive market.

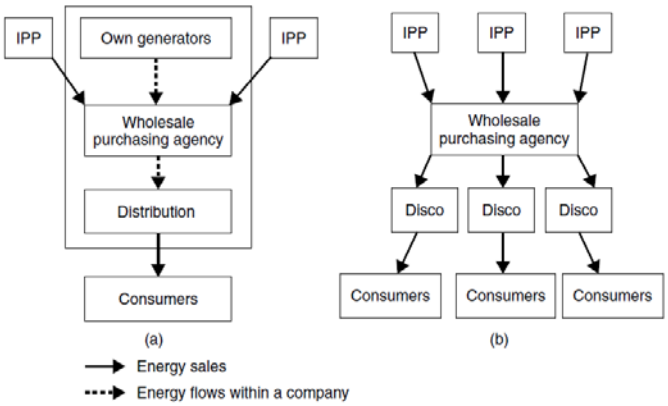

Fig. 2: Purchasing agency model of electricity market; (a) integrated version (b) disaggregated version [7].

Model 3: wholesale competition. In this model, DISCOs purchase the electrical energy consumed by their customers directly from generating companies. The transactions take place in a wholesale electricity market. In addition, large consumers are also allowed to make direct energy purchases from the wholesale market. There is open access to transmission grid. The wholesale market can take the form of a pool or bilateral transactions.

At the wholesale level, the only functions that remain centralized are the operation of the spot market and the operation of the transmission network. Each DISCO still has a monopoly over final consumers located in its service territory. There is considerably more competition between GENCOs since the wholesale price is determined by the interplay of supply and demand. However, the retail price of electrical energy must remain regulated since small consumers cannot choose a competing supplier if they feel that the price is too high.

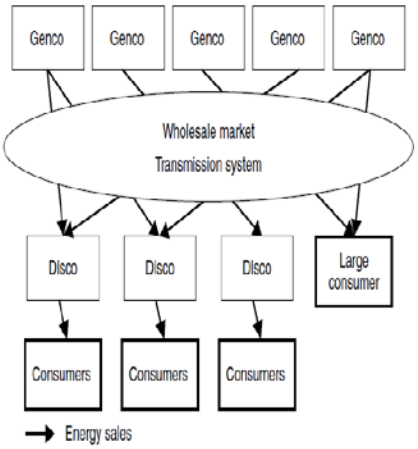

Fig. 3: Wholesale competition [7].

Model 4: retail competition. In this model, all consumers can choose their supplier. There is open access to transmission and distribution networks. The distribution is separate from the retail activity, which is fully competitive. Because of the transaction costs, only the largest consumers choose to purchase energy directly on the wholesale market. Most small and medium consumers purchase power from retailers, who in turn buy it in the wholesale market. This model makes the most competitive forces by bringing all final consumers into the market. However, it also greatly increases transaction costs due to requiring more complex trade arrangements and metering.

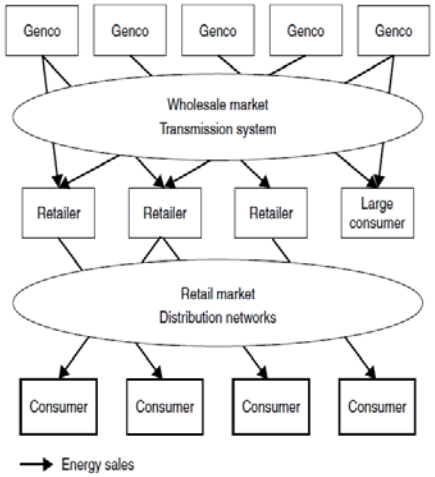

Fig. 4: Retail competition [7].

IV. STANDARD MODEL OF POWER-SECTOR REFORM/STANDARD TEXTBOOK MODEL

The standard model is also referred to as the standard textbook model. It was first applied in the Chilean power sector in 1982 and also became the reference model for reforms in other energy sectors. It prescribes the basic architecture for electricity restructuring and involves the following reform sequence and steps [9]:

1. *Corporatization:* Transforming the power utility into a separate legal entity, with all associated rights and obligations including governance structures, managing budgets, borrowing, procurement, labour employment, payment of taxes and dividends.
2. *Commercialization:* introduction of cost-recovery pricing, improvements in metering, billing and collections, adopting internationally recognized accounting practices as well as accounting for all subsidies.
3. *Requisite legislation:* Passing legislation that provides a legal mandate for restructuring, as well as the legal framework to allow private/foreign participation/ownership in the sector.
4. *Establishment of an independent regulator:* aims to introduce efficiency, transparency and fairness in the management of the sector, specifically to prevent anticompetitive activity, encourage appropriate investment and protect consumers.
5. *Independent Power Producers (IPPs):* introduce new (private) investment in generation, with long-term Power Purchase Agreements (PPA).
6. *Vertical and horizontal restructuring:* to separate potentially competitive generation and retail activities from the natural monopoly segments of transmission and distribution and thus facilitate competitive entry and mitigate market power.
7. *Divestiture of generation assets:* divesting state ownership (in part or in full) of generation assets to the private sector.
8. *Divestiture of distribution assets:* divesting state ownership (in part or in full) of distribution assets to the private sector.
9. *Competition:* introduction of wholesale and retail markets.

V. EXAMPLES OF FULLY RESTRUCTURED POWER MARKETS

A. United Kingdom

- The old England & Wales Pool

After restructuring, the vertically integrated Central Electricity Generating Board (CEGB) in England and Wales had been split into three generating companies: National Power, Powergen and Nuclear Electric [10]; one transmission company: the National Grid Company and twelve regional electricity companies (RECs) which were regarded as local distribution systems [1].The National Grid Company had two roles: transmission asset owner (TO) and Independent System Operator (ISO) [10] [11]. An electricity pool market had been established which arranged and managed electricity trades in England and Wales with wholesale market mechanism. *Fig. 5* shows the structure of electricity industry at privatization [adapted from [10]].

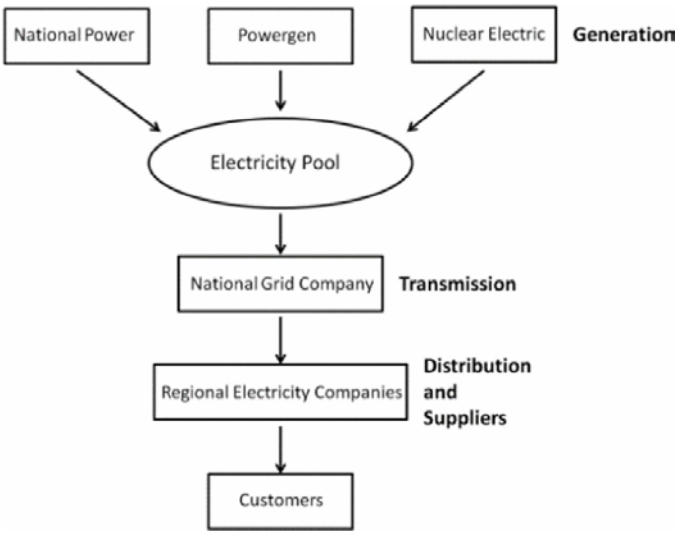

Fig. 5: Structure of Electricity Industry in England and Wales.

The old England & Wales Pool was a typical mandatory pool market; every energy trade had to be transacted only inside the pool market [12]. The SO would accept bids from the cheapest price to higher price until the forecasted demand was satisfied. Then, the SO would sort out a bids list containing names of the generation companies that had been chosen to generate electricity on the following day. Those generation companies were called "in merit" generation companies which means their bids have been accepted by the SO and those who have not been accepted by the SO were called "out of merit" generation companies [12]. At last, the SO would set prices for all pool market participants.

System Marginal Price (SMP) is the price bid by the most expensive generation company in the bids list [1]. In the pool market, the SO would pay for the Pool Purchase Price (PPP) to all the in merit generation companies. The Pool Purchase Price (PPP) is the System Marginal Price (SMP) plus Capacity Payment (CP) which is defined with Loss of Load Probability (LOLP) and Value of Lost Load (VOLL) [13]. On the other side, suppliers would pay for the price called Pool Selling Price (PSP) to purchase the electrical power from the pool [13]. The PSP is the PPP plus the Uplifts. The following equations defined the relationships between those prices [11]

$$PPP = SMP + CP \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$
$$CP = LOLP \times MAX(0, VOLL - SMP) \dots\dots\dots\dots (2)$$
$$PSP = PPP + Uplifts \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

CP is an incentive which is used to reward the generation companies who declare that their capacity is available regardless of whether they are required to or not. LOLP is the probability that electricity power capacity is unable to support the actual demand. LOLP is predicted in each half hour.

The pool structure is regarded as an innovation for energy industry restructuring [10]. However, electricity price decrease was slower than generator cost reduction and customers were unable to access to the deregulation benefits. The main reason is that, at most times, the three dominant generation companies could exercise their market power and determine price [14].

- *The British Electricity Trading and Transmission Arrangements (BETTA)*

On 27th March 2001, the New Electricity Trading Arrangements (NETA) was introduced to replace the pool with the concept that markets participants have rights to transact electricity power by bilateral trading [10]. On 1st April 2005, with the joining of Scottish network, the New Electricity Trading Arrangements (NETA) has been extended as the British Electricity Trading and Transmission Arrangements (BETTA) [10]. In the BETTA, electricity participants are able to trade by bilateral contracts. The bulk of electricity power is traded by Forward/Future contracts and short-term power exchange [15]. The Forward/Future contracts could be signed ahead of days, months or even years before actual power delivery [13]. The short-term power exchange is within 24 hours before electricity delivery which offers market participants an opportunity to adjust their contract details. Market participants are required to notify their predicted physical information in each half hour period, for seller is the planned generation output and for buyer is the metered demand, by 11 a.m. one day ahead. This information is called initial physical notifications (IPNs) [10]. Then market participants hand in their final physical notifications (FPNs) to the SO before the gate closure, usually 3.5 hours before delivery [10]. Figure 2 show the structure of BETTA [5] and figure 3 shows the diagrammatic representation of BETTA time frame process [12].

Apart from physical data, participants have an opportunity to voluntarily submit their offers and bids to the SO to take part in balancing mechanism [15]. The SO collects offers and bids then matches the balance between supply and demand so as to ensure system security. After offers and bids have been accepted by the SO, market participants will be paid or charged according to their contracted prices. The SO will punish the participant who violates the contract.

Because more price information is available, bilateral market provides more liquidity so that electricity price decreases remarkably [15]. However, in order to avoid penalty from the SO, generators might increase output whilst suppliers might reduce demand which will make inefficient elements arise. Another problem is that renewable generation is unable to guarantee the production accurately so it will be easier penalized than other generations [15].

B. Nordic Countries

The Nordic electricity market consists of four markets from four countries: Sweden, Norway, Finland and Demark [16]. The Nord Pool consists of two physical markets and several financial markets [17]. Figure 4 shows Nordic market's components [17]. Fig. 6 shows the diagrammatic representation of Nord pool time frame process [12].

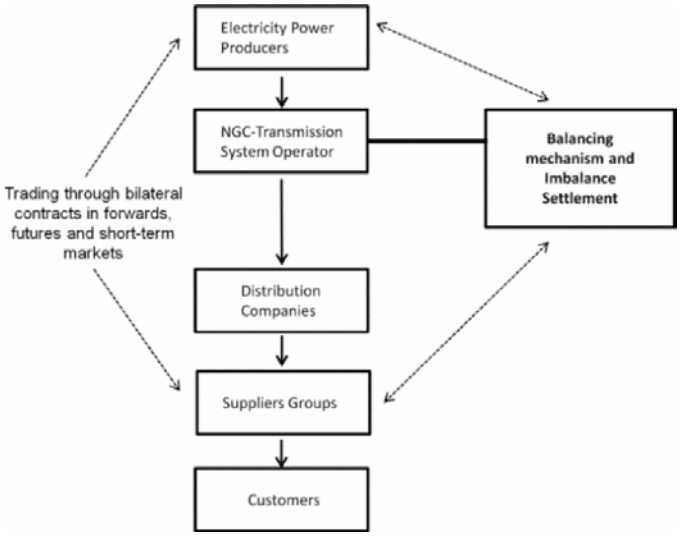

Fig. 6: The structure of BETTA.

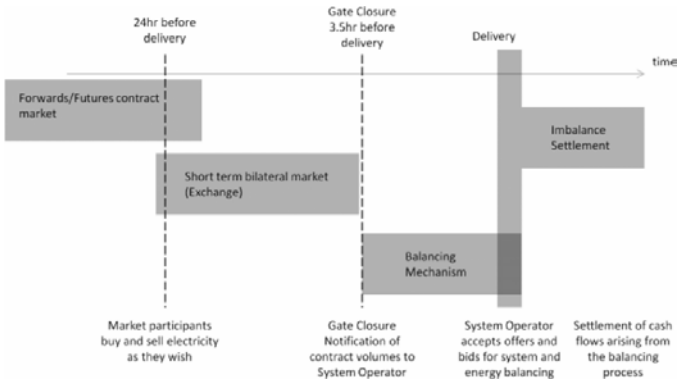

Fig. 7: Diagrammatic representation of BETTA time frame process.

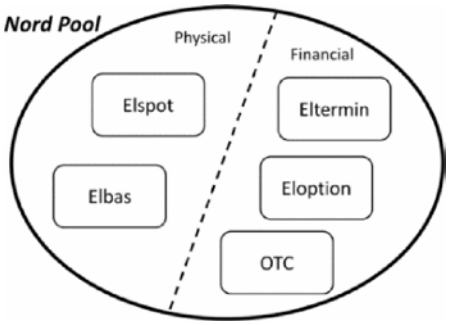

Fig. 8: Nordic Market components.

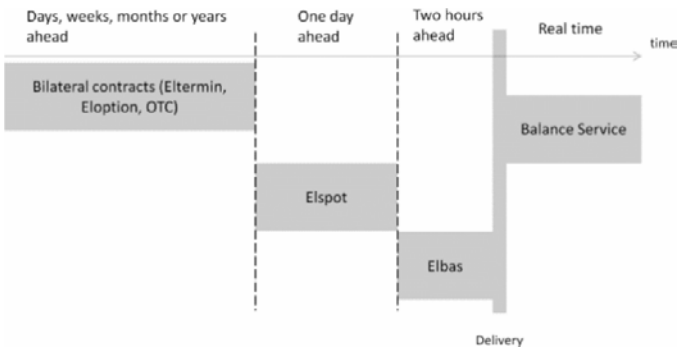

Fig. 9: Diagrammatic representation of Nord Pool time frame process.

Elspot market is referred as the main physical market which is a day-ahead market arranging hourly bilateral contracts. It determines the hourly spot price which will be regarded as the reference price both for financial and physical market. About one thirds of electricity consumption is traded in Elspot market and the rest of transactions take place through bilateral contacts [17]. Elbas is seen as a supplement of Elspot market for additional balancing services. It offers participants an opportunity to adjust their physical power position such as the price and volume of supply or demand within two hours period. There are two financial markets in Nord Pool; Eltermin and Eloption. Sellers and buyers can sign a forward and future contract in Eltermin market days, weeks, months and even up to four years ahead to hedge against the prices volatility risk. Eloption market is quite a new financial market which also provides contract services.

The Nord Pool also allows brokers to organize the over the counter (OTC) trading for market participants to make bilateral contracts [12].The Nord Pool power exchange is the key point of Nordic electricity market. System price is determined in spot market [18].When transmission network capacity is sufficient, the wholesale electricity prices in four countries are the same. Once transmission capacity shortage takes place, prices in different areas will be different [17]. Sufficient hydropower and low demand make Nordic market a nearly wonderful power system [18]. Having four electricity markets dilute the market power [18].

C. Pennsylvania-Jersey-Massachusetts (PJM) Interconnection

The PJM Interconnection is a Regional Transmission Organization (RTO) in the United States [19]. It serves the area of Pennsylvania, New Jersey, Maryland and other states in the eastern part of United States [20]. It serves 61 million of customers and has 900 participant power companies, making it the largest electricity wholesale market in the world. It has an energy market which consists of a day-ahead market and a real-time balancing market; a capacity credit market; a Financial Transmission Right (FTR) auction market and an ancillary service market which comprises of a regulation market and a pin reserve market [19]. Figure 6 shows the PJM market components [19]:

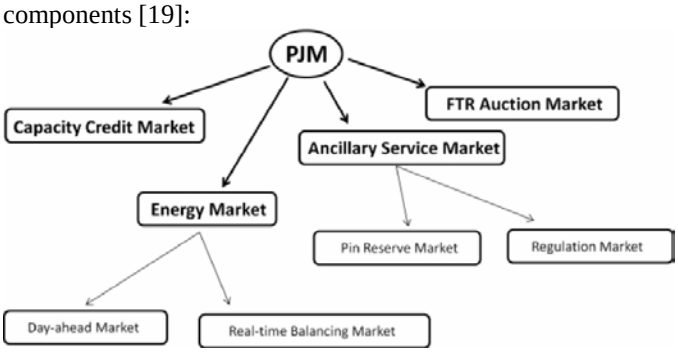

Fig. 10: PJM components.

The day-ahead market calculates the hourly clearing prices for each hour of the next operating day based on generator's offers, demand bids, virtual supply offers, virtual demand bids and bilateral transaction schedules. The balancing market calculates the clearing price in every 5 minutes period [20].

The day-ahead market settlement follows the planned hourly power quantities and day-ahead hourly electricity prices. The

balancing market settlement follows the hourly quantity deviations between planned values and real-time values. Both prices calculation are based on the mechanism of LMP. The day-ahead market allows participants to exchange electricity at binding day-head prices.

Generators who produce more than scheduled quantities will be paid by real-time LMPs. Customers who consume more than the planned power quantities are charged by real-time LMPs. If participants who exchange spot energy, their trades will be settled at real-time LMPs. Besides the day-ahead market and the real-time balancing market, PJM also provides financial instruments for participants to hedge the price variation risks. PJM can provide market liquidity and price transparency. Efficient and sufficient price signals help market participants to make correct judgement [20].

VI. Status of reforms in Sub-Saharan Africa, South Asia and Latin America

Power sector reforms have been implemented in Latin America with greater success. Most of the countries in Latin America have adopted Model 3 and considerable reforms have been carried out with adherence to the standard reform model [8]. Regulated wholesale and retail competitive arrangements are the norm. Today, most countries in this region combine competition for the market with competition in the market (mostly in balancing markets) [9].

The Sub-Saharan Africa countries are at different stages of restructuring their electricity markets from regulated monopolies to a competitive electricity market. For the most part, power systems in countries across Sub-Saharan Africa and South Asia have retained state-owned utilities, with varying degrees of unbundling, regulation, competition and private participation, mainly in the form of IPPs. The single-buyer model is dominant. Where elements of competition have been introduced, it has been competition for the market – through auctioning long-term contracts with IPPs – rather than in the market - where generators continuously compete for least-priced dispatch and sales through power exchanges and distribution companies offer competitive retail services to customers [2].

In Sub-Saharan Africa, wholesale and retail competition are entirely absent. The standard reform model has not been fully realized anywhere in Africa. The most pervasive features of power sector reform have been the corporatization and commercialization of state-owned utilities and the introduction of independent regulatory bodies. A 'hybrid market model' is emerging in many Sub-Saharan African countries. In this model, private and public investment coexist in a sector that continues to be state-dominated [9].

VII. Outcomes

In countries where electricity reforms have been pursued, there has been an improvement in the overall sector performance. Specifically, quality of service has improved as a consequence of a steady fall in power outages and a shrinking of energy losses (both technical and commercial). Also, improvement in labour productivity has been reported in some countries such as in Chile. Moreover, the reforms have better aligned prices with underlying costs. Wholesale competition has worked well in industrial countries because of excess capacity, moderate demand growth, and the availability of natural gas (which enabled the entry of gas-fired plants at modest scale and relatively low cost) [1].

VIII. Challenges

Two key challenging tasks encountered by policymakers in developing countries are [5];

(i) Formulation of electrical energy pricing schemes that balance between economic efficiency (by reversing underpricing and cross-subsidies) and social equity.
(ii) How to increase the availability of adequate, reliable, clean and competitively priced electrical power while mitigating climate change by adopting renewable energy sources.

IX. Lessons learned

The emerging international evidence suggests that: if implemented in the correct way, the standard reform model is a sound guide for successful electricity market restructuring. Significant departures from the textbook reform model are likely to lead to performance problems. Emerging consensus is that in the electricity sector [5] [21];

(i) When well designed and implemented in proper sequence, a combination of institutional reforms—vertical and horizontal restructuring, privatization, and effective regulation (particularly the application of incentive-based regulatory mechanisms)—can lead to significant improvements in several dimensions of operating performance and in a variety of country settings.
(ii) There is a strong link between good and credible regulation and the objective of securing foreign direct investment, and privately financed investment more generally, while delivering efficient service at sustainable but just and reasonable prices.
(iii) As a consequence of the reforms, retail prices have become more closely aligned with underlying costs, and cross-subsidies have been reduced and in some countries eliminated.
(iv) There is a logical sequence of reforms, and it is costly to undertake reforms in the wrong order; ideally, the reforming country should first raise prices to cost-recovering levels (with a return on capital to finance investment), then create regulatory institutions and restructure the sector, and only after that privatize.
(v) Most developing economies lack some of the institutional and other pre-conditions for the full and effective implementation of the standard reform model. In many parts of the world, electricity markets have evolved or are evolving into hybrid forms—not completely unbundled, privatized, or competitive.
(vi) Restructuring has its own set of problems that have to be considered and weighed against the benefits of the consumers. There is not one single winning market or "one size fits all" model. In each situation, important trade-offs must be made.

X. Conclusion

This paper has outlined the reasons for power restructuring. In addition, various options which chart the evolution of the Electricity Supply Industry (ESI) from a regulated monopoly to full competition have been discussed. Four typical and successful restructured electricity markets have been explained in detail. Moreover, the status of reforms in Sub-Saharan Africa, South Asia and Latin America has been explored. Existing literature suggest that; the standard reform model has brought about a fundamental paradigm shift in terms of the structure of the ESI, the role of the state and the regulation of the sector. The generation segment of the ESI has undergone privatization in many developing countries while the network segments remain publicly owned. Overall, many developing countries are still some distance away from the full adoption of liberalized standard model in their power sector and are in transition from state control to markets.

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