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Simulation analysis of emissions trading impact on a non-utility power plant

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ABSTRACT

Non-utility power plants can competitively participate in open electricity market to reduce operational costs but in the absence of pollution charges or emissions trading such generators are tempted to cause greater pollution for profit maximization. This paper presents a solution that incorporates pollution charges for nitrogen oxides and sulphur dioxide emissions in line with existing national environmental quality standards and a new carbon dioxide emissions trading mechanism. A novel approach has been used for allocation of allowable emissions that favors efficiently fuelled and environmentally friendly operation for maximizing profit. Impact of proposed carbon trading on economical utilization of enormous indigenous coal reserves has been analyzed and determined to be acceptable. Software developed in this paper, harnessing Sequential Quadratic Programming capabilities of Matlab, is shown to be adequate simulation tool for various emissions trading schemes and an useful operational decision making tool for constrained non-linear optimization problem of a non-utility power plant.

1. Introduction

It has been suggested that we are now entering the age of Natural Capital, in which resource depletion and environmental impact become key drivers (Harris, 2006). Both of these drivers are simultaneously taken care of while developing a novel approach to allocate emission allowances in this paper. Particular care needs to taken while deciding upon price of carbon dioxide (CO_2) emissions per ton. It should be high enough to deter any power generator from maximizing its own profit on the cost of environmental degradation to society at large. At the same time, carbon price must not be so high that it changes merit order of coal on supply curve which is possible if generators have to internalize their emissions costs (Denny and O'Malley, 2009). A change in merit will impede beneficial utilization of huge indigenous coal deposits, estimated to be more than 175 billion ton (Siddiqui, 2007), that are yet to be exploited. This paper proposes an appropriate price for CO_2 emissions that is shown to achieve both above mentioned objectives. Findings of this research are intended to act as guidelines for developing future government policies on energy and environment.

In addition to causing environmental damage and depletion of fossil fuel reserves, generators may use market power to achieve huge financial benefits by unfair practices like strategic pricing, capacity withholding and induced transmission congestion (Koesrindartoto et al., 2005). Market power mitigation procedures need to be introduced to penalize such unfair practices and ensure that benefits of deregulation reach electricity consumers. Appropriate mitigation procedures may be determined by agent-based simulation of market conditions and bidding mechanisms. Results from various agent-based simulations demonstrate that the multi-agent system approach enables effective modelling and simulation of the electricity markets (Yu and Liu, 2008).

This work presents a test-bed that can simulate economical operation of a thermal non-utility power plant (NUPP) under various possible market structures. This software is also intended to serve as an operational decision making tool for a manager of a thermal NUPP. Consequently, this development is of interest for both academic and practical circles due to its two distinct dimensions.

Operational cost and amount of CO_2 emissions are determined and compared for four market scenarios; business as usual (BAU) before deregulation, deregulation without emissions trading (NO-ET), 90% free-allocation (90%-FA) of allowances and 90% auctioning (90%-AC) of allowances. Optimal bidding strategies are established for a NUPP simultaneously operating in energy and environmental markets. A daily emission bid and twenty-four hourly power supply and demand bids are finalized on a

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day-ahead basis. Hourly generation levels for each generating unit of a NUPP are determined as well.

Section 2 discusses current restructuring trends in Power Sector of Pakistan and proposes a new deregulated market model for future. Various emission trading schemes are explored in Section 3. Section 4 presents a mathematical model capable of representing interactive operation of electricity and emission markets on an hourly basis. Section 5 explains optimization algorithm for daily operation. A case study of an oil-fired NUPP containing five generators is presented in Section 6. Section 7 shows simulation results and discusses the most important ones. Finally, Section 8 presents conclusions and Section 9 offers insight into future work.

2. Overview of power sector

The change from state controlled monopoly to competitive market takes place through a number of extensive reforms that are collectively termed as liberalization. The most important milestones of liberalization include corporatization, unbundling, fragmentation, privatization and eventually deregulation (Imran, 2008). Independent Power Producers (IPPs) were introduced into PPS to overcome acute shortage of power and these make up about one-third of total installed capacity in Pakistan today. Liberalization of Pakistan Power Sector (PPS) now faces the challenge of privatization of its fragments (Malik, 2007). PPS is expected to evolve into a competitive market place over the next decade as deregulation completes.

National Electric Power Regulatory Authority (NEPRA) was set up in December 1997 by an Act of Parliament (NEPRA, 1997). It was established to achieve competitive environment in PPS and ensure that interests of both investors and customers are protected. Its main responsibilities are to: "issue licenses for generation, transmission and distribution of electric power; establish and enforce standards to ensure quality and safety of operation and supply of electric power to consumers; approve investment and power acquisition programs of the utility companies; and determine Tariffs for generation, transmission and distribution of electric power" (NEPRA, 2009).

Traditionally PPS has been managed by state through Water and Power Development Authority (WAPDA). In December 1998, WAPDA Act was amended to pave way for establishment of Pakistan Electric Power Company (Pvt.) Limited (PEPCO) as well as simultaneous unbundling and fragmentation of WAPDA. PEPCO was initially constituted as a separate entity within WAPDA, to facilitate reform and restructuring of PPS in order to improve system efficiency on commercially viable basis (PEPCO, 2009). In 2007, PEPCO was made independent of WAPDA and assigned to take care of thermal power generation, transmission, distribution and billing. WAPDA retained responsibilities for hydro power generation stations after its de-integration into numerous entities.

Horizontal de-integration (fragmentation) led to further partitioning of the generation and distribution sectors to increase the number of participants and hence increase competition. Fragmentation of generation and distribution functions has resulted in four thermal power Generation Companies (GENCOs) and nine regional Distribution Companies (DISCOs) respectively. Breakup of total installed capacity of PPS into generation by WAPDA, GENCOs, IPPs and Nuclear is given in Table 1. Percentage utilization for different fuel types or power sources in PPS is presented in Table 2. Vertical de-integration (unbundling) of PPS led to separation of generation, transmission and distribution functions. Unbundling produced a single entity for transmission, due to strategic nature of its function, namely National Transmission and Dispatch Company (NTDC). NTDC was supposed to be backbone of PPS and it took control of all 220 kV and above grid stations and transmission networks from WAPDA with all due obligations and liabilities (NTDC, 2009). Subsequently, NTDC obtained an exclusive transmission license from NEPRA in December 2002 and was assigned to act as Central Power Purchasing Agency (CPPA), System Operator (SO), Transmission Network Operator (TNO) and Contract Registrar and Power Exchange Administrator (CRPEA).

Table 1
Breakup of total installed capacity of Pakistan power sector.

Power sector	Installed capacity (MW)
WAPDA (hydro)	6489
GENCOs (thermal)	6441
IPPs (thermal)	6012
Nuclear	462
Total	19,404

Table 2
Percentage shares of Pakistan power sector by fuel use.

Power source/fuel type	Power share (%)
Hydro	33
Gas	35.7
Oil	28.7
Coal	0.3
Nuclear	2.3

CPPA is responsible for procurement of power from GENCOs, Hydel and IPPs on behalf of DISCOS, for delivery through transmission networks. SO ensures secure, safe and reliable operation by control over switching of transmission system, dispatch of generation facilities and provision of balancing services through National Power Control Center (NPCC) in Islamabad. Operation, maintenance, planning, design and expansion of 220 kV and above transmission networks are handled by TNO. It is also responsible for generation expansion and economical planning and site selection of new generation facilities. CRPEA has been established for recording and notification of contracts and other matters relating to bi-lateral trading between the generation licensees and the bulk power consumers. Bi-lateral trading between generation licensees and DISCOs for future capacity needs in a long term market also falls under the domain of CRPEA. In addition, CRPEA handles a financial settlement system in close co-ordination with the SO for the real time balancing market (NTDC, 2002).

NTDC was bound by its transmission license to facilitate single buyer plus (SBP) Model by 1st July 2004. This has been achieved to a certain extent and consequently renewable energy power generators have been offered the facility of wheeling. Competitive market operation date (CMOD) was initially set to be 1st July 2009. However, as electricity market was not properly developed by that date, CMOD has been extended by one year. It may be further extended by one year at a time but to no later than 1st July 2012. After CMOD, NTDC will be responsible for transition towards a truly competitive environment and eventual establishment of a Competitive Trading Bi-lateral Contract Market (CTBCM) (NTDC, 2002). Major milestones of electricity market reform in Pakistan are summarized in Table 3.

However, a market wholly based on bi-lateral contracts raises a series of concerns regarding operational uncertainty due to absence of any central dispatch function. Bi-lateral contracts cannot reflect actual physical condition because it is impossible to know in advance how much energy will be needed or supplied in reality. Bi-lateral contract model reduces competition in market