An Agent-Based Electrical Power Market
(Demo Paper)

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ABSTRACT

This demonstration shows an agent-based model for the electricity power market, in which the optimal power flow is determined in a bottom-up fashion. Here, each agent controls a single electrical node consisting of several power generators, loads (consumer demand), and is connected to neighbouring nodes through transmission lines. Furthermore, each of the components has associated physical constraints, such as the line and generators' capacities. Through a process resembling tatonnement in markets, the optimal system solution which maximises social welfare is reached within a few iterations. The demonstrator visualises this process and also shows how the various constraints affect the system behaviour and how this changes with different settings.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems; G.I.6 [**Optimization**]: Convex programming

General Terms

Algorithms,Economics

Keywords

Electrical Power Markets, Distributed Constrained Optimization, Quadratic Separable Programming

1. INTRODUCTION

Over the past two decades electrical power markets (EPMs) have experienced radical changes as a result of the deregulation of the electricity industry [4]. From this came the introduction of several new stakeholders, including energy producers known as *Gencos* and consumer companies, known as *Custcos*. In addition, there are independent network operators, called *Gridcos*, who oversee the security and running of the system. Consequently, the system is characterised by a large-scale decentralised market where each agent has local information and none of the agents has a global view of the system. More recently, this large-scale nature of the market has been reinforced with the introduction of renewable energy generation which is characterized by many small distributed energy resources. Here, novel technologies such as microgrids allow for small-scale companies to plug to or unplug from the power grid depending on the market behaviour. Against this background, in this demonstration we visualise an agent-based, decentralised approach for solving the so-called *DC optimal power flow problem* [1], which involves optimising the electricity production and prices over the entire system, subject to physical constraints such as the capacity of the lines between different electrical nodes, and the capacity of the generators.

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2. THE ELECTRICAL POWER MARKET

The system consists of several agents, where each agent controls a single electrical node or *bus*. A node in turn may consist of several energy generators and loads (i.e., consumer demand), and is attached to other nodes via transmission lines. A node can either produce more than it consumes, or the reverse. Either way, this creates inter-agent constraints since power flow needs to be balanced at each node and therefore throughout the system. Furthermore, the transmission lines connecting the nodes have a limited capacity which cannot be exceeded. In addition to the inter-agent constraints, there exist intra-agent constraints such as the minimum and maximum capacity of the generators. An example of a basic EPM with two nodes is given in figure 1.

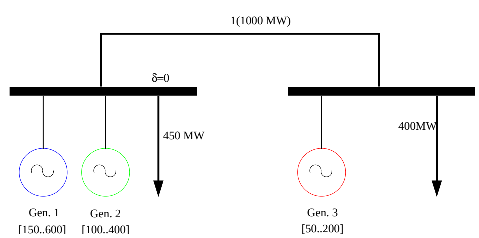

Figure 1: A basic electricity power market

In this example there are two generators attached to node 1 and one generator to node 2. In this case the loads are fixed, but it is also possible to have a demand with a price-elastic component. The problem to solve here is to assign a generation level to each generator such that the total generation meets the load level and without violating the physical constraints. For example, generator 1 cannot produce more than 600MW and the line cannot transport more than

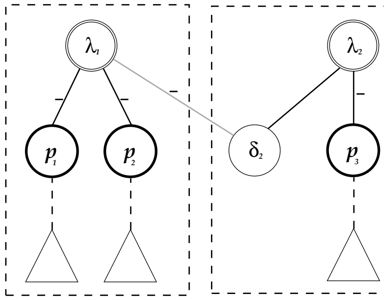

Figure 2: Graph corresponding to figure 1

1000 MW. In addition to satisfying the constraints, the other main consideration is for the solution to be economically efficient. This means that it has to maximize the social welfare, which is defined as the difference between the benefit of consuming the energy and the cost of producing it. When the loads are fixed, this reduces the problem to minimising the cost, which depends on the production functions of the generators.

3. THE AGENT-BASED MODEL

The optimal power flow problem, which is described in terms of a quadratic separable program is commonly solved using Newton's method applied to the Lagrangian which describes the mathematical model [3]. As there are inequality constraints, this involves the application of several Newton steps until all constraints are satisfied. Although this approach works well when the number of nodes is small, it does not scale well. Equally important, however, is the fact that the centralised approach requires all the agents to communicate their private information, such as their production function, to a central agent.

Now, our decentralised approach is based on the observation that the Hessian matrix is symmetric and very sparse and can be naturally represented by a graph, which in turn can be decomposed into the agents. Here, each agent controls the primal and dual variables associated with each node, and the links represent the direct dependencies between the variables in the system. If the variables of each link belong to different agents then it represents an inter-communication link between them (more details about the decomposition and the graph-based approach can be found in [1, 2]). The graphical representation of the earlier example with 2 nodes is given in figure 2. Here, p_g is the production level for each generator g (in this case optimising production), the triangle denotes the bounds on the variables (in this case the lower and upper bound on the production of each generator), λ is the dual variable as a result of the equality constraint that all flow in the system must be balanced, and δ denotes the voltage angle.

Each agent then solves their own local problem based on the local information and the information gathered through these communication links. To this end, each agent communicates the values of some of its variables to the other agents, which allows them to improve their solution. The information that needs to be shared consists of the voltage angle δ, and the dual variable λ which represents the local marginal price (LMP) of the energy. This scenario is akin to a so-called tatonnement process in markets, where prices are announced, and agents state their demand and/or supply at that price. Prices and demand and supply are adjusted, but no transaction takes place until the system reaches a state of equilibrium. Similarly, here agents shout their prices, in this case adjusting their generation level and modifying their own prices, until the systems reach equilibrium. This setting is complicated by the inter- and intra- agent constraints. In particular, due to the constraints on the transmission lines the prices can be different at different generators, hence the term *local* when referring to the marginal price. Using this iterative approach, the agent-based system is able to find the optimal solution within only few iterations.

4. DEMONSTRATION DETAILS

The demonstrator consists of several parts. First, the specification of the electrical power market components is represented using XML. This XML file is then transformed into a XML specification for quadratic separable programs. Then, based on this specification, the graph model is derived. Finally, based on this graph the system will be solved.

The GUI shown in figure 3 gives a screen shot of the latter part of the system process, depicting a number of agents or *buses*. The lines between the agents show how loaded they are, as well as whether they are binding or not. When a constraint is binding, this means that it affects the market price. Moreover, the direction and intensity of the power flows are shown and we can very easily show how they behave under different circumstances.

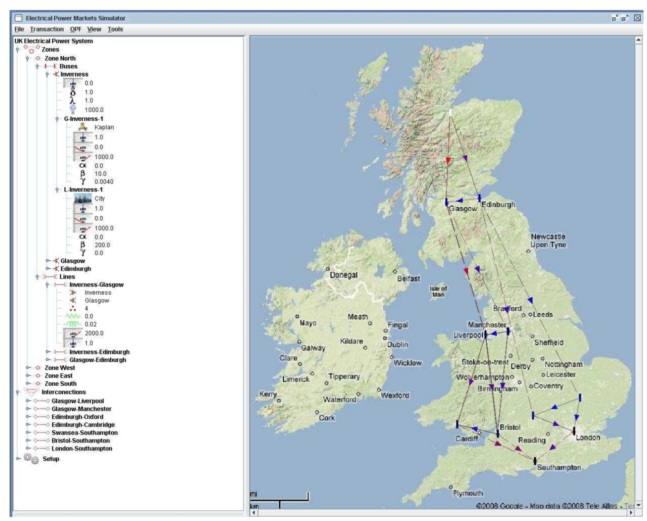

Figure 3: The agent-based power market demo

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