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To cite this article: A Touzene et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 168 012015

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Abstract. In this paper, we propose a new layered architecture for Smart Grid Resource Optimization using heuristic approach (SGROH). SGROH allows Smart Grid Constituencies (SGC) such as Power Generators (PG), Power Transporters (PT), Power Distributors (PD), and Power Consumers (PC) to optimize their pay-offs using the smart grid. The proposed optimization heuristic aims to support power consumers with sustainable energy from power distributors, transparently at the best price on a real time basis (variable pricing). It will also decide automatically for the power distributors the best power generators and connecting transporter lines. The SGROH engine is based on a greedy heuristic which aims at optimizing the profits and resource utilization over the whole smart grid. Experimental study shows that SGROH heuristic gives nearly optimal solutions.

1. Introduction
Nowadays, the general trend worldwide is towards upgrading existing power grids to Smart Grids. The key motivations behind modernizing the power grid are essentially the accommodation of future demand growth, the enhancement of efficiency, reliability, and sustainability. Power plants (generators) generate electrical energy, conventional and renewable, transmitted through high voltage lines (transporters) to distribution centers (distributors) where it is stepped down to lower voltages and delivered to end-consumers. A better system utilization should strike a balance between the expected consumer’s demand and the electrical energy to be generated. In many countries, the three components (generation, transportation, distribution) are owned and operated by different entities via many to many relationships. The consumer is directly connected to one among the electricity distributors operating within his/her geographical location. The consumer expects a continuous supply to his/her demand with a minimum electricity bill. In the meantime, electricity distributors, as businesses, target the maximum selling profile along a minimum electricity purchase. Similar objectives are set by electricity generators through selling profile maximization while minimizing electricity generation. Finally, electricity transporters aim at maintaining a balance between lines’ capacity and the amount of electricity transported. A recent study showed that the utilization rate of the energy generated is below 55% [1], that is, almost half the production is wasted. In this paper, we address this issue by developing a decision model that supports generating only the amount of energy that is needed by the consumer. There are several other challenges on the current electricity grids, such as variable load demand [2] heterogeneity of the used technologies [3], and incorporating more
renewable energy generation in response to new policies [4]. In order to meet such challenges, the need for changes in the current electricity grids, power design and operations has been recognized and discussed for several years under the Smart Grid concept [5]. The smart grid has been proposed as a new electrical grid to modernize current power grids and enhance their efficiency, reliability and sustainability [6]. Smart grids enforce the conventional electrical grids with a degree of intelligence based on tools strongly related to information and communication technologies [7]. Smart Grid concept considers different components of the electrical system, such as a smart transmission system, an energy management system, advanced distribution management, advanced metering, a demand response, and an electrical storage system [8]. Sensing, communication, decision making, and power flow capabilities are the key factors of a smart grid. Enhancing these factors will improve the efficiency and the reliability of the grid through (1) speeding up the response to consumer’s demand, (2) optimizing the capacity utilization and (3) increasing the flexibility of the overall resource management of the grid system.

In this paper, we propose a Smart Grid Resources Optimization heuristic approach (SGROH) that optimizes the resource management of the smart grid. SGROH acts as a broker to facilitate the interaction between the four smart grid constituencies (SGC): power consumers (PC), power generators (PG), power transporters (PT) and power distributors (PD). SGROH’s layered architecture attempts to optimize the management of the resources by decoupling the different SGCs. The decoupling approach provides more flexibility and freedom for real time connections between different SGCs. As an example, a PC can be connected to a given PD at a certain time of the day and may end up connected to another PD at another time. From the smart grid perspective, this will guarantee the best quality of service (QoS) for the PC at the best market price dynamically. In related literature, several solutions have been proposed to manage the grid resources as part of the demand side management process. A comprehensive review of the existing demand side resource management solutions is presented in [9]. Most of the proposed systems restrict the resource optimization process to only two components of the grid system (PC-PD or PD-PG). Our optimization process includes all the four SGCs (PC-PD-PT-PG). Some of the proposed solutions focus on developing scheduling algorithms to maximize the efficiency of the two components (generation, distribution) of the grid. Sergio et al. [6], proposed a dynamic energy management model with distributed energy resources. This model focuses on optimizing the resources between a PD and a PC with uncertain consumer load demand, distributed renewable energy resources and the energy storage devices owned by the consumer. The authors developed a real time pricing model to minimize the long-term average total cost to support consumer’s load demand. An energy scheduling model using a multi-objective function was presented in [10] with as objectives the minimization of the operation cost alongside the maximization of the minimum reserve in a day-ahead. The scheduling model focuses on different power generation resources including conventional power plants and renewable energy resources. Due to the heterogeneous nature of the hardware devices used in the electrical grid system, [7] proposed a software layer that abstracts this hardware heterogeneity and provides homogenous-looking appearance to the application layer of the smart grid. This middleware focuses on the data exchange between the smart devices and the smart applications to simplify the integration process and avoid dealing with data of different formats. Smart grid systems involve two way communications between the consumer and the grid through an advanced metering and monitoring system. The quality and reliability of the data collected is a key factor for optimizing the operations of the smart grid. Therefore, data mining and analytics tools are essential for the effective management and utilization of the available data [11]. A comprehensive review of the state-of-the-art for the exploitation of big data tools for dynamic energy management in smart grid platforms is presented in [12]. The rest of the paper is organized as follows. Section 2 describes the Architecture and Services. The system modelling and the heuristic approach is presented on Section 3. Section 4 presents the results and section 5 concludes the paper.
2. SGROH Architecture

Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented. Smart grid systems are the new generation of power grid systems in terms of technology, communication, and innovations. These innovations are endless and serve the comfort of the power consumer by providing them the best Quality of Service (QoS) at the best prices. As far as innovation is concerned, we propose a realistic smart grid resource management architecture which governs all possible smart grid constituencies (components) SGCs. Our layered smart grid middleware architecture SGROH decouples the interaction between the different SGCs and focuses on the services provided by each one of them. It is worth to note that the smart grid resource allocation network is dynamically reconfigurable. As an example a PD currently connected to a given PG might be reconnected to another PG later. As mentioned earlier, our SGROH system manages different Power Generation companies (PGs), different Power Transportation companies (PTs), different Power Distribution companies (PDs), and different Power Consumers (PCs). In our architecture, we consider the possibility that some PCs may act as PGs and sell power energy to the smart grid if they fulfill a certain QoS level. In SGROH, connecting a PC to a PD, or connecting a PD to a PG using a PT must be as smart as possible, automatic, variable in time and, most importantly provide the best QoS to all SGCs within the terms of the Service Level Agreements SLAs.

As shown in Fig. 1, the proposed SGROH consists of four horizontal power related layers: generation, transportation, distribution, and consumption. SGROH contains also two vertical layers across the four horizontal layers, that is, payment/billing and data collection and analytics. In what follows, we describe the services provided at each of the different layers along with their interactions.

**Power Generation Layer:** This layer deals with different sources of power energy generators. It manages different PGs taking into account the parameters of a PG such as: the type of energy (fossil fuel, hydro, wind, photo-voltaic, etc.); the cost of energy generation which depends on the type of generations for the specific PG; the period of time in which the PG is available for supplying the energy. The PG’s parameters are collected periodically using the smart grid communication network.

**Power Transportation Layer:** In our model, we consider the power transportation lines (TL) with related power equipment, like transformers which might belong to different PTs. The parameters of a TL are its location, its capacity, and its transportation cost.

**Power Distribution Layer:** We assume that many PDs are competing to deliver the power to the consumers. A PD is characterized by: the distributor supplied power, which is the load purchased from different generators; the distributor power cost, which might be variable, off-pick, normal, or high pick prices; the distributor failure rate. This parameter is very important when selecting a given PD to connect to a PC, based on the QoS and the SLA; the distributor capacity which quantifies the maximum power load that can be supported by the infrastructure of the given PD. This takes into account the low voltage lines (11KVA), the sub-stations, and the transformers.

**Power Consumption Layer:** This layer deals with the end-users or the power consumers (PCs). PCs can be individuals or companies supplying power energy to their factories or businesses. One of the most important characteristic of a PC is its power demand. Usually the power demand is collected through smart meters connected directly to the Smart Grid System. A feedback about the power...
consumption will be forwarded from SGROH to the PC about how power consumption could be reduced and its impact on the next electricity bill. Another important aspect is the possibility for a PC to sell his/her excess generated power (photo-voltaic) energy to the smart grid.

**Data Analytics and Optimization Layer:** Data analytics and optimization layer is one of the most important layers which implements the real smartness of the proposed SGROH architecture. It is a cross layer which collects data from different layers, analyses them and takes the optimal decisions based on the current configuration of the smart grid resource allocation. Data are collected continuously at different layers. As example, at the PC layer, smart meter readings are recorded and directly injected into the data analytics engine to reflect the PC’s current demand. The data analytics engine performs some statistics on the PC’s power usage at different time slots and builds the associated prediction profile to anticipate his/her future power demand. This analytical layer can alert a PC about his/her power consumption level and recommends power consumption hints for reducing the electricity bill.

**Payment Layer:** The payment cross-layer deals with bills and payments at different layers. At the PC layer, power billing is based on the consumed power at different prices during different time slots. We assume that, at a given time slot, a PC is connected to only one PD. In the case where PC produces power and sells it to the grid, the amount of power along with the price is recorded for each time slot. At the PD layer, the payment information is based on the amount of power offered by a given distributor to satisfy the demand of a set of PCs. At the PT layer, the payment information is related to the amount of power transported at a specific unit cost to supply a given power distributor PD during a given time slot. Similarly, at the PG layer, the payment information is recorded concerning the amount of power produced by a given generator and the associated cost, in order to service a given PD for any time slot. The overall and individual bills for all SGCs result from solving the optimization problem which models the smart grid operations.

### 3. SGROH System Model

We consider an electric power distribution network consisting of: a set consumers, denoted \( I = \{1, 2, \ldots, m\} \); a set of distributors, denoted \( J = \{1, 2, \ldots, n\} \); a set of generators, denoted \( K = \{1, 2, \ldots, p\} \); and a set of transporters, denoted \( L = \{1, 2, \ldots, q\} \). We consider that the smart grid system is time-slot based where resource management decisions are made in each time slot \( t \). We also assume that the whole system is completely driven by the consumers’ demands. Let \( D_i(t) \) be consumer \( i \)'s demand in time slot \( t \). We assume \( \{D_i(t)\}_{i=0}^{\infty} \) is an independent and identically distributed (i.i.d.) non-negative stochastic process, which is deterministically bounded, i.e., \( 0 \leq D_i(t) \leq D_i^{\max} \). It is assumed that the demand for each consumer should be fully satisfied by a single distributor. Therefore, the binary decision variable \( x_{ij}(t) \) is introduced:

\[
x_{ij}(t) = \begin{cases} 1 & \text{if } D_i \text{ assigned dist. } j \\ 0 & \text{otherwise} \end{cases}
\]

We also assume that each distributor \( j \), registered with the smart grid system, should serve at least one consumer:

\[
\sum_{i} x_{ij}(t) \geq 1, \text{ for all } j \in J.
\]

With regards to the relationship between distributors and generators, we introduce the positive decision variable \( y_{jk}'(t) \) which denotes the amount of power that distributor \( j \) receives through line \( l \) from generator \( k \). Therefore, the total amount of power received by distributor \( j \) through all lines from all generators should be equal to the demand of all the consumers (flow conservation) assigned to distributor \( j \):

\[
\sum_{k} \sum_{l} y_{jk}'(t) = \sum_{i} x_{ij}(t)D_i(t), \text{ for all } j \in J.
\]
On another hand, the total power produced by all generators must satisfy the demand of all distributers:

\[ \sum_k \sum_{l,j} y'_{kj}(t) \leq \sum_k G_k(t) \quad \text{for all } k \in K. \]  

(4)

Where \( G_k \) is the amount of power produced by generator \( k \) in time slot \( t \). Moreover, during each time slot \( t \), the smart grid system ensures that each generator \( k \) is not idle.

\[ \sum_j y'_{kj}(t) \geq G^\text{min}_k \quad \text{for all } k \in K. \]  

(5)

Where \( G^\text{min}_k \) is the minimum power level required to operate the generator economically. Similarly, each transporter \( l \) must participate to supplying the distributers:

\[ \sum_k \sum_{l,j} y'_{kj}(t) \geq T^\text{min}_l \quad \text{for all } l \in L. \]  

(6)

Where \( T^\text{min}_l \) is the minimum power level required to operate the transporter economically. Finally, each transporter has its line capacity. Hence, the amount of power transported in time slot \( t \) through transporter \( l \) is bounded by its line capacity:

\[ y'_{kj}(t) \leq T^\text{max}_l, \quad \text{for all } l \in L. \]  

(7)

Recall that the objective of this system is to optimize the smart grid resource utilization through the minimization of the overall cost, including generation, transportation, distribution, and consumption costs.

3.1. Consumption Cost Function

Let \( c_j \) be the unit selling price offered by distributor \( j \) to the grid. In fact, the smart grid middleware is looking not only to minimize the total consumers’ bills but also to encourage consumers to reduce their energy consumption through a discount scheme, as it will be shown in the billing functions section. Furthermore, such a strategy will contribute to reducing the total energy generation which will have a positive impact on the Carbone footprint. Accordingly, a higher discount price will be given to those consumers with lower power demand: The total consumers cost is:

\[ \text{ConsumCost} = \sum_j \sum_{i,j} D_i(t) x_{ij}(t) c_j(t) \]

3.2. Distribution Cost Function

The use of Let us assume that each distributor can buy the power from different generators through different transportation lines. We denote by \( C_k(t) \) the selling price applied by generator \( k \) in time slot \( t \) and \( C_{lj}(t) \) is the transportation price offered by transporter \( l \) to transport one unit of power from generator \( k \) to distributor \( j \). Therefore, the total distribution cost function is:

\[ \text{DistCost} = \sum_k \sum_{l,j} (c_k(t) + c_{lj}(t)) y'_{kj}(t) \]

The overall cost function for the smart grid includes both the consumption cost and the distribution cost. Our objective is to minimize the overall smart grid cost (GridCost):

\[ \min \left( \sum_j \sum_{i,j} D_i(t) x_{ij}(t) c_j(t) + \sum_k \sum_{l,j} (c_k(t) + c_{lj}(t)) y'_{kj}(t) \right) \]  

(8)

The SGROH optimization model is solved using a greedy heuristic algorithm which takes into account the defined constraints (1) to (7) and the objective function (8). This optimization problem could be modeled as a Mixed Integer Linear Program and solved using CPLEX software. Real life smart grids are often designed to serve millions of consumers using large numbers of distributors, generators and transporters. To solve a MILP of such a scale, CPLEX requires more computational time than entailed for quick decisions within time slots as short as one hour. As an alternative, we develop a heuristic approach to enable SGROH to provide an approximate solution for resource management when needed and, hence, save computational time and memory requirement.
3.3. SGROH Heuristic Description

The main idea of the SGROH heuristic is to assign lower demand consumers to cheaper cost distributors. This strategy privileges low demand consumers by servicing them at the best market prices prior to high demand consumers. The heuristic operates as follows. First, consumers are sorted according to their respective load demands in an ascending order, while distributors are sorted by price charges in an ascending order. Next, the heuristic starts by assigning low demand consumers to the first low price distributor until its load capacity is reached. Then, the following batches of consumers are assigned to the next distributor, and so forth, until all consumers are assigned. At the distribution layer, a different marketing strategy is adopted: higher distributor demand is assigned to lower price generator and transporter. Here, generators and transportation lines are sorted based on their price charges in an ascending order. Then, assign the most loaded distributor to the lower price generator through the lower price transportation line, until either the transportation line is saturated or the generator’s capacity is reached. If the current transportation line is saturated, assign the remaining load of the distributor to the next transportation line in the corresponding sorted list. In case the generator capacity is reached, assign the remaining load to the next generator in the generators’ sorted list. Once the distributor’s load is fulfilled, proceed with the next distributor in the distributors’ list until all distributors have been assigned.

SGROH Heuristic

1. Sort consumers according to their demand (ascending)
2. Sort distributors according to their distribution costs (ascending)
3. for all consumers
   {if(Distributor_Assigned_Load[j]+Consumer_Load[i]<=
   Distributor_capacity[j])
   { Assign consumer i to distributor j
   Distributor_Assigned_Load[j]+= Consumer_Load[i]
   } else
   { Go to next distributor (j++); Assign consumer i to new distributor j;
   Distributor_Assigned_Load[j]+= Consumer_Load[i]
   }
   }
4. Sort distributors according to their assigned load (descending)
5. Sort generators according to their generation costs (descending)
6. for all distributors
   {remaining_Generator_Load = distributor_load[j]
   while more generators
   {if ( Generator_Can_Take_More[k])
   {if ( remaining_Generator_Load - generator_capacity[k] > 0)
   {remaining_Generator_Load-=generator_capacity[k];
   remaining_Line_Load=generator_capacity[k];
   Generator_Can_Take_More[k]=false;
   }
   else
   {generator_capacity[k]=remaining_Generator_Load;
   remaining_Line_Load=remaining_Generator_Load;
   remaining_Generator_Load=0;
   }
   6.1 for all transportation line
   {if(remaining_Line_Load - line_Capacity[j][k][l] >0)
   { remaining_Line_Load-=line_Capacity[j][k][l]
   transport line_capacity[j][k][l] through the line
   }
   else
   { transport remaining_Line_Load through the line
   remaining_Line_Load=0
   }
   }
   }
   }


4. Experiments and discussions
In this section, an illustrative example of SGROH is presented to give an overview of the quality of our greedy heuristic. A system of ten customers, three distributors, three generators and two transporters was used to simulate the grid system. The system was tested under different load conditions namely low load, medium load and heavy load. An average of 15Kw, 20Kw, 30Kw consumer demands was considered for low, medium and heavy load conditions, respectively. To simulate the variable rate scheme, one distributor charge and one generator charge was increased by 5% compared to the low load scenario. During the heavy load scenario, the charges of all distributors and all generators have been increased by 5%. During the evaluation process, the distribution cost and overall system cost (distribution, generation, and transportation) were recorded for a period of 24 hours. The grid system is solved by both SGROH heuristic algorithm written in C++ and using CPLEX 12.6.2. [13]. Note that CPLEX software provide us with optimal solution when the heuristic gives near optimal solution. Table 1, shows the system total cost for the grid system with both MILP’s (CPLEX) and the heuristic algorithm under different load conditions. It can be seen that under a low load condition, both algorithms behave similarly. For medium and high loads, MILP's solution is 2% better than the heuristic.

| Load       | MILP  | Heuristic |
|------------|-------|-----------|
| Low Load   | 5064  | 5064      |
| Medium Load| 7296  | 7344      |
| Heavy Load | 11952 | 12216     |

In this example, the heuristic algorithm produces a relatively good resource allocation solution (close to the optimum). The advantage of the heuristic approach is its potential to solve large scale problems faster which may not be the case for MILP solver using CPLEX. As far as our experiment are concerned we could not run CPLEX for more than 50000 customers. As we mentioned earlier, real grid system consists of millions of users and large number of distributor, transporters, and generators.

5. Conclusion
We proposed a new layered architecture for resource management optimization SGROH. Each layer is responsible for collecting data. The SGROH engine selects the best resource allocation for all the smart grid constituencies and ensures that only the needed power energy is generated in each time slot. A heuristic approach has been developed and tested successfully on a prototype SGROH. The advantage of the heuristic algorithm is that it can be used as an efficient fast decision tool with nearly optimal solution when dealing with large scale smart grid systems. It is worthwhile noting that, in the ongoing research work, we are investigating the implementation of SGROH on real-life power grids.

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Acknowledgments
The authors gratefully acknowledge the support of Internal Grant IG/SCI/COMP/18/01, Sultan Qaboos University, Oman