Optimizing operation of integrated energy system considering distribution network and natural gas network

Juqin Xuan¹, Jiyun Zheng², Pengjia Shi³, Jueying Wang⁴, ⁵, Shiwei Xie³, Shunfei Kong³ and Zhijian Hu³

¹ State Grid Fujian Electric Power Co., Ltd, Fuzhou, China
² Economic and Technological Research Institute of State Grid Fujian Electric Power Co., Ltd, Fuzhou, China
³ School of Electrical Engineering and Automation, Wuhan University, Wuhan, China
⁴E-mail: jueying_wang@126.com

Abstract. In this paper, an optimizing operation model of integrated energy system (IES) based on distribution network and natural gas network is proposed. While meeting the safety operation constraints of these two networks, the cost of energy for the integrated energy system is minimized at the same time. The proposed model is a comprehensive non-convex problem which is difficult to solve. In order to solve this problem, the incremental piecewise linearization as well as second order cone relaxation (SOCR) is applied to convert the original model into a convex problem. Therefore, the operational scheme of the integrated energy system can be obtained through solving the proposed model. Finally, the effectiveness of the proposed model was verified by simulation on an integrated energy system consisting of the 20-node natural gas network and IEEE 14 node system.

1. Introduction

In order to realize the coordinated management of various energy resources and make full use of the complementarity of different energy resources, the IES emerges at the historic moment. The IES refers to the coordinated planning and optimized operation of various energy subsystems such as coal, oil, natural gas, electric energy and thermal energy within a certain area. Therefore, it is necessary to effectively improve the efficiency of energy utilization and promote the sustainable development of energy while meeting the diversified energy demand within the system. In a general way, to couple different forms of the network, the concept of energy hub (EH) was firstly defined in [1]. Authors in [2] proposed a method of multi-energy flow calculation for IES consisting of electricity, heat and gas. In [3], authors adopted a approach for IESs modelling and simulation to maximize efficiency and minimize waste. Integrating power systems into transport and heating/cooling requirements will facilitate a shift to cleaner and greener sources of energy, leading to an economical, efficient, reliable, stable and sustainable power production system [4]. Researches on the optimal operation of the IES had been discussed in [5-7]. Among them, authors in [5] aimed to realize a steady-state optimization of the IES operating by minimize the use of exergy destruction. A mixed integer linear programming model was prosed in [6] to provide optimal operating strategies aiming at minimizing the total energy cost for the process industry. In [7], authors presented an algorithm for making approximate optimal scheduling decisions in real time.
In this paper, an optimizing operation model of IES based on distribution network and natural gas network is proposed on the basis of EHs. The objective of the model is to minimize the total cost of energy purchase. The contents are as follows: the optimizing model is established in section 2, including objective function and operating constraints of the IES. Then, equivalent deformation of the original non-convex model is implemented in section 3. Finally, in section 4, the proposed model and method are verified by simulation.

2. Optimizing model

2.1. Objective Function

The main objective of the optimization model proposed in this paper is to minimize the total cost of energy for the IES during the simulated operation scheduling period. Therefore, the energy trading costs, including electricity purchase cost and gas purchase cost are mainly taken into consideration in the model.

$$\min C = \sum_{t \in T} \sum_{j \in TR} C^E_{jt} P^TR_{jt} \Delta t + \sum_{t \in T} \sum_{j \in GS} C^G_{jt} F^{GS}_{jt} \Delta t$$

(1)

where $C^E / C^G$ represent electricity and natural gas price in time $t$. $P^TR_{jt}$ represents the active power of transformer substation output. $F^{GS}_{jt}$ represents the natural gas injected into node $j$ by the gas source.

2.2. Modeling and Constraints

2.2.1. Energy hubs. In this paper, diversified energy demands such as electricity, heat and gas load exist simultaneously in the IES. In order to meet the demand of the terminal load effectively, EH, coupling distribution network and gas network is modelled, mainly consists of Combined Heat and Power (CHP), Gas Furnace (GF) and Power to Gas (P2G). it can be seen that not only can complete the conversion between electricity and gas, but also can supply heat load, as shown in Figure 1.

Based on the established EH, relevant constraints can be formulated as follows:

a) Thermal power supply and demand balance constraints

$$f_{j,CHP} \xi_{j,CHP} \eta_{j,CHP} + f_{j,GF} \xi_{j,GF} \eta_{j,GF} = L_{j,heat} \forall j \in L_{heat}$$

(2)

where $L_{j,heat}$ is the thermal load. $\eta_{j,CHP} / \eta_{j,GF}$ is heat generation efficiency of CHP/GF and $\xi_{j,fr}$ is a constant conversion coefficient for flow to power. $f_{j,CHP} / f_{j,GF}$ is the gas flow injected into CHP/GF of node $j$ at time $t$.

b) Energy conversion single-directional constraints
2.2.2. Distribution Network.

a) Nodal power balance constraints

\[ \forall j \in \Omega_F, \forall t \in T:\]
\[ \sum_{\delta(j) \in (j)} P_{ijt} = \sum_{\gamma((j)) \in (j)} P_{ijt} - \frac{f_{ijt}^{\text{CHP}}}{r_{ij}^p} P_{ijt}^p - P_{ijt}^{\text{load}} + f_{ijt}^{\text{GF}} P_{ijt}^{\text{GP}} - P_{ijt}^{\text{load}} \]
\[ \sum_{\delta(j) \in (j)} Q_{ijt} = \sum_{\gamma((j)) \in (j)} Q_{ijt} - \frac{f_{ijt}^{\text{CHP}}}{x_{ij}^p} Q_{ijt}^p - Q_{ijt}^{\text{load}} \]
\[ U_{ijt}^2 = U_{ijt}^2 - 2(P_{ijt} r_{ij}^p + Q_{ijt} x_{ij}^p) + I_{ijt}^2 (r_{ij}^p + x_{ij}^p) \]
\[ p_{ijt}^2 + q_{ijt}^2 = U_{ijt}^2 I_{ijt}^2 \]  

where \( r_{ij}^p \) and \( x_{ij} \) are the resistance and reactance of branch \( ij \). \( \delta(j) \) represents the set of buses whose parent is bus \( j \) and \( \gamma((j)) \) represents the set of buses whose child is bus \( j \). \( P_{ijt} \) and \( Q_{ijt} \) is the active/reactive power of the branch \( ij \) respectively. \( P_{ijt}^{\text{load}} \) and \( Q_{ijt}^{\text{load}} \) represent the active/reactive power of transformer substation output and electrical load demand, respectively. And \( f_{ijt}^{\text{CHP}} \) is equivalent to the active power injected into the distribution network.

b) Voltage amplitude constraints

\[ U_{\min} \leq U_{ijt} \leq U_{\max} \]  

where \( U_{ijt} \), \( U_{\min} \) and \( U_{\max} \) are the node voltage amplitude and its lower and upper limit respectively.

c) Current amplitude constraints

\[ 0 \leq I_{ijt} \leq I_{\max} \]  

where \( I_{ijt} \) and \( I_{\max} \) are the amplitude of branch current and its upper limit.

d) Power constraints of substation

\[ \begin{align*}
  P_{j_{\min}}^{\text{TR}} & \leq P_{ijt}^{\text{TR}} \leq P_{j_{\max}}^{\text{TR}} \\
  Q_{j_{\min}}^{\text{TR}} & \leq Q_{ijt}^{\text{TR}} \leq Q_{j_{\max}}^{\text{TR}}
\end{align*} \]  

2.2.3. Natural Gas Network.

As shown in Figure 2, the natural gas network is mainly composed of natural gas source, pipeline, compressor and gas load. And the network can be modelled as follows.

\[ \begin{align*}
  f_{ijt}^{\text{CHP}} & \geq 0, f_{ijt}^{\text{GF}} \geq 0, P_{ijt}^{\text{P2G}} \geq 0
\end{align*} \]  

(3)
a) Nodal flow balance constraints

\[ \sum_{p \in \sigma(jk)} f_{p,j} = \sum_{l \in \mu(ij)} f_{j,l} - f_{j,\text{Load}} + \frac{F_{j,\text{GS}}}{\eta_{\text{et}}} - f_{j,\text{CHP}} + \frac{p_{j,\text{GS}} \eta_{\text{et}}}{\zeta_{p,j}} \]  

(10)

where \( \sigma(jk) \) represents the set of pipes with \( j \) as the head node and \( \mu(ij) \) represents the pipe set with \( j \) as the terminal node. \( f_{p,l} \) represents the flow through pipeline \( p/l \). \( f_{j,\text{Load}} \) represents the gas load. \( F_{j,\text{GS}} \) represents the input flow from gas source. \( \frac{f_{j,\text{CHP}}}{\eta_{\text{et}}} \) represents the natural gas output for energy conversion of GF/CHP. \( \frac{p_{j,\text{GS}} \eta_{\text{et}}}{\zeta_{p,j}} \) is equivalent to natural gas input from P2G.

b) Compressor boost constraints

\[ \pi_{j,t} = \Gamma_c \pi_{i,t} \]  

(11)

\[ 0 \leq f_{c,j} \leq F_{c}^{\text{max}} \]  

(12)

Compressors are usually equipped in the pipeline to transport gas and to increase pressure that has been lost due to friction. The original model of a compressor is a non-convex expression describing the relationship between the pressure ratio and energy consumption. As indicated in [8], the energy (electric energy or natural gas) consumed by the compressor is very small. Following the method presented in [8], in this paper, the energy consumption during operation is ignored and only the relationship between the inlet and outlet ends of the gas compressors is retained. The relationship between the inlet and outlet of the compressor is described by (11), where \( \Gamma_c \) represents the booster coefficient. \( \pi_{i,t} \) and \( \pi_{j,t} \) respectively represent the pressure at the inlet and outlet of the compressor. And then, the flow through the compressor is limited by (12).

c) Weymouth steady-state constraints

In this paper, Weymouth steady-state flow model [9] is adopted to describe the relationship between the gas flow and pressure at both ends, which can be formulated as:

\[ \text{sgn}_p(\pi_{i,t}, \pi_{j,t}) f_{p,t}^2 = \phi_p(\pi_{i,t}^2 - \pi_{j,t}^2) \]  

(13)

where \( \text{sgn}_p(\pi_{i,t}, \pi_{j,t}) = \begin{cases} +1 & \pi_{i,t} > \pi_{j,t} \\ -1 & \pi_{i,t} < \pi_{j,t} \end{cases} \).

\( \phi_p \) and \( \text{sgn}_p \) respectively represent the transmission parameter and direction of the flow.

d) Pipeline flow constraints

\[ -F_{p}^{\text{max}} \leq f_{p,t} \leq F_{p}^{\text{max}} \]  

(14)

where \( F_{p}^{\text{max}} \) represents the maximum transmission flow through pipeline.

e) Natural gas output constraints

\[ F_{j,\text{GS}}^{\text{min}} \leq F_{j,t}^{\text{GS}} \leq F_{j,\text{GS}}^{\text{max}} \]  

(15)

where \( F_{j,t}^{\text{GS}} \) represents the flow injection from the gas source while \( F_{j,\text{GS}}^{\text{max}} \) and \( F_{j,\text{GS}}^{\text{min}} \) are the upper and lower limits.
f) Nodal pressure constraints

The pressure of each node in the natural gas network must operate within a safe and reasonable range, which can be stated as:

$$\pi_i^{\text{min}} \leq \pi_{i,t} \leq \pi_i^{\text{max}}$$

(16)

3. Solution method

The proposed model in section 2 is a comprehensive non-convex problem which is difficult to solve. To solve this problem, the second order cone relaxation as well as incremental piecewise linearization is applied to convert the original model into a mixed-integer linear problem.

3.1. Second order cone relaxation

Since Equations (4)-(6) contain nonlinear terms, in order to solve the problem, the SOCR method [10] is used to simplify the constraints. The new variable is introduced to eliminate the square term of voltage and current, as shown below:

$$
\begin{align*}
U^*_{j,t} &= U^2_{j,t}, \forall t, \forall j \\
I^*_{o,t} &= I^2_{o,t}, \forall t, \forall ij
\end{align*}
$$

(17)

By substituting the above equation back into the nodal power balance constraints, the nonlinear quadratic terms of voltage and current can be eliminated, as shown below:

$$
\begin{align*}
\sum_{k \in \mathcal{N}(j,t)} P_{k,t} - \sum_{i \in \mathcal{N}(j,t)} (P_{i,t} - I^*_{i,t} \beta_{i,t}) &= P^\text{TR}_j - P^\text{load}_j + f^\text{CHP}_j \beta_{j,t}^\text{CHP} - P^\text{PG}_j \\
\sum_{k \in \mathcal{N}(j,t)} Q_{k,t} - \sum_{i \in \mathcal{N}(j,t)} (Q_{i,t} - I^*_{i,t} \gamma_{i,t}) &= Q^\text{TR}_j - Q^\text{load}_j \\
U^*_{j,t} &= U^2_{j,t} - 2(P_{j,t} \beta_{j,t} + Q_{j,t} \gamma_{j,t}) + I^*_{j,t} (r_j^2 + x_j^2) \\
P^\text{PG}_{q,t} + q^2_{q,t} &= U^*_{j,t} I^*_{o,t}
\end{align*}
$$

(18)

And Equations (7)-(8) can be rewritten as:

$$
\begin{align*}
U^2_{\text{min}} &\leq U^*_{j,t} \leq U^2_{\text{max}} \\
I^*_{o,t} &\leq I^2_{\text{max}}
\end{align*}
$$

(21)

(22)

In Equation (20), there remains a nonlinear term, which can be further transformed into a second-order cone form through relaxation, as stated in (23).

$$
\begin{align*}
2P_{o,t} &\leq I^*_{o,t} + U^*_{j,t} \\
2Q_{o,t} &\leq I^*_{o,t} + U^*_{j,t} \\
I^*_{o,t} - U^*_{j,t} &\leq I^*_{o,t} + U^*_{j,t}
\end{align*}
$$

(23)

3.2. The incremental piecewise linearization

Similarly, a new variable is introduced to eliminate the non-linearity brought by the pressure square term in Equation (13), as shown below:

$$
\pi^{\star}_{j,t} = \pi^2_{j,t}
$$

(24)
Hence, Equation (13) can be firstly rewritten as:

\[ \text{sgn}_p(\pi_{i,j}, \pi_{j,i}) f_{p,i}^2 = \phi_p(\pi_{i,j}^* - \pi_{j,i}^*) \]  

(25)

Then it can be dealt with by the incremental piecewise linearization. Actually, the left of Equation (25) can be seen as \( Y_{p,i} \).

In a general way, for a nonlinear function \( f(x) \), the basic steps of incremental piecewise linearization can be summarized as follows:

**Step 1:** According to the size and characteristics of the solution model, set the appropriate number of linearized segments \( n \).

**Step 2:** divide the value interval of \( x \) into \( n \) segments on average, then \( n+1 \) interval points are obtained: \( x_0, x_1, \ldots, x_n \).

**Step 3:** Calculate the value of \( f(x) \) corresponding to \( x_0, x_1, \ldots, x_n \).

**Step 4:** Introduce new auxiliary variables, and meanwhile ensure the following equations.

\[
\begin{align*}
&\phi_p(\pi_{i,j}^* - \pi_{j,i}^*) = Y_{p,i}, \quad \sum_{m=0}^{10} (Y_{p,j,m+1} - Y_{p,j,m}) \cdot \delta_{p,j,m} \\
&f_{p,i} = f_{p,j} + \sum_{m=0}^{10} (f_{p,j,m+1} - f_{p,j,m}) \cdot \delta_{p,j,m} \\
&0 \leq \delta_{p,j,m} \leq 1, \quad \eta_{p,j,m} = \{0,1\}, m = 0, 1, \ldots, n \\
&\delta_{p,j,m+1} \leq \eta_{p,j,m}, \quad \delta_{p,j,m} \geq \eta_{p,j,m}, m = 0, 1, \ldots, n-1
\end{align*}
\]  

(26)

In combination with this method, Equation (25) can be further rewritten as:

\[
\begin{align*}
\forall p, \forall t, \forall j \quad &\phi_p(\pi_{i,j}^* - \pi_{j,i}^*) = Y_{p,i}, \quad \sum_{m=0}^{10} (Y_{p,j,m+1} - Y_{p,j,m}) \cdot \delta_{p,j,m} \\
f_{p,i} = f_{p,j} + \sum_{m=0}^{10} (f_{p,j,m+1} - f_{p,j,m}) \cdot \delta_{p,j,m} \\
0 \leq \delta_{p,j,m} \leq 1, \quad \eta_{p,j,m} = \{0,1\}, m = 0, 1, \ldots, n \\
\delta_{p,j,m+1} \leq \eta_{p,j,m}, \quad \delta_{p,j,m} \geq \eta_{p,j,m}, m = 0, 1, \ldots, n-1
\end{align*}
\]  

(27)

By linearization and conic relaxation, the proposed model is converted into a SOCP model which allows solver CPLEX to obtain the global optimal solution of the proposed formulation. As mentioned in [11], there exists a relatively small error gap between this solution and the solution to the original model. Since the equality Constraint (20) is relaxed to inequality Constraint (23) based on conic relaxation, the infinite norm of relaxation deviation [11] is defined in Equation (28) to evaluate the accuracy of the optimization algorithm.

\[
\Delta^\text{Gap} = \| \hat{u}^2_{i,j} - (\hat{p}_{i,j}^2 + \hat{q}_{i,j}^2) U^*_{i,j} \|_\infty, \forall ij
\]  

(28)

### 4. Case study

In this paper, a system consisting of a 14-node distribution network and a 20-node natural gas network is used for simulation analysis, whose data can be obtained from [12] and [8], respectively. The distribution network has 1 substation node, 7 power load nodes, 8 coupling nodes and 16 lines. The natural gas network has 2 gas source nodes, 10 gas load nodes, 8 coupling nodes and 25 pipelines. It is worth noting that the 8 coupling nodes can not only meet the demand of electricity and gas load, but also provide thermal power. By simulating 24-hour operation in a day, aiming at the minimum energy cost in the day, a cost-saving operation scheme can be obtained. The related 24-hourly data are
download from [13], and average values (including electric, gas, hot demand, wind and photovoltaic power) for each hour are computed to constitute the 24-hour curves. In addition, other relevant parameters can be required from authors. On the basis of the aforementioned solution method, the proposed original model can be solved smoothly by CPLEX 12.6.0 in MATLAB 2016a.

As electric energy is difficult to preserve and insufficient load easily leads to excessive network losses, real-time electricity price, which can stimulate and encourage power users to shift peak load and fill valley and optimize electricity consumption mode is usually adopted. Natural gas is convenient to store, therefore real-time gas price is generally not taken into consideration. The real-time energy price curves are shown in Figure 3.

![Figure 3. Real time energy price curves.](image)

In this paper, two examples are considered for analysis:

**Case 1**: IES considering CHP and P2G, which could make energy conversion according the electricity and gas price. In particular, the CHP could generate heat and electricity power simultaneously using natural gas, while the P2G can converts natural gas into electricity power.

**Case 2**: IES not considering CHP and P2G. In other words, there is no connection between distribution network and the natural gas network in terms of energy flow. And the thermal load could only be provided by GF.

| Case 1 (Considering CHP and P2G) | Case 2 (Not considering CHP and P2G) |
|---------------------------------|--------------------------------------|
| Total energy cost (yuan)        | Cost of gas purchase (yuan)          | Cost of electricity purchase (yuan) |
| 60065964.6                      | 59840624.9                            | 225339.7                            |
| 60089863.0                      | 59871395.3                            | 218467.7                            |

The cost comparison for the two cases is shown in Table 1. From the table, we could draw a conclusion that the total cost of energy for the IES considering CHP and P2G is 23898.4 yuan lower than that does not considering CHP and P2G, which again proves that the IES coupling the two networks has better economic benefits through coordinated management.
Figure 4 shows the operation curves of CHP and P2G. It can be noted that the operation of CHP and P2G show complementary characteristics to a certain extent and meanwhile, the operation curves of them are inevitably related to the electricity and gas price. Concretely, in the periods 7:00-9:00 and 18:00-23:00, electricity is heavily consumed, leading to the sufficiently high electricity price, and hence CHP converts more gas into electricity. From 23:00 -24:00 and 0:00-7:00, due to the low electricity load demand, the electricity price is relatively low, P2G converts more electricity power into natural gas. Especially in 2:00-6:00, the electricity supply has been increased to its maximum limit.

In order to further observe the operation of the EH, Figure 5 shows a bar chart which describes the composition of the thermal power generation. In the bar chart, the total height in each hour represents the heat load demand at this time, the dark green column height represents the heat production of CHP, and the yellow shaded one represents the heat production of GF at this time. It can be noted that the thermal power provided by gas furnace is determined by that provided by combined heat and power. The reason is that when the gas price is relatively high, there is no need for the CHP to convert gas into electricity, nor does it generate thermal power. On the other hand, when the gas price is relatively cheap (7:00-9:00 and 18:00-23:00), the CHP will convert as much gas as possible into electricity, along with generation of a certain amount of thermal power.
To evaluate the accuracy of the SOCR method on the proposed model, the relaxation gap of the tested 24 scenarios is computed based on aforementioned Equation (28), and thereby obtaining the results given in Figure 6. It is obvious that the maximum gap among all scenarios is not exceed $10^{-7}$, which can be considered to be precise enough. Moreover, we observe that the computation time of this case is 139.73s, which is acceptable for day-ahead operation issue.

5. Conclusions

Conclusions can be summarized as:

The optimal operation model of the IES consisting of natural gas and distribution network is described and verified. In order to meet diverse load demand effectively, such as electric load, natural gas load and thermal load, EH aiming at couple the distribution network and gas network is modelled.

The objective of the optimal operation model of the IES is to minimize the total cost of energy purchase in a day. Simultaneously, the safety and reasonable operation restraints of the IES are ensured.

The effectiveness of the prosed model was verified by simulation on an IES consisting of the 20-node natural gas network and IEEE 14-node system. Through the simulation, the economic effectiveness of the IES is demonstrated again. Meanwhile, a cost-saving, safety and reasonable operation scheme of the IES can be obtained, and the factors of electricity price and gas price variation are also taken into consideration.

Finally, the relaxation gap of SOCR is investigated. The results show that the utilization of SOCR can effectively deal with the proposed model while keeping the accuracy of results.

Acknowledgments

This work was supported by Science and Technology Project of SGCC (No. SGFJYY00GHJS1700060).

References

[1] Geidl M, Koeppel G, Favre-Perrod P, Klockl B, Andersson G and Frohlich K 2007 Energy hubs for the future Power & Energy Magazine IEEE 5(1) pp. 24-30
[2] Wang Y, Zeng B, Guo J, Shi J and Zhang J 2016 Multi-Energy Flow Calculation Method for Integrated Energy System Containing Electricity, Heat and Gas Power System Technology
[3] Mittal S, Ruth M, Pratt A, Lunacek M, Krishnamurthy D and Jones W 2015 A System-of-Systems Approach for Integrated Energy Systems Modeling and Simulation in Conference on Summer Computer Simulation
[4] Stanislav P, Bryan K and Tihomir M 2010 Smart Grids better with integrated energy system in Electrical Power & Energy Conference
[5] Jain N and Alleyne A G 2012 A framework for the optimization of integrated energy systems Applied Thermal Engineering 48(48) pp. 495-505
[6] Arivalagan A, Raghavendra B G and Rao A R K 1995 Integrated energy optimization model for
a cogeneration based energy supply system in the process industry *International Journal of Electrical Power & Energy Systems* **17**(4), pp. 227-233

[7] Firestone R, Stadler M and Marnay C 2006 Integrated Energy System Dispatch Optimization in *IEEE International Conference on Industrial Informatics*

[8] Hu Y, Hong B, et al. 2017 Integrated Planning of Natural Gas Network and Composite Power System *Proceedings of the CSEE* **37**(01) 45-54

[9] Mohammadi M, Noorollahi Y, Mohammadi-ivatloo B, Hosseinzadeh M, Yousefi H and Khorasani S T 2018 Optimal management of energy hubs and smart energy hubs – A review *Renewable and Sustainable Energy Reviews* vol. **89** pp. 33-50

[10] Xie S, Hu Z, Zhou D, Li Y, Kong S, Lin W and Zheng Y 2018 Multi-objective active distribution networks expansion planning by scenario-based stochastic programming considering uncertain and random weight of network *Applied Energy* vol. **219** pp. 207-225

[11] Li P, Ji H , Wang C, Zhao J and Song G 2017 A Coordinated Control Method of Voltage and Reactive Power for Active Distribution Networks Based on Soft Open Point *IEEE Transactions on Sustainable Energy* **8**(4) 1949-3029

[12] Fitiwi, Desta Z and Rao K S R 2010 Assessment of ANN-based auto-reclosing scheme developed on single machine-infinite bus model with IEEE 14-bus system model data *Tencon IEEE Region 10 Conference*

[13] (2016) EIRGRID GROUP. [Online] Available: www.eirgridgroup.com/