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# Minimizing Market Operation Costs Using A Security-Constrained Unit Commitment Approach

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**Abstract**: This paper presents the methodology and the results of the Must Offer Waiver process as applied in the California electricity market. The goal of this cost saving process is to minimize the market operation costs by deploying an optimal unit commitment approach. This procedure replaces the “first come, first served” Must Offer Waiver process that is currently in place. It uses a Security Constrained Unit Commitment application to commit enough units to meet the reliability requirement and minimize the total start up and minimum load costs over the specified time period. A post Must Offer Waiver procedure utilizing the Security Constrained Unit Commitment is also established to calculate and allocate the incremental costs associated with the local reliability requirement. The key components of the new Must Offer Waiver procedure, the methodology and computer algorithm of Security Constrained Unit Commitment, and the methodology of the incremental cost calculation and allocation are addressed in this paper. The paper finally presents computational results based on actual data to illustrate the benefits of the new approach.

**Keywords:** Must Offer Waiver (MOW)**,** Security Constrained Unit Commitment (SCUC)**,** start up cost, minimum load cost, incremental cost, Mixed Integer Linear Programming (MILP).

## I. INTRODUCTION

California’s electricity market experienced a major setback during its 2000 ~ 2001 energy crisis. System reliability was severely impacted during the crisis due to inadequate generating capacity being available when and where it was needed to meet native load. As a result of the crisis almost all non-hydro generators are currently designated by the Federal Energy Regulatory Commission (FERC) as “Must Offer Units” [1]. A Must Offer unit has to offer its available capacity to ISO’s real-time Imbalance Energy Market and be available for dispatch by the California Independent System Operator (CAISO). Units committed due to the Must Offer obligation are guaranteed to recover all their start up and minimum load costs. Depending on system conditions, certain Must Offer units may not be needed and the CAISO may waive their Must Offer obligation and commit other available generators to meet the system’s reliability requirement. This waiver action is part of the so-called “Must Offer Waiver” process.

The initial MOW procedure used a “first come, first served” approach to waive a Must Offer unit’s obligation. This lead to a non-transparent and non-optimal unit commitment practice and caused a significant increase in operation costs to the market participants. The new procedure relies on a SCUC application to commit in an optimal manner sufficient Must Offer units to meet the reliability requirement while minimizing the total start up and minimum load costs over the specified time period [2]. A post MOW procedure utilizing the SCUC is also established to calculate and allocate the incremental costs associated with the local reliability requirement.

The focus of this paper is the development and implementation of the SCUC application to resolve a deficiency problem in the market operation. Section II presents the methodology of SCUC application including the optimization objective, network constraints, unit inter-temporal constraints, network modeling, and other engineering considerations are addressed in detail in the paper. The formulation of the MILP algorithm along with the parameter setting and variable tuning used by SCUC application to meet the performance requirement is presented in Section III. Section IV describes the methodology of MOW process. Section V presents the incremental cost calculation along with the rationale of incremental cost allocation. Section VI presents numerical results using actual California ISO market operation data. The results show that the use of the SCUC application could achieve significant cost savings for the California consumers. The conclusions are presented in Section VII.

## II. SCUC OPTIMIZATION FORMULATION

The MOW process is basically a process of determining which Must Offer units should be committed in order to have enough additional capacity to meet the system energy net short which is the difference between the forecast system load and the Day-Ahead Market energy schedules. This commitment process ensures that the resulting unit schedule is feasible with respect to network and system resource constraints. Mathematically, this can be stated as a type of a SCUC problem [3]. The objective is to minimize the total start up and minimum load costs of the committed units while satisfying the power balance constraint, the transmission interface constraints, and the system resource constraints, including unit inter-temporal constraints.

The SCUC model is formulated as follows:

### *Objective Function*

The objective is to minimize the total start-up and minimum load costs of the committed Must Offer units.

$$\text{Min} \quad \sum_{h=1}^{T}\sum_{i=1}^{N}\left\{\left[C_{i,h}^{mlc} + C_{i,h}^{su}[1-U_{i,h-1}]\right]U_{i,h}\right\} \qquad (1)$$

Where,

| | |
|---|---|
| $h$ | Hour index |
| $T$ | Total number of hours in the time horizon |
| $i$ | Must Offer generating unit index |
| $N$ | Total number of units |
| $C_{i,h}^{mlc}$ | Minimum load cost ($) for unit *i* in hour *h* |
| $C_{i,h}^{su}$ | Start-Up cost ($) for unit *i* in hour *h* |
| $U_{i,h}$ | Commitment status; = 0 if unit *i* is off-line, and = 1 if unit *i* is on-line, in hour *h* |

The minimization of the objective is subject to the power balance, transmission, unit inter-temporal and other practical system resource constraints. Each of these constraints is presented in detail next.

### A. *Power Balance Constraint*

The power balance constraint requires that the total capacity of the committed Must Offer units by SCUC must be equal or greater than the energy net short.

$$\sum_{i=1}^{N} P_{i,h}^{gen} U_{i,h} \geq \Delta D_h \qquad (2)$$

Where,

| | |
|---|---|
| $P_{i,h}^{gen}$ | Capacity of unit *i* in hour *h* |
| $\Delta D_h$ | Energy net short of hour *h* |

$$\begin{aligned}\Delta D_h = \; & (\text{Demand Forecast})_h \\ & + (\text{Capacity Margin})_h \\ & - (\text{Average HA Net Scheduled Interchange})_h \\ & - (\text{Average HA Generation from non-Must Offer units})_h \\ & - (\text{Self Scheduled Must Offer Capacity})_h \\ & - (\text{Must Offer Capacity Required for Local Reliability})_h \qquad (3)\end{aligned}$$

Table 1 provides the description of each component in equation (3).

Table 1
Components of Energy Net Short Calculation

| **Component** | **Description** |
|---|---|
| Demand Forecast | Total Day-Ahead Load Forecast |
| Capacity Margin | Forecasted Operating Reserve Requirement |
| Average Hour-Ahead (AH) Net Scheduled Interchange, and Average HA Generation from non-Must Offer units | Values derived from recent historical Hour-Ahead schedule values. These historical averages will be representative of the operating day; such as choosing the last three Saturdays for the weekend commitment schedule |
| Self Scheduled Must Offer Capacity | All capacity from must-offer units that have either energy or ancillary service awards in the Day-ahead preferred market. |
| Must Offer Capacity Required for Local Reliability | All capacity from must-offer units that have been forced on to meet local reliability requirements by operators |

### B. *Transmission Constraints*

Currently the California ISO uses a zonal model to represent the transmission system within its control territory in its Day-Ahead (DA) congestion management and Real-time Market. The California ISO is also in the process of redesigning its market towards using a full network model to represent its transmission system. In order to be consistent with the transition to a full network model representation the SCUC application is being implemented using a two-phase approach. The first phase is using the zonal network model and the next phase will be using a full network model.

In the zonal model there are three zones within California ISO's control territory namely NP15, SP15, and ZP26. Since these three zones are radially connected to the other adjacent zones there are only two transmission interfaces that need to be modeled in the SCUC application. These transmission interfaces are PATH 15 between zones NP15 and ZP26, and PATH 26 between zones ZP26 and SP15.

The transmission interface constraint is represented as,

$$-P_{k,h}^{\max import} \leq \sum_{i \in zone\, k} P_{i,h}^{gen} U_{i,h} - \Delta D_{k,h} \leq P_{k,h}^{\max export} \qquad (4)$$

Where,

| | |
|---|---|
| $k$ | zone index |
| $\Delta D_{k,h}$ | Energy net short of zone k |
| $P_{k,h}^{\max export}$ | The maximum amount of real power that could be exported from zone *k* in hour *h* due to the transmission interface limit |
| $P_{k,h}^{\max import}$ | The maximum amount of real power that could be imported into zone *k* in hour *h* due to the transmission interface limit |

### C. *Unit Inter-temporal Constraints*

To mimic the actual generation production process and the generator's physical characteristics the following unit inter-temporal constraints are modeled,

1) Ramp rate constraint

$$-R_i^{\max} \le P_{i,h}^{gen} - P_{i,h-1}^{gen} \le R_i^{\max} \qquad (5)$$

Where,

$R_i^{\max}$ Maximum ramp rate of unit *i*

2) Minimum run time constraint

$$T_i^{up} \ge T_i^{\min up} \qquad (6)$$

Where,

$T_i^{up}$ Unit *i* up time

$T_i^{\min up}$ Unit *i* minimum up time

3) Minimum down time constraint

$$T_i^{down} \ge T_i^{\min down} \qquad (7)$$

Where,

$T_i^{down}$ Unit *i* down time

$T_i^{\min down}$ Unit *i* minimum down time

4) Maximum shutdown times

$$L_i^{shutdown} \le L_i^{\max shutdown} \qquad (8)$$

Where,

$L_i^{shutdown}$ Number of times unit *i* being shutdown

$L_i^{\max shutdown}$ Unit *i* maximum shutdown times

5) Start up time constraints

$$T_i^{startup} \ge T_i^{\min startup} \qquad (9)$$

Where,

$T_i^{startup}$ Unit *i* start up time

$T_i^{\min startup}$ Unit *i* minimum start up time

It needs to be pointed out that $T_i^{\min startup}$ is a function of unit's down time $T_i^{down}$. The longer the unit's down time the longer the unit's start up time.

### D. *Other Engineering Considerations*

The following practical issues are also addressed in the SCUC model,

1) Dynamic unit capacity limits

Due to the scheduled and forced outages and other operational changes, a unit's minimum and maximum capacity limits may be changed hourly during the day. These dynamic unit capacity limits are calculated externally and passed to the SCUC application as input.

2) Units with partial Day-Ahead self schedules

Some Must Offer units may have self-scheduled for some hours of the day but not for all 24 hours. SCUC must have the capability of incorporating these partial Day-Ahead self-schedules in its unit commitment plan.

## III. MILP BASED SCUC ALGORITHM

The most popular algorithms for the solutions of the unit commitment problems are Priority-List schemes [4], Dynamic Programming [5], and Mixed Integer Linear Programming [6]. Among these approaches the MILP technique has achieved significant progress in the recent years [7].

The MILP methodology has been applied to the SCUC formulation to solve this MOW problem. Recent developments in the implementation of MILP-based algorithms and careful attention to the specific problem formulation have made it possible to meet accuracy and performance requirements for solving such large scale problems in a practical competitive energy market environment. In this section the MILP-based SCUC formulation is presented in detail.

### *MILP Mathematical formulation*

### 1) Unit variables and constraints

The following variable notation is used to define the constraints,

| | |
|---|---|
| $u_{n,t}$ | unit *n* on/off (0,1) status variable for time step t |
| $y_{n,t}$ | unit *n* start-up variable (0,1) for time step t |
| $z_{n,t}$ | unit *n* shut-down variable (0,1) for time step t |
| $P_{n,t}$ | unit *n* capacity for time step t |

Minimum up and down times may be applied to the units using the following constraints for each time step:

$$u_{n,t} - u_{n,t-1} = y_{n,t} - z_{n,t} \qquad (10)$$

Minimum up time constraint,

$$y_{n,t} + z_{n,t+1} + z_{n,t+2} + z_{n,t+3} + \ldots + z_{n,t+NUP} \le 1 \qquad (11)$$

Minimum down time constraint,

$$z_{n,t} + y_{n,t+1} + y_{n,t+2} + y_{n,t+3} + \ldots + y_{n,t+NDN} \le 1 \qquad (12)$$

The number of start-ups in a given period may also be controlled using an additional constraint:

$$\sum_t y_{n,t} \le NS_{max} \qquad (13)$$

Where,

$NS_{max}$ the maximum number of unit start-ups allowed in the study period.

Additional constraints are added to correctly couple the integer variables to improve performance in the branch and bound search [8].

$$y_{n,t} - u_{n,t} \leq 0 \qquad (14)$$

$$u_{n,t} + z_{n,t} \leq 1 \qquad (15)$$

Other constraints couple the unit capacity variables to the integer variables:

$$u_{i,t}P_{max,n,t} - P_{n,t} \geq 0 \qquad (16)$$

$$u_{i,t}P_{min,n,t} - P_{n,t} \leq 0 \qquad (17)$$

Where,

$P_{max,n,t}$ unit $n$ maximum capacity limit for time step t

$P_{min,n,t}$ unit $n$ minimum capacity limit for time step t

**2) System Capacity Constraint**

The sum of the generating unit capacities must equal the forecast incremental system demand at each time increment.

$$\sum_n u_{n,t}P_{max,n,t} - \gamma P_{slack,t} \geq \Delta D_t \qquad (18)$$

A slack variable $P_{slack,t}$ is added with a penalty of $\gamma$ which is set to a large value to allow for infeasible cases.

**3) Zonal Capacity Constraint**

There is also a zonal capacity constraint:

$$\underset{(units\ in\ zone)}{\Sigma(u_{n,t}P_{max,n,t})} - \eta R_{slack,t} \geq \Delta R_t \qquad (19)$$

Where,

$\Delta R_t$ the incremental capacity margin constraint for the zone.

A slack variable $R_{slack,t}$ is added with a penalty of $\eta$ which is set to a large value to allow for infeasible cases.

**4) Objective Function**

The objective function is set to minimize the sum of the startup and minimum load costs:

Minimize

$$\sum_n \left( \sum_t \left( CML_{n,t} u_{n,t} + CSU_{n,t} \right) \right) \qquad (20)$$

Where,

$CML_{n,t}$ Unit $n$ minimum load cost at time step $t$.

$CSU_{n,t}$ Unit $n$ start up cost at time step $t$.

## IV. THE SCUC-BASED MUST OFFER WAIVER PROCESS

The SCUC-based MOW process uses an advanced methodology to evaluate requests for waiver of the Must-Offer obligation to minimize Must-Offer commitment and operating costs.

The time horizon of the SCUC solution is set to be the 24 hours of next operational day but could be configurable.

The Must Offer Wavier process will commit units for the following reasons,

1. **Committing units for system reliability reasons**

   These units are committed to meet the system wide energy net short as defined by equation (2).

2. **Committing units for zonal reliability reasons**

   These units are committed due to the inter-zonal transmission constraints enforced on PATH 15 and PATH 26 as defined by equation (4). Because of these transmission interface limits, SCUC may not be able to commit the cheapest units but have to commit units in a particular zone to meet the energy net short requirement in that zone. It should be emphasized that the units committed for zonal reliability reasons could also contribute towards meeting the system reliability requirement.

3. **Committing units for local reliability reasons**

   These units are committed to meet the local reliability requirement. The local reliability requirements are usually the result of the intra-zonal transmission system constraints within the zone such as the capacity limits of the transformer banks and/or transmission lines. Since the current market is based on a zonal model, these units are manually committed by the system operators prior to running SCUC and set as must run units during the SCUC run. It should be emphasized that the units committed for local reliability reasons could also contribute towards meeting the system and/or zonal reliability requirements.

The SCUC application performs two runs to identify whether a unit is committed for system or zonal requirement. The first SCUC run will enforce the PATH 15 and PATH 26 transmission constraints and the second SCUC run will execute with these constraints disabled. The units being committed by both runs are identified as being committed to meet the system requirement and the units being committed in the first run but not in the second run are identified as being committed to meet the zonal requirement. Special consideration has been applied to the convergence tolerances and the algorithmic settings to ensure that the SCUC convergences to the exact optimum to avoid units being incorrectly labeled as committed for zonal constraints when in fact the potential “slightly” different solutions may be due to multiple optimal, or near degeneracy of solutions.

The rationale of identifying committed units for system, zonal, or local reliability reasons is based on the cost causation principle. The committed Must Offer units are guaranteed to recover their start up and minimum load costs. In the current Minimum Load Cost (MLC) allocation methodology the CAISO allocates the MLC to the CAISO control area demands and exports. In the new MOW process, the MLC costs are allocated to different categories and thus paid by different entities. The costs associated with the system reliability requirement are charged to the net negative uninstructed deviation and, as necessary, control area demand and in-state exports, the costs associated with the zonal system reliability requirement are charged to the Load Serving Entity (LSE), while the incremental costs due to the local reliability requirement are charged to the Participating Transmission Owners (PTO).

When the full network model is implemented, there would not be any distinction between inter-zonal and intra-zonal constraints. SCUC will commit units to meet the system energy net short as well as satisfy all the transmission and other system resource constraints.

## V. INCREMENTAL COSTS CALCULATION

A committed Must Offer unit's incremental cost is the cost of committing and operating that particular unit above the cost of operating the least expensive unit that would have been committed and operated to meet the system wide energy needs if there had been no local reliability requirement. According to ISO's Tariff this incremental cost shall be charged to the PTO in whose service area the unit is located.

The SCUC application is utilized to calculate the incremental costs described as follows,

1. **1st SCUC run (Base case)**
   Set all the units committed for system and zonal reliability reasons during the MOW process as the must-run units, and set the units committed for local reliability reason as de-committed but available to be committed for the purpose of the SCUC run. Use the operating conditions for that day to run SCUC and calculate the unit's start up and minimum load costs (MLC).

   A unit's MLC is calculated based on the following formulas,

$$MLC_i = P_{i,ML} * P_{i,\min} \tag{21}$$

$$P_{i,ML} = AHR_{i,\min} * \left(GPI_i + IST_i\right) + OMC_i \tag{22}$$

   Where,

| | |
|---|---|
| $P_{i,min}$ | Unit *i* minimum output |
| $AHR_{i,min}$ | Average heat rate at minimum output ($P_{min}$) in Btu/MWh |
| $GPI_i$ | Gas price index in \$/mmBtu |
| $IST_i$ | The intra-state transportation cost in \$/mmBtu |
| $OMC_i$ | Operation and maintenance costs in \$/MWh |

   The zonal MLC is the sum of all the unit MLC by zone.

2. **2nd SCUC run**
   Calculate the start up costs and MLC using the list of units that were actually committed during the MOW process. In this mode, SCUC is not modifying the commitment but it is only calculating the cost.

   The zonal MLC is the sum of all the unit MLC by zone.

3. **Calculate Zonal Incremental Cost (ZIC)**
   Subtract the zonal MLC of the 1st SCUC run from the zonal MLC of the 2nd SCUC run to get the zonal incremental cost.

4. **Allocate Unit Incremental Cost (UIC)**
   We then pro-rata allocate the total zonal incremental cost to each generating unit within the zone committed for local reliability reason based on the MLC of the unit.

$$UIC_i = ZIC * \frac{MLC_i}{\sum_{i \in zone} MLC_i} \tag{23}$$

## VI. COMPUTATIONAL ANALYSIS

This section presents the results of a comparison analysis of the SCUC application and the current "first come, first serve" approach. It also presents the results of a computational performance analysis to ensure that the SCUC function meets specific performance requirements.

### 1. Minimum load costs reduction analysis

The SCUC application was executed to commit Must Offer units based on the actual operation conditions of the summer of 2004 and calculated their minimum load costs. The resulting MLC are then compared with the actual minimum load costs of the units that were committed based on the "first come, first served." The result is shown in Figure 1.

The reduction of the minimum load costs is especially important since the start up costs is a relatively small portion of the total costs. The actual market data of California ISO shows that the start up costs is about 10% of the total costs of committing and operating the Must Offer units.

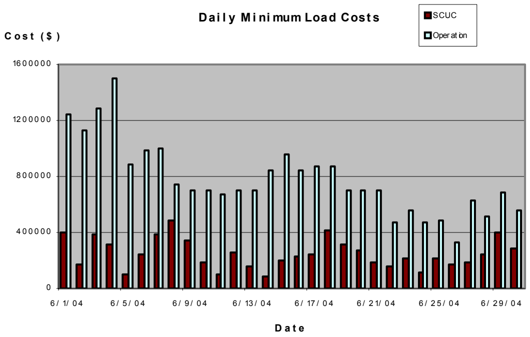

Figure 1 Minimum Load Costs Analysis

Figure 1 displays the MLC comparison for June of 2004. The light blue bars represent the actual daily minimum load costs, and the purple bars represent the daily minimum load costs of the units committed using the SCUC application.

The total monthly cost due to the system and zonal reliability requirement incurred during the actual MOW practice is 17.2 million dollars while the total monthly cost of using SCUC is 7.47 million dollars. The cost saving amounts to a percentage reduction of 56.6%.

### 2. Computational performance

The entire MOW process has to be completed (with published results) after the DA Initial Preferred market is closed and advisory schedules are published (at or around 11:00AM) and 30 minutes before the closing of the Revised DA market. The time window for the entire MOW process is about 30 minutes which is very taxing for such a large scale SCUC. Thus, the computational performance requirements for the SCUC application are very critical and an integral part of this development.

A common issue for unit commitment problems is the high dimensionality of the possible solution space that has to been searched by the software engine. This is so called dimensionality curse. Consider a time period of M hours with N Must Offer units to commit. The maximum number of possible combinations is $\left(2^{N}-1\right)^{M}$ . This the upper bound for the number of enumerations required. When M is 24 and N is 20 this number is 3.12 x $10^{144}$. For the MOW process the minimum number for M is 24 hours while the maximum number for N is about 120 Must Offer units. A more rigorous analysis of the dimensionality problem related to the MIPO technology is presented in [9].

We have paid special attention to ensure that the performance requirements are met. Specifically, special techniques have been applied to improve the SCUC computational performance, including adjusting the MILP variable priorities so that the $u_{i,t}$ variables are satisfied before the $y_{i,t}$ and $z_{i,t}$ startup and shutdown variables. Furthermore, we have added additional constraints to couple the integer variables to improve the branch and bound performance.

Table 2 shows the simulation results of the SCUC execution time vs. different Capacity Margin levels. The Capacity Margin is defined in formula (3). The simulation was conducted by running SCUC using one month of the California ISO market data. The number of Must Offer units is 122 and the unit commitment time period is 24 hours using a 1 hour time increment.

Table 2
SCUC Execution Times vs. Capacity Margin

| **Capacity margin** | **Average Execution Time (seconds)** | **Minimum Execution Time (seconds)** | **Maximum Execution Time (seconds)** |
|---|---|---|---|
| 0% | 17.4 | 9 | 105 |
| 3% | 24.3 | 9 | 105 |
| 7% | 148.9 | 14 | 600 |

These results were achieved by running the SCUC application on a Windows 2000 platform with 1.4 GHz CPUs and 256 M memory. Currently the California ISO's DA market operators use a default of 2 % Capacity Margin value when running SCUC for the MOW process. Thus, the SCUC's computational performance is well within the satisfaction range.

## VII. CONCLUSIONS

A SCUC application has been successfully developed by the California ISO to implement its Must Offer Waiver process. The SCUC application commits enough units to meet the energy net short, minimizes the total start up and minimum load costs, while all system resource inter-temporal and transmission constraints are satisfied. The SCUC application has also been successfully utilized to calculate the incremental costs of the Must Offer units committed to meet the local reliability requirement. The Mixed Integer Linear Programming solution algorithm used by SCUC proved to be efficient for providing robust solutions while meeting the required computational performance criteria. The market simulation results using actual operational data shows that the use of SCUC to implement the commitment of Must Offer units could achieve significant cost savings for the California consumers.

A parallel on going effort focuses on implementing a full network model for the California transmission grid. Therefore, all the transmission constraints could be modeled in the SCUC model and the operators would not need to manually commit units outside SCUC for local reliability reasons.

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## IX. BIOGRAPHIES

**Dr. Qin Zhou** (M'90) received his Ph.D. degree in electrical engineering from Iowa State University, Ames, IA, in 1992. He is the founder of NeoPower Consulting, Inc. Currently he is consultant with ECCO International providing consulting services to California ISO. Prior to founding the NeoPower Consulting, Inc., he was a lecturer teaching electrical engineering at Tsinghua University, Beijing, China, a senior consultant at PG&E, a senior engineer at NeoVista Software, Inc., and a senior specialist at Perot System Corporation. His research interests include the design and operation of electricity markets, and electrical distribution management systems (DMS). He is the member of Tau Beta Pai Honor Society.

**Roderick Frowd** (M'77, SM'95) is a principal consultant with ECCO International and is currently providing consulting services to the California ISO. Rod received his B.E.(Honors) degree in Electrical Engineering from the University of Queensland in 1976 and his M.E. degree from the University of Florida in 1980. He has been working in the real-time operation and control area for over 28 years and has been actively involved in the development and implementation of the advanced network analysis and scheduling applications for both EMS and DMS, with specialization in applying Mixed Integer Linear Programming techniques to unit commitment and scheduling problems. Rod is a Senior Member of IEEE and has written many papers in the advanced network analysis and scheduling areas.

**Dr. Alex D. Papalexopoulos** is president and founder of ECCO International, an Energy Consulting Company that provides consulting services on electricity market design and software issues within and outside the U.S. to a wide range of clients such as Regulators, Governments, Utilities, Independent System Operators, Power Exchanges, Marketers, Brokers and Software vendors. ECCO International is currently involved in various energy deregulation projects around the world including North America, Europe and Asia. Dr. Papalexopoulos received the Electrical and Mechanical Engineering Diploma from the National Technical University of Athens, Greece in 1980, and the M.S. and Ph.D. degrees in Electrical Engineering from the Georgia Institute of Technology, Atlanta, Georgia in 1982 and 1985, respectively. He worked at the Pacific Gas and Electric Company from 1985 till 1998. He has made substantial contributions in the areas of network grid optimization and pricing, market design, ancillary services, congestion management, competitive bidding, and implementation of EMS applications and real time control functions and forecasting in a utility environment. He has published numerous scientific papers in IEEE and other Journals. He is the 1992 recipient of PG&E's Wall of Fame Award, and the 1996 recipient of IEEE's PES Prize Paper Award. Dr. Papalexopoulos is a fellow of IEEE.

**Darren Lamb** is a Market Operations Engineer at the California ISO and is the Project Manager and Business Analyst for the SCUC project. He has recently managed several ISO projects in the area of compliance with FERC regulations and amendments to the ISO tariff. Darren was project coordinator for the ISO's Oasis Redesign effort, which incorporated XML technology into the ISO's Public Market Information application. He also has been employed at the ISO in the capacity of Senior Systems Analyst in the Information Services department. In that department, Darren acted as the Customer Relations Manager, interfacing with the Market Operations, Grid Operations, and Scheduling business units. Prior to his employment at the California ISO, Darren worked in the Enterprise Content Management Industry for 20 years, most recently with Anacomp Inc, as District Manager of Output Services.

**Eddie Ledesma** (M'05) is the Manager of Market Integration and Testing for the California Independent System Operator (CAISO). Eddie received his B.S. degree in Electrical & Electronic Engineering from the California State University, Sacramento in 1993 and his M.S. degree in Computer Information Systems from the University of Phoenix in 2002. He has been working in the power grid planning and market operations area for over 16 years. His last six years have been with CAISO, designing, testing and implementing forward-market changes related to inter and intra zonal congestion, ancillary services, and real-time operation. Eddie previously worked for the California Department of Water Resources as a Hydro-Electrical Engineer in the areas of planning, hydro re-licensing, FERC reporting, and data collection.