ENERGISE Program Kickoff

DOE Award #: DE-EE0008003

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DEEP SOLAR
Data DrivEn Modeling and Analytics for Enhanced System Layer ImPlementation

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University of Southern California

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Project Team

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Name	Role	Main Responsibilities (High level tasks/sub-tasks)
Viktor K. Prasanna (USC)	PI	• Work closely with the team members to meet the milestones and deliverables within budget and schedule • Co-ordinate and host the kick-off meeting, quarterly review meetings and annual meetings • Technical lead on developing predictive analytics and real-time control software

Rajgopal Kannan (USC)	Co - PI	• Work closely with the students
		  • Machine learning algorithms
		  • Software development of forecasting models
		  • Stochastic analysis and optimization

Valentino Tiangco (SMUD)	Subcontractor	• Utility guidance on interconnection standards, distribution grid issues and interoperability requirements • Utility perspective on distributed generation and renewable energy programs

Project Team

USC

- Viktor K. Prasanna

- Rajgopal Kannan

- Ajitesh Srivastava

- Athanasios Rompokos

- Atila Orhon

- Chi Zhang

- Chung Ming Cheung

- Sanmukh Rao Kuppannagari

SMUD

- Valentino Tiangco

- Elaine Sison-Lebrilla

Demonstration and Data Sets: SMUD

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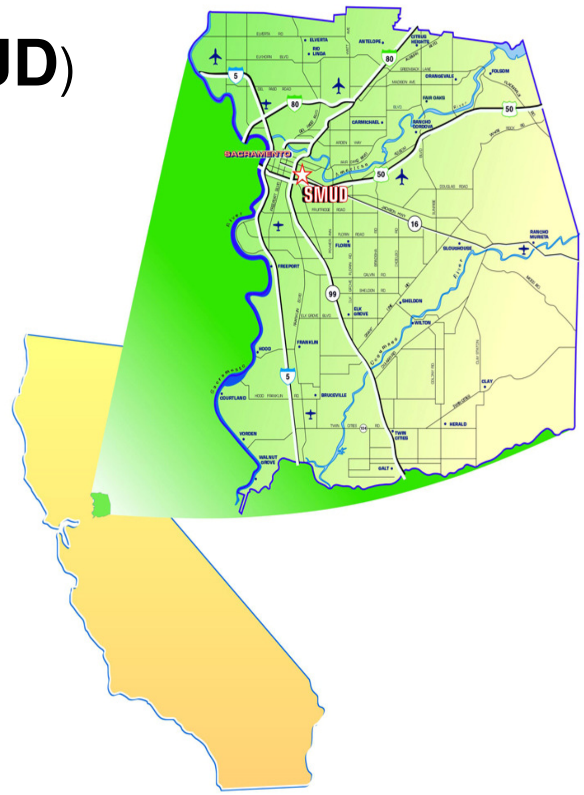
Sacramento Municipal Utility District (SMUD)

- Not for Profit, Publicly Owned Utility
- Sacramento County (small part of Placer County)
- Almost 600,000 Customers; 1.4 Million Population
- Record Peak Demand = 3,300 MW
- 5th Largest in CA and 6th Largest in the U.S.
- Manages Balancing Authority in Northern California (BANC)
- Low Rates, Innovative & Green
- 1st in customer satisfaction survey for the last 14 consecutive years (J.D. Power & Associates Survey)



Project Goals

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❖ Modeling and Optimizations to Enable Deep Solar Penetration

- > 100% relative to peak
- > 250% relative to day time minimum load

❖ Fast Data Analytics for Real-time Operations

- Grid Size: 1000 to 1 million node
- Response time: <1 min for short term, < 5min for long term planning

❖ Software for Situational Awareness & Operational Planning

- Preparation for spontaneous condition changes

Project Approach

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- Fast, robust predictive analytics for accurate load and generation **prediction**

- Real time scalable **optimization** framework for smooth grid operation

- Dynamic "**What-If**" Scenario Analysis for operational planning

Major Innovations

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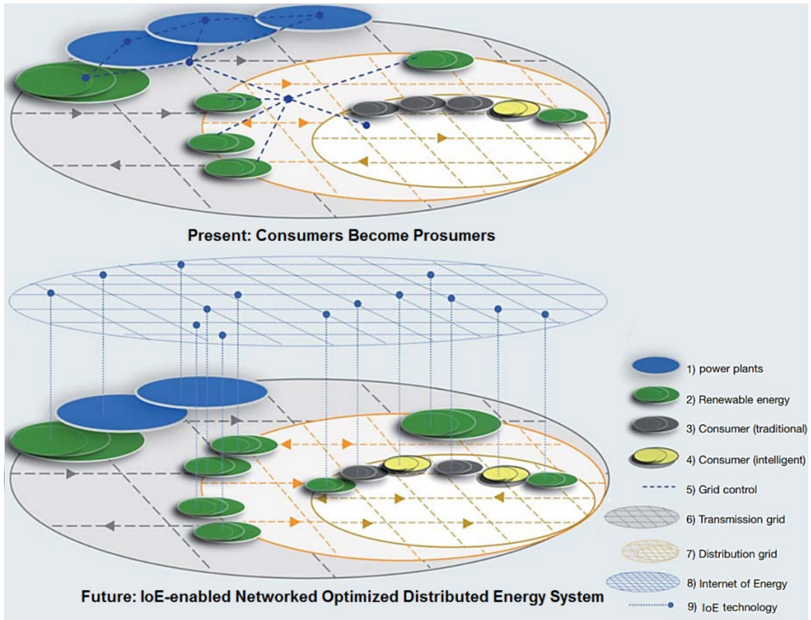
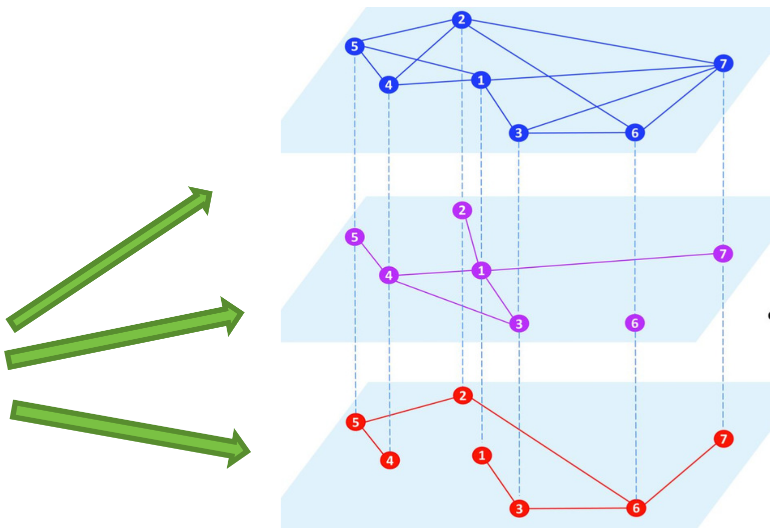
- Live Energy Map (LEM)
- Predictive Analytics
- Optimization Framework
- Data Modeling, Forecasting & Imputation
- Parallelization for Real-Time ESL Control

Live Energy Map (LEM)





- **Problem definition**
  - Effective representation of energy components
- **Challenges**
  - Granularity, support for fast analytics, scalability
- **Approach**
  - Multilayered heterogeneous, directed, time varying, labeled **network representation** to capture the physical, communication, logical network, etc., to fully express essential grid attributes
  - "Incremental" and "evolving" graph analytics algorithms for **real-time** computation of effect of change in a node or a link on the entire system

Predictive Analytics

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❖ Problem definition

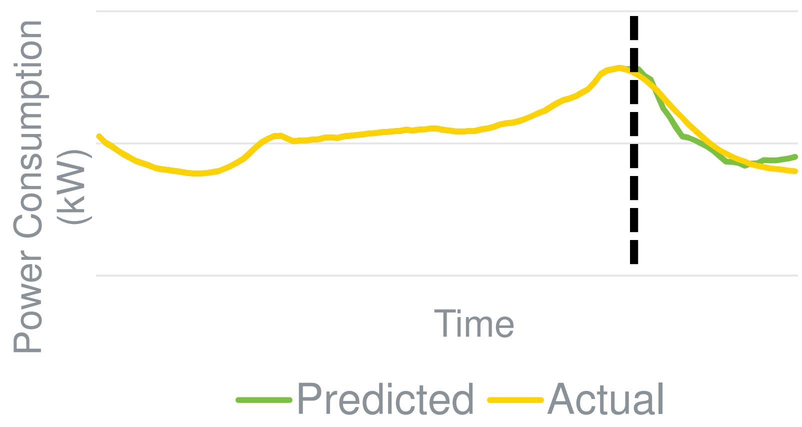
- Solar generation prediction
- Short term load forecasting

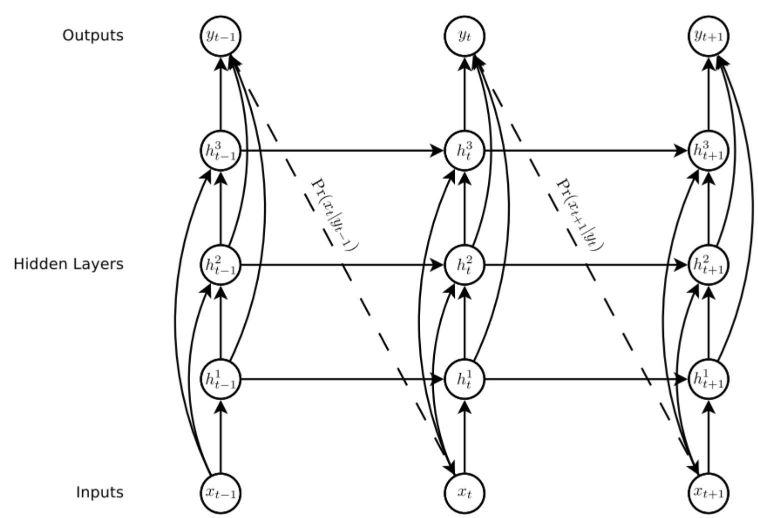
❖ Challenges

- Missing data
- Various time granularity of data

❖ Approach

- Model distribution of data with **mixture models**
- **Granger-causality** Graph representation to capture the node dependency
- **Recurrent Neural Networks**





Optimization Framework

❖ Problem definition

- Supply Demand matching in each interval
- Minimize cost of grid operations

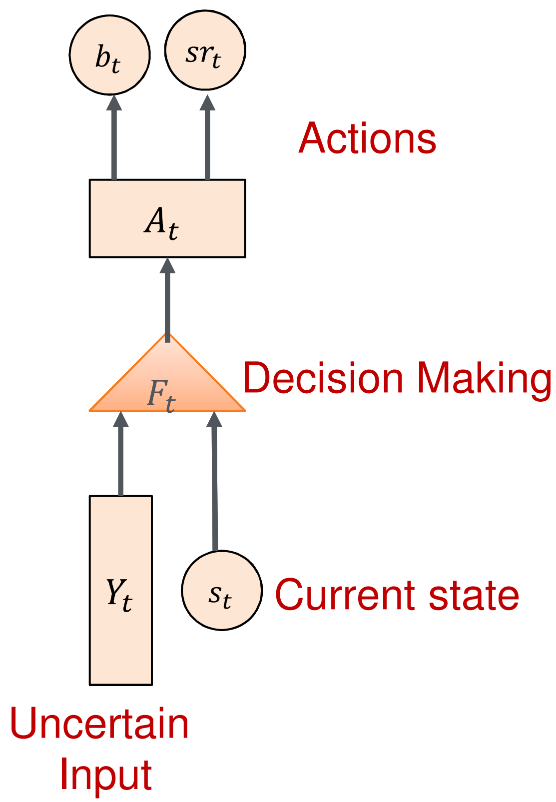
❖ Challenges

- Uncertainty in solar output due to weather conditions
- Error prone prediction

❖ Approach

- Markov Decision Process based sequential decision making framework to minimize expected cost under input uncertainty

Sequential Decision Making at time $\boldsymbol{t}$



Data Modeling, Forecasting & Imputation

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❖ Problem definition

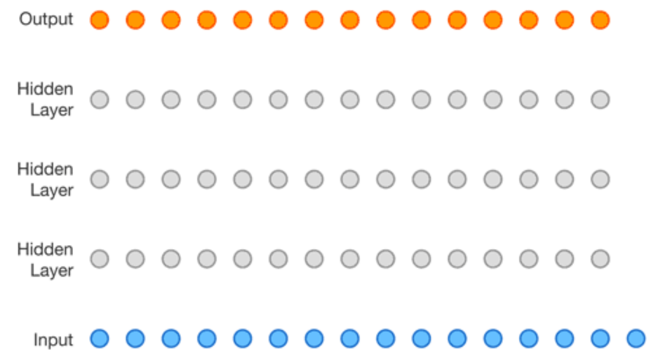
- Arbitrary Horizon Forecasting
- Synthetic Data Generation

❖ Challenges

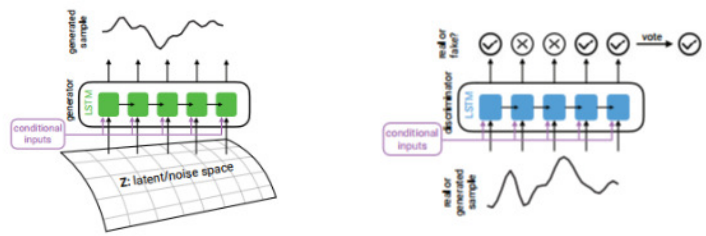
- Computational Complexity – need parallel and efficient extensions to State-of-the-art models
- Models that learn from small datasets

❖ Approach

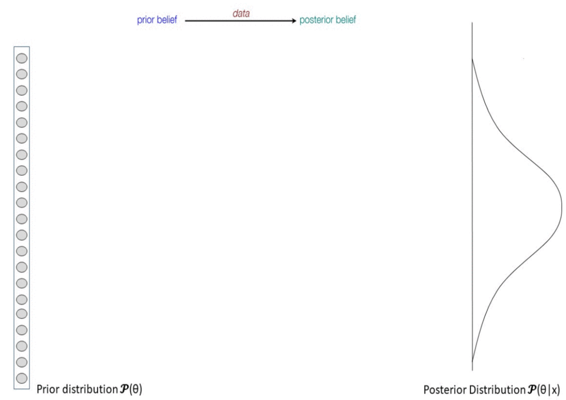
- Fully Visible Belief **Neural Networks**
- Generative **Adversarial Networks**
- **Markov Chain Monte Carlo** (MCMC)



Deep Neural Network



Generative Adversarial Networks



MCMC Metropolis–Hastings algorithm

Parallelization for Real Time ESL Control

❖ Problem definition

- Real time operation of Dynamic Scenario Analysis toolkit to meet ENERGISE response time targets

❖ Challenges

- ML algorithms parallelization
- Computational complexity of optimization algorithms

❖ Approach

- Partitioning the LEM representation of distribution network (graph representation)
- Develop cloud enabled parallel algorithms

Project Architecture

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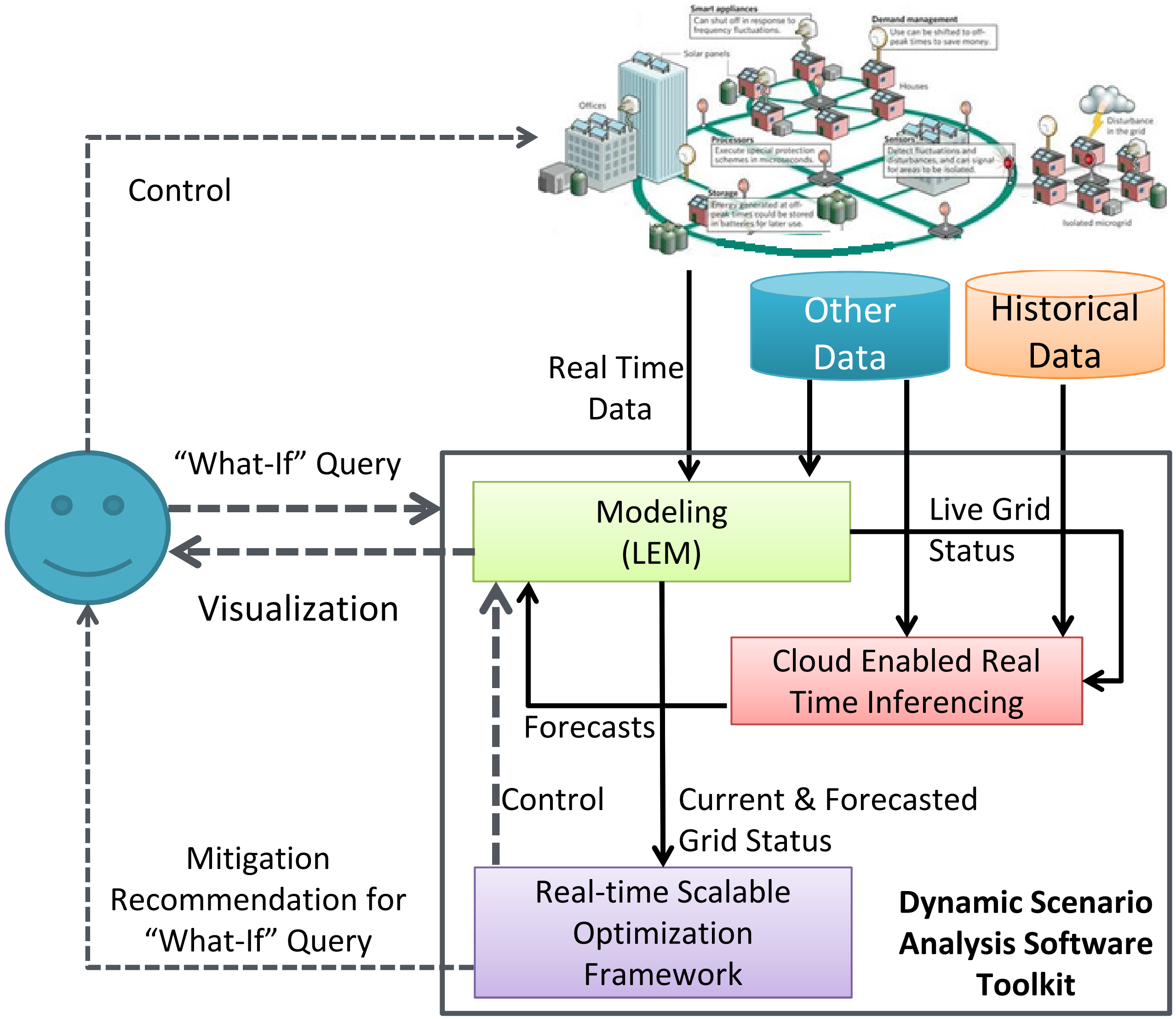

Main Project Tasks/Subtasks

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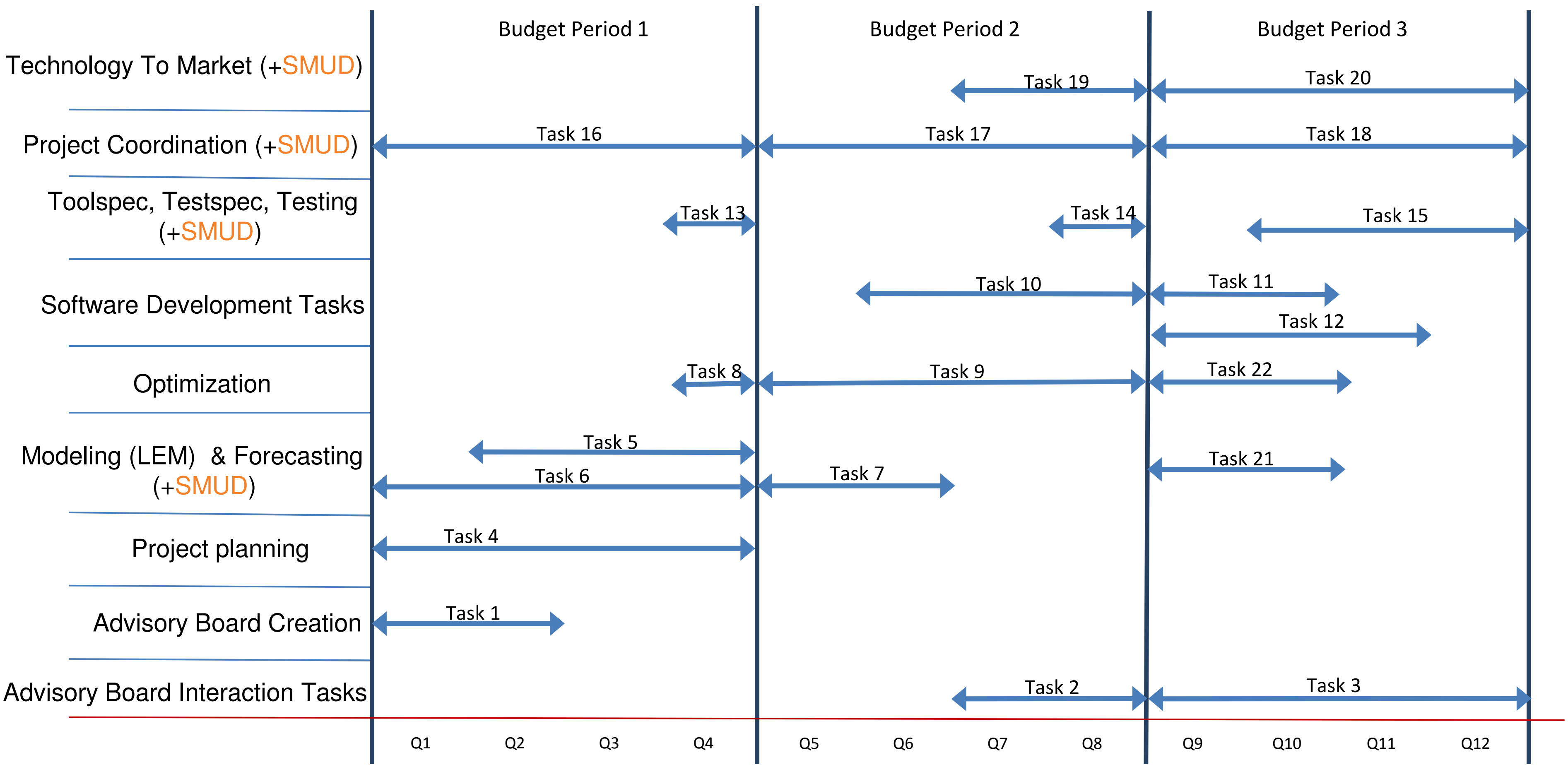
TIMELINE



Project Milestones/Deliverables

- Development of a mockup of Proof-Of-Concept (POC) software for LEM
- Development of accurate load/generation forecasting models
- Development of a functional Dynamic Scenario Analysis Software Toolkit with integration of the LEM, forecasting and optimization algorithms
- Functionality and scalability demonstration of the Dynamic Scenario Analysis Software Toolkit (+SMUD)

Project Milestones/Deliverables

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- **Budget Period 1**
  - Report on forecasting model
  - Draft Market Transformation Plan
  - Cybersecurity and Interoperability Plans (+SMUD)
  - IP Agreement Plan
- **Budget Period 2**
  - Report on the Dynamic Scenario Analysis Software Toolkit integrated with the LEM, forecasting and optimization algorithms
  - Report on the requirements of the market
  - Updated Cybersecurity and Interoperability Plans (+SMUD)
  - Updated Market Transformation Plan
- **Final Deliverable**
  - Functionality and scalability demonstration of the Dynamic Scenario Analysis Software Toolkit (+SMUD)

High Risks & Mitigation

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Risk	Mitigation Strategy
LEM model accuracy	Development & testing using network and operational data from SMUD
Forecasting models accuracy	Validation using network and operational data from SMUD
ESL software scalability	Task development on parallel algorithms Methods implementation in a cloud-enabled software platform
ESL meets ENERGISE metrics	Enhancement of ESL's computational capability Design changes based on testing

Cybersecurity & Interoperability

- Fast graph-theoretical optimization algorithms minimizing protection cost while ensuring situational awareness
- Remove/Mitigate cloud computing model risks
- Interaction with SMUD and advisory committee
- Follow established interface standards to develop interoperable software

Recent Progress

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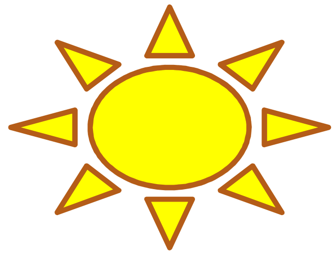
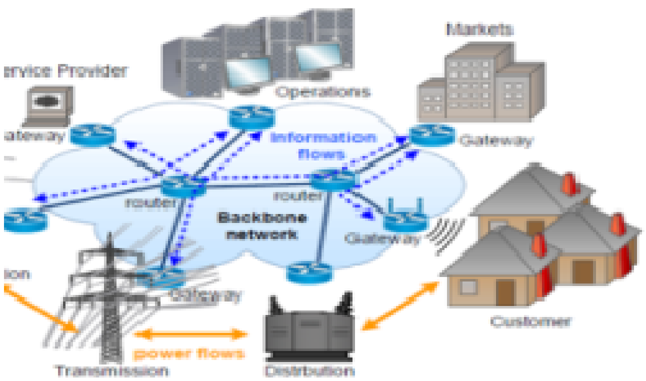
To Appear in ACM BuildSys '17, Submissions to ISGT '18.

- "**Temporal Ensemble Learning of Univariate Methods for Short Term Load Forecasting**," C. Cheung, R. Kannan, V. K. Prasanna
  - Novel ensemble learning method partitioning with temporal features
  - **11.2%** and **30%** decrease in mean absolute percentage error for kernel regression and support vector regression respectively
- "**Optimal Net Load Balancing in Smart Grids with High PV Penetration**," S. Kuppannagari, R. Kannan, V. K. Prasanna
  - Unified solar and load curtailment framework
  - Linearly in number of nodes and intervals, Bounded Error Guarantee: $(1 + \epsilon)$ factor
- "**NO-LESS: Near OptimaL CurtailmEnt Strategy Selection Algorithm for Net Load Balancing in Micro Grids**," S. Kuppannagari, R. Kannan, V. K. Prasanna
  - Curtailment selection with fairness and strategy switching overheads
  - Bounded Error Guarantee: $(1 + \epsilon)$ factor
- "**Risk Aware Net Load Balancing in Micro Grids with High DER Penetration**," S. Kuppannagari, R. Kannan, V. K. Prasanna
  - Sequential decision making for storage scheduling for net load balancing under prediction uncertainty

Concluding Remarks





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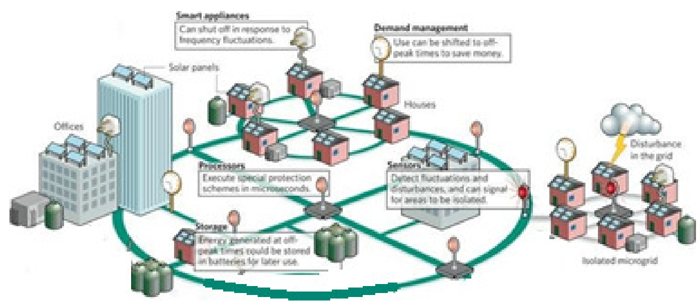
Transform



Today

Data Science
Smart Grid
Parallel Computing

2030, Cognitive Grid

DEEP SOLAR: deepsolar.usc.edu
DSLAB Team: dslab.usc.edu