Energy Efficient Data Centers for On-Demand Cloud Services

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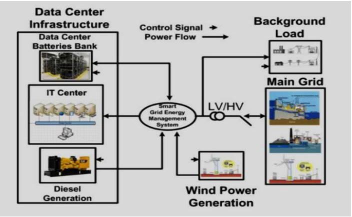
Motivation

- Cloud computing has offered tremendous benefits to the modern technological world. Some of its features are,
  - Flexibility, Disaster Recovery, Less Capital expense, Work From Anywhere, Environment Friendly and Many more
- Enhancing all the services offered requires higher efficiency in operation of cloud computing data centers
- In this research work, the goal is to develop a comprehensive power management scheme for Data Center (DC) operations which includes models for,
  - DC workload and Service Delay
  - DC Power Consumption
  - Power Management
  - Battery Bank and Energy Cost
  - Power outage on Main Grid
  - Intelligent Forecasting for DC load, wind energy and CPU utilization

DC Power Scheme Layout

- Operation Modes
  - Grid Connected
  - Islanded



- Grid Connected

  Smart Grid (SG) and Main Grid (MG) to exchange power transactions. When wind energy is available in excess, SG sells energy to MG at a lower price compared to power purchase
- Islanded

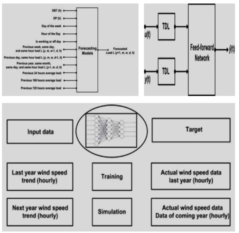
  When outage occurs on MG, SG disconnects itself from MG and islanded operation begins. Wind energy, batteries and diesel generators are used for uninterrupted DC operation

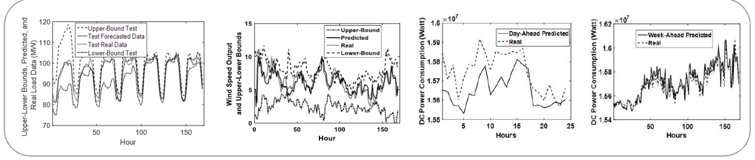
Days and Week Ahead Forecasting Model

- Non-linear Autoregressive Network with Exogenous Inputs (NARX) is used for Forecasting DC load, Wind Energy and CPU utilization
- NARX model equation is,

  $y(t)=f(y(t-1),y(t-2),\ldots,y(t-nx),u(t-1),u(t-2),\ldots,u(t-ny))$

  where the next value of the output is regressed by previous values of the outputs and independent inputs.
  - Implemented as feedforward neural network to approximate the non linear function f
  - With previous known true output valves, series-parallel feedforward architecture is used during training process





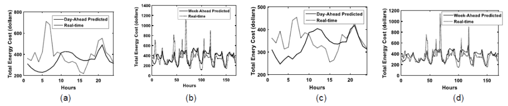
Main Models

- Data Center Models
  - DC workload and Service Delay: Cloud Computing jobs cannot be delayed than a certain amount of time (SLA)
  - DC Power Consumption: Sum of power consumed by computer servers, cooling plants and lighting facilities
- Smart Grid Models
  - Power Management: Determines availability of power from Main Grid and Wind Energy
  - Battery Bank: Keeps track of battery charging cycle and minimum backup power availability.
  - Energy Cost: Energy balancing is done with emphasis on energy utilization from cost perspective
- Model for Power Outage on Main Grid
  - Looks for power outage on Main Grid

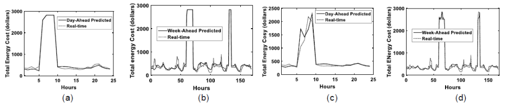
Data Sources

- CPU Utilization – Google Cluster Data
- Electrical Load – Electric Reliability Council of Texas
- Wind Speed – National Estuarine Research Reserve System
- Electricity Pricing Data – Day/Week ahead pricing tariffs of Houston Texas

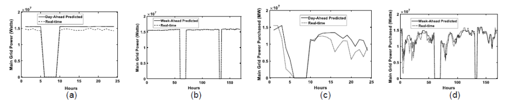
Simulation Vs Real Time Results



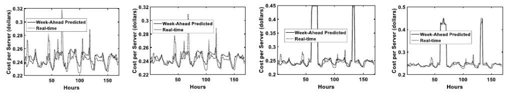
DC Total Energy Cost with No Main-Grid Power Outage: (a) Day-ahead Forecast w/o Wind Power (b) Week-ahead Forecast w/o Wind Power (c) Day-ahead Forecast with Wind Power (d) Week-ahead Forecast with Wind Energy



DC Energy Cost under Main-Grid Power Outage: (a) Day-ahead Forecast w/o Wind Power (b) Week-ahead Forecast w/o Wind Power (c) Day-ahead Forecast with Wind Power (d) Week-ahead Forecast with Wind Energy



Power purchased from Main-Grid: (a) Day-ahead Forecast w/o Wind Power (b) Week-ahead Forecast w/o Wind Power (c) Day-ahead Forecast with Wind Power (d) Week-ahead Forecast with Wind Energy



DC per Server Cost Estimation using Chargeback Model under four scenarios: (a) no power outage in main grid and no wind power generation (b) no power outage in main grid and presence of wind power generation (c) power outage occurred in main grid and no wind power generation, (d) power outage in main grid and presence of wind power generation

Results

- Two sub-cases (with wind energy and without wind energy) were evaluated for DC energy consumption under no Main-Grid Power Outage and with Main-Grid Power Outage.
- The difference in price for the first case is solely due to forecasting based electricity tariffs
- In second case, the energy cost is further lower due to wind energy generation impact

DC Energy Cost (Dollars) Comparison

		Without Wind Power Generation	With Wind Power Generation
No Main Grid Power Outage	Day-ahead Predicted	$8,195.60	$8,016.80
	Real-time	$9,536.20	$8,456.60
	Week-ahead Predicted	$60,641.20	$59,717.00
	Real-time	$61,375.00	$59,806.00
Main Grid Power Outage	Day-ahead Predicted	$18,233.00	$13,469.00
	Real-time	$18,520.00	$14,134.00
	Week-ahead Predicted	$95,374.00	$90,862.00
	Real-time	$95,971.00	$92,252.00

* Cost Value is sum of hourly energy cost.

Conclusion

- The problem of DCs energy cost is addressed while maintaining quality-of-service.
- Forecasting algorithms proved effective in minimizing the overall cost.
- Note that the proposed method is not limited to DCs only; it is generalizable to reduce energy cost in geographically-connected commercial/industrial flexible clients.