Impact of Plug-in Hybrid Electric Vehicles and Their Optimal Deployment in Smart Grids

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Outline

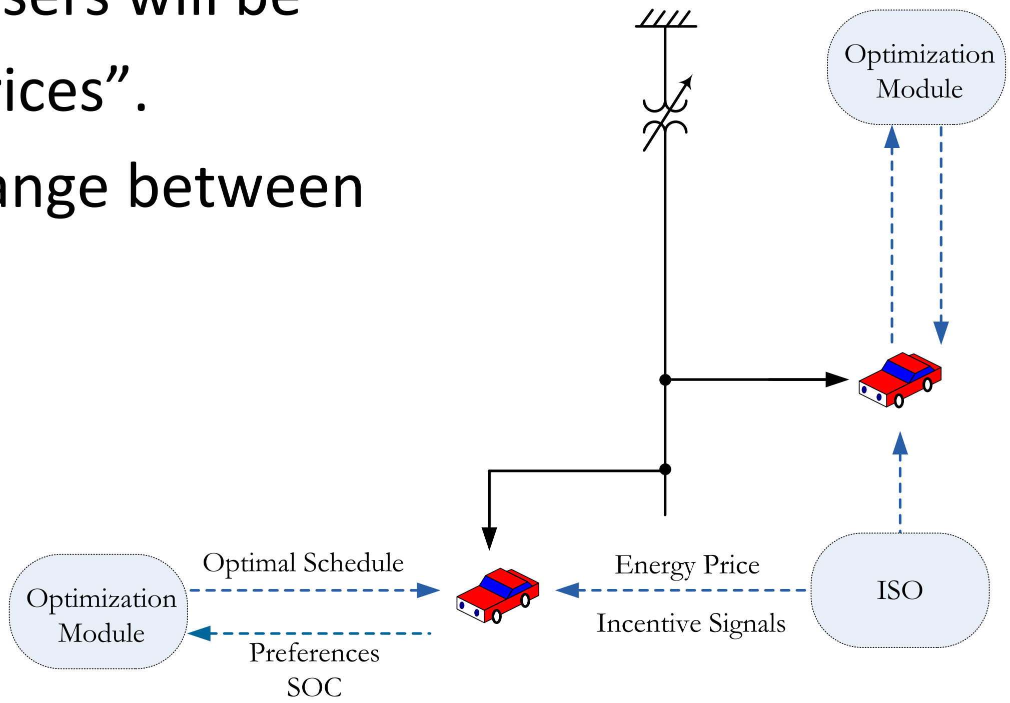
- Motivation
- PHEV Charging Approaches
- Mathematical Modeling
- Case Studies
- Conclusions

Motivation

- Transportation sector→ major environmental emissions (e.g., 24% global CO_2 emissions).
- Large fleet of PHEVs will penetrate distribution systems
  - Environmental concerns,
  - Incentives from the regulators.
- Coordinated operation of numerous PHEVs is possible
  - Advanced Metering Infrastructure (AMI),
  - Advanced communication and control.

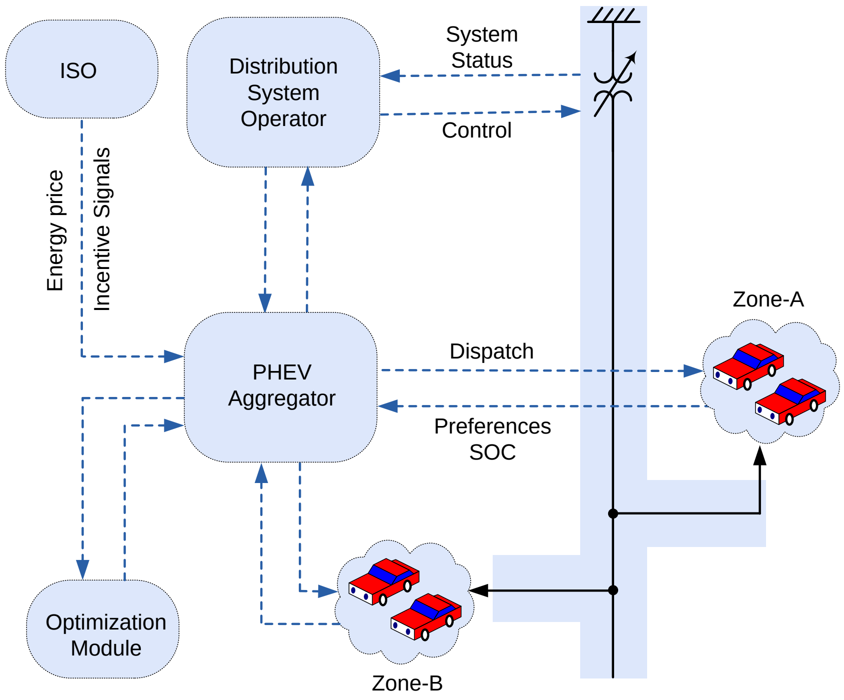
PHEV Charging Approaches

- Uncoordinated charging
  - No PHEV aggregator exists.
  - PHEV owner might use local "Optimization Module" to generate charging schedules.
  - Objective for most of the users will be "Minimization of Energy Prices".
  - Primary Information exchange between ISO and PHEV are,
    - Energy price
    - PHEV parameters
    - Owner preferences



PHEV Charging Approaches

- Coordinated charging
  - PHEVs aggregator facilitates the coordinated charging of PHEVs.
  - Aggregator communicates with PHEV owners, ISO, distribution system operator and an “Optimization Module”.
  - Communication and control are basing on the infrastructures of Smart Grids.
  - Aggregator can set different objective functions beneficial to PHEV owners, and/or the Grid.



Mathematical Modeling

- Each PHEV model is developed based on,
  - Hourly state-of-charge (SOC), initial available SOC, and final desired SOC.
  - Time instances PHEV is available for Grid connection.
  - Average driving distance and mileage.
  - Efficiency of Charging/discharing process.
  - Power rating of charging socket.
  - Hourly SOC when the PHEV is off the Grid.
  - Minimum and maximum SOC allowed.
- Distribution feeder model
  - A balanced single phase equivalent model.

Mathematical Modeling … (Contd)

- Objective Function
  - Uncoordinated charging: Minimization of energy cost for each PHEV.

$$F_1 = E_{\max}(j,n)\sum_{h=H_i}^{H_f-1}\rho(h)\big(C(j,n,h+1)-C(j,n,h)\big)$$

  - Coordinated charging-I: Minimization of distribution losses.

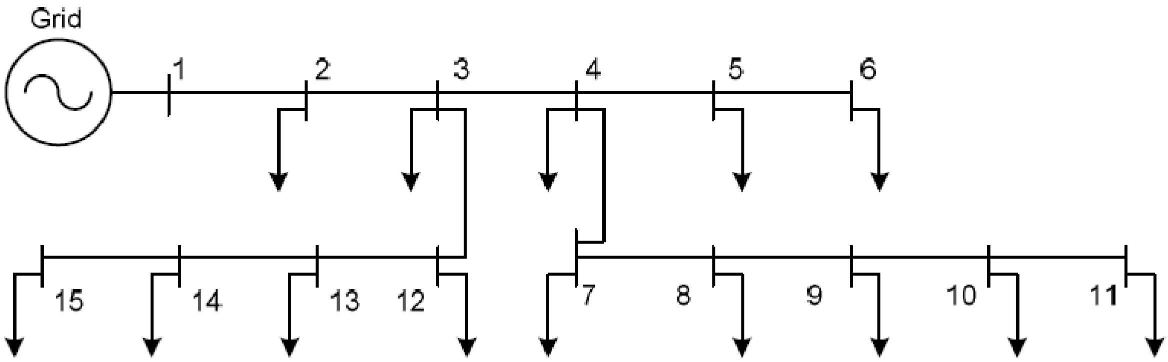
$$F_2 = \sum_h \left(P_G(h) - \sum_j \left(P_L(j,h) + \sum_n \left(P_{EV}(j,n,h)\right)\right)\right)$$

  - Coordinated charging-II: Maximization of distribution load factor.

$$F_3 = \frac{\sum_h P_G(h)}{h_{\max} MAX[P_G(h)]}$$

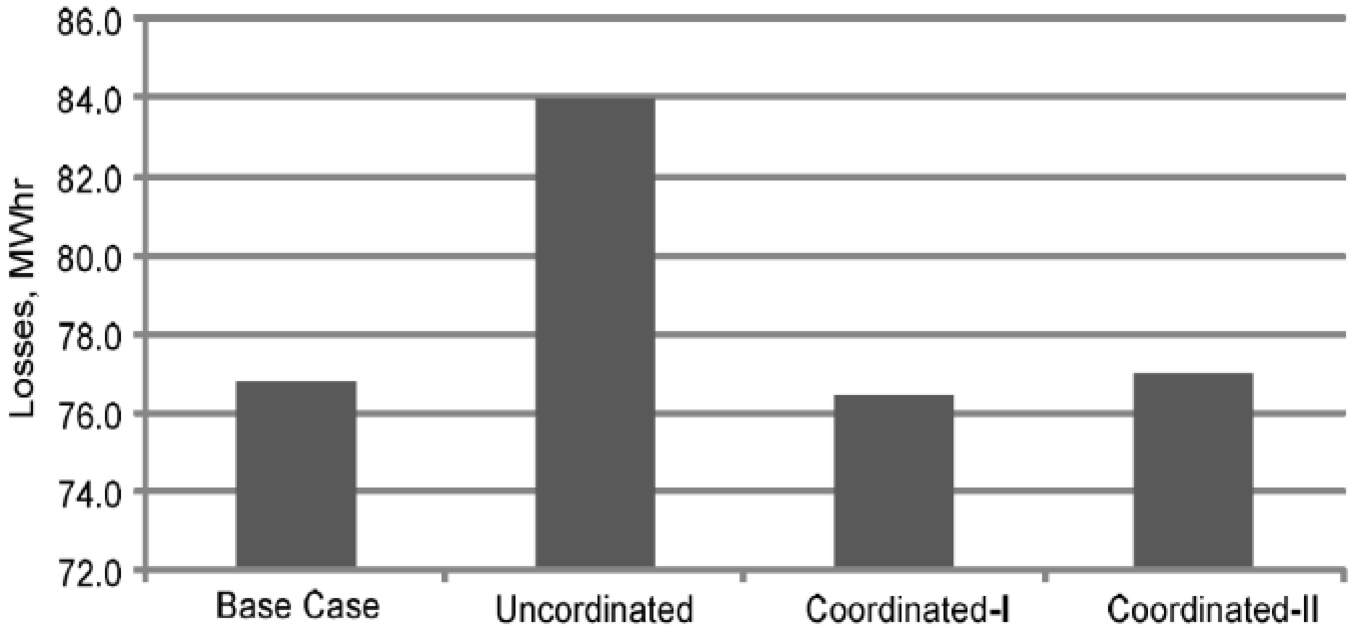
Case studies

- System descriptions
  - 15-node, 11.43kV radial distribution system is considered.
  - A Day-a-head forecast of a utility is used as energy price.
  - Uncoordinated and coordinated charging of PHEVs are studies considering 10%, 25%, and 50% PHEV penetrations.
  - Model is developed in GAMS and solved using BARON solver.



Case studies…(Contd)

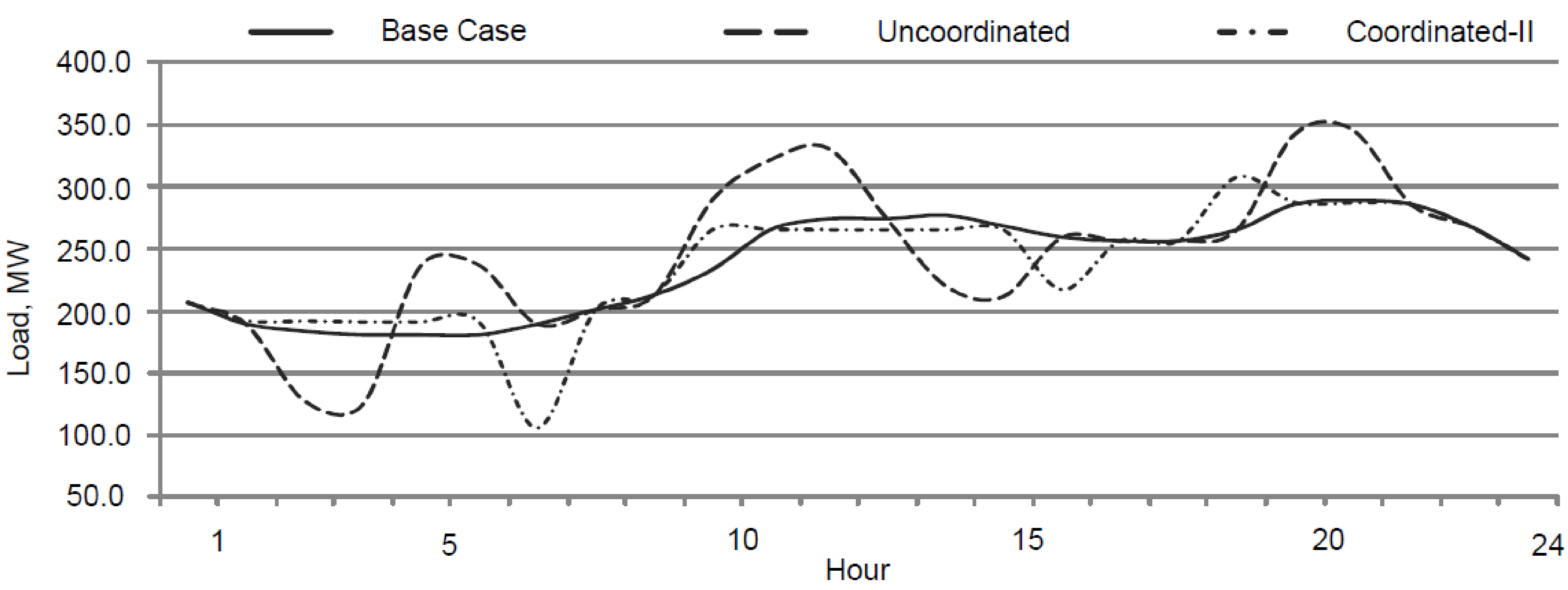
- Simulation results
  - Impact on power losses (50% PHEV penetration)



  - Note: Base case does not account for the PHEV loads

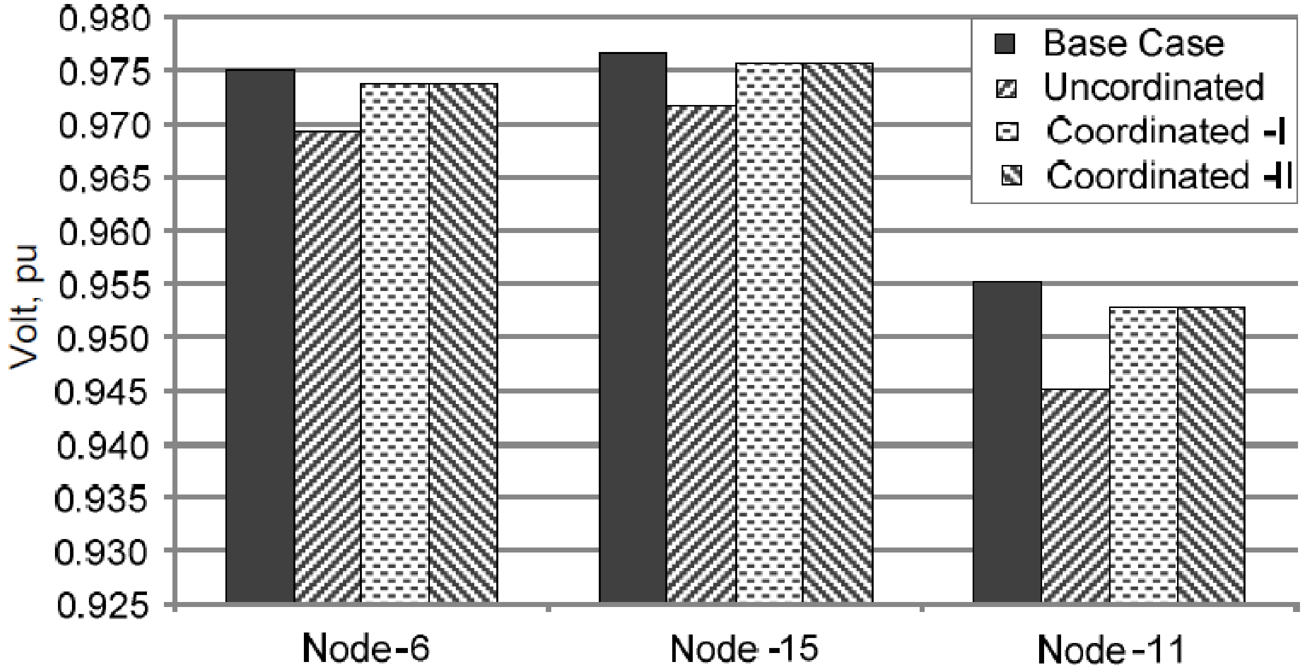
Case studies…(Contd)

- Simulation results
  - Impact on system load profiles



Case studies…(Contd)

- Simulation results
  - Impact on voltage profiles



Conclusions

- Uncoordinated charging options are beneficial to the PHEV owners as it leads to the minimized energy cost.
- On the other hand, the uncoordinated charging is not desirable from the system operation point of view as it leads to the increased peak, increased losses, low load factor, and low voltage profiles.
- The Smart Grid infrastructures will support the concept of “PHEV aggregator” which can deploy numerous PHEVs in coordination.
- Coordinated operation of PHEVs impart benefits to the distribution system operation and/or the PHEV owners.

Thank You

Additional Data

A DAY-AHEAD FORECAST OF HOEP (ρ = \$/MWHR) USED

h	$\rho(h)$	h	$\rho(h)$	h	$\rho(h)$	h	$\rho(h)$
1	23.12	7	34.81	13	36.01	19	45.57
2	22.31	8	40.2	14	32.30	20	45.01
3	18.63	9	35.34	15	36.23	21	40.42
4	20.09	10	34.79	16	37.33	22	37.79
5	21.91	11	38.96	17	36.6	23	30.09
6	20.57	12	43.02	18	37.57	24	33.5

Additional Data

NORMALIZED LOAD PROFILE USED FOR THE CASE STUDIES

h	%	*h*	%	*h*	%	*h*	%	*h*	%	*h*	%
1	72	5	63	9	74	13	95	17	89	21	100
2	66	6	63	10	81	14	96	18	89	22	99
3	64	7	66	11	92	15	93	19	92	23	93
4	63	8	70	12	95	16	90	20	99	24	84

Additional Data

NO. OF PHEVS CONNECTED AT DIFFERENT NODES IN THE DISTRIBUTION SYSTEM (FOR 100% PENETRATION OF PHEVS)

j	n	j	n	j	n	j	n	j	n
1	—	4	4160	7	2770	10	1216	13	126
2	904	5	1832	8	1402	11	9422	14	700
3	2150	6	578	9	924	12	574	15	604

Additional Data

VARIOUS PARAMETERS OF PHEVS CONSIDERED

Total no. of PHEVS	27,364 (100% penetration)
Maximum battery capacity	15 kWhr
Power rating of charging socket	4.8 kWhr
Average daily distance covered by PHEV	32 miles
Average mileage	4 miles/ kWhr
Minimum allowed SOC	20%
Maximum allowed SOC	80%
Initial SOC	20%
Final SOC desired	40%
Time at which PHEV comes to parking lot	10am (office), 8pm (home)
Time at which PHEV leaves parking lot	4pm (office), 7am (home)
Optimization time interval	1 hr