Ramping Capability with Transmission Formulation

Nicholas A. Brown

Iowa State University, Department of Electrical and Computer Engineering

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Introduction

Objectives in Power System Operation

- Maintain power balance
- Supply load reliably at least cost

Background

Power Balance and Frequency

- Electric power system depends on power balance
- Alternating current is based on the standard of 60 Hz
- Consequences of imbalance in short term: frequency outside desired range
- Frequency constantly fluctuating due to relatively small changes

Load Uncertainty

Forecast error

- Load forecast has error
- Forecast may be higher or lower than actual load
- Market ensures that generating capacity is available to make up for continuous forecast error

Net Load Uncertainty

Forecast error

- Net load is Load minus Renewable generation
- Uncertainty in net load currently driven primarily by uncertainty of load itself
- Higher penetration of renewables should lead to more uncertainty due to renewables
- Forecast may be higher or lower than actual load

Reserves

Reserves Scheduled to Be Available

- Reserves dedicated to address lesser and greater magnitude and duration of forecast error
- Some reserve is meant to handle normal variability and uncertainty
- Contingency reserves are in place for sudden, infrequent events, such as the loss of a generator
- If contingency reserves are insufficient, a contingency can lead to a severe change in frequency
- Contingency reserves are only intended for contingencies

Reserves

Greater Uncertainty Requires More Flexibility

- If the amount of reserves that is scheduled falls below required amount, system is at risk of a loss of stability
- Reserves are not free
- Plants providing reserves may not be operating at their most efficient level
- Starting up and shutting down plants also incurs a cost, so does building additional plants
- Reserves are not necessarily used.

What is Ramping Capability?

Ramping Capability

- If a unit can be controlled, and can change its output in a sustained way, it has ramping capability
- The amount of ramping capability it can provide in any period depends on its ramp rate and operating point at the beginning of the interval

Expected, Maximum and Minimum Net Load

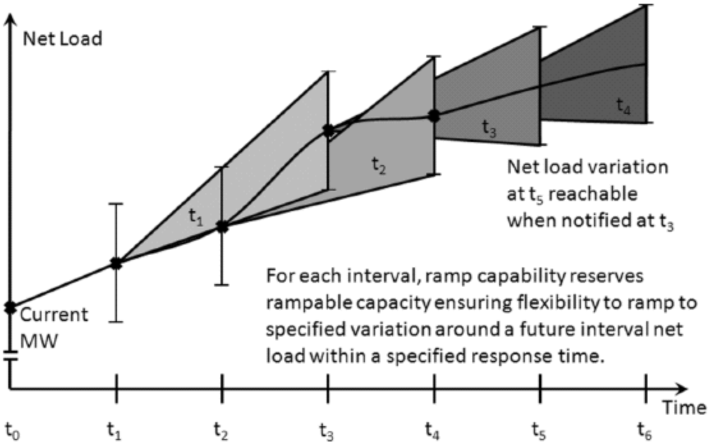


Fig. 1. Up- and down-ramp capability in SCED.

Figure : Fig 1, Navid et al. (2012)

Implied Probability in Navid

Control Variables are Deterministic

Possible variation in control variables is not expressed in Navid's formulation through explicit probability functions covering ranges of possible values for those variables.

One Set of Control Variable Values

It is understood that the probabilities are assumed to be 1.

Cases of Insufficient Ramping Capability Not Considered

The ramping capability requirements are, however, are not intended to cover the actual operational requirements for ramping 100% of the time, as will be explained.

Variables

Decision Variables

$$P_{G_i,t=5}$$

$$VoltageAngles_{B_i,t=5}$$

Control Variables

$$Cost_{G_i}\forall t$$

$$Demand_{B_i,t=5}$$

$$RampingRequirement_Up_{B_i,t=5}$$

$$RampingRequirement_Down_{B_i,t=5}$$

Objective Function

Objective Function

$$min$$

$$\sum_i c_i P_{G_i} + \left[\sum_i C_i(RC_{up_i}) + \sum_i C_i(RC_{down_i}) \right]$$

Variables in Objective Function

C_i	incremental cost of generator i
P_{G_i}	real power output of generator i
RC_{up_i}	up-ramp cleared for generator i
RC_{down_i}	down-ramp cleared for generator i

Ramping Capability Requirements

Requirement: Online generating units meet forecast net load with scheduled output and total ramping capability 99% of the time

Therefore, ramping up and ramping down capability will each be insufficient compared to the uncertain part of the net load 0.5% of the time

$$\Pr\left(\sum_i P_{G_i,t=15} + \sum_i RCup_{DC,t=5} \leq \sum_i D_{i,t=15}\right) = 0.005$$

$$\Pr\left(\sum_i P_{G_i,t=15} - \sum_i RCdn_{DC,t=5} \geq \sum_i D_{i,t=15}\right) = 0.005$$

Ramping Capability of Units

Requirement: Each controllable generator can ramp up to its maximum operating point (P_max) and down to its minimum operating point (P_min)

$$P_{G_{i,t}} + RC_{up_{i,t}} \leq P_{Gmax_{i,t}}$$

$$P_{G_{i,t}} - RC_{down_{i,t}} \geq P_{Gmin_{i,t}}$$

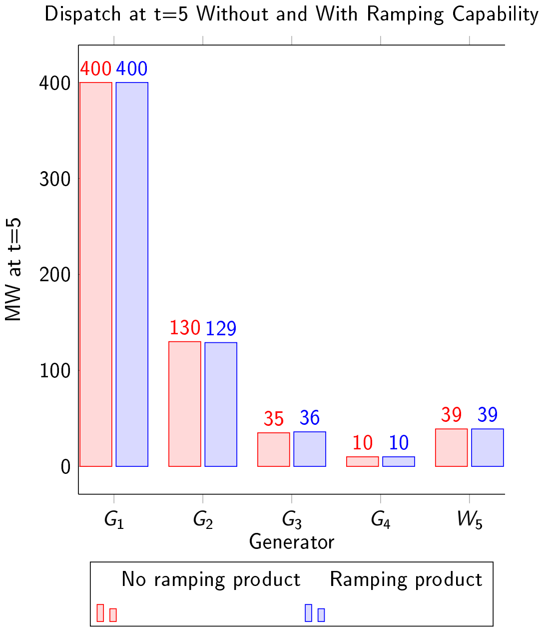
$P_G max_i$	Maximum operating point for generator i
$P_G min_i$	Minimum operating point for generator i

Generator Characteristics

Gen	*Min* (*MW*)	*Max* (*MW*)	*UpRamp* (*MW*/*Min*)	*DownRamp* (*MW*/*Min*)	*Offer* ($/*MWh*)
C1	100	400	1	1	25
C2	10	130	4	4	30
C3	10	130	1	1	31
C4	10	100	1	1	36
W1	0	50	-	-	-

Table : System Generation Mix

No-Network Dispatch, t=5 (Navid)



Impact of New Assumptions

Increased Wind Penetration

- Wind as a percentage of gross load was 6% in original case described by Navid
- New case increased this percentage to 38%
- Higher wind increases the possible net load forecast error

Dispatch at Low and High Wind Penetration

	LowWind	*HighWind*
Load forecast (MW)	614	614
Wind forecast (MW)	39	234
Wind forecast as % of load	6	38
Up Ramp Requirement (MW)	21	84
Down Ramp Requirement (MW)	3	12

Table : Ramping Requirements at Low and High Wind Penetration

Impact of New Assumptions

Created Five-Bus Network

- The case illustrated by Navid had no transmission network
- Five-bus network was specified based on PJM training illustration
- The network supported a DC-OPF set of constraints

Five-Bus Network

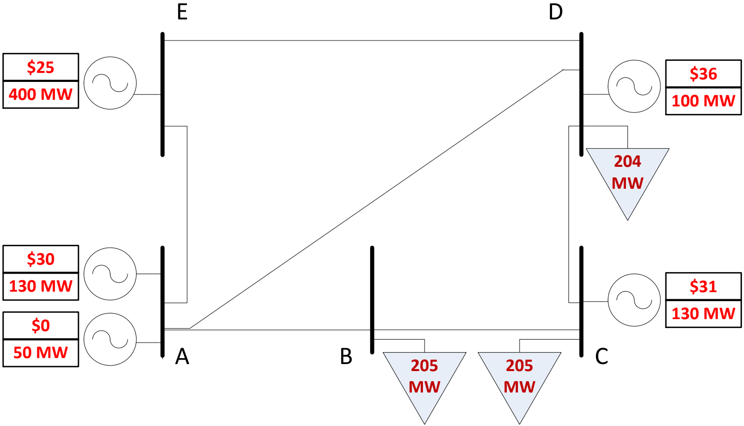


Figure : 5-Bus Network

Transmission Assumptions

	$A-B$	$A-D$	$A-E$	$B-C$	$C-D$	$D-E$
$X\%$	2.81	3.04	0.64	1.08	2.97	2.97
$Limit(MW)$ $(HighCase)$	999	999	999	999	999	999
$Limit(MW)$ $(LowCase)$	250	250	250	250	250	250

Table : Line Impedances and Flow Limits

Transmission Constraints (Thermal Limits)

Transmission	*High*	*High*	*Low*	*Low*
Wind	*Low*	*High*	*Low*	*High*
P_{G_1}	400	348	400	313
$RCup_1$		10		10
P_{G_2}	129	12	123.6	10
$RCup_2$	1	40	6.4	40
P_{G_3}	36	10	41.4	47
$RCup_3$	10	10	10	10
P_{G_4}	10	10	10	10
$RCup_4$	10	10	4.6	10
W_{G_5}	39	234	39	234
$RCup_5$				
Total Ramp up	21	21	70	70

Table : Single Interval Dispatch at Alternate Thermal Limits and Low and High Wind Penetration (MW)

Transmission Constraints (Thermal Limits)

T15	*Load*	*Wind*	*Net*
Expected	620	213	407
Actual	644	203	441

Table : Case Demonstrating Insufficient Flexibility Due to Transmission

Although ramping capability of 70 MW was procured, and this was greater than the change in net load between T=5 and T=15 of 61 MW, it could not be delivered due to the dispatch at T5, the flexibility of the generators, and the topology of the network.

Conclusion and Further Work

Transmission Means Ramping Capability Has Locational Dimension

Transmission clearly impacts the range of operating points of generators, and constrains their ability to provide ramping capability.

The Source of Uncertainty Is Also Location-Specific

Ramping capability from different generating units should not be treated as equivalent in ability to satisfy ramping requirements. The ability to dispatch ramping capability to address forecast errors depends on the location and magnitude of uncertainty.

Further Investigation is Need to Explore Particular Forecast Errors Based at Specific Locations

May not be possible to handle all possible errors, but dispatch should be treated as security-constrained. The difference between ramping-constrained dispatch and security-constrained dispatch is that contingencies are binary (occurs, does not), while wind-driven forecast errors are continuous (can occur to different degrees).