Renewable Voltage Regulation, Transformer Parameters, and a Tapping Tradeoff

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Introduction

- Load-tap-changing (LTC) transformers regulate voltage in subtransmission and distribution networks.
- LTCs must be used sparingly: excessive tapping hastens costly failure.
- Renewable energy fluctuations increase LTC tapping frequency.
- Renewable voltage regulation diverts this effect upstream (Figure 1).

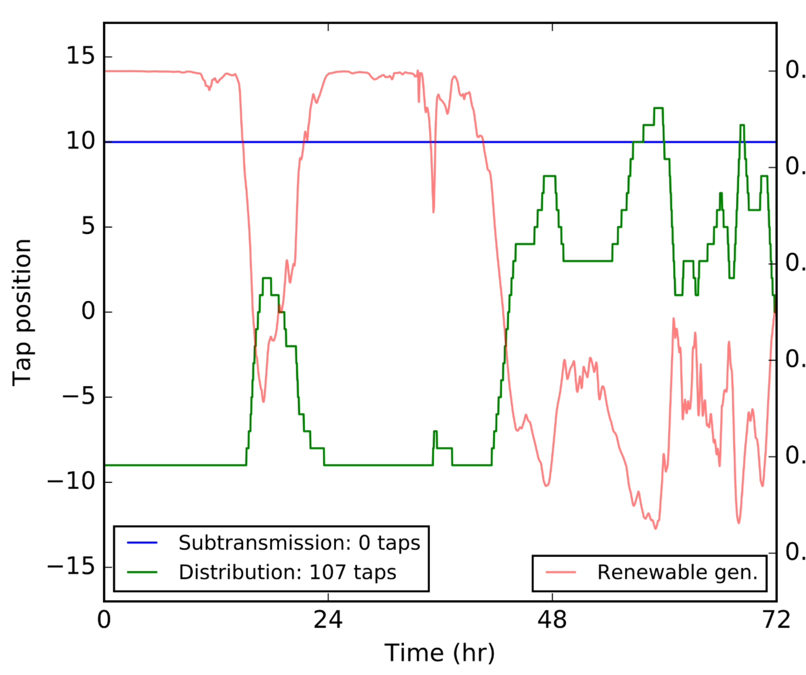

Figure 1a: Loose regulation, downstream (distribution) tapping.

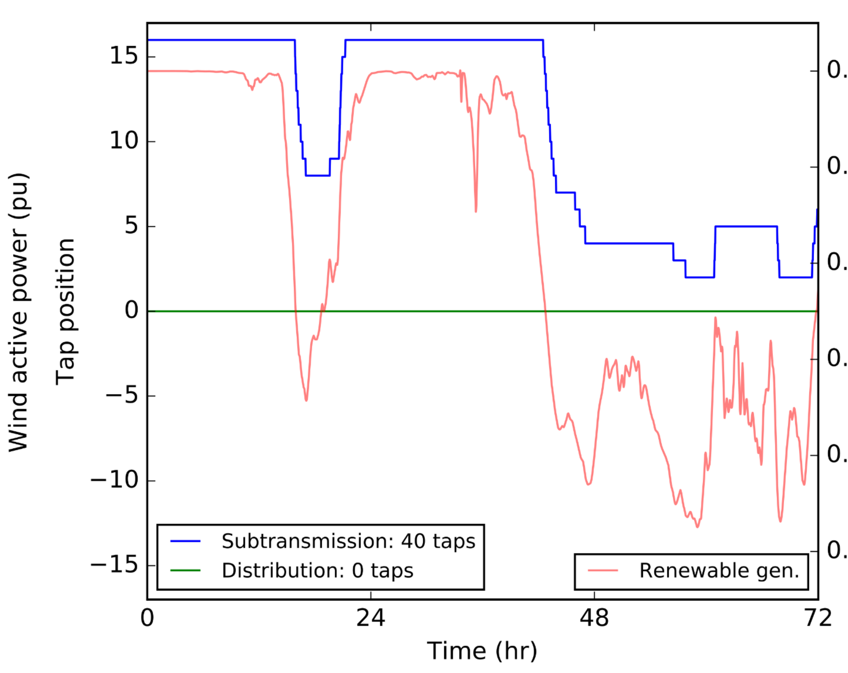

Figure 1b: Tight regulation, upstream (subtransmission) tapping.

Models

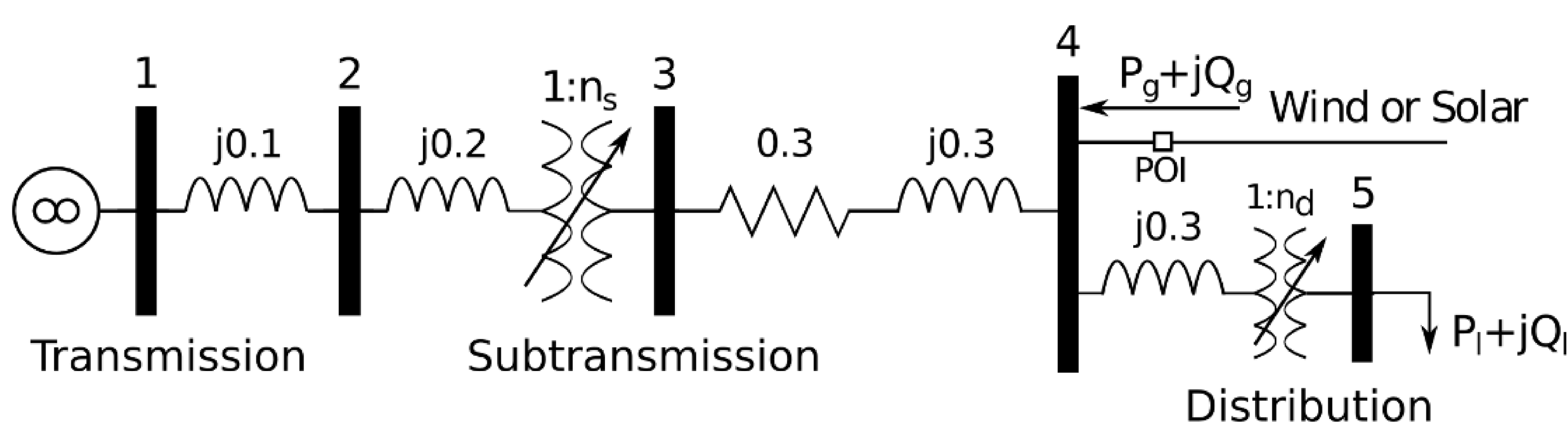

Figure 2: Test network

- Definite-delay model: DLTC

$$d(t) = \begin{cases} 1 \text{ if } \Delta V(t) > DB \\ -1 \text{ if } \Delta V(t) < DB \\ 0 \quad \text{otherwise} \end{cases}$$

$$c(t) = \begin{cases} c(t-\Delta t) + \Delta t \text{ if } d(t) = \ \ 1 \text{ and } c(t-\Delta t) \geq 0 \\ c(t-\Delta t) - \Delta t \text{ if } d(t) = -1 \text{ and } c(t-\Delta t) \leq 0 \\ 0 \quad \text{otherwise} \end{cases}$$

$$T(t) = \begin{cases} T(t-\Delta t) + 1 \text{ if } d(t) = \ \ 1 \text{ and } c(t) > \ \ C \\ T(t-\Delta t) - 1 \text{ if } d(t) = -1 \text{ and } c(t) < -C \\ T(t-\Delta t) \quad \text{otherwise, and when } T \text{ at limit} \end{cases}$$

- Inverse-delay model: ILTC

$$\frac{de(t)}{dt} = \begin{cases} \frac{1}{\tau}(\Delta V(t) - DB) \text{ if } \Delta V(t) > \ \ DB \\ \frac{1}{\tau}(\Delta V(t) + DB) \text{ if } \Delta V(t) < -DB \end{cases}$$

$$e(t) = \begin{cases} e(t-\Delta t) + \frac{de(t)}{dt}\Delta t \text{ if } T(t) = T(t-\Delta t) \\ 0 \text{ otherwise, and when } V \text{ in deadband} \end{cases}$$

$$T(t) = \begin{cases} T(t-\Delta t) + 1 \text{ if } e(t) > \ \ \alpha \\ T(t-\Delta t) - 1 \text{ if } e(t) < -\alpha \\ T(t-\Delta t) \text{otherwise, and when } T \text{ at limit} \end{cases}$$

Table 1: Transformer parameters

Parameter	Description	DLTC Value	ILTC Value
α	Tap size	5/8%	
T_{lim}	Tap limits	$(-16, 16)$	
V_{sp}	Setpoint	1.02 pu sub., 0.96 pu dist.	
DB	Deadband	2 taps ($\pm$1.25%)	
C	Max. counter value	120s sub., 240s dist.	NA
τ	Time constant	NA	120s sub., 240s dist.

Simulation

- Let P_g be simulated wind or solar data from NREL.
- Let Q_g, renewable voltage support, be limited to $[-Q_g^{lim}, Q_g^{lim}]$.
- Simulate for 1 year at 1-min resolution (one power flow per minute).
- Count LTC taps and plot distribution vs. subtransmission.

Trade-off Curves

- Repeat simulation for many values of Q_g^{lim} to obtain many points.

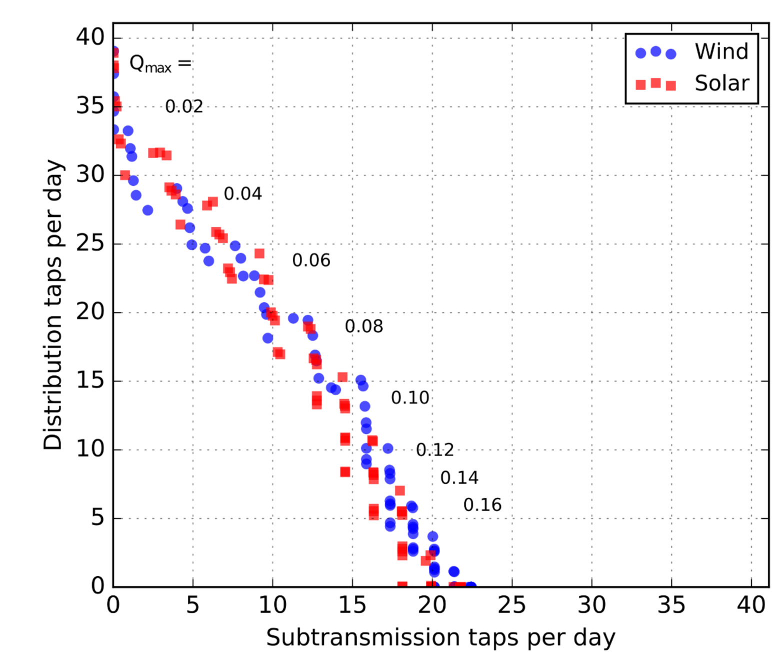

Figure 3a: Trade-off curve for definite-delay LTCs.

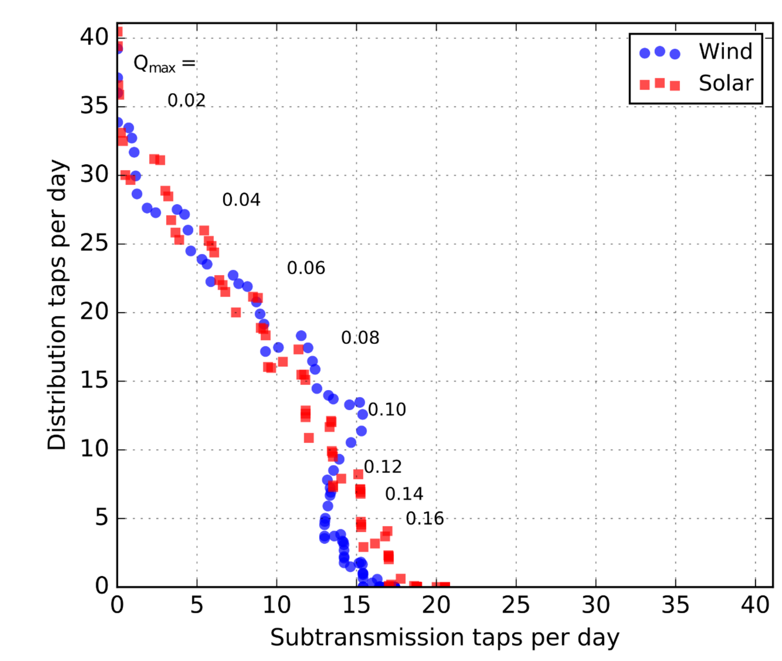

Figure 3b: Trade-off curve for inverse-delay LTCs.

LTC Setpoint Sensitivity

- Vary voltage setpoint for an LTC, generate several trade-off curves.
- Color points according to $V_{metric} = \|V_{actual} - V_{desired}\|$.

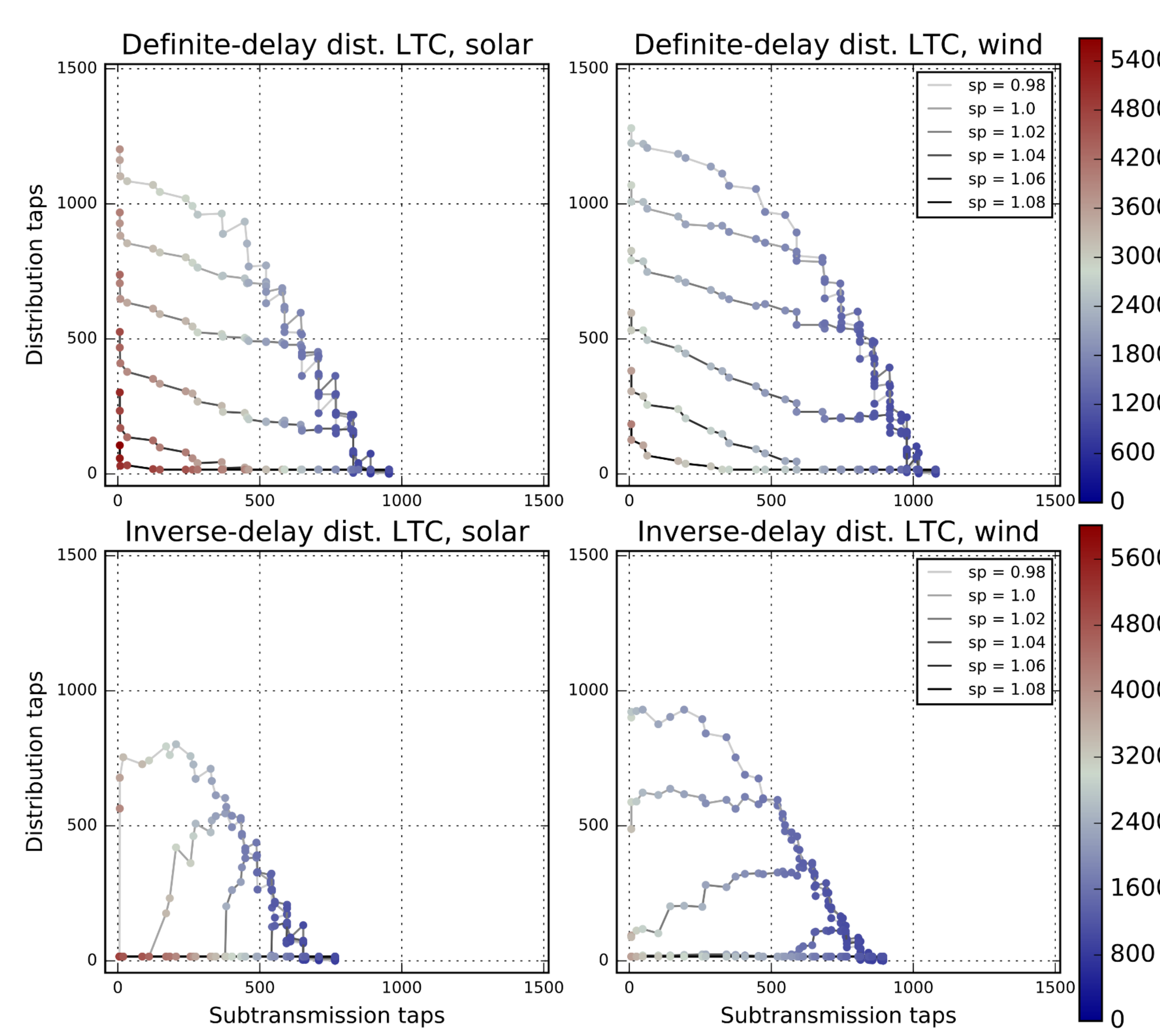

Figure 4: Varying distribution voltage setpoint.

Conclusions

- Renewable voltage support balances the effects of fluctuation between distribution and subtransmission LTCs.
- The trade-off is nuanced even for simple networks.
- Understanding relationships between parameters enables extension to more general networks.
- The tapping trade-off calls for sophisticated joint tap minimization.

Acknowledgements

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