Conclusions and Next Steps

1. Conceptual Journey: From Basic SEPIC to 9th-Order PFC Model

- ✅ **Foundation:** Standard SEPIC converter theory (4th-order, 2-state averaging) provides baseline understanding
- ✅ **Extension:** Interleaved bridgeless topology requires 9 states (6 inductors, 3 capacitors) and 4 switching topologies
- ✅ **Advancement:** State-space averaging generalized from classical 2-state to 4-topology weighted sum
- ✅ **Control-ready:** Jacobian linearization yields transfer functions, including explicit CPL destabilization term

2. Key Technical Achievements

- ✅ **36 equations rigorously derived** from KVL/KCL, traceable to COMPLETE_36_EQUATION_DERIVATION.md
- ✅ **Correct A_{11} matrix representation** in slides, showing reverse charging of L5, L6 and capacitor dynamics
- ✅ **Duty cycle weight formulas** for overlapping/non-overlapping cases correctly derived from switching timing
- ✅ **CPL Jacobian term $+P/(C0 \cdot vC0_0^2)$** explicitly calculated, explaining negative incremental resistance

3. Physical Insights from Analysis

- ✅ **Storage vs. Transfer modes:** Switches ON → energy builds in reverse; switches OFF → energy releases forward
- ✅ **Direct input charging:** L1, L2 charge from Vin via diode+switch path (no capacitor voltage in KVL loop)
- ✅ **Capacitor staging:** C1, C3 buffer energy between input and output phases, critical for SEPIC operation
- ✅ **CPL instability mechanism:** Constant power draws more current as voltage drops, acting like negative resistance

Future Work

📋 Immediate (Weeks 1-4)

- Update MATLAB scripts to full 9th-order implementation
- Extend analysis to negative half-cycle ($V_{in} < 0$)
- Develop Simulink switching-level model for validation
- Design PI controllers for dual-loop control

📋 Medium-Term (Weeks 5-12)

- Construct hardware prototype (PCB design and assembly)
- Experimental validation of per-topology equations
- Closed-loop control implementation (DSP or microcontroller)
- Measure THD, power factor, efficiency

📋 Long-Term (Future Research)

- Extend to DCM (Discontinuous Conduction Mode) analysis
- Multi-objective optimization (efficiency vs. power density)
- Adaptive control for wide input/output voltage range
- Integration with renewable energy systems (PV, wind)