A Klystron Phase Lock Loop for RF System at TPS Booster Ring

Fu-Yu Chang, Mei-Hsia Chang, Shian-Wen Chang, Ling-Jhen Chen, Fu-Tsai Chung, Ming-Chyuan Lin, Zong-Kai Liu, Chih-Hung Lo, Yi-Ta Li, Chaoen Wang, Meng-Shu Yeh, Tsung-Chi Yu
Introduction

• As the energy shortage in the whole world, the accelerator should work for decreasing power consumption.

• The time for injection is about 3~7 seconds while the booster ring is operated at 900 kV gap voltage with ramping mode.

• The transmitter gets into standby condition and decreases the cathode current when the time is not injecting.

• Energy saving module regulates the cathode current by changing the anode voltage setting.
Phase Change Due To Energy Saving Module @ TPS BR

- Total time of this injection is 6 seconds from 3 to 9 sec.

- The cathode current of klystron increases from 1.87 A to 5.0 A at ~2.6 sec and comes back to 1.87 A at ~9.6 sec.

- As the changing of cathode current, the transmitter phase has a large jump from $82^\circ$ to $-2^\circ$ at ~2.6 sec and the other jump from $61^\circ$ to $142^\circ$ at ~9.6 sec.

- PI controller sometimes is easy to saturation or hang due to providing such large phase compensation.
KPLL

- KPLL is developed to compensate the klystron phase change and used to stabilize the PI controller.

- Calibration function is the compensation angle of the difference between $\theta_{Pt}$ and $\theta_{out}$ at non-feedback mode (PI controller output is constant).

- KPLL is put in front of IQ modulator and used to compensate the dynamic phase shift due to the klystron (or the transmitter) which works in different conditions, including low/high power and various cathode currents.

DLLRF architecture of the TPS
KPLL Logic

- If the difference $\theta$ between $\theta_{\text{Pi}}$ and $\theta_{\text{Pf}}$ is different from the initial $\theta_0$, it means that a phase shift occurs to RF system.

- According to the variation of $\theta$, KPLL can provide the dynamic compensation angle for the transmitter under the different cathode currents while RF system is in feedback mode.
Effect of KPLL

- The transmitter increases the cathode current at 700 ms, the gap voltage begins to ramp at 1100 ms, and also $\theta_{pt}$ has spikes at every ramping cycles.

- The maximum phase spike is about $1.5^\circ$ with KPLL off and it reduces to $0.35^\circ$ with KPLL on.
Effect of KPLL

- $\theta_{PI}$ represents the phase of cavity and it keeps stable at $198^\circ$.

- $\theta_{PI}$ is the output signal phase of PI controller and it has a large drop about $40^\circ$ at $700$ ms and comes back immediately.

- $\theta_{DAC}$ is the final output signal phase of DLLRF system and it has a large change from $230^\circ$ to $145^\circ$ at $700$ ms.
Effect of KPLL

- The curve of KPLL phase compensation fits to the phase change of klystron.

- Because the speed of KPLL is 1°/ms, the PI controller gives temporary compensation about -40° at the star of injection and about 30° at the end.
Power Consumption

• Before the KPLL function is applied, $I_{cc}$ is set as 2.86 A at standby period, the PI controller sometimes is easy to saturation or hang and affects the injection efficiency when $I_{cc}$ raises from 2.86 A to 5.0 A.

• After KPLL function is applied, the loading of phase compensation of PI controller decreases. PI controller can work smoothly while $I_{cc}$ raising and falling.

• We can set $I_{cc}$ as 1.87 A at standby and the power consumption is 62 kW.
Conclusions

• In this study, the KPLL is successful to stabilize the PI controller while regulating the cathode current of klystron.

• After applying KPLL, DLLRF system at TPS BR can suffer ~88° klystron phase change.

• Under this operating condition, the standby (not injecting) power consumption reduces from 135 kw to 62 kw. The maximum saving power is about 797 MWh a year.