- Web services to provide the ability for the user to monitor the real-time information relevant to the RTAP through the web using any modern browser on any operating system.

Generally, RTAPs run on the PC-based real-time embedded operating system, and it can be extended for the cooperative process, or it can be a complete automation system which capable to communicate with another environment such as power plant DCS (Distributed Control System). Therefore, by utilizing the capability and flexibility of RTAP features, it enables TNBR to develop new power plant apparatus with the capabilities to control the reactive power production of the multiple generating units by taking into account the actual operating constraints, like reactive power limit, stator voltage limit, excitation system failure, communication failure and etc. Fig. 3 shows the functional scheme of the PPVCs inside the RTAP which consist of control system block, finite state machine, and communication protocol.

III. Results and Discussion

In order to verify the performance of the power plant voltage controller, unit testing on the actual PPVC device is conducted in the TNBR power system laboratory through a hardware-in-the-loop (HIL) simulation using the OPAL-RT real-time digital simulator. In this simulation, the whole TNB power grid is simulated in the phasor domain simulation, and the physical PPVC device is interfaced with the selected TNB power plant which modelled in the simulator using communication protocol IEC104 and MODBUS. The dynamic response of the PPVC is studied under three different kind of network perturbations; step variation of the load demands (reactive power), step variation of high-side bus voltage setpoint and also the transient response of the PPVC under three-phase fault at the high side bus of the power plant. Fig. 5 shows the deployment diagram of the HIL test setup which conducted in TNBR power system laboratory.

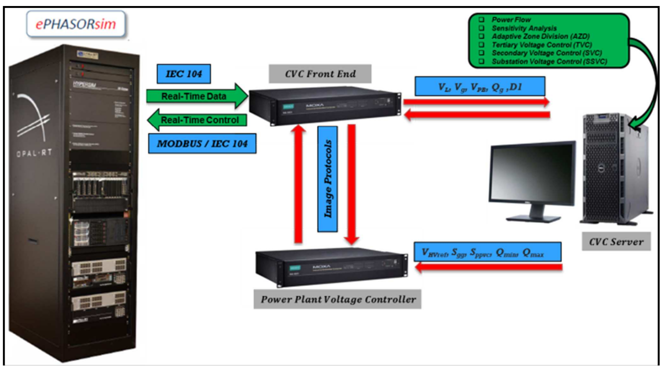

Fig. 5 Deployment diagram of the HIL test setup for CVC system

Fig. 6 shows the dynamic response of high side bus voltage, without and with PPVC device under a sudden reactive power load change occurs at the high-side bus. It can be seen that the high-side bus voltage can be maintained even after the load disturbance occurred; the PPVC automatically send the new set point to the generators AVR to adapt this perturbation. Meanwhile, without the PPVC is operated, there is no mechanism to update generators AVR set point to adapt to this new change. Therefore, generators AVR only maintained its previous setpoint value, causing the high side voltage to drop to a new steady state value.

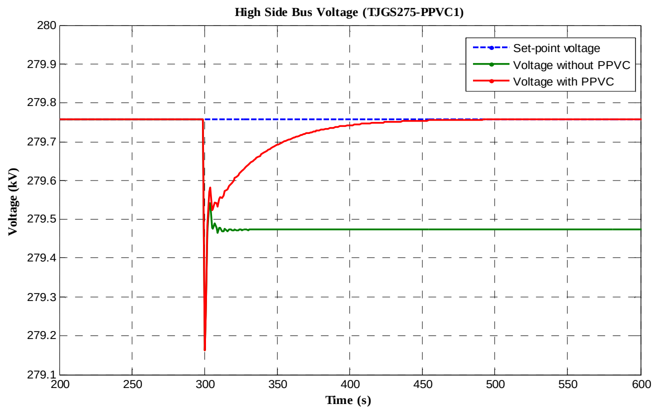

Fig. 6 Dynamic response of V_{HV} under step variation of the load

In order to prove that there is no appreciable interference between PPVC controller and existing power plant controller, a three-phase fault is applied at the high side bus of the power plant. Fig. 7 shows that there is no significant difference on the high side bus voltage during the transient phenomena due to the fact that the nature of the PPVC controller is really slow compared with the response of the other controller in the power plant.

To demonstrate the behavior of PPVC under the regulation of different voltage setpoint, adjustment of ± 0.01 p.u from current-voltage setpoint is performed. The result shows a very stable response with PPVC controller successfully achieve its setpoint value within 250s. The dynamic response of the generator reactive power is also shown here to indicate the effectiveness of the balancing algorithm for generator reactive power in PPVC. Furthermore, there is no dynamic interaction among the multiple controlled generators occurred, which proves that the control parameter is good for PPVC using a quasi-steady-state sensitivity. The result of this experiment is shown in Fig. 8 to Fig. 10.

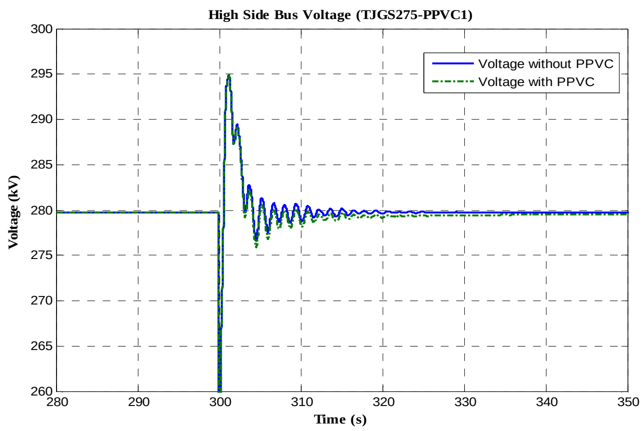

Fig. 7 Transient response of V_{HV} under three-phase fault at high side bus of the power plant

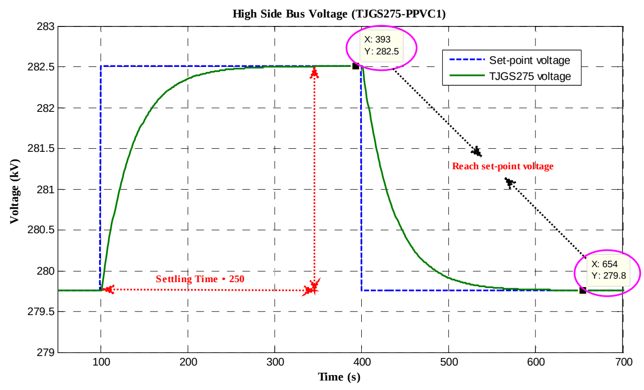

Fig. 8 Dynamic response of V_{HV} under step variation of voltage setpoint

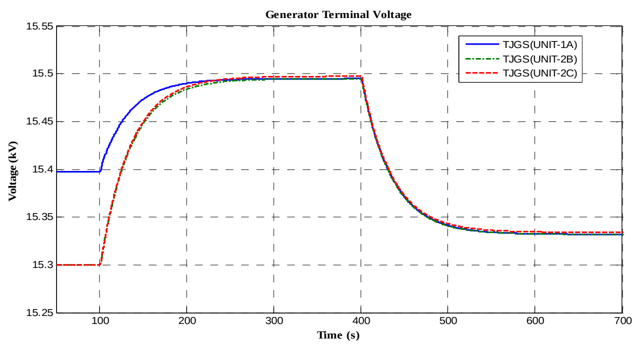

Fig. 9 Dynamic response of generator voltage under step variation of voltage setpoint

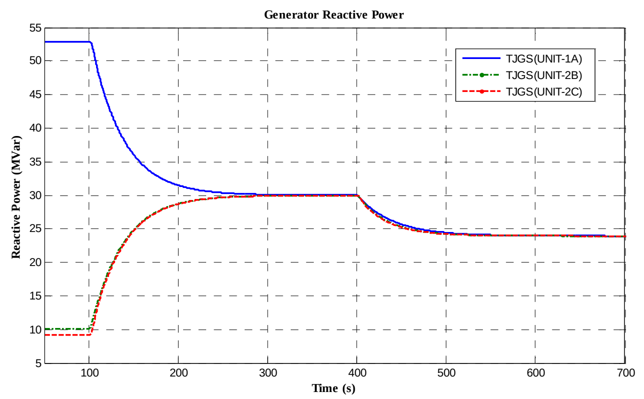

Fig. 10 Dynamic response of generator reactive power under step variation of voltage setpoint

IV. Conclusions

The paper has presented a details description on the design and implementation of the power plant high side voltage controller for Coordinated Voltage Control system in TNB. The working principle of PPVC has been described in great details in the earlier section including the functional component in PPVC and its dynamic design. The mathematical formulation to compute the quasi-steady-state sensitivity analysis is also presented in this paper. The proposed method utilizing a quasi-steady-state sensitivity module (QSENS) which calculated online at CVC Control Center Master Station (CCMS) using online data from the State Estimator (SE) results in Energy Management System (EMS). Generally, an almost entire main component in CVC utilizing quasi-steady-state sensitivity in their control strategies which make it as the most essential module in CVC system. Through a simple control strategy, an adaptive control can be achieved by using online quasi-steady-state sensitivity result to update the controller parameter. The result on the dynamic performance of the PPVC is very promising for practical applications; the PPVC able to maintained their dynamics design under different kind of network perturbations.

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