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KONČAR ENGINEERING CO.

C2 - Power System Operation and Control

PS2: Operational Planning Strategies, Methodologies and Supporting Tools

Paper 10942

PRACTICAL EXPERIENCE OF USING FULLY AUTOMATED CENTRALIZED VOLTAGE REGULATION IN TRANSMISSION SYSTEM

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Introduction

- The Croatian Transmission System Operator HOPS has implemented VVC (**Volt Var Control**) system.
- VVC system implementation was one of the subprojects included in the EU co-founded (EU CEF) **Sincro.Grid** smart grid project.
- The main goals of the Sincro.Grid project were:
    - raise of voltage quality in the transmission network,
    - minimization the active power system losses in the supervised power network (HOPS network),
    - Better integration of renewable energy sources (RES),
    - Enhancement of the ICT infrastructure,
    - Transmission capacities increase of overhead transmission lines

Motivation

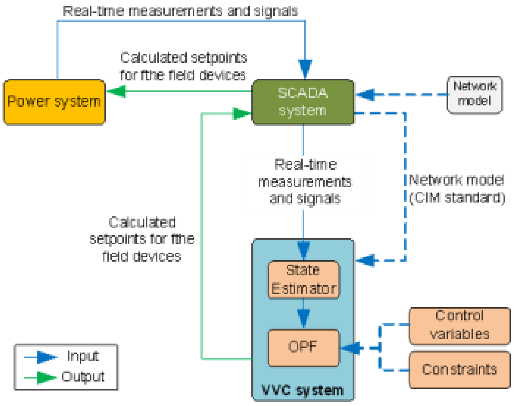
- HOPS observes growing issues in keeping the voltage profile of the transmission network inside the prescribed limits.
- Hierarchical regulation rests on implementation of three temporally and spatially separated control levels:
    - primary,
    - secondary,
    - and tertiary control
- In HOPS the implemented voltage and reactive power regulation scheme, referred to as tertiary control on a national level and is based on an optimal power flow (OPF) type algorithm.
- OPF algorithm is the heart of the VVC system.

Primary and tertiary regulation

- Local voltage regulators on transformers typically regulate the lower voltage side of transformers
- Central VVC system has insight into the entire network and the ability to manage voltages throughout the power network.
- The calculation of the optimal power flows of the central optimizer is defined by the objective function and the set voltage limits.
- The objective function of the VVC system is set to minimize the operating losses in the system.

VVC system design

- The VVC system consists of the transmission network model, modelled in the accurate AC manner imported via the Common Information Model (CIM) standard from the production SCADA/EMS system.
- The real time measurements and breaker status are imported via IEC 61870-5-104 protocol cyclically with a time interval of one minute.
- The VVC system runs a state estimation process, and the results are the base case for the OPF process.
- OPF results (setpoints of control variables) are transferred back from the VVC system to the production SCADA/EMS system via ICCP protocol and dispatched to field devices.



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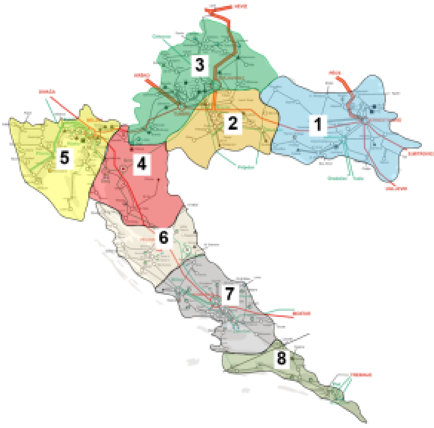
System operation

- The VVC system can be run in:
  - Manual / advisory mode,
  - Semi-automatic mode (the dispatcher sends the controls manually to field devices from the SCADA/EMS system) or
  - Automatic i.e., closed loop control mode where no dispatcher intervention is needed, and the set points are automatically sent to field devices after each OPF execution.

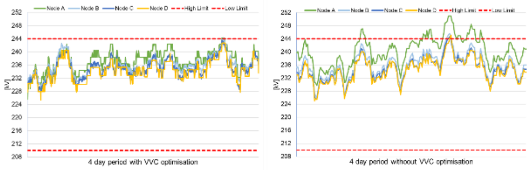
Voltage constraints and optimization zones

- Initial voltage low an upper limits or constraints for the 400, 220 and 110 kV voltage levels are defined to be compliant to the COMMISSION REGULATION (EU) 2017/1485 SOGL (System Operation Guidelines) documents and Network Codes.
- The result of the sensitivity analysis divided the HOPS power network into 8 optimization zones in order to determine the range of influence of control variables to voltage magnitude.

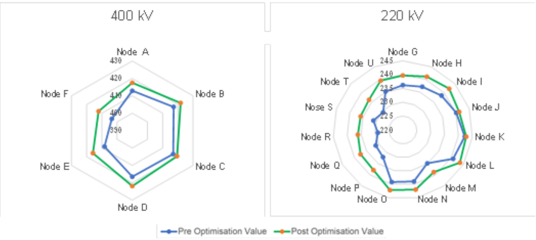


VVC system optimization

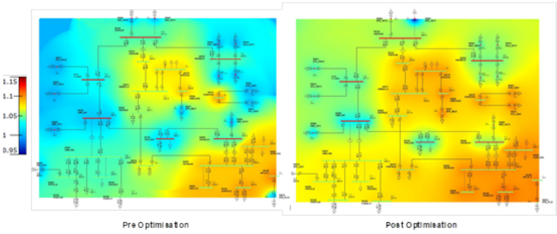
- Figure bellow shows the graphical representation of 220 kV node voltages in one region of the transmission network, during a 4-day time span when VVC performed the optimization cycles (left side) and the equally long period without reactive power optimization (right side).



- Figure bellow shows a radar diagram of 220 kV and 400 kV node voltages in the power network before the implementation of VVC optimal setpoints and the same node voltages after the implementation of the VVC optimal setpoints.



- A heat map of network before and after the optimization cycle is also given for the same example in bellow Figure.



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VVC security mechanisms

- Implementing such a complex system in a transmission system, implies the need to constantly monitor the entire process consisting of receiving measurements, signals and indications from the network, availability indications form devices included in the optimization, control of the OPF calculation and configuration, display and verification of result, sequencing, and coordination of commands.
- Security mechanisms implemented in the system:
    - State Estimation Quality,
    - Control of OPF calculation quality,
    - Emergency stop,
    - Monitoring of the devices included in the optimisation,
    - Monitoring and control of VVC setpoints execution.

Setting up of the optimal power system state

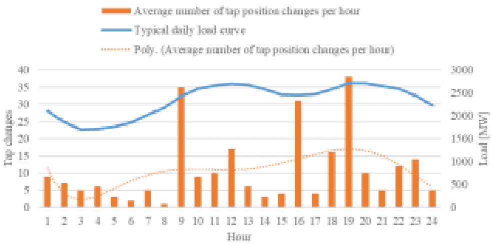
- The first step in implementing the VVC results is to switch off the local automatic control on individual objects in the optimization, i.e., to give the regulating control of individual objects to the VVC system.
- In the first run of the optimal power flow algorithm, a larger number of shifts in control variables occurs as a result the control variables now move in a coordinated manner to achieve the target function i.e., to reduce the operating losses in the system.
- Part of the test results is shown in Table below for two consecutive days of the field tests.

VVC run	1st run	2nd run	3rd run	4th run	5th run	6th run	7th run	8th run	9th run
1st day	10:42	11:42	12:42	13:42	14:42	15:42	16:44	17:51	18:42
D shifts	39	5	8	0	16	9	12	7	4
D losses [MW]	-0.952	-0.523	-0.818	-0.913	-0.515	-0.535	-0.363	-0.296	-0.309
2nd day	-	11:37	12:40	13:42	15:13	16:37	17:54	-	-
D shifts		16	8	5	2	4	8		
D losses [MW]		-1.296	-0.911	-0.358	-0.857	-0.801	-0.836		

- The test started in the morning hours . The delta shift value shows the total number of shifts of tap changer position (transformers, VSR) from the initial value.
- The initial value in the first run of the VVC algorithm is the value inherited from the situation while the local (primary) control was active.

Changing of control variables during VVC operation

- Figure below contains the average number of changes in control variables per hour per day during a multi day VVC trial run.
- The number of changes in the control variables in this figure refers only to changes of transformers and variable shunt reactors tap changers.



- Observing the graph above, higher number of changes in control variables are happening during the hours in which a significant change in load occurs.
- Load changes that occur at night and in the morning are highly reflected in the change of voltage profile.
- Devices used in tests: 28 power transformers and 2 variable shunt reactors (facilities owned by TSO), 11 production units (5 generators in Hydro Power Plants, 3 generators in Thermal Power Plants and 4 generators in Wind Power Plants).

Conclusion

- The advantage of the VVC system implemented in HOPS is the possibility to operate the VVC in a closed loop without operator\dispatcher intervention.
- Due to its complexity, the closed loop approach of reactive power regulation is rarely used in the TSO community and HOPS is one of the first TSOs that implemented regulation in such manner.
- In conclusion, regardless of safety algorithms implemented to avoid many unwanted situations in the power system (such as voltage breakdown, overloading of regulating equipment and similar), transmission system operator should be aware of possible risks.
- For this reason, HOPS initially opted for safer approach and mostly used semi-automatic mode which is additionally under the control of the dispatcher\operator.