ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE,TAKES YOU FAR

XXX IV Cycle

Study of Key Power Equipment Response under Transient Electrical Disturbance

Ning Dong

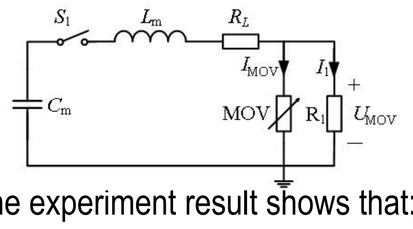
Supervisors: Prof. Yan-zhao Xie, Prof. Flavio Canavero

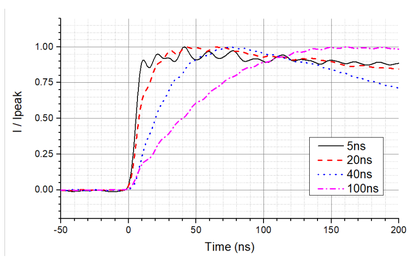
Research context and motivation

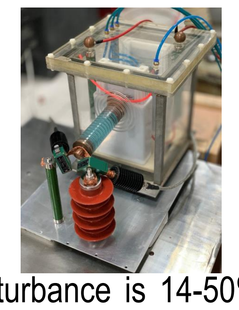
- This research is part of co-directed thesis project “Novel modeling concepts for the resilience assessment of next generation smart grids”, which is focused on a novel modeling concept for resilience assessment of the next generation of resilient smart grid under unforeseen extreme external disturbances (e.g., transient electrical disturbance, geo-storms, lightning storms, etc.). Several different model structures will be investigated depending on their purpose, from graph-based models for resilience and self-healing up to physics-based reduced-order models for detailed prediction of transient voltages under external disturbances combined with normal and abnormal operation.
- This research mainly concentrate on the physics-based power girds modeling under external transient electrical disturbance. In order to predict the grid behavior and reliability when facing transient electrical disturbance, transient response on power grids especially on key power equipment need to be studied. Therefore, the research context is divided into three aspects: transient electromagnetic disturbance characteristics study, power line coupling and response study, and as a result of above two, key power equipment transient behavior study. (The next section will mainly introduce the third part.)

Addressed research questions/problems

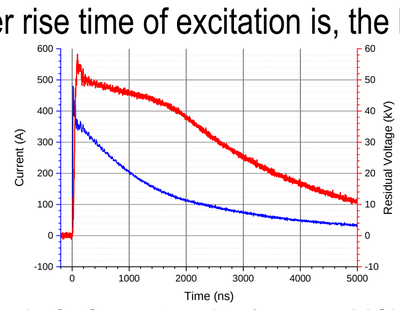
- In this research, electromagnetic pulse is taken as a transient electromagnetic disturbance example. (The transient electromagnetic disturbance will specifically refer to the electromagnetic pulse in this poster.) It has the feature of very fast pulse, wideband frequency and high amplitude, which is different from classical external overvoltage source like lighting. This kind of transient electromagnetic disturbance may cause faults in a very short time and increase the possibility of cascade and black out by coupling and conduct overvoltage on power line and related power equipment.
- Transmission line micromodel based on telegraph equation solved by characteristic method combined with analog behavior modeling algorithm in SPICE is utilized to deal with transient electromagnetic disturbance coupling problem with characteristics of high frequency and uniform electrical field. The transient electromagnetic disturbance coupling response along the power line and on the terminal load including both linear equipment (transformers, etc.) and nonlinear equipment (arresters, etc.) can be simulated.
- Arresters is a kind of key equipment have nonlinear electrical characteristic. Since the classical electromagnetic pulse rise time is much faster than lighting or other transient over voltage, a high frequency model is needed instead of IEEE MOV model under standard lighting wave.
- Experiment is carried out to test the behavior of MOVs under transient electromagnetic disturbance. The proposed experiment circuit and setup is shown. Transient electromagnetic disturbance is generated by a gas-gap adjustable Marx source. HY5W-10/50 used in 10kV distribution grid is chosen as equipment under test. Different rise time is applied.

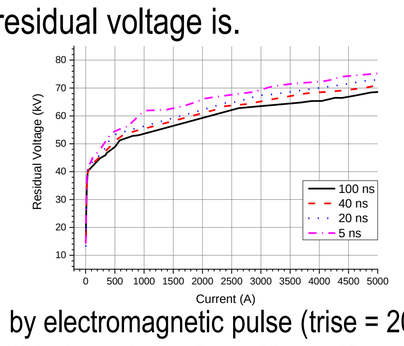






- The experiment result shows that:
- Residual voltage under high frequency transient electromagnetic disturbance is 14-50% higher than that under standard lighting wave (8/20 μs);
- Arrester (MOV) has not only nonlinear behavior, but also frequency dependent characteristics;
- The faster rise time of excitation is, the higher residual voltage is.





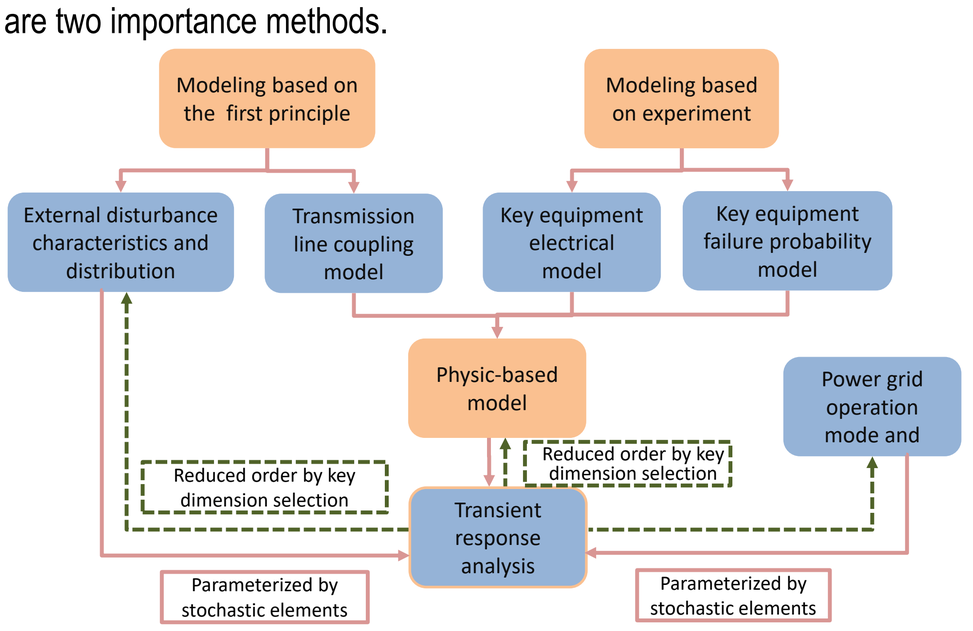
Left: Current and voltage on MOV excited by electromagnetic pulse (trise = 20ns);
Right: Residual voltage - peak current on MOV when trise = 5 ns, 20ns , 40 ns, 100ns.

Novel contributions

- In order to establish the power grid transient electromagnetic disturbance analysis model, transient electromagnetic disturbance characteristic parameters (including electrical field intensity, rise time and pulse width) and its spatial-temporal distribution, statistical distribution is studied. (The result is already published and listed below.)
- With the specific transient electromagnetic disturbance waveform information, macromodel method for transmission line is utilized to simulate the coupling response along the power line and on the terminal.
- Arresters, which is the front line of power grid over voltage protection and is directly connect to the power line, is not able to be ignore in transient analysis. A transient response model for MOV is studied by Experiment. Result shows that MOV provides less protection under high frequency over voltage and the residual voltage is sensitive to rise time.

Adopted methodologies

- The main idea of this research is to build a physics-based modeling under external transient electrical disturbance. Modeling based on the first principle and experimental result are two importance methods.



- Extreme transient electromagnetic disturbance, such as electromagnetic pulse, cannot be predicted nor experimented, modeling based on the first principle and simulating by finite element method (FDTD is utilized in this case) is the best way to obtain electrical characteristics and distribution of external disturbances.
- The first principle models of key equipment in power grid (including generators, transformers, storage components and communication network) are too complex and redundant for such complex network models simulation. Therefore, electrical model based on experiment data is valuable in order to get the key parameters we concerned.
- The key equipment transient response modeling can be guided by the transient response analysis in turn through key parameters selection and model reduction. For instant, since the MOV is more sensitive to rise time, a surrogate model as a consequence of rise time, current amplitude is able to replace the time domain electrical model.

Future work

- Extension of current research activities will be proposed on three aspect:
- More experiments to construct the transient response of other key equipment in power girds (insulators, transformers need, etc.) under external transient electrical disturbance need to be finished.
- Low-complexity surrogate models of complete physic-based power grids transient response model facing external transient electrical disturbance will be investigated depending on purpose. In one hand, reduced-order modeling can be constructed due to key parameters selection based on uncertainty quantification. In the other hand, the scalability to high-dimensional heterogeneous systems parameterized by many stochastic elements need discussion.
- In order to evaluate the power grids resilience, power system cascade analysis need to be combined with the transient model under external transient electrical disturbance.

Submitted and published works

- Dong Ning, Xie Yanzhao. “*Early-time high-altitude electromagnetic pulse simulation and analysis considering parameter uncertainty*”. High Power Laser and Particle Beams, vol. 31, no. 07, 2019, pp.070002.1-7
- Dong Ning, Xie Yanzhao. “ *HEMP environment distribution simulation and statistical analysis*”. Asian Electromagnetics 2019, Xi’an, 2019,pp:110.1-3

List of attended classes

- Enrolled in co-directed thesis project between PoliTo and XJTU, courses are taken in XJTU.

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering