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Some aspects of smart grids' system integration

(stability assessment; system restoration – synchronization; voltage–reactive power control)

PhD Thesis

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Thesis I.: Developing the RTSI indicator

Introduction

Nowadays there is a growing demand for continuous and high quality electrical energy supply. Technological development and the industrial and domestic needs establish increased requirements against electricity supplier. Huge utilization and complexity of the power transmission system and the support of growing needs are serious professional challenges for the engineers. Some recent system faults are remarking how important and necessary is the continuous monitoring of the dynamical security and resistance against the errors of the electrical power system.

There are different methods to analyse the effects of state changes on the power system, which possibly endanger the synchronism of the power system (especially the generators). It is possible to examine the transient stability either by means of time-domain simulation of electromechanical processes or by so-called direct methods of transient stability assessment. For time-domain calculations, a detailed dynamical model is required, on which the simulation of different faults at various locations and several durations can be performed. The number of such cases can be very high, therefore suitable accuracy of results and transparent amount of calculations are inevitable. Additionally the format of the results should be easy to understand and evaluate. The previous criteria often cannot be met simultaneously. For the detailed time-domain analysis of transient processes, the available software are based on sophisticated numerical methods to solve the multiple coupled, nonlinear differential equation systems which have a relatively simple physical background. Results from such software tools are accurate, but the necessary computational capacity can be significant. For complex systems, often only a high number of simulations can lead to the correct decision on which fault cases have to be considered at all for stability assessments. Determination of places and types of failures affecting the system mostly requires professional experience and very good knowledge on system behaviour and characteristics; therefore the automatic calculation is rather difficult. From the above considerations the conclusion can be drawn, that measuring or describing „transient stability" of a certain case with one single quantity is by far not a trivial task.

Several examinations were simulated on a micro grid model to compare more different direct methods, while searching for the most reliable one, i.e. the most accurate one from simulation results. A new index has been defined and a MatLab program has been created to calculate it. The RTSI (Revised Transient Stability Index) indicator is suitable for get an approximate estimation about the stability of the given system state.

Results

The basic idea was that calculation of angular accelerations of the machine units at the instant fault can be used to get useful information about the system. An index can be formulated from these accelerations that will give information about the disturbance on the whole system. There is a correlation between the angular accelerations (Δ) and the critical clearing time (CCT) (TSI=f(Δ,CCT)). The CCT values were calculated with the HTSW software package. The MatLab program is suitable to calculate the Δt parameters and the load changes (Δ') belonging to these values also were calculated. With this two values it was possible to specify RTSI (RTSI=f(Δ', Δt)), and the two methods became comparable.

It can be seen that the results from RTSI method fit more precisely to the expected characteristics. The parameters calculated by the angular acceleration by the two methods are quite similar, showing 0,97 correlation. At the same timer the critical clearing time shows only 0,59 correlation which is a week coherence between the two results.

On Figure 1. the comparison of the two methods can be seen. Several simulations were calculated on different system cases. The stability characteristic could be defined from the results, meanwhile the difference between the two methods could be demonstrated as well. The two system cases are really transparent: at first the TSI method forecasted a stable system case but the time-domain simulation confuted it (Δ=8,706 rad/sec^2). The RTSI method was correct for this system case. In another situation the TSI method forecasted an instable system case, while the RTSI forecasted a stable case. The RTSI was correct again (Δ'=4,489 rad/sec^2). These examinations verified the RTSI method, as this process is more accurate and reliable than other known methods.

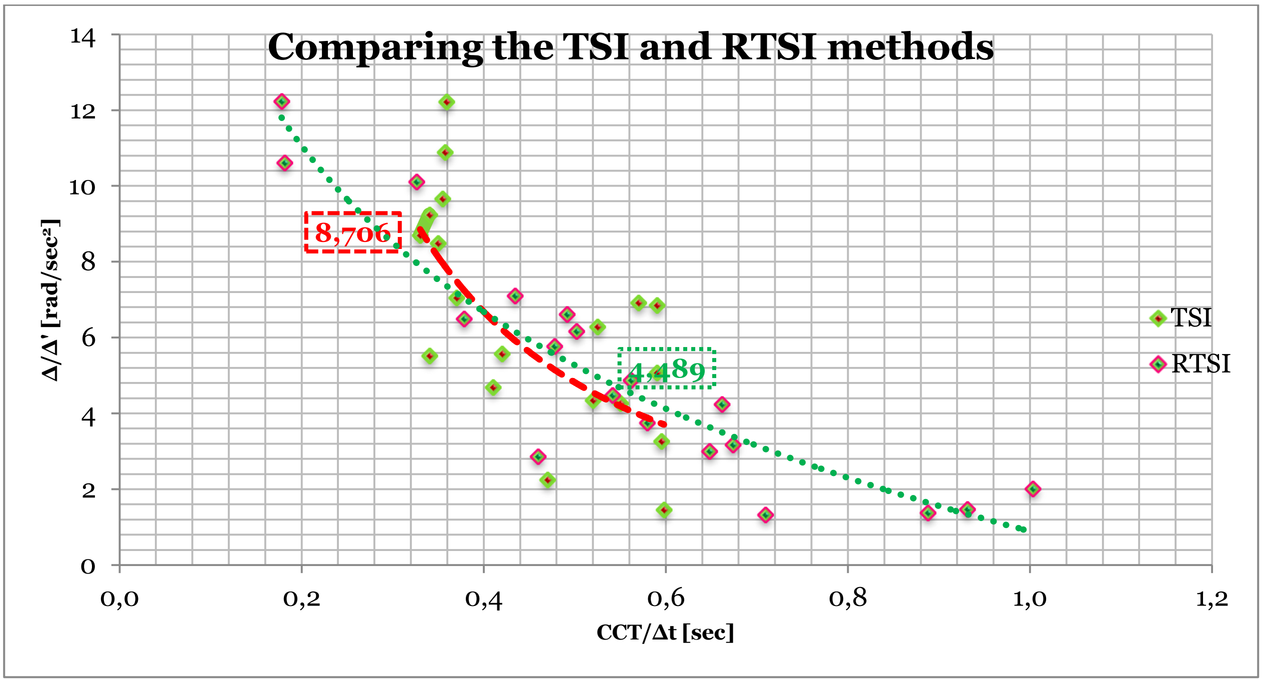

Figure 1.: Differences between the two methods

Summary, thesis I.

Summarizing the results of the manual calculations, literature research, model development and simulations the following conclusions can be drawn:

- The examined stability indices contain significant simplification to handle network changes more easily.
- In case of large systems the number of calculations can be very high. The calculations of time-domain analysis are faster nowadays due to the high power computers, but not as fast as the RTSI method. In these cases the new method could also be useful.
- The stability indices were originally created to reduce the number of calculations by substituting complicated, time-domain analyses. Nowadays this aim has lost its importance as a consequence of

available computational capacity growth. However, stability indices can be very useful to monitor stability state of the system on-line by automatic calculations.

- The RTSI method provides more accurate and reliable results than the TSI method on the same network and system cases.
- Calculating RTSI is more simple and faster than the other methods known in the literature.

Steps of the RTSI calculation procedure:

1.: First a three-phase short circuit should be simulated on the node of the i^{th} generator. It will cause a change in the acceleration of all the generators of the system.

2.: An average system-acceleration value ($\bar{\varepsilon}_i$) can be defined from the ε values calculated in step 1.

3.: The difference between the maximum accelerations and the average system-accelerations is the Δ' value.

4.: The stability characteristic came by the Δ' and the Δt.

Thesis I.

It can be concluded that determination of stability conditions of the synchronous-generator systems with RTSI method is faster and more accurate than the other known procedures.

Publications on thesis I.: [S8], [S9], [S11], [S14].

Thesis II.: Synchronization criteria, using under frequency load shedding (UFLS)

Introduction

In the traditional electric power systems the power flow is practically directed from the centralised producers (power stations) to the decentralised consumers. The fundamental architecture of these networks has been designed to meet the needs of large, mostly carbon-based production technologies. The power stations are located usually far away from consumption areas, but near to coal fields. This world of electricity will be changed dramatically in the near future. Drive for lower carbon emission and distributed generation technologies and greatly improved efficiency of the demand side will enable consumers to become much more interactive with the grid. The future consumer friendly network is currently not reachable. However, these fundamental changes will determine the design and control of future networks.

The EU recognized the task and set up the European Technology Platform of Smart Grids in 2005, which aimed to create a shared vision for European grids of 2020 and beyond. The platform incorporates representatives from industry, transmission and distribution system operators, research groups and regulators. The strategy, developed by this group, was one of the first in Europe that has set the criteria for Smart Grids. It includes the following criteria:

- Flexibility: the network has to fulfil customers needs, while it also has to respond to different challenges
- Accessibility: all network users have to be granted with connection access, especially renewable power sources and low CO_2 emission, and with high efficiency (combined heat and power) units
- Security: the network has to assure and improve the quality of service, consistently with demand of 21st century with resilience to network events and uncertainties
- Economy: the network has to provide the best possible performance through innovation, efficient energy management and regulations.

Key elements of the vision include:

- Establishing a toolbox of proven technical solutions that can be deployed rapidly and cost-efficiently, enabling the existing grid to accept power injections from all sources
- Harmonization of regulatory and commercial frameworks, to facilitate international trading of both power and grid services
- Establishing shared technical standards and protocols that will ensure open access, enabling the deployment of equipment from any chosen manufacturer
- Developing information, computing and telecommunication systems that enable businesses to utilize innovative services to improve their efficiency and service models
- Ensuring compatibility of devices from different generations, in order to support interoperability of automation and control.

Research is continuous both in Europe and all over the world, based on similar visions like the one mentioned before. The aim of our research is to make propositions to evolve the Hungarian scheme taking the home specifications into account.

Summary, thesis II.

The simulated smart grid was examined in aspects of power- and frequency control. The known methods of active power and frequency control were implemented into the simulation model, and with help of the simulation environment different scenarios were tested.

An important point of view was the analysis of the circumstances of interconnection with the infinite network. The consideration was the following: if any kind of event affects a group of generators and consumers to operate in island, and this group is able to find a steady-state case, after the fault the group may be re-connected to the infinite network. The main questions were: whether the grid could operate stable with normal frequency and voltage values; and what kind of conditions must be fulfilled for successful interconnection to the infinite network. This part of the simulations had several stages, depending on the changing parameters. The two most important parameters to be changed were the frequency- and the voltage angle differences (between the infinite network and the micro grid).

A possible other important control tool was the UFLS (Under Frequency Load Shedding). In spite of the fact that no information was found in the literature about UFLS operation in smart grids, the author proved its importance. The summary tables show how the UFLS decreased the power flow transient amplitude. It was found that 38 % of source outages could be "handled" with 30 % UFLS operation, so it was possible to keep the smart grid system in synchronous state, and to re-synchronize.

To conclude: using the UFLS helps to keep the grid stable really effectively from the view point of dynamic stability, however it might lead to load shedding at some consumers.

Using the UFLS makes large frequency differences avoidable.

As per the examinations results it is possible to give a proposal how parameters of the inverters of renewable power plants should be set. Changing the integrator time constant it can be concluded that from regulation point of view not necessarily the most rapid generator is the most effective one (Figure 2.). If the generator reaction time is too short, the rate of consumers affected in UFLS will rise (at phase one it can reach 11%).

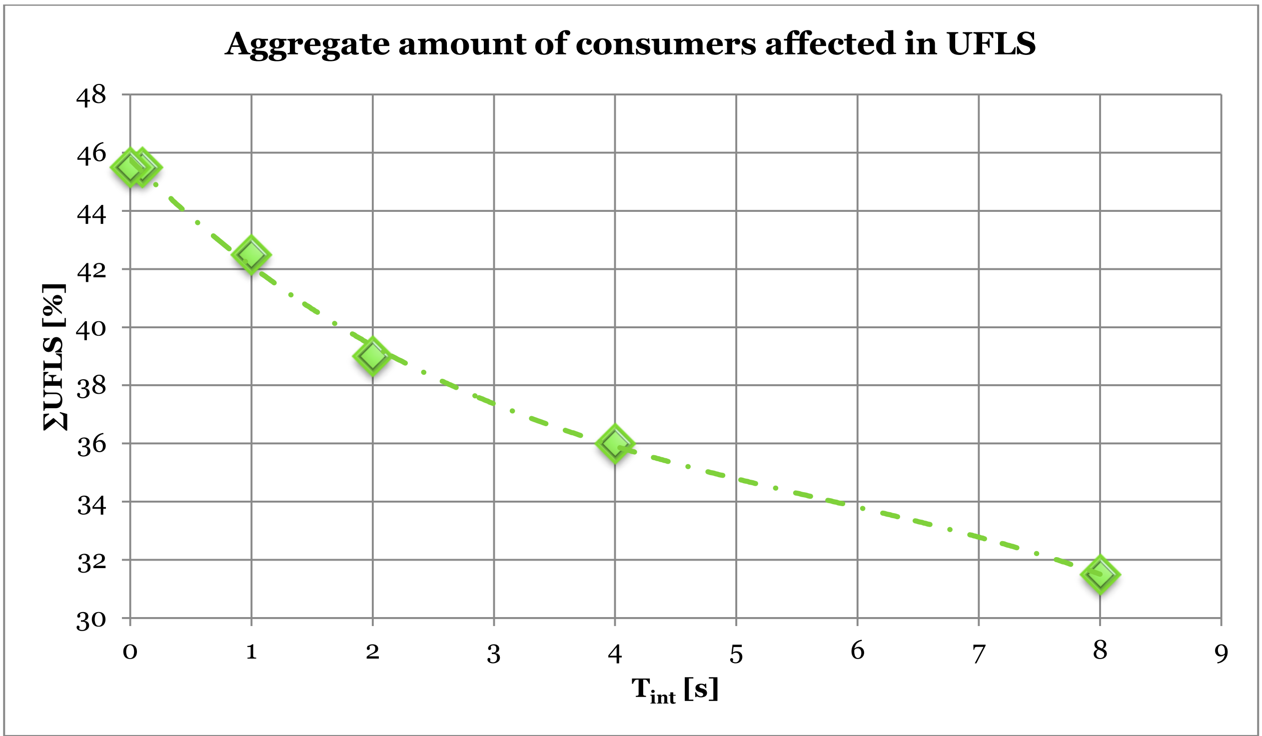

Figure 2.: Aggregate amount of consumers affected in UFLS in function of integration time constant

It is worth mentioned that UFLS used traditionally by TSO (transmission system operator). During the simulations it was examined what kind of benefits can caused by using UFLS in micro grid scale.

The number of steps and the amount of affected consumers at each step were established according to ENTSO-E Operation Handbook Policy 5.

The exact amount of the affected consumers were calculated to reach 50 Hz±0,1% after the switch.

Examining the power electronics I made a proposal for the settings of inverter's outer P-f characteristic.

Thesis II.

The inverters of renewable power plants should be parameterized to follow a synchronous generator – turbine unit primary and secondary control. Increasing the turbine controller integration time constant the aggregate amount of affected consumers will increase.

Nevertheless according to Thesis II. two sub-thesis were established:

A. *To reach the optimal 36-40% UFLS rate (ENTSO-E OH P.5), the time constant of the integrator should be between 2-4 sec. It is also the suggested value for the inverter's P-f characteristic.*

B. *Using the UFLS in micro grid scale operating in island helps to keep the grid in steady-state really effective and to re-synchronize.*

Publications on the 2nd thesis: [S2], [S3], [S5], [S12].

Thesis III.: Voltage- reactive power control

Introduction

The increasing integration of smart grids means a lot of new challenges. Up to now the stability, the frequency balance and the reliability of the system were examined. These are the most relevant parameters in aspect of the TSO (Transmission System Operator). Providing the electrical energy continuously and reliably is not enough for the consumers, energy provision also has strict quality criteria. The most important standard is the EN50160, which considers the quality of the provided voltage. Therefore it is unavoidable to examine the issues of the voltage- and reactive power regulation.

First of all take the criterion of global reactive power balance for the whole system.

The balance for the reactive power in a whole- or a part of a system is the next:

$$\sum \mathbf{Q_E} + \mathbf{Q_I} = \sum \mathbf{Q_F} + \mathbf{Q_H} \tag{1-1}$$

where:

ΣQ_E is the amount of reactive power from power plants

Q_I is the balance of imported reactive power flows (incoming is the positive)

ΣQ_F is the amount of substations reactive power consumption

Q_H is the amount of system elements reactive power consumption (wires, cables, transformers, reactors, static compensators, etc.)

The reactive power flows from the capacitors and overexcited generators is called reactive power production, the under-excited generators and inductances reactive power is called reactive power consumption. The reactive power is positive, if the current is delaying to the voltage, while the active power is positive compared to the power flows on an arbitrary system element S=P+jQ.

These principles apply to the high/middle voltage level systems, but there is no reason not to be used in micro/smart grid systems as well.

Results

It can be concluded that using the inverters of the wind power plants for reactive power generation is an effective solution in the voltage- reactive power regulation. The incidental extreme voltage conditions caused by the topology are terminated, and the compliance with the standards is easier. This solution is effective not only at medium voltage level, but at other voltage levels as well. Basically two parameters specify the need of reactive power: the drop of the transformer and the usage. Knowing the parameters of the most popular L/M and M/H voltage transformers it can be stated that 0,95 power factor is enough to serve the reactive power needs.

Summary, thesis III.

Up to now the micro/smart grids were examined from different views: under what circumstances is it possible to maintain the stable operation or the island operation. For the appropriate operation it is necessary to provide the quality criteria and hold the voltage level near to the nominal.

The examinations of three different influences were subject to this thesis. First of all the effect of an active compensator, the effect of a gas turbine used for reactive power- voltage regulation, and at finally the wind power plants were used for voltage control by the inverters.

As the gas turbine so the active compensator are optimizing the voltage levels in the grid. The gas turbine as the active compensator optimizes the voltage levels in the grid. The greatest fluctuation is at MSZ20 bus, it was more than 10% of the nominal voltage. By using the reactive power- voltage regulation methods the fluctuation is increasing and the excess is almost between the limits.

It is worth evolving the operation to avoid cross-flows, i.e. the opposite flow of active- and reactive power.

It is expedient to realize the reactive power needs at local levels.

General conclusions:

- the topology, the places of the active compensators and the power flows are definitive in voltage control
- scaling of transformers is really important: voltage conditions are influenced by the reactive power needs of the overloaded transformers
- it is better to provide the reactive power needs of the consumers locally
- the solution for these problems could be one or more SVS (Static Var System) at the appropriate places; or using synchronous machines in the reactive power- voltage regulation
- it is really effective to provide reactive power locally by the power electronics
- the voltage- reactive power regulation in micro grids should be realized in several steps in order to reduce network losses caused by the unnecessary reactive power flows; the first step is the local

reactive power regulation: the reactive power needs could be served by the inverters of wind power plants at 0,95 power factor as well as on high and medium voltage levels

- the second step is to involve synchronous machines of the system into the reactive power regulation if the need is close enough in electric aspect
- the third and really effective solution is to install SVS (Static Var System), in case if application of the first two steps are not satisfactory

Using the mentioned three solution together it is possible to keep the expected voltage levels meanwhile the network losses could be minimized as well

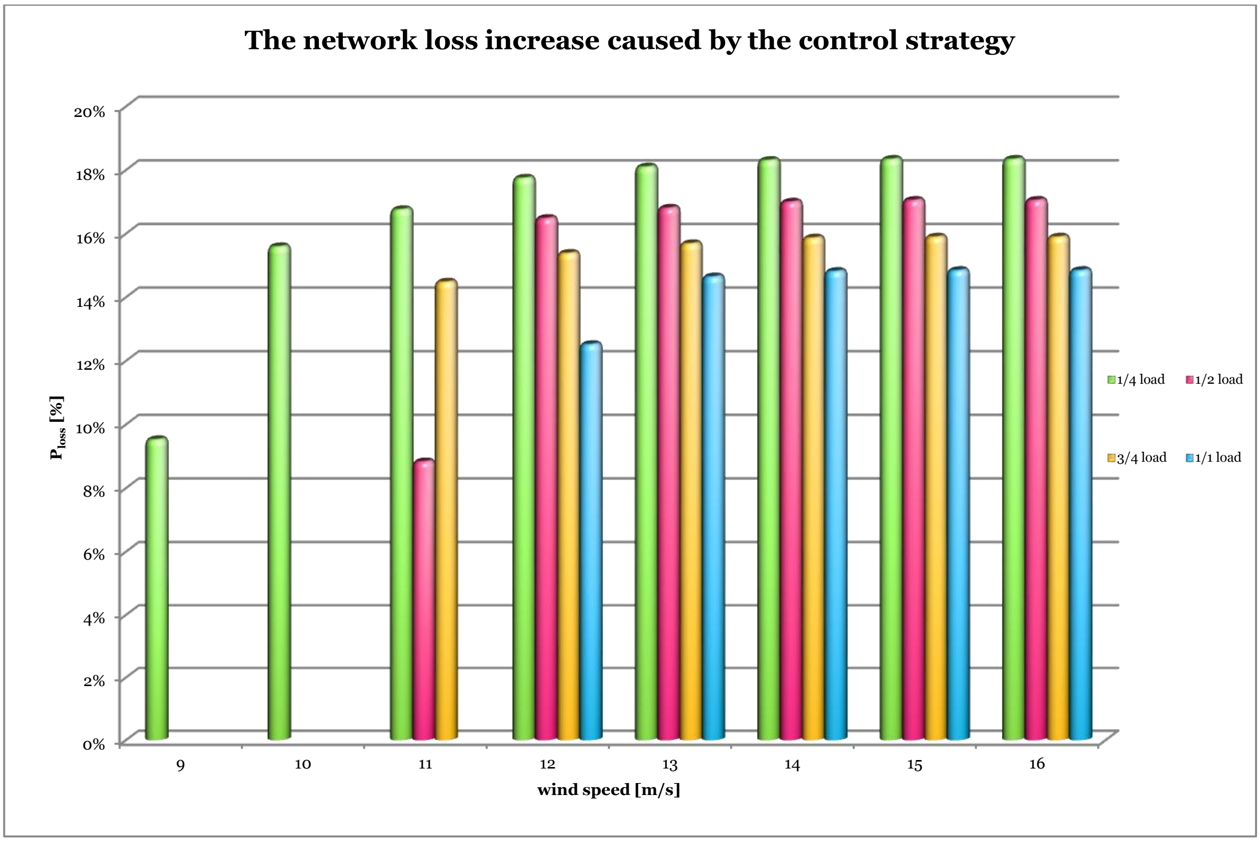

Figure 3.: The reachable network loss increases in % at different load profiles in function of wind speed

Concluding the results it is necessary to draw up a defined framework which is an effective support in case of island operations of micro/smart grids.

Thesis III.

Here a load dependent mixed-multi-stage control strategy is introduced. The controllable equipment are dispersed in space and time, and the control is made stepwise minimising the network losses and keeping the node voltages between the set ranges.

Publications on the 3rd thesis: [S1], [S4], [S10].

Practical application of the theses

The field of micro/smart grids is a very popular and nevertheless a really new/young area. In conventional meaning it is not possible to mention practical applications, as these kinds of systems do not yet exist. Developing and testing similar pilot systems entail huge costs; therefore a simulation model can be useful and practical. An appropriate model can give almost the same results like a real micro/smart grid for the fractions of the costs. The results and the experience will be useable in reality in the near future.

Nothing shows better the necessity of such researches, than the study led by the Integrated Energy Knowledge Center at Budapest University of Technology and Economics. The usage of smart networks is examined mandated by the ELMŰ PLC. The work is basically about the "smartness" of the smart networks. Voltage conditions, network losses and characteristics of the production and consumption are examined in an appropriate software environment. The work is carried out in a network model, which contains distributed generation and renewable sources. The opportunities of energy storage are examined and a proposal is going to be made for the further steps.

It can be seen that these researches fit to the need of industrial clients, although the results are for the near future. The results and practical experience in the applications later, when the micro grids will be developed in the reality will be used. The results and practical experience in the applications will be used later in live, when micro grids will be developed.

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