Network Security Management Tool for Distribution Systems

Zbigniew A. Styczynski SM IEEE and Chris O. Heyde M IEEE[1], Bernd M. Buchholz and Olaf Ruhle[2]

***Abstract*—In this paper a network security management tool, which is integrated in a power system simulator, has been introduced. The network security management (NSM) is used by network operators to avoid insecure network states due to high penetration of DGs. Especially in situations of low load and strong wind the operation parameters e.g. current or voltage can exceed the allowable values [5]. The NSM tool introduced in this paper is performing new NSM algorithms within the power flow calculations. On the one hand, it can be used as an online application to support the network operator in his decisions using measurements and short time forecasts. On the other hand, by using the tool for long time simulations it can be used to optimize the NSM algorithms, to optimally plan network reinforcement and to predict the intensity of the NSM system on the profitability of the DG operators.**

***Index Terms*—Power System, Network Security, Network Security Management, Generation Response, Power System Simulation, Remedial Measures**

I. INTRODUCTION

The integration of decentralized generators (DGs) has nowadays a very high priority in many countries in Europe and America [7]. In some regions, e.g. of Germany, the generation level of DG has exceeded the local demand by far. Especially in regions with very good wind conditions this is often the case. In situations with low load and strong wind or in other than normal network situations the high penetration of DGs may lead to violations of the operation parameters and hence to security problems [5]. Therefore, the network operators have installed a network security management system (NSM) to reduce the power output from the DGs in order to ensure the secure operation of the network [5], [7].

The reduction of the possible power output results in less economical benefits at least in the case of wind and PV generators because the primary energy that is not used is lost. This practice is against the current renewable energy law, and must be fixed in the contracts and can lead to penalties. On the other hand the network reinforcement is cost intensive and time consuming which is why the NSM is a temporal compromise in order to integrate as much as possible DGs into the network. For reasons mentioned above the NSM must be well coordinated and its impact to the DG operators must be determined.

In recent investigations the impact of the NSM to the DGs was determined e.g. with the use of Monte-Carlo simulations [2]. A DC load flow method was applied to recognize the bottlenecks that were usually assumed to be located at the border of the considered network to the connected transmission network. In this way the long term impact of the NSM can be determined but the effect of different NSM algorithms like additional load response for example or bottlenecks located within the network can not be analyzed. Therefore, an NSM tool which is integrated into a power system simulator was developed that is able to:

- Observe all operation parameters concerned,
- Assess the actual power injections of all DGs in the network,
- Consider load and generation forecasts,
- Choose remedial measured in case of parameter violations (NSM algorithm).

In section two of this paper some of the presently working NSM systems in Germany are described. Section three gives an overview of the methodology of the long term application for the investigation of the intensity of the NSM to the DGs and of the short term application for supporting the network operator in finding the best solution in cases of network insecurity. A study case will be described in section four and first results will be discussed in section five.

II. NSM SYSTEMS IN GERMANY GENERAL PROCEDURE

As aforementioned the NSM system reacts to an unwanted system state which can influence the power system security, caused by high power injections from DGs, with the limitation of their output power. Therefore, previously defined operation parameters are observed. In case of a violation of these parameters, the NSM instructs power limitations to the dispersed generators. The communication is done via wired networks if available, or by an unidirectional radio signal. The network operator usually knows the possible bottlenecks in his network and pools the generators that are most likely responsible for the bottleneck situation. In such a pool every generator gets the same signal from the network operator.

[1] Prof. Dr. Z. A. Styczynski and C. O. Heyde are with the Otto-von-Guericke University Magdeburg. (sty@ieee.org).

[2] Dr. B. M. Buchholz, Dr. O. Ruhle are with PTD Services, Power Technologies, Siemens AG, Germany, Erlangen.

As a rule, the power limitations are differentiated in three steps:

- step 1 – limitation to 60% of the installed power,
- step 2 – limitation to 30% of the installed power,
- step 3 – limitation to 0% of the installed power.

In order to avoid permanent switching, the network operators usually wait a certain time (normally 15 to 30 minutes) before they decide whether to cancel the limitation or not. In most cases network operators also use weather forecasts or measurements from the influencing factors like wind speed or outside temperature for this decisions. Some network operators also use the installation date to form subgroups within the pools of generators in order to burden the DGs that were installed the latest more than the ones that were installed earlier in times when no bottleneck existed. This is called the "first-in-last-out principle" [1],[5]. Other network operators treat all generators in one pool the same which is called the "solidarity principle".

III. Methodology

There are two targets aimed by using the NSM tool. Firstly, to determine the impact the NSM has on the DGs in the near and far future by performing long term simulations. And secondly, to use it as an online application in order to find the best solution in case of insecure network states and to suggest it to the network operator. For both cases the methodology is slightly different.

A. Long Term Simulations

To determine the impact of the NSM on the DGs, long term simulations have to be performed. The results of these long term simulations are the network security level indices $E(n_{NSM})$ and $E(d_{NSM})$. Because insecure network situations are very rare in power systems, a very long time (several hundred years) has to be simulated to reach statistical convergence of the indices. For this reason the authors have developed stochastic models to simulate [2], [3] the behaviour in time of loads, wind generators and PV generators and to generate synthetic time series for any number of years. These normalized time series are then scaled up for each node in the network. They serve as input for the power network simulation.

The NSM tool then is observing the operation parameters and, in case of a violation, it reacts using the algorithm defined before. This algorithm should include both the way of recognition of and the way of reaction to a network violation. In this paper the recognition of parameter violations is simulated by the exceeding of certain boundary values. The reaction of the NSM is, until now, simulated by the "solidarity principle" as described above.

The aforementioned network security level indices are defined by the expectancy values of the yearly number of NSM cases $E(n_{NSM})$ and their average duration $E(d_{NSM})$. For the number of NSM cases only the activation of one consisting limitation counts. This means, after the DGs are limited once and this limitation lasts without interruption for a certain period of time, it counts only as one NSM case. The calculation of the indices is done as shown in (1)-(4).

$$E(n_{NSM}) = \frac{1}{m} \cdot \sum_{y=1}^{m} \sum_{t=0}^{a/\Delta t} k_n(t) \tag{1}$$

with

$$k_n(t) = \begin{cases} 1 & \text{if NSM state changes from not-active to active} \\ 0 & \text{else} \end{cases} \tag{2}$$

and

$$E(d_{NSM}) = \frac{\sum_{y=1}^{m} \sum_{t=0}^{a/\Delta t} k_d(t) \cdot \Delta t}{\sum_{y=1}^{m} n_{NSM}^{m}} \tag{3}$$

with

$$k_d(t) = \begin{cases} 1 & \text{if NSM is active} \\ 0 & \text{else} \end{cases} \tag{4}$$

In this formulas $k_n(t)$ indicates only the changes from no limitations to any limitations, whereas $k_d(t)$ indicates all time steps where limitations are active. Δt presents the chosen time step (here 15 minutes) and a stands for one year. In order to reach high confidence of the results, m years are simulated.

Generally these indices can reflect three cases:

- both indices values are high – undesired security level,
- both indices values are low – acceptable security level,
- one value is high and one is low – undesired security level.

Therefore, to get a quantitative information about the security level, both indices can be multiplied. This provides the expected absolute duration the NSM is activated during one year.

B. Short Term Simulations

In short term simulations the main target is to find an optimal reaction of the NSM system to the current network situation. The input for the power system simulator is the current network state and the prediction for the near future (15 min to 24 hours) of the load and generation behaviour. The NSM tool observes the operation parameters calculated with the current and predicted situation. In case of a violation, the NSM tool proofs a list of possible remedial measures to successfully remove the parameter violation. If the measure is successful, it can be proposed to the network operator. The list of remedial measures can contain the limiting of the power injections of DGs as well as demand response plans or network topology changes [6].

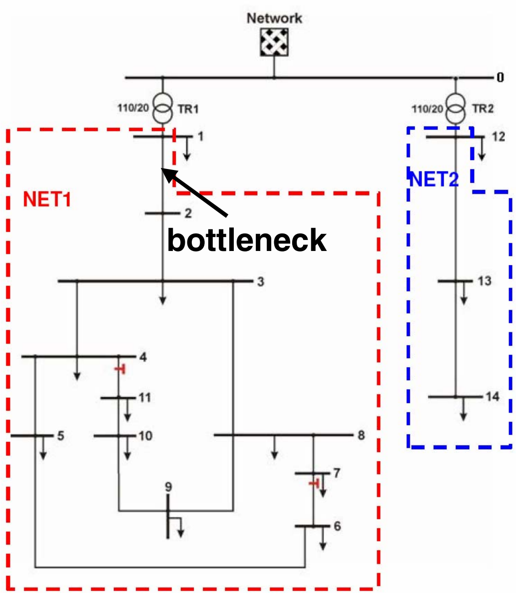

Fig. 1. Topology of the CIGRE benchmark network.

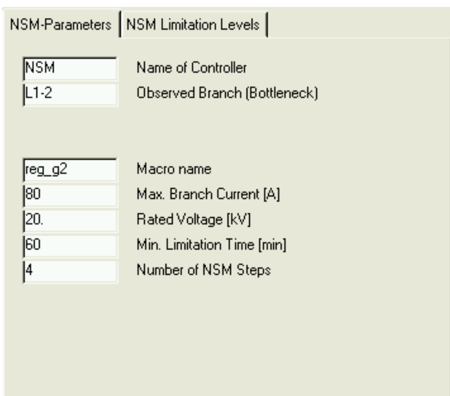

Fig. 2. Parameter mask of the NSM - Tool in NETDRAW.

IV. Study Case

For the study case the CIGRE distribution benchmark was chosen (see Fig. 1) [4]. This network is a 20kV distribution network. In this paper the long term simulations with the NSM tool are going to be represented. The input time series are generated with the stochastic processes as described in [3]. The installed DG power was set to a level where parameter violations become possible. In numbers: the generation power

was set in three steps from 250% to 300% of the maximum demand in this network. The bottleneck is, as indicated, the line between node 1 and node 2. The maximum thermal current $I_{1\text{-}2\ max}$ on this line is 80 Ampere.

The NSM tool now has to be configured as shown in Fig. 2. Any number of bottlenecks can be considered. In the following the simulation has to be started and the NSM tool will react in cases of exceeding the thermal current of line 1-2. After each simulated year the network security level indices are given and after these indices converge statistically the expectancy values can be calculated.

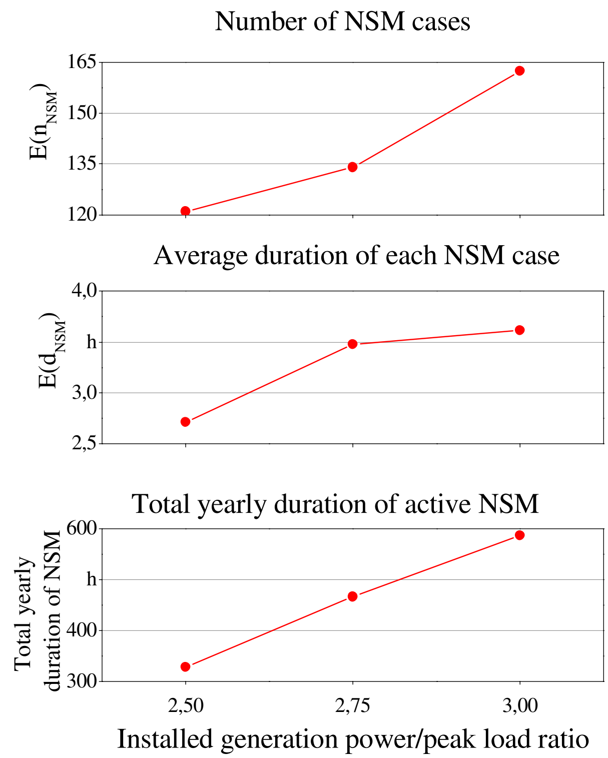

Fig. 3. Results of long term simulations with three scenarios, 250%, 275% and 300% DG power in relation to the maximum load.

V. Results of the Long Term Simulations

In Fig. 3 the results are presented. The diagram a) shows the expectancy value of the yearly frequency of NSM cases and diagram b) shows the average duration of those NSM cases. The multiplication of both values represents the total amount of time the NSM had to be activated during one year (diagram c)), it represents the impact of the NSM system on the DGs in quantity. As expected the NSM intensity increases when the installed power of DG generators is increasing.

The results can be used for decisions concerning either investment in the network (network extensions), or for profitability questions in DG installation planning. In this case, at 300% installed DG power the total yearly NSM duration lies at about 600 hours (Fig. 3 c)). For a CHP with 6000 full load hours and the opportunity to store the primary energy, this would be 10%. A wind generator that has 1500 to 2000 full load hours and no opportunity to store the wind energy, 600 hours refer to 30 – 40%.

In Fig. 4 the resulting time curves from applying the NSM tool to the study case with DG power of 300% of the maximum power demand are presented. As one can see, NSM cases are occurring, when the load demand (diagram c)) is very low and, at the same time, the available DG power (diagram d)) is between 70 and 80% of its maximum.

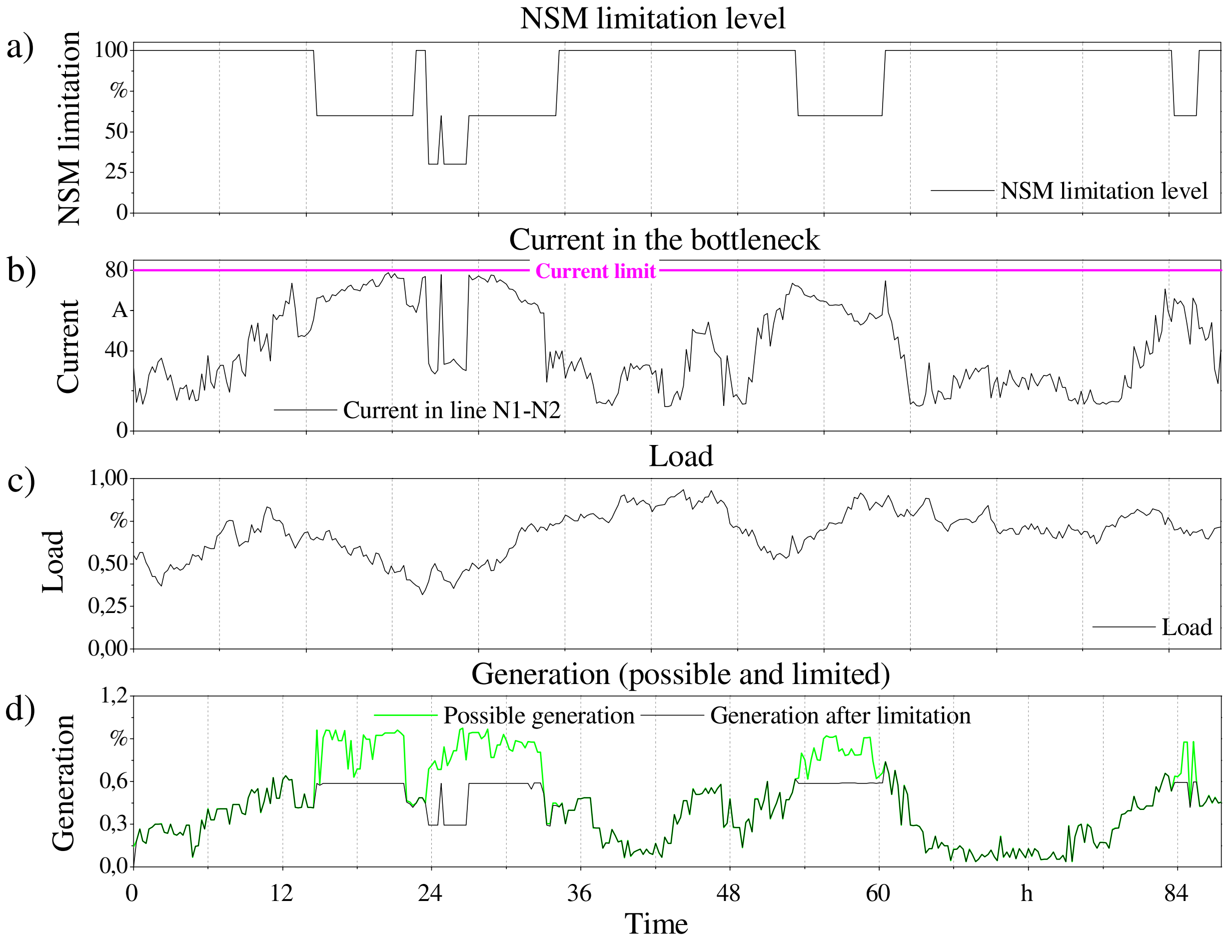

Fig. 4. Results from the NSM – Tool over 3.5 days.

The NSM tool limits the generation power successfully, so the current limit is not exceeded (diagram b)). If desired, also the "green energy" that is "lost" can be calculated by subtracting the surfaces under the "Possible generation" curve and the "Generation after limitation" curve in plot d) of Fig. 4.

VI. Discussion

The integration of an NSM algorithm into a power system simulator has been found very reasonable. It makes it possible to observe all operation parameters that are located anywhere in the network. Through the execution of the algorithms during the load flow, the real behavior of existing and new algorithms and NSM procedures can be analyzed. The long term simulations using synthetic input data makes it possible to obtain the long time performance of new algorithms and to determine the influence of the NSM on the DGs. The short term application of the NSM tool gives the network operator the opportunity to test several remedial measures before making the decision which one to use. In the future the NSM tool should be included in other online network security applications, because applying the NSM to a network in emergency state can change the situation significantly.

VII. Acknowledgement

The presented methods and tools in this paper were developed partially with a financial support of the Local Government of Saxonia Anhalt, Germany and local power utilities EnviaN and E.ON Avacon. The authors would like to express their special thanks to Dr. Hans Roman and Mr. Lutz Schulze for the many discussions and support for this work.

VIII. References

[1] *Funktionsbeschreibung zum Netzsicherheitsmanagement (NSM) der envia Verteilnetz GmbH (envia NETZ)*, www.enviam.de/dokumente-/pdf/funktionsbeschreibung_nsm.pdf, 2006

[2] Heyde C.O., Styczynski Z.A., Rudion K., Ruhle O.; *Stochastic Computation of Power System Security Level*, PowerTech 2007, Lausanne, 2007.

[3] Heyde C.O., Styczynski Z.A.; *Calculation of Network Security Management (NSM) Intensity in the Distribution System*, CIRED, Vienna, 2007.

[4] Styczynski Z. A., Orths A., Rudion K., Lebioda A., Ruhle O.; *Benchmark for an electric distribution system with dispersed energy resources*, IEEE/PES Transmission and Distribution Conference & Exhibition May 21 - 24, Dallas, USA, 2006,.

[5] Roman H., Dorendorf S.; *Integration of Wind Power Into Distribution Networks*, CIRED, Vienna, 2007.

[6] Brauner G., Poppl G., Einfalt A., Tiefgraber D.; *Balancing of Fluctuating Regenerative Generation by DSM*, CIRED, Vienna, 2007.

[7] Hawkins D.L., Blatchford J., Makarov Y.V., *Wind Integration Issues and Solutions in California*, IEEE Power Engineering Society General Meeting, Tampa, USA, 2007.

IX. Bibliographies

Chris O. Heyde studied electrical engineering at the Otto-von-Guericke University Magdeburg, Germany. He graduated in 2005 at the same University with the degree Dipl.-Ing.. He joint the Chair of Electric Power Networks and Renewable Energy Sources at the Otto-von-Guericke Univerity Magdeburg, Germany as a research engineer in 2005. His primary field of interest is network security.

Zbigniew Antoni Styczynski (SM ‘01) served from 1973 until 1991 at the Technical University of Wroclaw. From 1991 until 1999 he worked at the Technical University of Stuttgart, Germany. In 1999 he became the Professor and the Chair of Electric Power Networks and Renewable Energy Sources at the Otto-von-Guericke University, Magdeburg, Germany. From 2002 until 2006 he was the dean of the EE Faculty and since 2006 he is the president of the Centre of the Renewable Energy Saxonia Anhalt, Germany. He is author of more than 150 scientific papers, senior member of IEEE PES, member of CIGRE SC C6, VDE ETG und IBN and fellow of the Conrad Adenauer Foundation.

Bernd Michael Buchholz graduated in electrical engineering and received his Ph.D from MEI, Moscow. From 2000 until 2006 he was the director of the business unit “Power Technologies” in the “Service” division of the Power Transmission and Distribution group in Erlangen. Between 1995 and 2000 he worked as editor for the parts 4 and 7 of IEC 61850. He is author of many papers and member of many organizations e.g. the German member of the SC C6 of CIGRE “Dispersed generation in distribution systems”, member of the Advisary Bord of Technology Platform Smart Grid of the European Commission.

Olaf Ruhle graduated in electrical engineering at the Technical University of Berlin, Germany, and received his Ph.D there in 1994. In 1993 he joined the Power Transmission and Distribution Group of the Siemens AG, Erlangen, Germany where he is currently a senior researcher and head of the PSS™NETOMAC group. His special field of interests include power system stability, dynamics of mulitimachine systems, control, optimisation and identification problems in electric power systems.