Active Distribution Network – Demonstration Project ADINE

O. Samuelsson, S. Repo, R. Jessler, J. Aho, M. Kärenlampi, A. Malmquist

Abstract—Since Distributed Generation (DG) often involves renewable energy, it is important to facilitate integration of DG into existing networks. This is the aim of the EU FP6 demonstration project ADINE. It is based on the Active Network Management (ANM) concept, where automation, ICT and power electronics are used to integrate more DG by exploiting active resources instead of just reinforcing the network. The resources are mobilized through ancillary services or requirements. Five enabling solutions within ANM are pushed forward in the project: Protection relay and fault location applications, coordinated protection planning, voltage control with microturbine, centralized voltage control with SCADA/DMS and a new STATCOM. All these are demonstrated in real-life. Finally the performance of each technical solution during conditions with large amounts of DG are analyzed using a real-time simulation environment with RTDS/dSPACE. Introducing appropriate parts of the ANM concept will permit connection of more DG in distribution networks.

Index Terms—Distributed Generation, voltage control, STATCOM, relay protection, loss of mains.

I. INTRODUCTION

The traditional passive network management or “fit and forget” principle for connection of Distributed Generation (DG) has little future compared to Active Network Management (ANM). With proper management of DG and other active resources the overall system performance may be improved from presently used practices. DG provides a good potential as a controllable resource for the active network. Other existing controllable resources are direct load control, reactive power compensation and demand side management.

ANM adds value by increasing the potential for renewable energy, by improving efficient utilization of distribution network assets and by supporting distribution network by ancillary services from customer-owned resources.

The aim of ANM is to add more flexibility for network management in order to utilize existing network assets more efficiently. The addition of flexibility comes from the utilization of active resources through grid code requirements or ancillary services. Active resources are needed for integration as a part of the distribution system instead of just connection to it. Active resources are typically utilized in extreme network conditions e.g. when the network is not capable of transferring produced wind power.

The distribution network management concept can be based on existing systems like SCADA, Distribution Management System (DMS), substation and distribution automation and Advanced Metering Infrastructure (AMI). The ANM system operates on protection, decentralized control and area control levels. The intelligence of ANM is based on investments in controllability and ICT. Area control level may e.g. be used to coordinate individual resources and thereby increase the synergistic benefits of network management. An example of ANM concept is presented in Fig. 1.

To implement the ANM concept a collection of partial ANM solutions are needed. These bring new features for protection system and automatic control system levels. New protection system features are e.g. distance and differential protection schemes, and communication based Loss-of-Mains protection. At the decentralized control system level the ANM concept includes local voltage, power quality and frequency control, load shedding and production curtailment. Many new features are also added for the area control level: coordinated voltage control, power flow management, fault location schemes, automatic network restoration and island operation.

ADINE (Active Distribution Network) is an EU FP6 demonstration project. Its key idea apart from presenting a number of partial ANM solutions is to also demonstrate these in real-life and to analyze their performance with much DG in a real-time simulation environment. This paper reports on the status of the ADINE project about half a year before its ending. In the next section, the brief facts about the project are given and after that the work is outlined under the headings Protection, Voltage control and STATCOM. Finally the interaction simulations are described where the different solutions are tested in a model power system with amount of DG are described.
II. ADINE PROJECT

ADINE is an EU project financed under FP6, Priority 6.1 Sustainable Energy Systems as a Specific Targeted Research Project (STREP). The total budget is 3.2 MEUR with 2.1 MEUR community funding. The project runs from October 2007 to November 2010.

A. Partners

The partners forming the ADINE consortium are: Hermia LTD (coordinator), ABB Ltd Distribution Automation, AREVA T&D Ltd, Compower AB, Lund University and Tampere University of Technology.

B. Demonstrations

The real-life demonstrations of ANM solutions form an important part of the project. The three feeders in Fig. 1 correspond to the three demonstration activities (left to right):

- ABB and Tampere University of Technology carry out field tests to demonstrate coordinated voltage control and new protection solutions. The demonstration makes use of new IED-s and new versions of DMS software.
- Compower and Lund University demonstrate how a microturbine can be used to improve voltage quality.
- AREVA operates a STATCOM to demonstrate improvement of power quality and fault ride through capability of a wind farm.

III. PROTECTION

The work on protection in ADINE includes distance, line differential and anti-islanding protection and management of protection settings. In the following anti-islanding protection and management of protection settings are described.

A. Anti-Islanding Protection

Unintentional islanding is not allowed in distribution networks due to a number of reasons: Safety hazards for repair crews, potential risks of components being damaged and unintentional islanding can cause autoreclosing failures. Because of these reasons, it is obligatory that all DG units are equipped with a Loss-of-Mains (LOM) relay which ensures that unintentional islanding does not occur.

The most utilized LOM detection methods fail to detect islanding when the production matches closely with the consumption in the islanded zone. This blind area is called the
non detection zone (NDZ). The size of the NDZ can be reduced by tightening the LOM relay settings but it may cause unwanted tripping. Stricter settings are also problematic in the sense that DG should support the power system during voltage dips (Fault ride through (FRT) requirements).

Many protection studies including real protection relays have been carried out with the help of a real time digital simulator (RTDS) in the ADINE project. An example of simulation results is shown in Fig. 2 where the NDZ of real LOM protection relay was tested. The figure illustrates the functioning of LOM protection when ROCOF function is included. Blue (0.7 s delay) and pink (3 s delay) colors represents the area where LOM relay has operated, i.e. NDZ is located in the middle. Only the surroundings of the origin are depicted in the figure, because larger active- and reactive power imbalances (difference between load and generation at island) are not interesting from the NDZ point of view. The more voltage dependent the loads are the more the NDZ twists towards clockwise direction. Detailed simulation results may be found in [1].

The ADINE project has also demonstrated substantial benefits in generator protection using fast communication between IEDs. The communication uses both standard IEC 61850 GOOSE messages and user definable signals using Binary Signal Transfer (BST) that RED 615 IED offers. A high bandwidth optical link transfers information between the line ends in digital format. The total signal transfer time delay has been below 30 ms using two REF 615 and two RED 615 IEDs (BST between 2 RED 615 IEDs < 5 ms). Two basic advantages of fast communication based LOM protection scheme are:

- Fast tripping of generator when the fault is in the generator feeder or on the substation.
- Securing FRT when the fault is on the other feeders.

![Fig. 3 Fast communication based LOM protection scheme.](image)

Fig. 3 shows the proposed LOM protection scheme. A fault in location Fault 1 causes a voltage dip. IED of CB1 trips and sends block as a goose message to IED of CB2. IED of CB2 sends the message via BST to IED of CB3. IED of CB3 sends the block message to LOM IED as a goose message. The fast communication and block message improves the selectivity of the protection system without sacrificing the FRT requirement of the DG unit because the DG unit will not be disconnected due to voltage dip. Also a local LOM protection relay may be utilized as a backup relay for communication based protection scheme.

In case of Fault 2 overcurrent protection in IED of CB2 trips and sends a command using BST to IED of CB3. This IED sends a trip message to the LOM IED. In this way the DG unit will be disconnected without unnecessary delay.

### B. Protection Management

The presence of DG will affect the fault currents flowing in the network. In the worst case fault currents measured by the relay are reduced so that fault detection is disturbed. On the other hand, the DG unit or even the whole DG feeder may become disconnected during a fault elsewhere in the network.

Typically network planning is made by using network information systems (NIS) or similar systems. Possibility of studying the DG impacts with the same planning tools is widely anticipated among network operators. As the normal NIS fault calculation is based on a steady-state approach and rms values, the dynamic behavior of DG unit is difficult to model. However, as the present calculation has proved to be reliable and to offer suitable information for planning purposes, it has been assumed that basic calculation should not be modified.

Instead, the fault calculation is repeated in time steps between which the generator values are modified. This
enables more accurate studies on relay operation times. Wrong operation sequences can be found with suitable analysis.

The core of the developed method is the protection planning procedure [2], which performs the necessary studies automatically in the correct sequence. The process goes through network faults point by point and saves results for further analysis. This calculation is iterated with time steps. The time step approach enables also studying different generator types. As a result, the impact of new DG unit on system protection can be studied. Incorrect operation on certain fault locations is reported and modifications can be made according to the results. The developed planning method has been implemented in NIS during the ADINE project.

IV. VOLTAGE CONTROL

Impact of DG on voltage is an issue both on low voltage level and medium voltage level, but with very different conditions. The work on voltage control in ADINE has one activity dedicated to the low voltage level and one related to the medium voltage level.

A. Voltage Control with Microturbine

The active power from DG units affects voltage, which is one of the factors limiting the amount of DG. While reactive output of large power plants is used to control voltage, it is normally required to be zero for DG units. The very small rated power of DG units and the resistive character of low voltage cables also strongly limit the impact of reactive power on voltage at LV level. A DG unit at LV level can therefore hardly control voltage.

But connecting the unit through a series inductance as depicted in Fig. 4 gives a connection point at the microturbine terminals where voltage can be regulated. This provides improved voltage quality for loads of limited rating. The solution effectively rejects both voltage dips caused by switching of local loads and disturbances originating in the feeding network. Network strength and impedance character are not critical.

In the ADINE project, a Compower microturbine prototype rated 5 kW has been equipped for voltage control. The commercial single-phase power electronic converter is replaced by a three-phase prototype connected to the network through 7 mH inductances. The converter is controlled using a standard vector control scheme with a voltage controller setpoint equal to nominal network voltage.

The power electronic converter of the microturbine has been modeled in Matlab and in RTDS/dSPACE together with its controllers. The simulated events include disturbances originating both on the LV and MV levels. Examples of the former are starting of motors in the low voltage network, while capacitor switching belongs to the latter type. The simulations indicate that the control scheme eliminates steady state voltage deviations. Also at transients voltage deviations are efficiently reduced. More details are found in [3].

Fig. 4 Connection to LV network through decoupling inductance

Fig. 5 Measured response to direct starting of 0.37 kW three-phase asynchronous motor.

The microturbine field test site in Kristianstad has easy access to biogas, but has a very strong network connection point. To emulate a more remote site, 100 m of low voltage cable is inserted which yields a weaker connection point. This resistance has also been included in the simulation model. Starting of a 0.37 kW motor on the weak side of the added resistance causes a clear voltage dip. As shown in Fig. 5 this is well suppressed at the protected point, which indicates that the control scheme is both feasible and efficient.

B. Co-ordinated Voltage Control

Connections of DG to weak MV distribution networks often experience voltage rise problems. The voltage rise can be mitigated using passive methods such as increasing the conductor size but this can be quite expensive. Network maximum voltage can be reduced also using active voltage control methods (e.g. reducing substation voltage) which in some cases can reduce DG connection costs substantially [4].

In coordinated voltage level management the operation of individual devices participating in network voltage control is coordinated by a centralized voltage controller that consists of a state estimator and a coordinated voltage control algorithm. The centralized controller determines set points for the lower level controllers and sends these to the local voltage controllers through SCADA system.

The coordinated voltage control algorithm developed in ADINE project controls the substation voltage and the reactive power of DG based on the state of the whole network [5]. The control algorithm comprises two functions: Basic control is used to restore the network voltages to an acceptable level when voltage rise or drop at some network node becomes excessive. Restoring control restores the DG’s power factor set point to unity when the network state allows it and normalizes the voltages when the voltage level of the whole network has remained unusually high or low.
The inputs to the coordinated voltage control algorithm are network maximum and minimum voltages, substation voltage and generator connection point voltage. The network voltages are estimated using network information obtained from the DMS, load information obtained from the load curves and measurements obtained from the SCADA.

The developed control method was implemented in Matlab and connection to SCADA was realized through OPC server. The field demonstration was organized in Koillis-Satakunnan Sähkö Oy (Finnish distribution network company) where setting values of automatic voltage control (AVC) relay of online tap changer at 110/20 kV substation and automatic voltage controller of DG unit at the end of one feeder were controlled. In the demonstration, the control is realized only as an advisory tool and the operator executes the suggested control actions. RTDS simulations use a closed-loop system.

Fig. 6 represents real-life measurement results of the proposed algorithm when DG reactive power is primarily controlled in coordinated voltage control. At the beginning of the test, the DG real power was set to 100 kW, AVC relay set point was 1.03 pu, substation voltage 1.03 pu and tap at position 4. The results represented in Fig. 6 start from the point where DG real power has been raised to 500 kW. At this time the estimated network maximum voltage exceeds its limit and basic reactive power control decreases DG power factor to 0.98 which is its minimum value. This change is not, however, adequate to restore the maximum voltage below its limit and, therefore, also substation voltage control is activated and the tap changer operates at approximately 300 seconds. When DG output power is lowered to 200 kW, the network maximum voltage is lowered enough to enable restoring reactive power control. The restoring power factor control restores DG’s power factor to unity and restoring substation voltage control initiates a tap changer operation to increase the voltage level in the network.

Based on the simulation and demonstration results it can be stated that the coordinated voltage control algorithm defined in this project is able to increase the maximum allowable penetration of DG in an existing distribution network. The algorithm is quite simple and can be easily implemented, for instance, as a part of the DMS. In the Finnish DMS, state estimation is already available and, therefore, only the coordinated control algorithm needs to be added.

V. STATCOM

A STATCOM in a distribution network with a high level of DG helps to increase the efficiency and power quality in the distribution network by:

- compensating harmonics and reactive power,
- eliminating negative sequence currents,
- reducing voltage flicker,
- stabilizing the voltage level,
- improving the network recovery during line fault.
For these applications both large steady-state operating range and fast transient response are important. The advantage of a STATCOM over the conventional SVC is the extensive operative range. For comparison, the voltage-current characteristics of (a) SVC and (b) STATCOM are shown in Fig. 7. The maximum capacitive current of the SVC is limited by the reactance of fixed capacitor when the system voltage decreases. As the result, the voltage support capacity of the SVC impairs with the decreasing system voltage.

On the contrary, the STATCOM is able to provide full capacitive current independently of the system voltage, almost down to zero. A further advantage is the increased transient rating in capacitive operation region, which is in the SVC again limited by the fixed capacitor value. As the result, a STATCOM provides a superior capability for compensating dynamic power system disturbances.

The voltage source converter technology with high switching frequency thus makes the STATCOM superior to an SVC in both the transient and the steady state operating regime. The three-level converter topology with IGBT-s used in ADINE further improves the performance regarding harmonics.

For the validation of the theoretical results, gathered during extensive simulations with Matlab/Simulink and RTDS, a STATCOM demonstrator for a windfarm application in the Republic of Ireland is designed. It is placed in the substation of Dunneill wind farm in the northwest of the Republic of Ireland, see Fig. 8.

The ±6Mvar STATCOM demonstrator must ensure that the overall wind farm is fully compliant with the Grid Code of the TSO EirGrid. More specifically it has to support the voltage of the entire network at 21kV-level, eliminate fast voltage variations and enhance the voltage ride through capability of the wind farm. The commissioning of the STATCOM is planned in the fourth quarter of 2010.

The focus in ADINE is on the development of a novel STATCOM controller consisting of a Master Controller and 1…n parallel Power Modules. The control is based on local measurement at the substation and remote measurements from PCC via SCADA connection. The master controller of the unit is communicating with the user interface (HMI) to receive control commands and to send status information.

VI. INTERACTION SIMULATIONS
In addition to demonstrating the ANM solutions one by one in pilot installations, they are brought together with large amount of DG in a real-time simulation environment.

A. Simulation Environment
The real-time-digital-simulator (RTDS) shown in Fig. 9 was used for performing the simulation studies of ADINE project. The simulator performs the network calculations and communications between external devices in real time which enables the interaction studies of real physical devices and modeled power systems. The idea in the real time simulations of ADINE project was to test the functioning of real commercial IEDs and controllers in the presence of DG and examine whether the protection is or is not affected by DG or how the control should be done in order to improve distribution network operation. Also SCADA was connected as a part of real time simulation environment in order to simulate developed software applications. The hardware in the loop simulations extends the product development between prototype and field tests. Also versatile tests compared to field tests may be done especially all kind of fault conditions may be tested.
The combination of the power system simulator RTDS and the control system simulator dSPACE provides excellent environment for wind turbine and network interactions studies. The purpose of the combined simulation environment is to study the interactions between power system and power electronics more precisely. The simulation environment used makes it possible to develop control strategies for wind turbines to qualify more demanding grid codes in the future. Minimization of simulation time is additional benefit.

In the simulations analog signals have been used between the systems. The systems form a closed loop including system calculation blocks and A/D- and D/A-converters thus significant delays can be expected. The reduction of delay can be done for instance by synchronizing the systems with additional signal or by compensating the delay with phase shift methods.

### B. Simulations of fault ride through and LOM

The penetration of wind generation has increased in many areas to a significant level. In such areas, modern wind turbines are required to be able to endure deep voltage dips. Otherwise, major problems to the power systems stability would occur. In addition to staying connected during the fault, modern wind turbines should be able to support the grid voltage during the voltage dip by injecting reactive power.

FRT requirements are mainly meant for high voltage connected wind farms, but it is likely that similar kinds of requirements will be issued for medium voltage connected units in the future as well especially in areas of high wind power penetration level. If medium voltage connected wind turbines shall have to comply with FRT requirements, attention has to be paid not only to the design of the wind turbines but also to the compliance of the LOM protection with the requirements. Fulfilling the FRT requirements by loosening the protection settings of passive LOM extends the size of NDZ. The realization of the FRT capability thus increases the risk of unintended islanding not only because of the necessity of loosening the LOM protection settings but also because a DG unit that has FRT capability is more capable of maintaining power islands. In this sense, LOM protection settings are a compromise of some kind between enabling FRT and avoiding unintended islanding [6].

The two most common variable speed wind turbine types are the doubly-fed induction generator (DFIG) wind turbine and wind turbine with full-power converter interface to the grid. FRT capability of both wind turbine concepts presented above is assessed together with LOM protection. In addition, the different methods for achieving the FRT capability are compared and analyzed. The simulation results show that the full-power converter wind turbine concept has much more stable performance during network fault compared to DFIG concept. However, the FRT of DFIG concept can be enhanced by reasonable converter control during the fault.

### C. Simulations of fast autoreclosing and LOM

The functioning of fast autoreclosing (AR) on feeders including DG is often mentioned as one of the main concerns related to DG. AR has a significant importance for the reliability of electricity supply since the majority of faults on overhead distribution lines are temporary and AR helps restoring electricity supply. The situation is, however, becoming more difficult as DG is connected along distribution lines. This stems from the fact that DG can sustain the voltages during the open time of the circuit breaker performing the AR thus causing the AR to fail. It is, therefore, crucial that all DG units on the tripped feeder are disconnected before the reclosing attempt. The disconnection is meant to be taken care by the LOM protection.

RTDS simulations with feeder and LOM protection relays where performed to study how different kinds of protection settings influence the successfullness of AR. The results indicated that the success rate of AR is strongly dependent on the chosen protection settings and from the prevailing imbalance between production and consumption [7].

The simulations indicated that success of AR as in Fig. 10 can be reached with relatively simple LOM protection provided that strict LOM relay settings are used. Strict LOM relay settings, however, have the disadvantage that they make the protected DG unit prone to nuisance tripping which is unwanted both from the network and the DG unit point of view. Nuisance tripping of DG can also be risky for the system stability in certain areas where DG penetration is high. The simulation results also indicated that under voltage (UV) function of LOM protection has a very significant role in ensuring a high success rate of ARs. The utilization of strict UV thresholds may, however, not be allowed in the future if DG units are needed to contribute to system stability – that is, if the FRT requirements are diffusing to MV level as well. The utilization of strict UV limits is clearly conflicting with the FRT requirements which demand that generation units are able to ride trough deep voltage dips without losing their stability.
Another option for improving the success rate of ARs is prolongation of AR open times. This option is unfortunately also unwanted since this measure has a degrading effect on power quality. The problems with AR and unintentional islanding could, of course, be tackled by equipping all DG units with a LOM protection technology that is not prone to the NDZ problem. Communication based LOM protection methods are one of such solutions but they generally require some additional capital compared to passive and active detection methods.

VII. CONCLUSIONS

The ADINE project demonstrates in real-life several technical solutions that make integration of DG easier. The issues dealt with are protection, protection settings management, voltage control at low and medium voltage level, power quality, fault ride through and anti-islanding. The solutions are based on power electronics, automation and computer systems and help to optimize the use of the existing network.

The solutions developed in the project may be used on their own or together. The real-time simulations demonstrate how the technical solutions interact with a power system with much DG. They also illustrate how some technical issues are closely related such as loss-of-main protection and fault ride through.

Several of the ADINE solutions are near being commercially available and the project has helped bringing prototypes of the solutions closer to the market.

VIII. ACKNOWLEDGMENT

The demonstrations have been made possible thanks to C4 Energi (biogas-fired microturbine), Koillis Satakunnan Sähkö (co-ordinated voltage control), Airtricity (STATCOM).

IX. REFERENCES