# ADINE – EU DEMONSTRATION PROJECT OF ACTIVE DISTRIBUTION NETWORK

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## *ABSTRACT*

*The aim of ADINE project is to develop and to demonstrate new methods for the electric distribution network management including distributed generation (DG). The active network management (ANM) method needs enabling solutions such as protection, voltage and reactive power control and planning and information systems of networks. The actual devices and monitored data from the real-life demonstrations are taken into a combined real-time simulation environment in order to study the interaction of the demonstrations. The paper describes shortly the objectives and tasks of ADINE project. It includes a description of active distribution network and the ANM method to be developed. The combined real-time simulation environment and the way of utilising it at the development of the ANM method are also described.*

## INTRODUCTION

The vision of smart grid is still shaping up and a lot of research and development work has to be done to reach this goal. At the moment many proposals and some real examples are presented from different perspectives. The concepts of smart grid are e.g. Active network, IntelliGrid, Power cells, Virtual power plant and Microgrid.

### Drivers of active network

The increment of distributed generation (DG) based on renewable energy sources is the main driver for the development of active distribution network at the moment. DG provides also 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. Although the increasing amount of DG brings the complexity of transmission network to distribution network level, the integration of DG in distribution network will benefit the network when managed appropriately. The traditional passive network management or "fit & forget" principle in DG connection needs to be changed into active network management (ANM).

The regulation of network monopolies is realised in many cases by the regulation of network profit which may also be affected by power quality. That kind of regulation encourages companies for efficient utilisation of network assets without sacrificing the reliability of power supply. Also customers´ expectations for extreme reliability and quality of power are increasing simultaneously with an aging network infrastructure. It is time to reconsider traditional network solutions in order to secure the efficiency, security and reliability of networks in the long run.

### Impacts of DG on distribution network

The production of electricity close to consumers will reduce the transfer of electricity. This will also affect network losses. Network losses may also increase when a large DG unit, e.g. wind farm, is located far from consumption.

However the intermittent (non-dispatchable, uncertain and uncontrolled) production in passive network does not benefit network rating. The worst case planning principle of DG interconnection in passive networks should be replaced with a statistical planning approach in active networks [1]. The intermittent production in weak rural distribution network may cause voltage rise problems. The increment of fault current level due to new DG units may cause major investments in urban networks if the rating of components is exceeded. In opposite case increasing fault level will be acceptable because it will improve customers' quality of supply by reducing the magnitude of voltage disturbances. The voltage control or reactive power capability of DG units could also be utilised in network management.

Requirements for the protection of distribution networks are changing considerably. Protection schemes designed for unidirectional power flow may become ineffective. Unnecessary tripping as well as undetected faults or delayed relay operations may occur due to high DG penetration. DG may also disturb automatic reclosing. The operating sequence of protection devices during a fault is thus important [2].

The current operational practice of distribution network requires disconnection of DG units when a fault occurs. This will keep the operational conditions simple and clear, safe and suitable for auto-reclosing. The purpose of DG unit connection point protection is to eliminate the feeding of fault arc from a DG unit and to prevent unintended island operation. When the penetration level of DG increases the consequences of immediate tripping of DG units may become adverse when short-circuit in transmission grid is seen by several DG units. Even during a fault at distribution network unnecessary disconnection of DG units may occur. The current operational practice clearly creates a contradiction between network safety and stability [3].

## ADINE PROJECT

The aim of the ADINE project [4] is to develop new management methods for the electric distribution network including DG. When the distribution network is managed according to the ANM method the interactions of different active network devices can be planned and controlled to benefit the operation and stability of the network. The new methods developed in the project maximise the use of existing electricity networks and reduce the need for installing new power lines without compromising reliability and safety. The project provides better understanding of the potential benefits and problems when different active devices are participating in the network management.

The extraordinary feature of the project is that it develops and demonstrates the ANM method and the enabling solutions simultaneously. Either one alone would not solve the problem described above. When active devices are interacting with each other according to the ANM method, the overall system operates better than it would by letting individual solutions interact randomly – which is the common practice today.

The ANM method needs enabling solutions such as protection, voltage and reactive power control and planning and information systems of networks. The project will develop and demonstrate:

1. Protection of distribution network including DG
   - Application of communication based relays at distribution network
   - Fault location with the influence of DG
   - Co-ordinated protection planning application on Network Information System (NIS) [2]
2. Voltage control of distribution network including DG
   - Droop control of small-scale micro-turbine.
   - Co-ordinated voltage control application on SCADA/DMS which is controlling the setting values of local voltage/reactive power controllers. [5]
3. New-generation medium voltage STATCOM
   - capable of filtering harmonics, eliminating flickers and compensating reactive power [6]
   - on top of above characteristics it can participate in mitigation of voltage dips and in controlling the voltage level of the distribution network.

The technical solutions are first tested individually in appropriate simulations and after that in real-life networks. Then the actual devices and monitored data from the demonstrations are taken into a combined real-time simulation environment to study the interactions of the demonstrations. The viability of the ANM method is demonstrated through these simulations including real-life devices and measurements. The final ANM method is defined according to findings and conclusions based on interaction simulations.

## ACTIVE DISTRIBUTION NETWORK

### Active network in general

The concept of active distribution network may be characterised by words like flexible, intelligent, integration and co-operation. The active network is flexible because it utilises controllable resources throughout the network. Respectively the passive network has flexibility by network capacity i.e. network itself may handle all probable loading conditions. Intelligence is simply investments in controllability and information and telecommunication technologies instead of passive wires. Active networks also require that DG units are integrated into the network instead of connecting them by the "fit&forget" principle. The co-operation of individual controllable resources will generate synergy benefits for the active network by higher level decision aid or management system.

DG-GRID project investigated on a very general level how much savings may be achieved by active networks in typical UK and Finnish distribution systems [7]. The cost of DG connection is obtained by calculating the cost of network reinforcement needed to mitigate the technical problems and the benefit of DG is determined by computing the reduction in distribution losses and the ability of DG to release network capacity which can be used to accommodate future loads. The benefit of active management for reducing network reinforcement costs is clear for UK networks and Finnish rural networks.

**Distribution issues**

The control of DG unit voltage instead of unity power factor requirement will help network development and operation in weak networks [1, 8]. This does not require new technical innovations but a new way of thinking. The co-ordination of voltage controllers will further improve the situation which however requires some additional measurements for state estimation purposes. Other consequences of voltage control are increased reactive power flow and network losses which may be influenced by the co-ordination of controllers.

In extreme network conditions power flow management (e.g. production curtailment or generation constraints) may also be applied due to limitations in network capability [1, 8]. The unfirm network capacity is much higher than firm capacity which enables to increase the amount of generation to be connected and operated under normal network conditions, but the generator will face up to constraints in extreme conditions. The probability of extreme conditions should be low enough in order to have economically attractive solution. If DG units are used as a means to increase the firm network capacity, active resources should be controlled almost in real-time to reduce power transfer at overloaded part of network.

Protection problems may be eliminated or alleviated for example by proper co-ordination of protection settings. The co-ordination of feeder protection relays will improve the selectivity of feeder protection. This may also be achieved for example by directional over-current protection, distance protection or by communication based protection schemes which may be applied in more critical conditions. In order to avoid unnecessary disconnections of DG units there should be proper co-ordination of network and DG unit protection. DG unit protection should be slow enough to let network protection clear faults in the supply network or in the adjacent feeders, and at the same time it should be fast enough to disconnect DG units on faulty feeder [2].

**System issues**

DG unit voltage and frequency relays must be set quite tight in order to detect unintended islands fast enough. From the system point of view this creates a remarkable risk for power system instability. When a DG unit has fault ride through (FRT) capability and it participates on frequency control, the settings of DG unit under-frequency and under-voltage relays must be loosen. This creates a safety risk which has to be solved by developing the relay protection schemes of distribution network without immediate need to disconnect DG unit in every fault situation. DG units should also withstand much greater variations in voltage and frequency without tripping of DG unit which would benefit the balancing and stability of power system and would make possible to utilise island operation at distribution network level [9].

The penetration of DG is forcing system operators to reconsider the contribution of DG units to system services as voltage control, reactive power support, FRT capability, frequency control, reserves, etc. [3] When the penetration level of intermittent power production increases additional disturbance (secondary) reserves and/or contribution of uncontrolled production units to participate on frequency control are needed [9, 10].

**Active network management**

The management of active network will at least in short-term perspective be based on SCADA/DMS and substation and feeder automation systems. The monitoring and telemetry of medium and low voltage networks are still very few although the number and characteristics of secondary substation monitoring devices and automatic meter reading (AMR) meters are increasing rapidly. The need of real-time information from the status of DG units and their production is becoming more important when the penetration level of DG is increasing or when a DG unit has strong local influence. The local intelligence at substation via processing and communication capability of intelligent electronic devices will also increase in the future.

The existing control hierarchy of distribution network includes three levels: protection system, automatic control system, and network reconfiguration. Typically ANM concepts add new features for protection system and automatic control system levels. New protection system features in distribution network are e.g. distance and line differential protection schemes. The ANM concept includes at automatic control system level local voltage and frequency control, load shedding and production curtailment features. ANM concepts may also add completely new hierarchical level called area control level. The area control level will be above the automatic control system level and it includes co-ordination of voltage controllers, power flow management, automatic network restoration and island operation.

Because the active resources have a central role in the ANM, there should be a solid mechanism to bring these resources available for a network company. The market based approach relies on ancillary services bought from an ancillary service market like the regulating power market or from a dedicated contract between the resource and the network company like reserve contracts today [11]. The idea of the grid code approach is to share the responsibilities needed in power system operation between the users of power system [12]. The application of local reactive power or voltage control service would be straightforward in distribution network. The power flow management service could be based on similar approach than the counter-trade principle to release transmission network bottlenecks inside a price area in Nordel [13]. The island operation would require many services like black start, frequency control, reserves and voltage control.

## Active network in ADINE

Figure 1 is visualising the control levels of distribution network and how the ANM method is affecting them. Protection relays are working on the lowest level like in passive networks, but new feeder protection schemes like directional over-current, distance and differential protection, and new fault location applications are introduced. Automatic voltage regulation (AVR) of DG unit and STATCOM controller are added to automatic control system level. Customer-owned active device will participate in distribution network management by interconnection requirement or by ancillary service contract. Demonstrations will show how the protection and voltage regulation in distribution networks can be improved through advanced protection schemes and decentralised control of DG units.

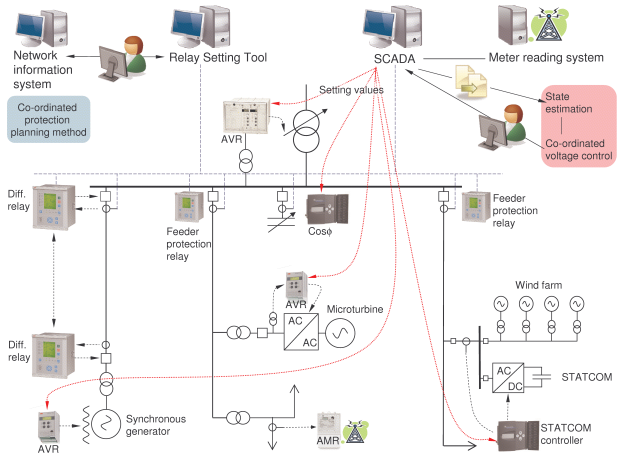


Figure1. Overview of the active distribution network in the ADINE project.

The area control level is used to co-ordinate the functioning of individual devices. This is done by sending new setting values through the Relay setting tool or SCADA system. Fault recordings offer valuable information for a protection setting planning. This information may be collected via the Relay setting tool and used as an input for a new protection setting task. The co-ordinated protection planning method will analyse and plan protection settings for protection relays based on information from NIS. Two of the key features of the method are a procedure for studying protection aspects in proper sequence, and a novel method for defining the protection requirements for a new DG unit in an unambiguous manner. The fault calculations of NIS as well as the modelling of generator units are developed to support these new functionalities [2].

Similarly the SCADA system may be used to co-ordinate the settings of voltage control devices. The results of state estimation based on SCADA and AMR data are inputs for the co-ordinated voltage control method which computes best possible setting values for voltage controllers. The co-ordinated voltage control method will be implemented in SCADA/DMS. Demonstrations will show how the voltage regulation in distribution networks can be improved through centralised control of OLTC, DG units and capacitors.

In the most basic version the co-ordination controller is adjusting the setting of AVR of OLTC. The basic co-ordination controller is based on control rules which have limits for normal and restoring control. Restoring limits are applied to increase voltage level after a DG unit disconnection when the voltage level in the whole network is low. The controller is also capable of preventing the hunting of OLTC by the defined rules to select the parameters of controller. The aim of the research is to continue the development of the co-ordinated controller to be able to manage cases where several and different kind of controllable resources are available. The studies will consider the functioning of controllers in normal, fault and disturbance situations [5].

## REAL-TIME SIMULATION ENVIRONMENT

### Combination of RTDS and dSPACE

The real-time simulation environment in Figure 2 combines the simulation environments of RTDS (real-time digital simulator for electricity network) and dSPACE (real-time digital simulator for power electronics). It includes also a library of simulation models of DG units and their control algorithms. RTDS/dSPACE is not a traditional simulation environment rather it is test bed for secondary devices of power system.

The electricity network can be modelled and simulated in transient level in RTDS side and developed applications in dSPACE side via Simulink interface. The uniqueness of the simulation environment is the combined operation of these two simulation environments. It provides a general simulation environment for any combination of devices and situations which are not possible to demonstrate in real network without special arrangements. The two simulators are combined in order to exploit the capabilities of both simulators for interaction studies of power system and power electronic devices. Minimisation of the simulation time and the possibility to distribute calculation power between two simulators can be considered as additional benefits.

The hardware environment of combined simulation environment has been developed in two previous national projects and the operation of it has been demonstrated with constant and variable speed wind turbine applications interconnected into a distribution network [14]. Wind turbine, generator, converter, line filter and wind turbine controller are modelled in dSPACE while rest of the power system is modelled in RTDS. The development of hardware environment will be continued in order to increase the accuracy of simulations and to minimise the delay between simulators.

### Utilisation of real-time simulation environment

The idea of real-time simulations is to combine demonstration site models together at appropriate level and to use hardware in loop in the simulations. The hardware includes protection relays, voltage controllers and STATCOM controller. These simulations are used to demonstrate the functioning of proposed ANM method. The results of interaction simulations based on ANM method are compared to traditional network management method.

The sensitivity and the selectivity of different protection schemes are studied in order to find out the influence of DG on network feeder protection. Another kind of study is the interaction between feeder re-closing and the DG unit connection point protection. The third type of interaction is the

co-ordination of feeder protection and the DG unit connection point protection, which is used to study the stability of DG unit when a fault occurs on the supply side or on an adjacent feeder.

The interactions between voltage controls are studied at automatic control system level and at area based control level. The interaction of fast local controllers may appear between parallel operated controllers (AVRs of synchronous machines, converter based DG units or STATCOM). There may also appear interaction (hunting) between slowly acting local controllers like AVR of OLTC and power factor controller of capacitor bank. The interaction of decentralised and centralised controllers in normal and in disturbance situations is describing the functioning of the area based control level. Voltage control schemes may also have influence on relay protection and fault location which are also studied.

The real-time simulations are utilised to find out how traditional and advanced network protection schemes are functioning when DG units have the FRT capability and the DG unit connection point protection settings are wide enough to withstand variations in frequency and voltage. Another type of interaction study related to power system stability is the voltage dip mitigation of STATCOM.

## CONCLUSIONS

The main idea of ADINE project is to develop and to demonstrate the interactions of the proposed ANM method and the functioning of enabling solutions like protection relays, fault location functions, de-centralised and centralised voltage controllers, and new generation medium-voltage STATCOM. Individual solutions are first simulated and field tested which is followed by real-time simulation of all solutions together.

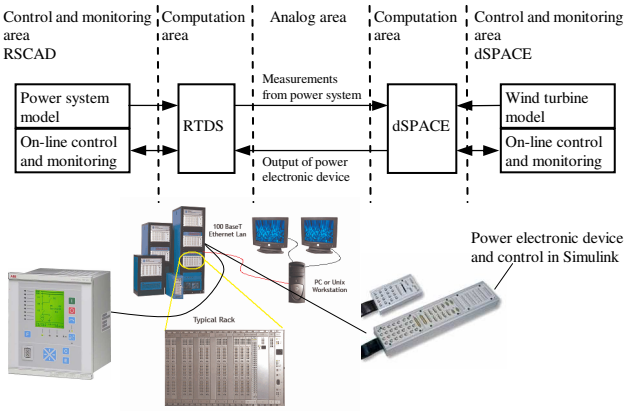


Figure 2. Combined simulation environment of RTDS and dSPACE.

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