INTEGRATION OF RENEWABLES INTO THE DISTRIBUTION GRID NEEDS NEW SOFTWARE TOOLS FOR COORDINATION OF PROTECTIVE RELAYS

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ABSTRACT

Traditional software tools developed for distribution system simulation and overcurrent protection coordination need to be revised to cope with the progressive integration of renewable distributed energy resources (DERs) in distribution grid to achieve better relay protection and coordination. Meanwhile, adoption of the microgrid concept results in certain problem for the protective relays using conventional techniques because of the downstream sources that can feed the fault and also the appreciable difference between the utility-grid connected mode and autonomous (islanded) mode. Traditional distribution grid protection is based on the overcurrent scheme with the flow of fault current from the upstream sources. However, the protection confronts with two main issues: firstly, the radial configuration of the distribution network is jeopardized by the distributed resources; and secondly the DERs have a stochastic nature and the contribution of fault current from the downstream is no longer a certain parameter that could be evaluated at the design stage. This paper analyzes the new requirements and strategies expected to be included in the traditional software tools in order to be applicable for the complex future distribution grids.

INTRODUCTION

Integration of small and medium size renewable distributed energy resources (DERs) into electric distribution networks is one of the most challenging issues that the power system are experiencing. Most modern DERs are interfaced with the utility-grid through power-electronic converters. The increasing proliferation of electronically coupled DERs, such as photovoltaic systems, micro gas turbines, wind power systems, and fuel cells has motivated the designation of sub-networks that embed DERs and loads with the capability of operating in deliberate and controlled ways; referred to as microgrids [1]. Microgrids are able to operate independently, as well as in conjunction with the rest of the distribution network with enhancing the continuity of service and offering superior power quality, higher reliability, and operational optimality [2].

Adoption of the microgrid concept results in certain problems for the protective relays using conventional techniques because of the downstream sources that can feed the fault and also the appreciable difference between the utility-grid connected mode and autonomous (islanded) mode. Traditional distribution grid protection is based on the overcurrent scheme with the flow of fault current from the upstream sources. Meanwhile the protection confronts with two main issues: firstly, the radial configuration of the distribution network is jeopardized by the distributed resources; and secondly the DERs have a stochastic nature and the contribution of fault current from the downstream is no longer a certain parameter that could be evaluated at the design stage [3]-[6].

Commercial off-the-shelf software tools have a deterministic nature and are developed for coordination of the overcurrent relays in a conventional distribution system. There are deficiencies in these software tools that make them unsuitable for future distribution grids with DERs. Some of these deficiencies can be listed as follows:

1) The traditional software tools are based on fault level at different distribution buses which is a relatively deterministic value and depends on the number of sub-transmission transformers in parallel, while the distribution grid with DERs has a wide range of fault level, depending on the status of the grid whether it is connected to the upstream utility grid or the loads are feed by the DERs and are disconnected from the upstream network. The fault current is uncertain and depends on the status of the energy of the DERs.
2) The traditional software tools have not the capability of including the sophisticated communication infrastructure that is progressively developing and can be best used to enhance the protective concepts of the distribution grid.
3) New protection concepts could be developed and enhanced if the new capabilities of the distribution grid would be considered. The salient feature of the future distribution grid is the communication infrastructure that provides easy access to the data from other relays and circuit breakers. These inherent potentials of the distribution grid are ignored in traditional software tools.
4) Traditional software tools can not accurately model the new generation of protective relays which would be extensively used in future smart grids. The new generations are numerical or microprocessor-based relays with the protective multi-function, user-programming, control, communication and remote access capabilities.
5) The high degree of penetration of DGs critically affects protection coordination by changing the fault current level and probable false tripping, protection blinding, undesirable network islanding and out-of-synchronism of reclosers. Therefore, new software tools need to overcome the overcurrent relay coordination problem for distribution systems with and without DGs.

This paper proposes remedial improvements and developing strategies to be included in the traditional software tools in order to cope with the comprehensive progress in the distribution grid to achieve better relay protection and coordination. As an example, a strategy for protection of LV microgrids in both modes of operation is proposed in [2] based on programmable microprocessor-based relays and directional elements. The paper presents the concept and structure of a new relay that aims to detect and isolate the faults impacting the microgrid in a coordinated manner. In order to show the effectiveness of the proposed strategy and relay so many blocks are used and developed to demonstrate the programmable relay in a conventional software environment. It is worth noting that most of the software tools are actually power system simulators and originally have simple level detectors as protective relays. The laborious task with the traditional software packages to analyze the new challenges in distribution systems could be alleviated by inserting new algorithms and models for the new generation of microprocessor-based relays. In this way, a microgrid could be very well modeled; meanwhile the proposed relays with/without communication links could be easily inserted in the simulation environment to validate their performance in real time. As another example, the possibility of stochastic modeling of the DERs in the microgrid could be adopted to evaluate the stochastic fault level necessary for relays' coordination. The main focus of the paper is on the proposals to enhance the traditional protective relaying software tools in order to be applicable for the complex future distribution grids.

NECESSITY OF MODELING NEW RELAYS IN FUTURE SOFTWARE TOOLS

High penetration of DERs in distribution grids and evolution of microgrids necessitates the application of new microprocessor-based relays with the capability of sending and receiving signals through communication links. The application of such protective relays is a sophisticated task that requires both hardware and software considerations. The algorithms should be developed based on the hardware capabilities. If the computation requirements are not fulfilled by the selected relays, the selection needs to be reevaluated. The common practice is selection of a type based on the preliminary evaluation of the computational requirements of the protection, control, monitoring, oscillography and communication tasks. Hence, there is a need for a simulation tool, which could simulate the relay both from the hardware and software point of view.

Well-known software packages can be used to simulate power system faults in both the time-domain and phasor modes. In these cases it is difficult to add the modeling and simulation features to a specific protective relaying concept that go beyond the level of detail originally provided by the software. Additions of new relay models and implementations of specific fault scenarios as well as the flexibility of changing the way the models of relays and power system interact is a necessity that should be embedded in the existing software tools. The relays can be more accurately and more efficiently modeled by using sophistically designed commercial software package with pre-defined libraries for these purposes.

DEVELOPING NEW SOFTWARE TOOLS FOR SIMULATION OF MICROPROCESSOR-BASED RELAYS AS AN EXAMPLE

To demonstrate how the traditional software tools could be enhanced to deal with the issues related to the distribution changes, in this paper, the widely used MATLAB with the enhanced Simulink/SimPowerSystems is selected as the main engineering tool for performing modeling and simulation of power systems and relays as well as for interfacing the user and simulation programs [7]. In this simulation example following points are indicated:

1) New subsystems pertaining to the new requirements are developed to help the user to implement a pre-defined task. For example, feeder management relay is a multifunctional protective relay composed of many protective functions. Such a relay is developed and stored in the software library, easily accessible to be implemented in the simulation of a microgrid.
2) The user can enter the settings for each protective function without any involvement in the modeling of each function. A rich library would help the user to collect a variety of different protective devices and use them as an independent entity.

In order to demonstrate the improvements and extra features that could be inserted in the commonly used software tools, an example is developed which the operator is able to select and set models of the appropriate power systems and relays, to adapt the relay models to the models of the power system, to define power system disturbance scenarios and to initiate various simulations corresponding to specific time intervals of the disturbance just through one interface. The salient feature of the proposed software would be an interactive environment for the evaluation of different protective relays, such as multifunctional feeder protection. The user can assemble the hardware of the relay by selecting different modules. Experienced users can design their own relay software by selecting the protective devices from the prepared library. For the ease of design, all the common protective devices for a relay are grouped under its name; for example, generator relay consists of devices such as differential, pole-slipping, reverse power, stator/rotor earth-fault [8].
In order to closely emulate the actual relay, a user-friendly model with different capabilities is designed and presented in Figure 1 applicable in Simulink modeling page. The status indicates normal operation or tripped condition. Trip type indicates the protective device function and number (for example: instantaneous overcurrent 50). Trip date and

time is for data logging and indicates the date and time of the event. The last line is for the simulation time starting from the beginning up to the relay trip. Since the user determines the instant of fault, this value shows the relay trip time from the inception of fault to the issue of the trip command. Figure 1 is the masked subsystem of the relay, not a picture.

By right-clicking on Figure 1 in the Simulink environment, and clicking on "Look Under Mask" command, Figure 2 appears. This block shows analog multiplexer, anti-aliasing filter, A/D convertor, DC offset removing block and processor. Although the general blocks like analog filter and A/D can be built by different methods, but the important point is the sampling rate. In this regard fixed interval processing loops can be designed and evaluated.

User can click on any block in Figure 2 and enters desired settings. For example, in the anti-aliasing filter, it is possible to determine filter type (Butterwoth, Chebyshev, and Bessel), cut-off frequency and order of the filter in an interactive environment. The filter response can be visualized graphically. In the A/D block, the sampling rate and the type of conversion are determined. The other blocks have the capability of selecting the parameters.

The basic blocks (protective devices) have been developed as masked subsystems with s-functions performing the required operations. The inputs to this relay are: 3 phase currents, 3 phase voltages. By double left-clicking on Figure 1 in the Simulink environment Figure 3 appears as setting menu. This figure shows different relays such as Motor, Generator, Line, Transformer, etc. By clicking on any equipment, the related protective devices will be opened. In Figure 3 the protective device for motor management relay are shown. The user can enable or disable any device and perform the settings by clicking on the desired icon. One important point in this simulation is the sampling interval adjustment for having constant samples per cycle. Since the sampling rate depends on the system frequency, which, changes with time, the system frequency is measured per arrival of (one or multiple) of new samples. Based on the measured frequency, the sampling interval is determined. Another point is the sliding window approach for updating the phasor measurements. The user can select the updating period by clicking on the “SAMPLING” icon in setting menu in Figure 4. User can select 0 (means updating every cycle) to 15 (means updating every sample) for an instance of 16 samples per cycle.

APPLICATION OF THE DEVELOPED RELAY IN A MICROGRID

As an example of the application of such enhancements in the conventional software tools, the developed relay is applied in a microgrid to protect different feeders and laterals.

Figure 1: Developed multifunctional microprocessor based subsystem in MATLAB/Simulink environment.

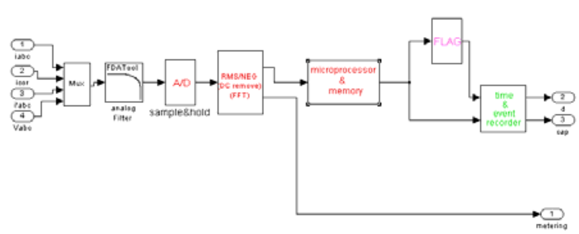

Figure 2: Relay hardware block diagram visible by right-clicking on Figure 1 in the Simulink environment and clicking on "Look Under Mask" command.

Figure 3: A sample developed relay model in Simulink

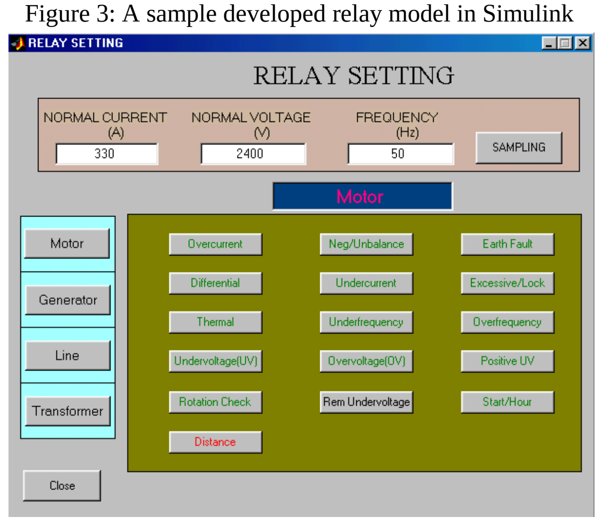

Figure 4 shows the advanced and sophisticated protective protection of a sample microgrid implemented by applying the developed relay on each feeder and lateral. The sample microgrid has one main feeder, it is similar to the LV network proposed in [9], but with some changes and modifications. The network comprises different feeders serving a primarily residential area, an industrial area with a small workshop and one feeder with commercial consumers. The power factor of all loads is assumed to be

equal to 0.85 lagging. A variety of DG sources, such as a microturbine, a solid-oxide fuel cell (SOFC), a non-directly coupled wind turbine, and several photovoltaics are installed in the residential feeder. It is assumed that all DG sources produce active power at unity power factor, i.e., neither requesting nor producing reactive power.
The setting of overcurrent relays depends on the fault level of the system under study. The fault level within the microgrid depend on its operating mode, which is appreciably decreased when the microgrid is disconnected from the utility-grid, because the fault point is feed by local microsources that have limited capacity in comparison to the utility-grid. Needless to say that in these conditions, the overcurrent relays within the microgrid cannot optimally protect the microgrod in different operating modes. The microgrid in Figure 4 is simulating the power system and protective relays' performance simultaneously in an interactive interface. Different signals from the relays could be used in a particular relay to simulate the sophisticated protection.

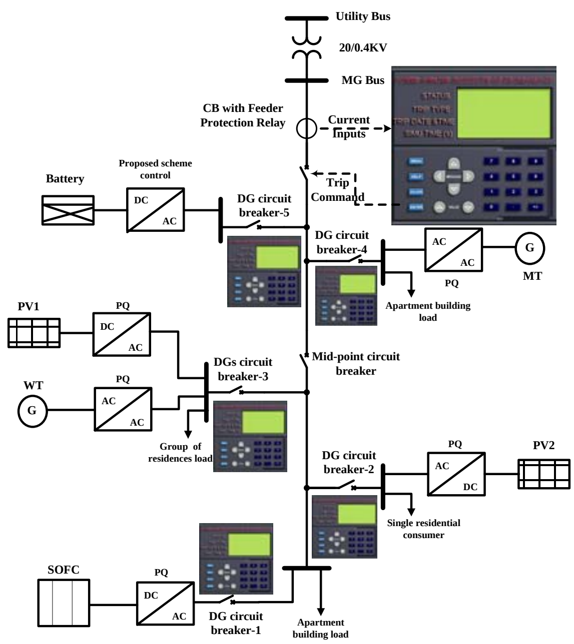

Figure 4: Sample microgrid used to show the necessity of software tools to coordinate the multifunctional relays.

CONCLUSIONS

In this paper, traditional software tools are analyzed to show their deficiency in simulating the progressive integration of DERs in distribution grids. Microgrid protection could not be easily coordinated using conventional techniques readily available in commercial software packages because of the downstream sources that can feed the fault and also the appreciable difference between the utility-grid connected mode and autonomous mode. A novel modeling and simulation environment is developed and presented as an example of upgrading software tools that could serve as an aid to evaluate the protective algorithms and hardware structures. Both relay performance and power system behavior are simulated in one unique environment. All the protective devices are collected and optimized in one unique s-function that emulates the actual relay. The relay operates in a dynamic manner and its status is visible on the screen. Advanced protective algorithms could be best tested and debugged by the developed environment. It allows evaluation of both individual protective devices as well as the interactions among them under a variety of power system operating conditions.

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