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Improving Smart Grid Operation with New Hierarchically Coordinated Protection Approach

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***Abstract*— Nowadays, power systems are characterized with heavy loading conditions, abrupt changes in generation patterns, extensive switching of power system configuration and high penetration of distributed generation (DG). Under those conditions performance of the conventional relays that rely on predefined settings may deteriorate leading to system wide disturbances and blackouts. To ensure reliable system operation, monitoring, control and protection have to be improved. In this paper, new Hierarchically Coordinated Protection (HCP) approach to mitigate the effects of increased grid complexity on its operation is proposed. The proposed approach utilizes local and wide area measurements and relies on the three HCP framework levels: fault anticipation and prediction, adaptive fault detection, and relay operation correction in case of unwanted tripping. It brings intelligence to the relays at all voltage levels and uses information and statistics from the systems such as weather, lightning, animal and bird migration patterns, component outage history, etc to enhance protection system tripping dependability and security.**

***Index Terms*— adaptive relaying, distributed generation, neural nets, protective relaying, synchronized sampling.**

I. Introduction

DUE to the rise in energy demand and favorable governmental policies a number of DG units have been installed in the power systems. In the last few years, energy from renewable sources has experienced larger percentage growth compared with the energy growth from conventional sources. European Union (EU) heads of states assumed a target of 20 % of energy generated from renewable sources by 2020 [1]. A similar plan for 25 % renewable energy sources requirement until 2025 has been adopted in the US [2]. In the last decade large scale wind generation is being rapidly installed while small scale wind generation has not found broad applications. On the other hand, photovoltaic (PV) systems have slower growth and are evolving from very small residential units to higher generation sizes.

To smooth the DG impact on the grid operation many countries and utility companies have established guidelines while IEC, IEEE and other standard bodies are formulating standards for DG interconnection to the grid. The biggest issue is to make sure that DG operates in a safe environment and that their disconnection will not worsen grid reliability. Depending on their type and technology, size and interconnection point, DGs deployment is specified by the standards and different guidelines, such as the IEEE standard 1547 [3] and FERC order 661-A [4].

Also, the transmission infrastructure upgrade has not followed the increase in electric power generation. Thus, the system now needs to operate with tight margins and less redundancy under dynamic grid operating phenomena such as power and voltage oscillations, as well as voltage, frequency and angular instability. In addition, introducing distributed generation in the distribution system changed its behavior from passive network that transfers power from substation to the customers in a radial fashion to the active network with generation sources causing bidirectional flows and short circuit (SC) current levels that may vary under different circumstances. These new phenomenon may have impact on relay operation since in some situations; conventional relays may not be able to discriminate between fault and normal conditions.

According to the historical data, relay mis-operation is one of the major contributing factors to 70% of the brown out and black out disturbances in the United States [5], [6]. Several cases of inadequacy of relay operation were quoted as possible causes of the disturbances. To prevent tripping due the swing condition, some transmission line relays are armed with the blocking function. However, the relays still may mis-operate for the faults occurring during the power swing period since they are blocked from operation [7]. The distance relay mis-operation in Zone III has caused cascading events leading to major blackout [17]. Protection under-reach, sympathetic trips, unsuccessful clearing of faults and unintentional islanding are all major problems associated with the utilization of DGs in the distribution systems [8]. Study in reference [9] shows that the only way to keep existing distribution system protection philosophy in presence of high DG penetration is to disconnect all DGs instantaneously in the case of the faults, even if the faults are temporary. It would enable the system to capture its radial nature and steady short circuit current levels. However, if such practice continues the system reliability will be deteriorated and DG full potential will not be utilized.

The main focus of this paper is the role of the protection system in mitigating reliable operation of future smart grids. The paper first discusses background of the interconnection standards. The next section reviews the current relaying practices and potential problems. Then the grid protection issues in the modern grids are analyzed followed with the novel protection approach, a case study and conclusions.

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II. THE GRID INTERCONNECTION STANDARDS

IEEE standard 1547 2003 for Interconnecting Distribution Resources with Electric Power Systems provides requirements for performance, operation, testing, safety and maintenance of the interconnection [3,10]. The requirements are applicable for DGs in 60 Hz system with generation capacity less than 10MW and they should be met at the point of common coupling. The main idea of IEEE-1547 is that DG should not affect operation, protection and power quality of the distribution system and that it should be quickly disconnected under abnormal conditions. Standard does not allow utilization of inverter-based DG control capabilities and it prohibits voltage regulation and reactive power generation. There are eight complementary standards designed to expand upon or clarify the initial standard, four of which are published, and the other four are still in the development phase [11], see Fig 1.

In attempt to maintain integrity of the transmission grid with high wind energy penetration, Federal Energy Regulatory Commission (FERC) proposed low voltage ride-through (LVR) requirements during faults. Order 661-A implies that wind energy sources should stay connected to the grid during most disturbances. The wind plant should stay connected for a grid disturbance resulting in voltage drop of 85% for 625ms time period. Further, the wind plant should stay connected if voltage returns to 90% of the rated power within 3s from the beginning of the voltage drop (see Fig. 2). Moreover the wind plant shall maintain power factor in the range of 0.95 leading to 0.95 lagging at the point of interconnection. To accomplish these requirements, the wind energy source must be equipped with power electronics converters designed to supply such a level of reactive power or fixed and switched capacitors.

Although those two standards have the same objective to smooth DG impact to the grid operation, their requirements in case of the local fault are contradictory; IEEE 1547 requires DG disconnection while FERC 661A expects LVR during the fault. In the case of high DG penetration in distribution systems, simultaneous disconnection of all DGs under some circumstances may reduce system reliability. It may cause incorrect relay operation followed by system wide disturbance, and system instability problem at transmission level due to sudden increase in the load. Thus, the regulators for DGs at distribution level are slowly moving toward wind transmission type performance requirements. FERC 661-A and the emerging new standards for large transmission-connected PV generation still appear to be at odds with the IEEE-1547 standard for interconnection in the distribution system [12]. On the contrary, German BDEW guidelines have imposed a LVRT requirement, automatic real power regulation and automatic mandatory reactive power contribution corresponding to 0.95 power factor.

III. Issues with Current Protective Relaying Approaches

The main goal of protection relay is to quickly and reliably detect the fault and disconnect the faulted area. In the case of transmission lines, relays should differentiate the internal faults from external faults so that only the faulted line is removed, provide the exact fault type selection so that advanced tripping and reclosing can be applied, and locate the precise fault position on the line so it can be repaired and restored quickly.

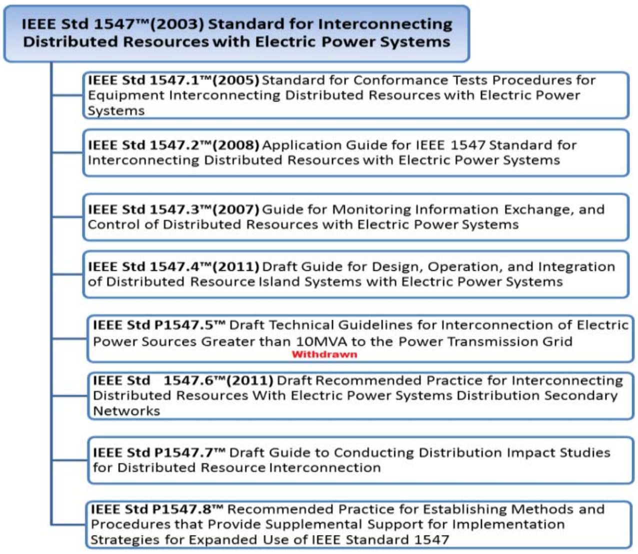

Fig 1. IEEE 1547 2003 Standard Series [11]

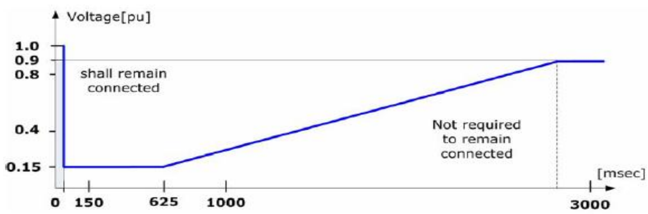

Fig 2. Required wind plant response to emergency low voltage by FERC 661-A [13]

The traditional operating principles of the conventional relays as classified in [14] may have some selectivity and reliability of operation issues:

- Magnitude Relays: The operating logic of such relays is based on the comparison of the magnitude of one or more operating quantities to the threshold. For example, the overcurrent relay responds to the changes in the magnitude of the input current, over/under voltage and frequency relays responds to the changes in voltage and frequency. Such relays are sensitive to the major changes in relay quantities that are caused by normal system operation rather than the faults since in that case the safety margin for differentiating between the faults and normal operating conditions may be significantly reduced, as discussed in section IV.b.
- Directional Relays: The operating logic of such relays is based on the comparison of the phase angle between two AC inputs. The comparison can be based on current and voltage phasor, or only on current phasors. Such relays if based only on current flows may create false fault detection due to bidirectional power flows, as discussed in section IV.D
- Ratio Relays: The operating logic of such relays is