PREFACE

The great emphasis and environmental concern have globally driven Renewable Energy (RE) integration into the power grid. The penetration of RE at the lower level to the grid does not pose any challenge. However, the RE integration at the higher level may pose additional challenges to grid operation because of the intermittency and variability of RE. Moreover, the inclusion of renewable sources poses additional significant challenges such as bidirectional power flow in the network that may cause malfunctioning of the relays, relay coordination, voltage/frequency control, and islanding detection issues.

The present work exploits the signal processing-based advanced approach for ascertaining, classification, and depicting abnormal events in Active Distribution Networks (ADN). Islanding is a phenomenon when a portion of ADN is isolated from the rest of the power network due to disturbances/faults or intentional isolation in the power grid. The Power Quality Disturbances (PQD) such as sag, swell, and interruption are also caused by abnormal events and faults in the system. The load demand is increasing day by day in the electric grid, and to meet the increased power demand, more emphasis is given to renewable energy resources due to the faster depletion of fossil fuel and environmental concerns associated with it. Ascertaining unintentional islanding conditions is challenging for power utility operators due to the pervasive penetration of Distributed Energy Resources (DER). The presence of DER has a significant adverse impact on islanding detection schemes for various types of Distributed Generators (DG) and inverter-based DERs. Before integrating DG into ADN, the issue of unintentional islanding detection has been desirable to be deliberated.

The conventional islanding protection method such as Vector Surge (VS) and Rate of Change of Frequency (ROCOF) relays has usually been used to detect islanding, but its performance is limited by the large Non-Detection Zone (NDZ), wherein islanding events are undetected by these conventional relays. For VS and ROCOF relays, NDZ is a function of active and reactive power deficit, which may exist inside the islanded segment. This thesis's proposed approaches are developed based on multiple features of three-phase voltage signals that can be recorded in ADN through Potential Transformers (PTs). However, the voltage selection over the current signal is advantageous because these voltage and current signals are passed through the instrument transformers, i.e., Potential Transformer (PT) and Current Transformer (CT). The voltage and current, which come out from the instrument transformers, are inputs to the abnormal events detection devices, such as relays or other intelligent devices. Therefore, the reliability of PT and CT is an essential aspect for the detection devices to detect abnormalities effectively. CT suffers from issues like magnetic saturation and non-linearity, especially during fault or abnormal conditions. In contrast, PT/CCVTs provide excellent reproduction of primary voltage during both transient and steady-state. Some CCVTs may exhibit a subsidence transient when the system voltage is suddenly reduced, such that the secondary voltage is not the replica of the primary voltage. Modern design CCVTs are available to eliminate this problem. Usually, PT does not experience saturation since power systems are not operated above the voltage limit, and in most cases, faults result in a collapse or reduction in voltage, or sometimes voltage may rise, but it does not cause saturation. Therefore, classification and characterization of abnormal events utilizing only voltage parameters would undoubtedly provide an accurate insight into the events. Hence, voltage and its associated features have been taken as input parameters for the proposed method.

This thesis proposes a Variational Mode Decomposition (VMD)-based approach for detecting and classifying islanding events in an ADN. The prime attributes of VMD are noise immunity, robustness, and non-recursive signal processing approaches, making it more promising and competent for signal decomposition than other extant signal processing methods. The energy-based index has been assigned for islanding detection. In this thesis, using the concept of NDZ, the performance of the Islanding Detection Technique (IDT) has been evaluated for islanding detection. The limitations of the VS and ROCOF relays for islanding detection, in case of a minor power mismatch between load and generation, exist in the islanded network. From the perspective of the problems and the limitations of the conventional methods, this thesis proposes VMD based technique for islanding detection of synchronous, Doubly Fed Induction Generator (DFIG), and inverter type DG. The proposed method addresses a passive islanding detection mechanism based on mode energy index using VMD in ADN. In this, three-phase instantaneous voltages at the targeted DG end have been acquired to compute modal voltage signals, and VMD has been applied to decompose the obtained signals into four modes. Thereupon, the mode energy index has been calculated for the selected mode. The estimated energy index has ultimately been utilized as an islanding detection indicator. Two different test systems have been modeled in this work simulated on EMTDC/PSCAD using test system data. Furthermore, all possible combinations of mismatch of active and reactive power, which may exist during the occurrence of an island, have been considered in the testing. A comparative study between conventional relays (VS and ROCOF) and the proposed VMD-based IDT has been conducted, and the proposed method's relative performance has been evaluated. The simulation outcome reasserted that the developed approach effectively ascertains the islanding and non-islanding events.

Furthermore, the proposed islanding detection technique has been validated using the Real-Time Digital Simulator (RTDS). The simulator consists of NovaCor chassis with four licensed cores and RSCAD 5.013 versions. The simulation is performed in Power system mode, having a solution time step of 50 microseconds. NovaCor chassis has 12× 12 bit digital to analog channels (GTAO) operating over a range of ±10 V peak. The PCC three-phase voltage has been sent from the front panel interface of RTDS (GTAO) to MicroLabBox (dSPACE1202) ADC pin, where the proposed algorithm has been implemented. The modal voltage has been decomposed, and the energy of the second mode is computed. The computed energy is compared with the threshold value. If it is greater than the predefined threshold, a trip signal is generated and sent to RTDS by the GTNET-SKT communication protocol.

The work is further extended for the assessments of Power Quality Disturbances (PQD) as they pose a significant challenge due to the increased usage of electronic equipments since all these equipment are susceptible to voltage and frequency variations. These devices are highly sophisticated, and their performance depends on the quality of the power supply. Voltage sag is generally considered a power-quality problem of equal importance as long and short interruptions in the supply. It has become very challenging to control the external factors that cause voltage dips. Thus, proper mitigation techniques are desired. However, the development of mitigation techniques requires the accurate diagnosis, characterization, and classification of voltage sag. Furthermore, the classification of voltage sag and swells plays a vital role in assessing voltage sag ride-through capability and immunity of electrical equipment. This thesis proposes a signal processing-based classifier to detect and classify PQD effectively. The VMD-based signal processing has been used to extract the decomposed mode. The decomposed modes carrying the signature of disturbances are segregated. The sag, swell, and interruption are disturbances that depend on the Root Mean Squared (RMS) of the voltage signal. One of the decomposed modes has been utilized to classify the disturbances, which depends on

RMS. Frequency-dependent disturbances are classified by THD of the mode and center frequency estimated by VMD. A mathematical model for PQD assessment has been developed in the MATLAB environment, and various types of disturbances, i.e., voltage sag, swell, interruption, and THD, are obtained. The proposed technique is tested with the dataset obtained from the models simulated in PSCAD/EMTDC platform. Furthermore, actual measurement data provided by the IEEE Task Forse database is utilized to test the technique's efficacy. Moreover, a real-time co-simulation platform has been developed to validate the proposed PQD detection method using RTDS/RSCAD and MATLAB.