Malfunction of Differential Relays in Wind Farms

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Abstract— The distributed generation (DG) including wind power, solar power etc is one of the solutions for the sustaining energy shortage in the existing power grid. Distributed generation is defined as the generation of power using a set of small sized generators that produces electric power at low voltage levels which are usually designed to be connected directly to the distribution network near load centers. The distributed generations have certain disadvantages in the existing power grid. The DG sources like wind, solar etc are dynamic in nature. Due to the intermittent nature of distributed resources, the source impedance is varying in nature. So in the presence of distributed generation the fault current characteristics are also changing. The existing relay settings are not able to identify these changes, which results in malfunction of relays. Transformers are the most important component in the power system and differential protection is the most commonly used protection scheme adopted for it. In this paper a typical wind generation farm in Kerala is taken as the case study and found that the differential relay maloperates in the presence of varying penetration of wind farm output. The solution method suggested in this paper is adaptive relaying.

Index Terms— Distributed generation (DG), Differential relay, Inrush current, Malfunction, Adaptive relaying.

I. INTRODUCTION

The distributed generation (DG) can be used as a solution strategy for the sustaining energy shortage worldwide. The need of distributed generation in Indian power system is given in [1]. India suffers from grave power shortage which is likely to worsen over the next few decades. There are problems with the lack of adequate generation capacity with power cuts ranging to several hours still prevalent in many cities. The development of new generation plants is at slow rate. India‘s transmission and distribution losses are among the highest in the world, averaging 30% of total electricity production, with some states as high as 50%. When non technical losses such as energy theft are included in the total, average losses are as high as 40%. The earliest electric power systems were distributed generation (DG) systems intended to cater to the requirements of local areas. Later technology developments resulted in the development of large centralized grids connecting up entire regions and countries. Centralized generation alone is not necessary to meet the power requirement in India. To avoid sustaining energy shortage, Distributed Generation (DG) can be a solution method which is the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer site.

The IEEE defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system. Distributed generation refers to relatively small scale generators that produce several kilowatts (KW) to tens of megawatts (MW) of power and are generally connected to the grid at the distribution or substation levels [2]- [3].

A. Impact of Distributed Generation in Protection Level

The following are the issues due to intermittent nature of distributed generation in protection level. [4]- [5]

1) Increase in Fault Current

The connection of wind power, solar power etc to a distribution system may cause some local changes in the characteristics of the distribution network. The connection of local generator to a distribution network results in increasing the fault levels of the network near to the point of connection. When fault levels exceed its limits, it will cause damage and failure of the plant, risk of injury to personnel and interruption to supplies. The new fault level and settings of relays, circuit breakers etc should be calculated before DG is added to the existing system.

2) Coordination Problem

The faults must be eliminated as fast as possible, isolating the smallest part of the system containing the cause of the fault. The presence of distributed generation can cause mis-cordination, such that more areas will be isolated.

3) Reverse Power Flow

Distribution networks are usually designed for unidirectional power flow, form the source to the loads. The normal directional protection scheme is based on this consideration. The power flow situation may change with the addition of DG on distribution feeder. The current flow may change its direction if the local production exceeds the local consumption. Bidirectional power flow is a severe problem and it is to be considered in the protection system design, especially directional relays.

4) Islanding

The portion of the distribution system becomes electrically isolated from the remainder the power system, but continues to be energized by DG then it is called islanded system. Distribution networks with DG are normally not designed to operate in island mode. If unintentional islanding occurs it causes severe problems in protection level and to be avoided. The fault current seen by the relay is different when the system is islanded. It also causes stability problems because DG alone cannot meet the power demand.

5) Protection Under Reach or Blinding of Protection

The distributed generation is connected at the load side and it is supplying energy locally to load. In some cases the fault current seen by the relay is small which results that the relay fails to trip.

6) Sympathetic Tripping

Sympathetic tripping is defined as the case in which the protection devices trips instead of the other. The protective device operates unnecessary for faults in another protection zone which results in the tripping of healthy feeder.

The above situations can be solved by taking adaptive relaying as the solution strategy. Adaptive relaying is defined as the protection strategy which makes adjustments to various protection schemes according to changing power system conditions.

The paper is organized in such a way that the necessity of distributed generation and various issues associated with protection level are addressed in section I. In section II, the differential protection scheme for the transformer is explained. A typical wind generation farm in Kerala is taken as the case study and mal-function of differential relay in the transformer which connects the wind farm to grid is reported in section III. The solution technique is adaptive protection and an algorithm for it is given in section IV. Section V gives the conclusion.

II. TRANSFORMER DIFFERENTIAL RELAY

Transformers are the important component in the power system. The major protection philosophy adopted for transformer is differential protection which provides the best overall protection. The differential protection should operate for internal faults and not to operate for external faults, inrush conditions and over excitation conditions.

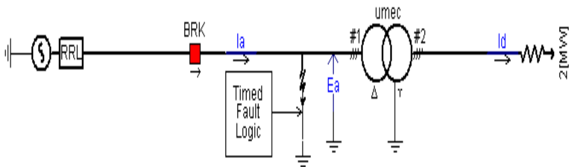

Figure 1. Transformer Inrush Phenomenon

The inrush current waveform is shown in figure 2. As shown in figure the waveform is highly distorted.

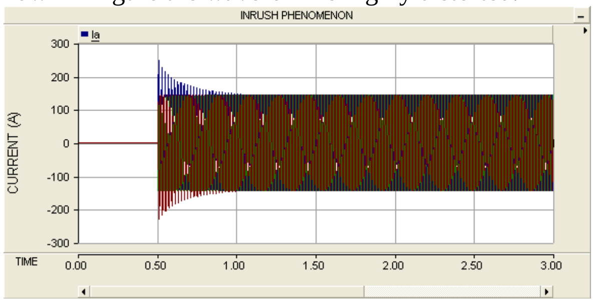

Figure 2. Inrush current waveform

The following tables discriminates the different conditions of the transformer using harmonic analysis. During the inrush condition the percentage of the second harmonic component is higher compared to other conditions. The fifth harmonic component is used to discriminate the over excitation condition and the fault condition.

Table - 1 Inrush condition

Component	Current (A)
Fundamental	382.83
Second Harmonic	201.92
Third Harmonic	119.36
Fourth Harmonic	72.81
Fifth Harmonic	74.09
Sixth Harmonic	80.57
Seventh Harmonic	98.21

Table - 2 Over excitation condition

Component	Current (A)
Fundamental	350.32
Second Harmonic	4.71
Third Harmonic	0.043
Fourth Harmonic	1.469
Fifth Harmonic	37.06
Sixth Harmonic	0.618
Seventh Harmonic	0.4755

During fault condition the different harmonic components is shown in table 3. The percentage of second as well as fifth harmonics is less compared to fundamental component.

Table - 3 Fault condition

Component	Current (A)
Fundamental	8996.00
Second Harmonic	184.82

Third Harmonic	191.08
Fourth Harmonic	201.17
Fifth Harmonic	219.33
Sixth Harmonic	262.00
Seventh Harmonic	379.56

III. CASE STUDY

A typical wind farm in Kerala is taken as the case study and it has total nine units of Vestas V27 225kW wind turbines. The total installed capacity of wind farm is 2.125 MW. The turbine has a rotor diameter of 27m and has 43rpm of nominal speed. The cut-in speed of wind is 3.5m/s and the cut-out speed is 25m/s. The turbine uses i.e. a Squirrel cage induction generator (SCIG) which has a two set of winding of 6 pole and 8 pole each for 1000 rpm and 750 rpm synchronous speed respectively. The squirrel cage generator output is at 400V, 50Hz.The 9 units are connected to the main 3MVA, 400V/22kV, 50Hz transformer bank which is then connected to the grid by 25MVA 110kV/22kV substation transformer.

The wind farm output is varying in nature. The following graph shows (Fig 3 -7) the varying nature of wind farm output.

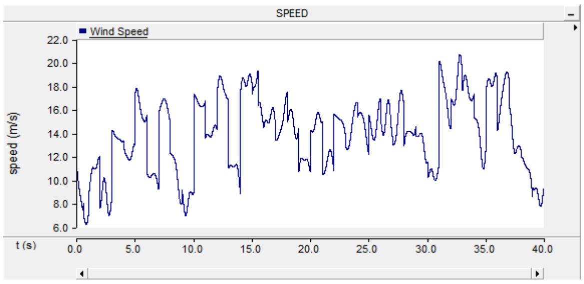

Figure 3. Wind speed

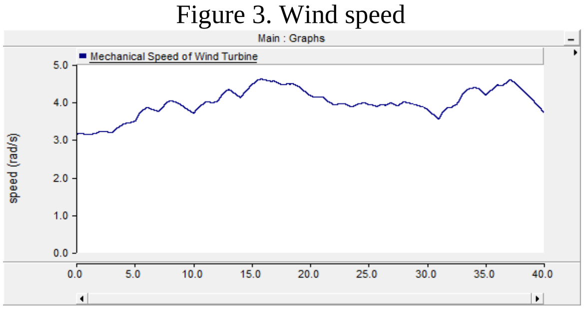

Figure 4. Mechanical speed of wind turbine

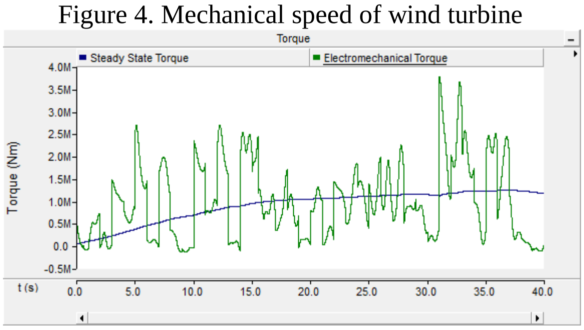

Figure 5. Steady state and electromechanical torque

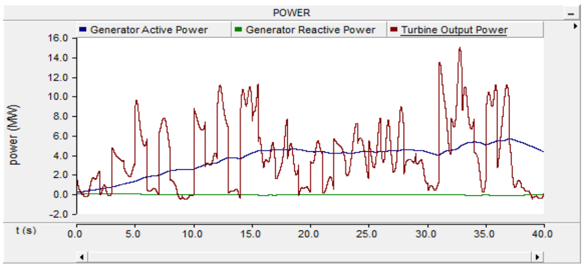

Figure 6. Turbine output power, Generator active power and reactive power

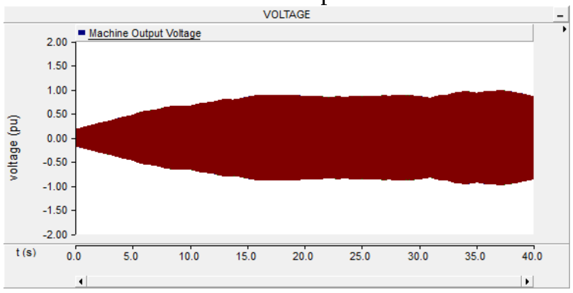

Figure 7. Output voltage

The entire wind farm is modeled using PSCAD software. Conventional relay settings maloperate in the presence of distributed generation. The trip signal in this case with conventional setting is irregular and unwanted tripping is identified. This type of pattern is seen for different kinds of faults. It can be concluded that conventional relay settings tend to mal-operate in presence of DG sources in the system. When the number of generator changes the figure shows that the relay trips for unnecessary initial conditions. (Figure 8) and not tripped for internal faults This calls for the development of an adaptive relaying scheme to ensure secure protection..

With adaptive settings, the relay has a higher chance of providing the correct decision. It is evident that the adaptive relaying scheme developed provides satisfactory results in case of various types of faults, by maintaining stability under external faults and other system transients. The adaptive relaying techniques senses the changes in system operating condition including the addition of new generators and modify the differential relay setting according to that.

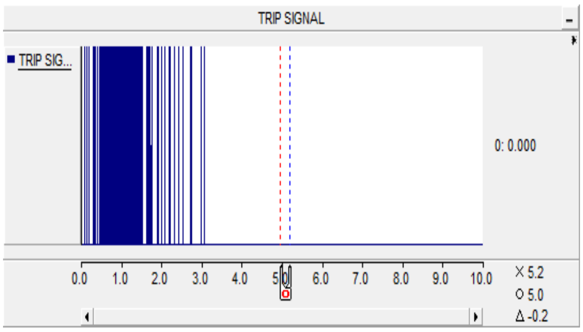

Figure 8. Trip Signal for differential relay (No. of wind generators connected is 9)

IV. ADAPTIVE PROTECTION

Relays are used to protect electric power systems in a predetermined manner. The relay settings are selected after studying most of the critical power system conditions. It is difficult and impossible to identify and analyze all operating conditions of concern in advance and to determine relay settings that would the optimum for all normal and abnormal operating conditions. The scenario has been changed with the development of microprocessor-based relays, because they can collect information, handle complex logic and communicate with other relays and control devices. It is possible to continuously monitor the state of a power system, analyze it in real-time, and change the relay settings to most appropriate at that time. Microprocessor based relays forms an adaptive approach which reduces the relay operating times and provides proper relay coordination at all operating conditions [6] – [8]. The simple flow chart for adaptive relaying is shown in figure 9 [8].

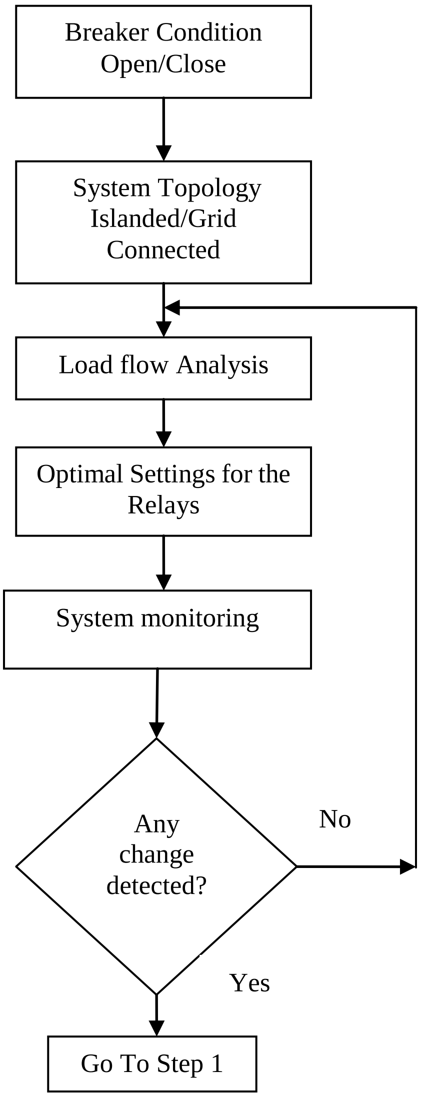

Figure 9. Flow chart for Adaptive Relaying Technique

Adaptive protection is a protective system which permits and seeks to make adjustments to protection functions in order to make them more attuned to prevailing power system conditions. The changes in power system topology include planned and unplanned switching operations, addition of distributed energy resources etc. The relay setting has to adapt itself to the real time system and when the system conditions change. Usually adaptive relaying is an online activity but can include timely human intervention. Adaptive relaying can change the system conditions or requirements in a timely manner by means of externally generated signals or control actions. It provides required flexibility and stability of the power system without affecting speed and selectivity of the system [9] – [11].

Adaptive relaying includes changes in relay settings or relay characteristics in online manner according to environmental changes. The changes include generator outage, line outage or load variations. In the current scenario more and more DG's are connecting to the existing grid. The addition of distributed generation also requires some variations in the relay setting. Adaptive relaying improves relaying reliability and power system security. Adaptive relaying is defined as an on-line activity that modifies the preferred protective response to a change in system conditions or requirements which is automatic, but can include necessary human intervention. Adaptive relay is defined as the relay that can have its settings or characteristics changed on-line in a timely manner by means of externally generated signals or control action [12].

The relays sample bus voltages and line currents via voltage and current transducers and transformers, analog to digital converters and multiplexers. Each relay processes quantized samples and calculates voltage and current phasors. During normal conditions, each relay provides its measurements to its station control computer at regular intervals. The relays check the status of local isolators and circuit breakers and provide the information to the station computers. In addition to communicating with the relays, the station computers pass on the collected information to the central computer which estimates the system state and decides whether the relay settings should be changed or not. If it decides to change the settings, it calculates them and conveys them to the relays via the station control computers. The relays implement the new settings and send confirmation messages to the central computer via the station computers. If the central computer decides not to change the settings, the decision is passed to the relays for sharing information and confirming that communication facilities are working properly. Adaptive relaying provides less operating times and maintains proper relay coordination. A change of system configuration affects the selectivity adversely unless relay settings are changed. The adaptive relaying is a key requirement for smart grid operation which includes distributed generation [13].

V. CONCLUSION

The entire wind farm is simulated with transformer differential protection scheme. There is no maloperation of differential relay for internal or external faults. The differential relay trips when transformer and wind farm are energized together. The need of adaptive relay arises because there might be situation when there is addition of more number of wind generators, the THD level of the inrush current changes. The setting of the relay is different with the addition of generators. The threshold point of different harmonic restraints in the relay has to modify adaptively by the addition of wind generators.

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