Ferroresonance Avoidance by Distributed Resources 
Reconfiguration in Islanded Power Grid

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Abstract: - In a distributed resources power grid, a capacitor bank is used for compensation purpose when this grid is connected to the utility. However, when this grid is islanded, the capacitor bank will be needed for induction generator operation. If a great capacitance is permanently connected, it may cause a severe over-voltage due to ferroresonance. In this work, a simulation approach is made for reselecting an adequate size of this capacitor that will not cause this abnormal phenomenon in the islanded power grid. The obtained simulation results using Simulink/MATLAB may be useful.

Key-Words: - Induction generators, Capacitor bank, Distributed Resources grid, Island, Ferroresonance.

1 Introduction

Generally, distributed resources (DR) islanded grid consists of gas turbines and/or traditional wind turbines that are equipped with induction generators. Induction generators are preferred because they are inexpensive, rugged, and require very little maintenance. Unfortunately, induction generators require reactive power from the grid to operate and/ or some capacitor compensations are often used with self-excited induction generators. Static capacitors are generally employed to achieve the required performance in a self-excited induction generator[1,2]. In this situation, the distributed devices in a distributed resources island can drive the circuit into ferroresonance (C. Wagner et al., 1989)[3]. The peak voltage during this ferroresonance can reach three per unit. Both induction and synchronous generators can create ferroresonance, and it can occur with all three phases connected (single phasing is normally involved with ferroresonance). According to the previous works, three conditions are necessary for DR islanding ferroresonance to occur:

1. The island driven by the induction generator must be isolated from the power system.
2. The induction generator must supply more power than the connected load in the island.
3. The isolated circuit must have enough capacitance to resonate (3 to 4 of the induction generator rating). This can be due to power system capacitor banks or/and from capacitor banks required by the utility first and by induction generator operation after islanding.

Literature survey reveals that a few papers has been published that studied effects of capacitor bank on the distributed resources islanded grid characteristics [4, 5]. In this work, a simulation approach is made for reselecting an adequate size of this capacitor that will not cause a ferroresonance in the islanded power grid.

2 Ferroresonance

Ferroresonance is a non-linear resonance phenomenon that can affect power networks. It typically involves the saturable magnetizing inductance and a capacitive distribution, capacitor bank or transmission line [6]. Its occurrence is more likely in the absence of adequate damping devices. The term “Ferroresonance”, which appeared in the literature for the first time in 1920, refers to all oscillating phenomena occurring in an electric circuit which must contain at least: a non-linear inductance ferromagnetic, saturable capacitor and a voltage source (generally sinusoidal) as shown in Fig.1.

Figure 1. Typical circuit may produce the ferroresonance.
A resonant phenomenon involving inductance that varies with saturation. It can occur in a system through the interaction of the system capacitance with the inductance, for example, that of an open-circuited transformer. Ferroresonance resembles, to some extent, the normal resonance that occurs wherever L-C circuits are encountered. If the capacitance is appreciable, ferroresonance can be sustaining or result in a limited over voltage enough to damage the cable or the equipment itself which in turn leads to the whole system collapse.

Practical solutions to avoid ferroresonance as mentioned in previous publications are [6]:
- using a higher loss transformer,
- using a three pole circuit breaker (CB) instead of a single-pole CB device,
- using a transformer connection not susceptible to ferroresonance,
- limiting remote switching of transformers to cases where the capacitive yards of the cable are less than the transformer’s no load losses.

3 Distributed Resources Island

Distributed resources are defined in this work as meaning distributed generation and distributed storage devices which are connected to the utility power system at the distribution level. They will have enhanced value to electric customers and to distribution utilities, due not only to improvements in DR device technology, cost, and efficiency, but also to the rapid growth of the deregulated electricity marketplace, which has spurred interest in non-standard and dispersed sources of generation to meet increasingly competitive requirements for energy, ancillary services, and other energy services. Pressures from customers are increasing for improved power quality, including power availability and backup sources of energy. In some deregulated regions, customers are also looking for relief from high prices during peak load conditions. Many are looking to interconnect the DR to the electric power system, with the idea of selling excess energy and ancillary services as one means to offset the price of purchasing and installing these devices. As a result of these pressures, more DR devices will become interconnected with distribution power systems and will impact the electrical characteristics of these systems. Therefore, to derive maximum benefits from DR and avoid all possible oscillation adverse system impacts, distribution utilities will need the ability to simulate the effect of interconnected DR devices such as capacitor bank, distribution transformer and induction generator on their power systems, in order to determine any distribution system modifications in its configuration that may be needed for avoiding some severe disturbances such as ferroresonance. Currently, various simulation tools as ATP and Simuink/Matlab are used by utilities for distribution network study purposes [7, 8]. Most of these simulation tools are used to analyze the impacts of each distributed devices on the distribution system operation. Other simulation tools determine the optimal size of electric equipment, such as capacitor banks and...
transformer, for efficient and reliable operation of the power system without self disturbance.

3.1 System Description
The DR system Simulink model as illustrated in Fig.2 consists of 480V, 50 Hz, 275-kVA, induction generators driven by wind turbine a fixed resistive customer load of 75 kW. The presented system also uses a 480 V, 300 kVA synchronous machine and a variable secondary load (0 to 446.25 kW) the same as the HPNSWD system [7, 9]. In the all-wind mode, the synchronous machine is used as a synchronous condenser and its excitation system controls the grid voltage at its nominal value. A secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand.

The three-phase delta connected capacitor bank is connected at the bus of the induction generator as compensator for the whole utility and exciter when the grid is islanded.

The value of this capacitor bank can be changed in order to determine its optimal size for avoiding the ferroresonance in one hand and having better induction generator operation performance in the other hand. The wind speed is kept constant at 10 m/s for this work[10].

The Wind Turbine block uses a 2-D Lookup Table to compute the turbine torque output (Tm) as a function of wind speed (w_Wind) and turbine speed (w_Turb). The Pm (w_Wind, w_Turb) characteristic was automatically loaded in the workspace (psbwindgen_char array). According to turbine characteristic, for a 10 m/s wind speed, the turbine output power is 0.75 p.u. (206 kW)

Because of the asynchronous machine losses, the wind turbine produces 200 kW. Scope is used to record the p.u. values of terminal voltage and current of the induction generator.

4 Simulation Results and Discussion
The above system was simulated in MATLAB using the Simpower system toolbox of SIMULINK to determine the size of variable capacitive compensation for obtaining good voltage waveform and at the same time avoiding the severe over-voltage (ferroresonance phenomenon). The SIMULINK model of the system is shown in Fig.2. The simulation time is 10 sec.

When the value of the capacitor bank is changed to 175 kVAR the improvement in the voltage profile is observed as shown in Fig.3. After the duration of 5 sec, the magnitude voltage becomes stable at value nearly 1 p.u.. Considerable variations in the output voltage can be noticed at starting.

However, when capacitor bank is changed to 190 kVAR the ferroresonance phenomenon starts to appear after 4 seconds. The overvoltage occurs and its magnitude can attain 3 per unit. If the generator is not rapidly disconnected, the whole power system may collapse. Before the appearance of this phenomenon, it can be noticed that a variation in the voltage and the current.

It can be observed that in the distributed resources power grid, a capacitor bank is used for compensation purpose when this grid is connected to the utility. However, when this grid is islanded, the capacitor bank will be needed for induction generator operation. But if a great capacitor value is permanently connected, it may cause the ferroresonance.

5 Conclusion
In this paper, an attempt is made to use the MATLAB/SIMULINK to reselect the adequate three-phase capacitor bank size. Simulation results show that the importance of such reselection and for a specific machine (used for simulation), reactive power source with 175 kVAR gives smooth voltage profile and best results. However, it is observed that reactive power source with 190 kVAR gives overvoltage around 3 per unit that may be due to the ferroresonance. This results
in from the interaction of induction generator effect and the capacitor bank. The possible source of ferroresonance in this setup is due to magnetic saturation of the rotor iron core. The tap changer, the power factor, and the level of generation of the wind turbine affect the level of saturation, and thus, the nature of the ferroresonance. This emphasize for the need of appropriate technique to select the optimum rating of capacitor bank that can be used for avoiding the ferroresonance. If this phenomenon persists, it may pose a hazard to an electric power system because it causes over-voltages and hence over-currents. Poorly understood, it is generally not accounted for in islanded power grid.
studies. It is rare and cannot be analyzed or predicted by the computational methods based on linear approximation normally used by electrical engineers. This lack of knowledge makes it a probable culprit responsible for the unexplained destruction and malfunctioning of equipment.

Solutions that may be suggested for this type of ferroresonance include:

• **Reconfiguration** — Changing the distributed devices sizes to change the criteria given above (limit or expand the area that could island or remove or change the size of the capacitor bank).

• **Relaying** — rely on the over-voltage relaying to remove the generators during an over-voltage condition. Use an instantaneous element (59I), apply relays on each of the three phases.

**References:**


