Analysis of the Disturbances in Distribution Networks using Matlab and ATP

S. Boutora, H. Bentarzi and A. Ouadi

***Abstract*—**The capacitance bank is generally used for compensation in a distributed power grid, if the latter is connected to the utility. An islanded power grid is a distribution grid disconnected from the utility. It can undergo a disturbance namely the ferroresonance phenomenon if the capacitance bank has a non adequate value. In this paper, a study of an islanded power grid is attempted to show the effect of the reconfiguration of the capacitance bank on the ferroresonance. A simulation of the circuit is conducted using Simulink/ MATLAB. In another part of this work, an example of overvoltage study in a distribution medium network using ATP is also presented.

***Keywords*—**Transformer, Capacitor bank, Distributed Resources grid, Disturbances.

I. INTRODUCTION

IN A BROAD definition, the distribution system is that part of the electric utility system between the bulk power source and customer's service switches. This system can be subjected to a sudden change or transient conditions of very short period usually and extremely important for it is at such times that the circuit components are under the greatest stresses from excessive currents or voltages.

In this paper, two parts will be studied: the first case is the ferroresonance study in a distributed resources islanded power grid, the second case is a study of overvoltages in a distribution system

Adistributed 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 required performance in self-excited induction generator[1,2].

S. Boutora, A.Ouadi and H. Bentarzi are with the Laboratory of Signals and Systems, IGEE, Boumerdes University, Algeria. (E-mail: sisylab@yahoo.com).

In this situation, the distributed devices in a distributed resources island can drive the circuit into ferroresonance [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 generator must be isolated from the power system.
2. The generator must supply more power than there is load on the island.
3. The isolated circuit must have enough capacitance to resonate (30 to 40% of the generator rating). This can be due to power system capacitor banks or/and from capacitor banks required by the induction generator operation.

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 part of the 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.

II. 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. Its occurrence is more likely in the absence of adequate damping. The term "Ferro-résonance ", 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.

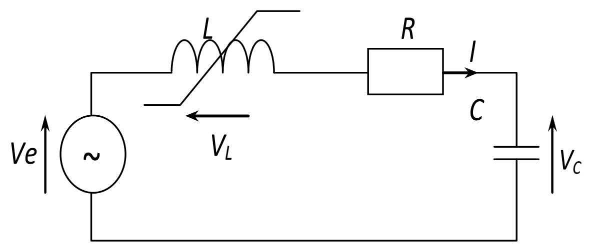


Fig. 1. Typical circuit may produce the ferroresonance.

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 transformer 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.

III. Distributed Resources Island

Distributed resources (DR) are defined in this document 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 possible adverse system impacts, distribution utilities will need the ability to simulate the effect of interconnected DR devices such as capacitor bank 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

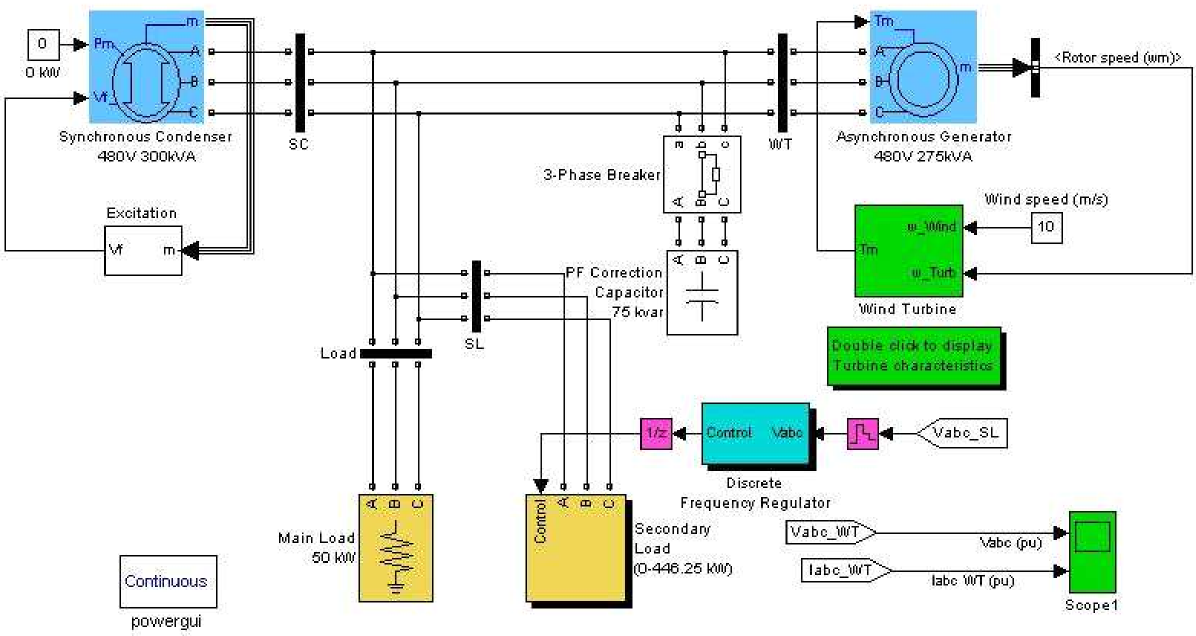


Fig.2. Simulink model for distributed resource islanded.

capacitor banks and transformer, for efficient and reliable operation of the power system without self disturbance.

A. 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, 300kVA 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.

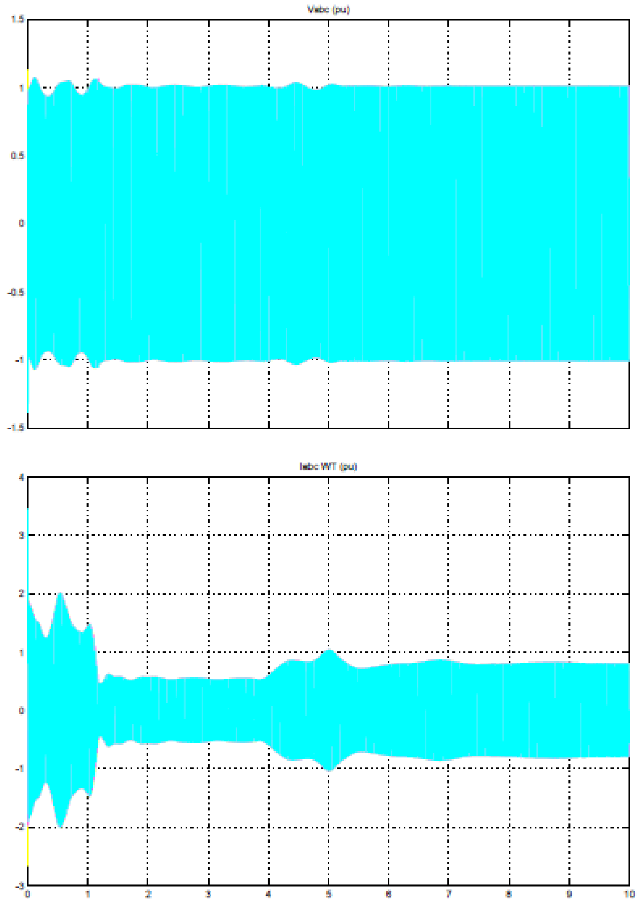
IV. Simulation Results and Discussion

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 figure.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 figure 4, 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 oberved 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.



Time (second)

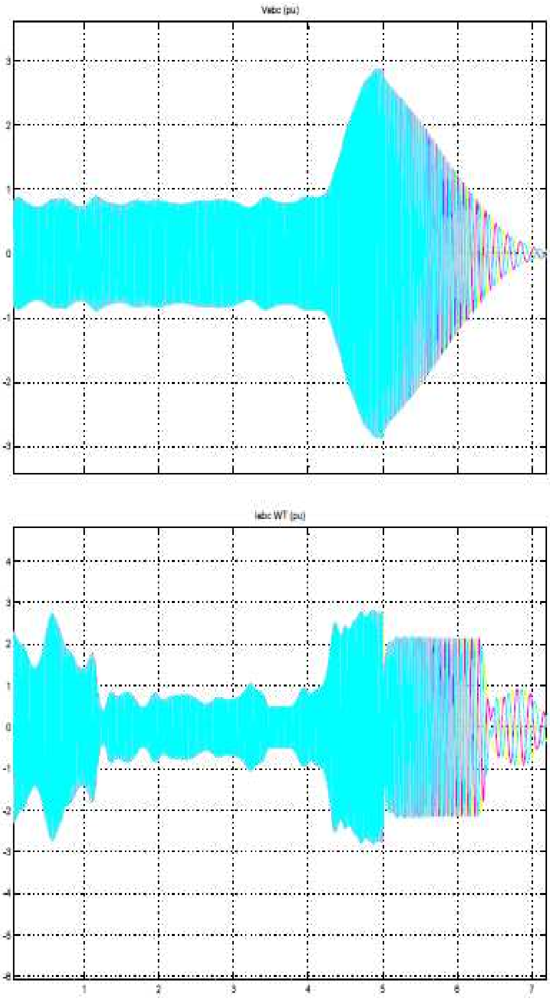
Figure 3 The voltage waveform at bus (WT).

This ferroresonance may be due to the nonlinearity of the coil which is due to the nonlinearity of the magnetization characteristic of the iron core [12].

V. OVERVOLTAGES IN A DISTRIBUTION NETWORK

In the simulation of transient phenomena in powers systems it is necessary to use models of elements which have electrical properties corresponding with real elements of power systems. Just the model of transformer which respect real hysteresis loop has been a subject of miscellaneous researches for a long

Figure 4 The overvoltage at bus (WT) due to the ferroresonance



Time (sec)

Fig. 4 The overvoltage at bus (WT) due to the ferroresonance.

time[13] In this study we used a transformer close to the ideal one.. See figure 5.

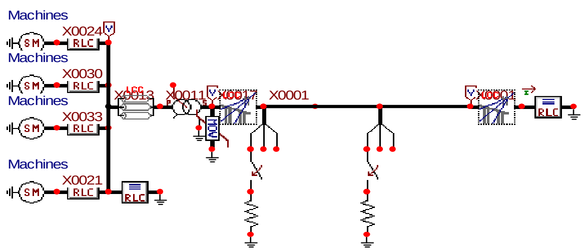


Fig 5. Model of a medium voltage network

The circuit is formed with four synchronous machines used as sources connected to an underground cable, two medium lines and a load. The faults in the system are created by time-controlled switches, connected to splitters to distinguish the faulty phases.

In this analysis the transformer will be delta Y grounded connected then, the lengths of the two lines will be varied.

figure 5Among many types of faults, the single grounding fault may develop into double-grounding fault, which is very dangerous for the power system [14].

In this second part of the paper, the Alternating Transient Program will be used to analyse a medium voltage circuit, with a single grounding fault. We will attempt to see the effect of the line lengths on the peak values of the overvoltages.

The length of the first line takes the following values: 2, 10 and 30 km while the length of the second line takes the values:

Table 1 The voltage peak values in p.u. on the busbar for several line length values.

Line1 (km)	Line2 (km)	PhA (p.u)	PhB (p.u)	PhC (p.u)
2	2	1.26	1.14	1.28
10	20	1.03	1.08	1.00
30	25	0.92	1.02	1.02

Table 2. The voltage peak values in p.u. on the secondary of the transformer.

Line1 (km)	Line2 (km)	PhA (p.u)	PhB (p.u)	PhC (p.u)
2	2	1.34	1.28	1.32
10	20	1.02	1.05	1.01
30	25	1.02	1.01	1.03

2, 20, 25 km.

Simulation results are grouped in tables and discussed below for three nodes:

X0013: the node on the busbar

X0017: the node just after the secondary of the transformer

X0001: the node between the two lines.

The fault occurs at the node X0001. After simulation, the overvoltages of the three phases for different values of lengths, are shown in the followed figures:

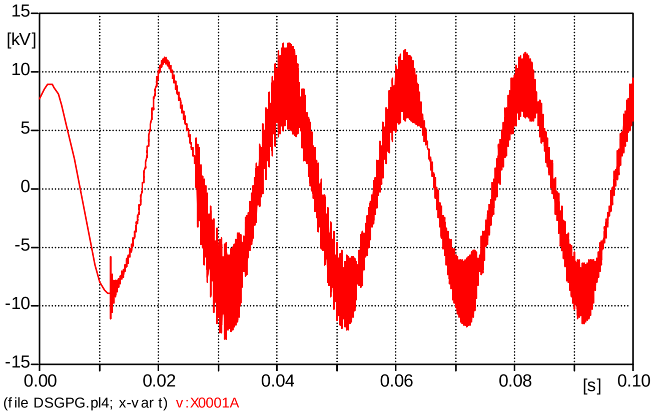


Fig 6. Variation of phase A voltage of node (X0001) at L1=2km, L2=2km

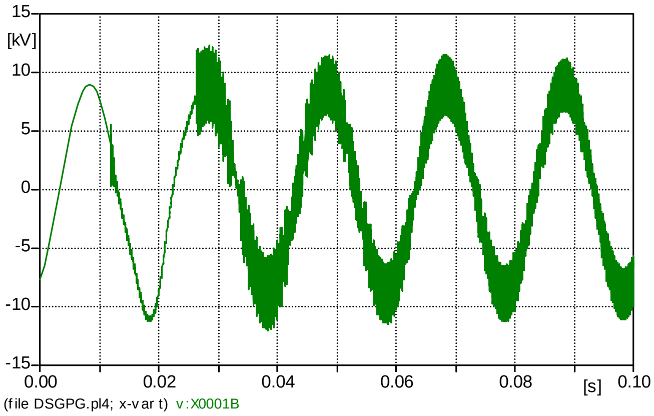


Fig. 7. Variation of phase B voltage of node (X0001) at L1=2km, L2=2km

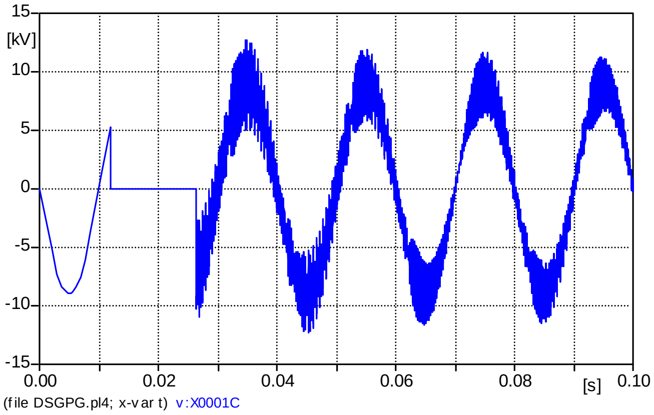


Fig. 8. Variation of phase C voltage of node (X0001) at L1=2km, L2=2km

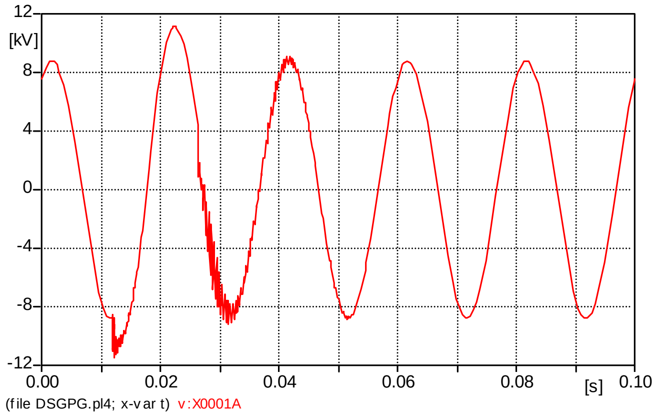


Fig. 9. Variation of phase A voltage of node (X0001) at L1=10km, L2=20km

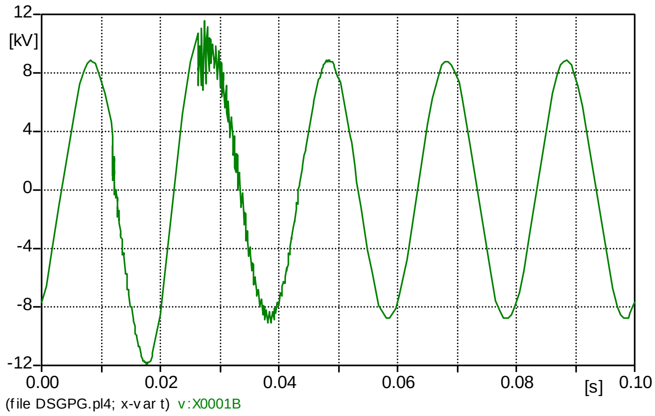


Fig10. Variation of phase B voltage of node (X0001) at L1=10km, L2=20km

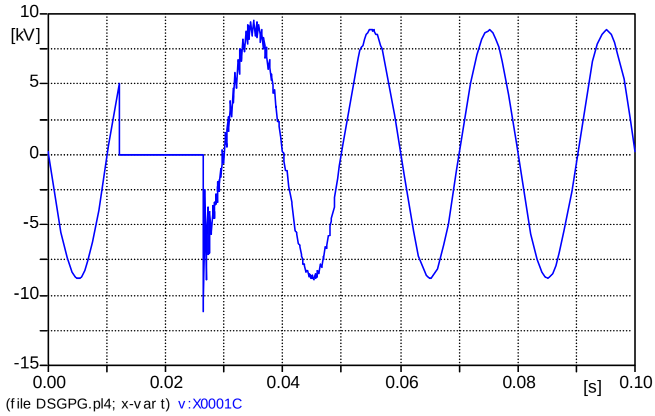


Fig. 11 Variation of phase C voltage of node (X0001) at L1=10km, L2=20km

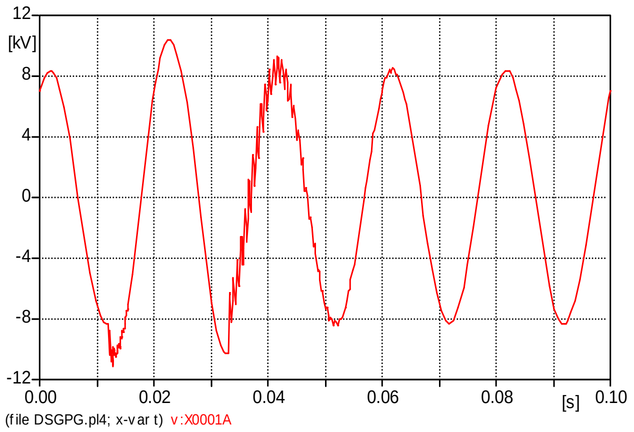


Fig. 12 Variation of phase A voltage of node (X0001) at L1=30km, L2=25km

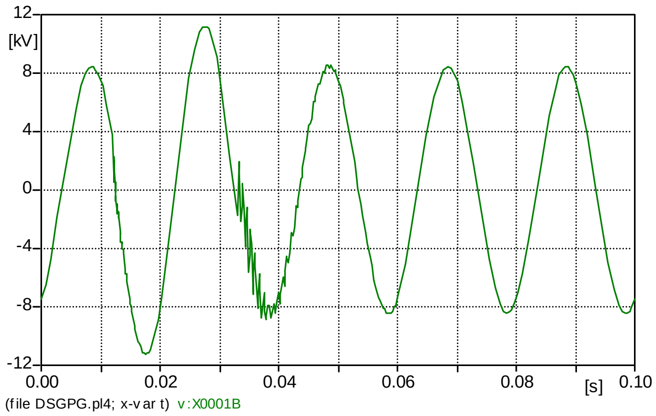


Fig. 13 Variation of phase B voltage of node (X0001) at L1=30km, L2=25km

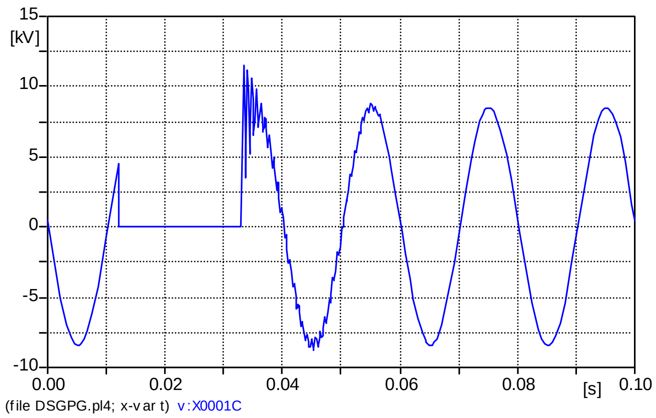


Fig. 14 Variation of phase C voltage of node (X0001) at L1=30km, L2=25km

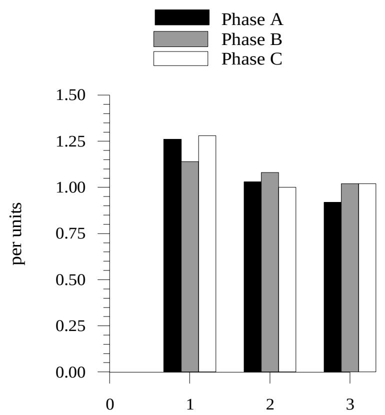
A summary of the obtained results at the node (X0001) voltages is given in the table 3.

Table 3. The voltage peak values in p.u. at the node (X0001).

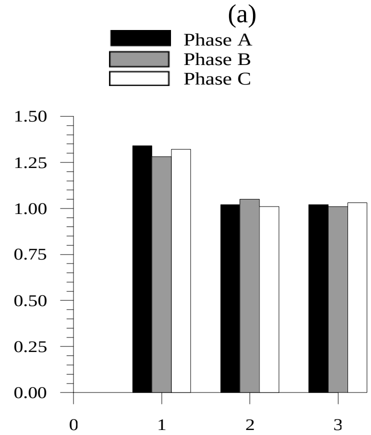
Line1 (km)	Line2 (km)	PhA (p.u)	PhB (p.u)	PhC (p.u)
2	2	1.42	1.36	1.41
10	20	1.24	1.32	1.24
30	25	1.23	1.25	1.27

At the node X0001, the maximum overvoltages that appear in the system occurs in the transitory period after the closing of the two switches.

It is important to note that the most adverse situation, occurs only when the two lines are 2km, the overvoltage peak value reaches 1.42 p.u. with high frequency of oscillation after the opening of the second switch as shown in figures 6, 7 and 8. These oscillations decrease considerably when the lines lengths increase, as shown in figures 9, 10, 11, 12, 13 and 14. The results are grouped in figure 15.



(a)



(b)

Fig 15: variation of the voltages peak values with the lines lengths

VI. Effect of Feeding Line

The feeding cable is replaced with a line, as shown in the figure 15.

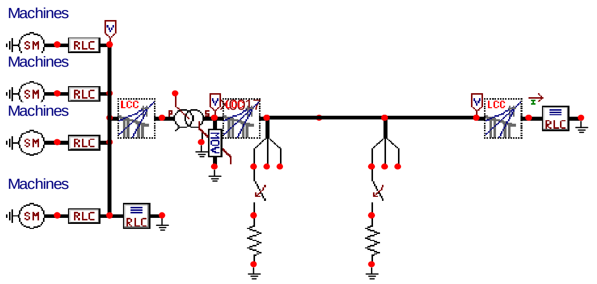


Fig. 16. Model of MV circuit, the cable feeding the transformer is replaced with a line.

Simulation results are given in the following:

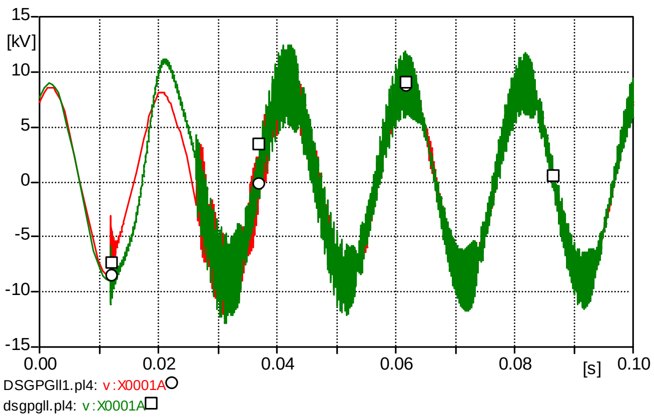


Fig. 17. Comparison between the variation of phase voltage A, in the case of cable feeding the transformer, and the case when the cable is replaced with a power line.

The overvoltage peak value for the line (green curve) is higher than the overvoltage peak value for the cable (red curve), the frequency of oscillation is nearly the same, because the capacitance of the cable is greater than the capacitance of the line.

VII. Conclusion

In this work, an attempt is made to use the MATLAB/SIMULINK to reselect the adequate three- phase capacitor bank size and the ATP to study the overvoltages in a medium voltage circuit. For the first part of the work, 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 ofcapacitor 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.

About the second part of this paper, simulations of the overvoltages in distribution network were attempted using the ATP. These simulations showed that the distribution transformer connections have a high effect on the overvoltages peak values when the faults occur. In the case of delta-star grounded transformer connection, for L1=10km and L2= 20km at the phase C of the node X0001, the maximal overvoltage peak value is 1.24 p.u., the distribution branch lengths have also an effect on the overvoltage peak values, as we noticed from the simulation results. Finally, when the lines of the circuit are replaced with cables, we can see a decrease of the overvoltage peak values and considerable damping of the frequency of the oscillations.

A distributed circuit is optimal if the size of the capacitance bank is appropriate to the values of the system to avoid ferroresonance, and a good size of the lines lengths is chosen.

References

[1] R. C. Bansal "Three-Phase Self-Excited Induction Generators: An Overview" *IEEE transactions on energy conversion*, vol. 20, no. 2, pp-292-299, 2005.

[2] Mustafa A. A1-Saffar, Eui-Cheol Nho, Thomas A. Lipo "Controlled Shunt Capacitor Self-Excited Induction Generator" *IEEE* 0-7803-4943-1/98, *1998*.

[3] L. C. Wagner, W. E Feero, W. B.Gish, and R. H.Jones, "Relay Performance in DSG Islands," IEEE Transactions on Power Delivery, vol. 4, no. 1, pp. 122–31, 1989.

[4] Weisser Daniel, Raquel Garcia S. "Instantaneous wind energy penetration in isolated electricity grids: concepts and review" Renewable Energy 30, pp.1299–1308, 2005.

[5] W. E. Feero and W. B. Gish, "Over voltages caused by DSG operation: Synchronous and induction generators," IEEE Trans. Power Delivery, vol. 1, no. 1, pp. 258-264, January 1986.

[6] P. S. Moses, M. A. S. Masoum, "Modeling Ferroresonance in Single-PhaseTransformer Cores with Hysteresis" Proceedings of the 8th WSEAS International Conference on SYSTEM SCIENCE and SIMULATION in ENGINEERING, Genova, 2009.

[7] Gish, W. B.; Feero, W. E.; and Greuel, S. “Ferroresonance and Loading Relationships for DSG Installations.” IEEE Transactions on Power Delivery, vol. PWRD-2, no. 3, pp. 953–959, 1987.

[8] R. Gagnon, B. Saulnier, G. Sybille, P. Giroux; "Modeling of a Generic High-Penetration No-Storage Wind-Diesel System Using Matlab/Power System Blockset" 2002 Global Windpower Conference, Paris, France, April 2002.

[9] B. VAHIDI, A. HAGHANI ABANDANSARI, “Teaching Ferroresonance in Power System to Undergraduate Students by Using MATLAB_SIMULINK “ Wiley Periodicals Inc., pp.1-12, 2009.

[10] B. Saulnier, A.O. Barry, B. Dube, R. Reid; "Design and Development of a Regulation and Control System for the High-Penetration No-Storage Wind/Diesel Scheme" European Community Wind Energy Conference 88, Herning, Denmark, pp.6-10 June 1988.

[11] G.K Singh. "Self-excited induction generator research—a survey" Electric Power Systems Research 69, pp. 107–114, 2004

[12] K. MILIČEVIĆ, I. RUTNIK "Impact of Initial Conditions and Voltage Sourceon the Initiation of Fundamental Frequency Ferroresonance", 12th WSEAS International Conference on SYSTEMS,, July 22-24, Heraklion, Greece, 2008.

[13] J. DRÁPELA, P.TOMAN, J. ORSÁGOVÁ, M.KRÁTKÝ "Simulation of Ferroresonance Phenomena in Power Systems) "Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp373-377 "

[14] T.Dumitru. "A Fuzzy Approach Used in Expert System for Optimal Neutral Grounding " Proceedings of the 10th WSEAS International Conference on FUZZY SYSTEMS, 2009, Prague.