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Progressive usage of the synchronous machine in electrical power systems

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ABSTRACT

In traditional electric-power systems, synchronous generator based center electric-power plants have been the main origin of dynamic reactive power sustenance, but owing to the steady growth in the number of renewable power generating plants across the globe and the concurrent dismantling of these rotating synchronous machines principally driven by the demand to decrease carbon emission and reliance on fossil fuels, the need for grid-stabilizing systems is increasing. Also, traditional electric-power generating units are approaching the end of their useful operational life and utility authorities are faced with a difficult resolution of retiring electric-power plants. One way of resolving these issues is the refurbishment of these machines that is the electric-power plants to synchronous condensers. This paper presents a brief assessment of the synchronous machine and the motivation for this research work. It discusses the importance of the synchronous machine in electrical power systems, and the progressive trend in the use of the synchronous machine in electric-power networks. It stresses the need for the use of the synchronous machine for reactive power compensation purposes, with a vivid description given with MATLAB/Simulink simulation model. When the synchronous condenser is connected to the power system model at the terminating end of the network and switched ON, the medium voltage (MV) electrical power network simulation model effectively allows the control of reactive power, which improves voltage stability and power flow control of the proposed network.

Keywords: synchronous machine; refurbished synchronous machine; synchronous motor; synchronous generator; synchronous condenser; reactive power compensator; electrical power systems.

1. INTRODUCTION

A machine is a device using mechanical power and having various parts, each with a well-defined purpose and jointly performing a specific task. In usual term, it is a semi or fully automated piece of equipment that magnifies human physical and/or mental ability in carrying-out one or more task. And, from systems frame of reference, it is a purposefully efficient set of components whose interconnections and inner mechanism are clearly understood. The behavior of a correctly functioning machine is absolutely predictable: its current state controls its next state, and the same inputs every time produces the same outputs. [1], [2], [3], [4], [5], [6], [7], and [8]. Synchronous means happening at the same time; contemporaneous; coinciding in time; simultaneous, happening, existing, or arising at exactly the same time, recurring or operating at exactly the same periods, requiring or designating synchronism, having the same period; also, having the same period and phase [9] and [10].

Synchronous machines are rotating electrical machines with Direct Current (DC) field winding on the rotor, and Alternating Current (AC) armature winding on the stator; it works as a generator when it changes mechanical energy to electrical energy. Also, it can function as motor when it changes electrical energy to mechanical energy [11] and [12]. It supplies vital part of the energy in an electrical power system, and usually comprises of a few kVA to a few hundred MVA, the largest are normally rated 1500 MVA. This machine plays significant part in electric power systems, in that they impose the frequency of sinusoidal voltages and currents, they supply energy buffer, through the kinetic energy deposited in their rotating masses. And they can supply or absorb reactive power, which is needed to control voltage in electrical networks [13].A synchronous machine is an AC rotating machine whose speed under steady state situation is proportional to the frequency of the current in its armature. The magnetic field generated by the armature currents rotates at the same speed as that generated by the field current on the rotor, which is rotating at synchronous speed, and a steady torque result is produced. Synchronous machines are often utilized as generators mainly for sizeable power systems, such as turbine and hydroelectric generators in electrical grid power supply. Because the rotor speed is proportional to the frequency of excitation, synchronous motors can be utilized in circumstances where constant speed drive is essential. Since the reactive power produced by a synchronous machine can be modified by controlling or regulating the magnitude of the rotor field current, unloaded synchronous machines are as well frequently inserted in power systems exclusively for power factor rectification or for regulation of reactive kVA flow. Such machines, known as synchronous condensers, can be made cheaper with the production of bigger dimensions of the device [14], [15], and [16].

This research paper emphasizes the need for the refurbishment of the synchronous machine to synchronous condenser for reactive power control purposes, a clear illustration is established with the MATLAB/Simulink simulation of a 33 kV MV electrical power network supply. Simulation results obtained with the Synchronous condenser installed onto the network, shows that, the synchronous condenser when switched ON effectively allows the regulation of reactive power which improves voltage stability and power flow control of the proposed electrical network model.

2. MOTIVATION FOR THIS RESEARCH WORK

Nowadays, renewable energy generating plants are being added promptly to power system networks worldwide, this is principally motivated by the need to minimize carbon emission and over-reliance on fossil fuels. Many countries have set goal to realize its electricity generation from renewable power sources. This has led to the continual displacement of traditional electric-power plants by renewable power generating plants as hitherto being accomplished in some countries, center Conventional Power Plants (CPPs) are even then being taken out of the electric-power grid network with the desired result of least or non CPPs attached to the grid in the near future [17], [18], [19], [20], and [21].

Traditional electric-power plants are being replaced by renewable power generating plants, nevertheless as an alternative to dismantling these traditional power plants, the refurbishment of these machines to synchronous condenser by de-clutching their turbine shaft from the rotor shaft can be one of the practical solution to the much-needed problem of dynamic reactive power provision in large-scale renewable power integrated electric-power systems. Also, every power plant will one day get to the end of their useful operational life and utility authorities are confronted with a difficult resolution of retiring the plants, the option is still to refurbish these existing electric-power plants to synchronous condensers. Refurbishment of conventional power plants in existence or operation at this current time to synchronous condensers can be one of the straightforward method to realize a cost-effective approach to tackle dynamic voltage control issues in electric-power systems. This methodology can reduce or even keep away utility authorities from installing new infrastructure that or else would be required to continue dependable and steady functioning of large-scale renewable integrated electric-power systems. Nonetheless, in addition to the dynamic reactive power provision gotten from the equipment, refurbished Synchronous Condensers (SCs) can as well provide more services such as short term overloading, inertia etc. It is of benefit to know that the operating and maintenance cost estimate of synchronous condensers is on the high side as compared to its Flexible Alternating Current Transmission Systems (FACTS) technology counterparts [20], and [21].

3. IMPORTANCE OF THE SYNCHRONOUS MACHINE IN ELECTRICAL POWER SYSTEMS

The synchronous machine is a significant electro-mechanical energy converter. Synchronous generators normally function together or in parallel, to form a big power system providing electrical energy to consumers. For these applications, synchronous machines are built in big units, their rating spanning tens to hundreds of megawatts. For high-speed machines, the prime movers are normally steam turbines utilizing fossil or nuclear energy resources. Low-speed machines are frequently driven by hydro-turbines that use water power for generation. Smaller synchronous machines are occasionally employed for private generation and as standby units, with diesel engines or gas turbines as prime movers. In a big generator, the rotor is magnetized by a coil wrapped around it. Figure 1, shows a two-pole rotor, it will be of note that salient-pole rotors usually have more than two poles. When intended for use as a generator, big salient-pole machines are driven by water turbines. Figure 2, displays the three-phase voltage gotten at the terminating ends of the generator and the equation given portrays the speed of the machine, its number of poles, and the frequency of the voltage outcome.

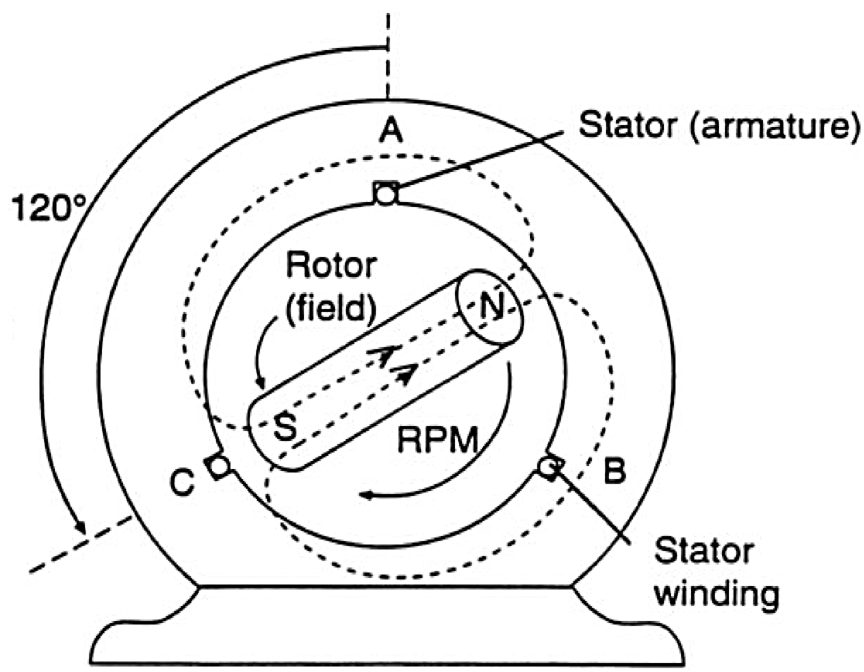

Figure 1 Schematic cross section of a salient-pole synchronous machine [22].

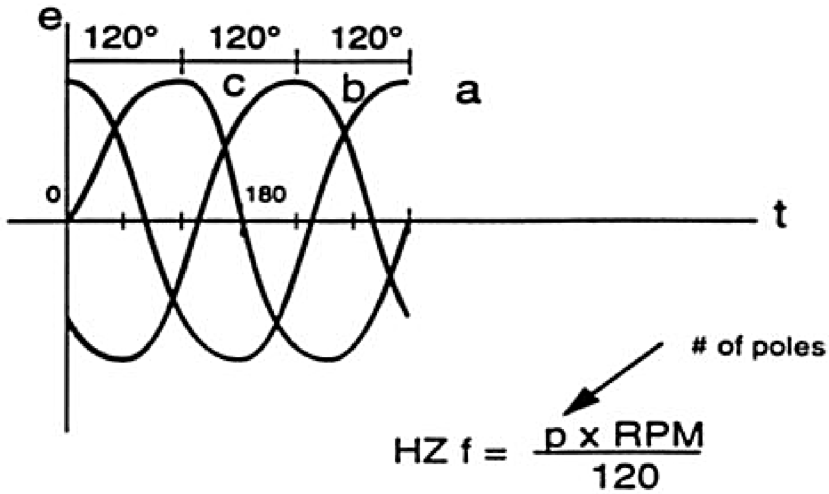

Figure 2 A three-phase voltage waveform gotten at the terminating ends of a salient-pole synchronous machine used as a generator [22].

Where in figure 2; f = electrical frequency in Hz, p = number of poles of the machine and RPM = speed of the revolving field in revolutions per minute (rpm).

Synchronous machines can also be utilized as motors, but they are normally built in very big dimensions. The synchronous motor functions at an exact synchronous speed, and consequently is a constant-speed motor; it has variable power factor attributes, and thus fits for power factor correction applications. A synchronous motor functioning without mechanical load is called a compensator or synchronous condenser. It acts correctly as a variable capacitor when the field is over-excited, and as a variable inductor when the field is under-excited. It is frequently utilized in critical locations in electrical power system network for reactive power control [23].

4. PROGRESSIVE TREND IN THE USE OF THE SYNCHRONOUS MACHINE IN TRANSMISSION AND DISTRIBUTION NETWORKS

Electrical power utility authorities always make sure that grid reliability, efficiency, and security is their main concern. But as grid network progresses and load profiles undergo changes, transmission and distribution networks are also being overstretched, which then make the need for voltage support and grid management much more demanding. Universally, electric power utilities are facing numerous new grid challenges and conditions, these includes: Transformations in generation mix; Reduction in conventional or traditional generation; A rise in renewable and distributed generation; Environmental and regulatory policy alterations, and driving the retirement of traditional generating stations. These problems have operational effect on electrical infrastructure, particularly producing an overall deficiency in: Reactive compensation support; Voltage support; System inertia; and Low short circuit strength. This has raised renewed interest and necessity for synchronous condensers in fragile grid applications, most especially in support of renewable generation and High Voltage Direct Current (HVDC) Systems. The synchronous condenser provides electricity utility authorities an easy and dependable solution to address reactive power compensation and voltage support requirements. It supply's power system operators with proven robust and reliable solution, which can deliver both steady state and dynamic support to electric power systems efficiently. Synchronous condensers have been utilized conventionally in electric power applications to sustain electrical networks that has insufficient power factor and to regulate or control voltage in a network. The function of the synchronous condenser has been relatively fulfilled by static devices such as static VAR compensators (SVCs) and static synchronous compensators (STATCOMs). These static devices have the benefit of quicker responses. In some grid fault conditions, the synchronous condenser supply higher reactive power, and, more significantly, the kinetic energy accumulated in the rotor gives inertial support to the power grid during fault situations. The inertial support ability and fast response time become more significant as the grid-connection prerequisites, such as low voltage ride-through become more inflexible. Synchronous condenser devices are capable of providing real power during fault conditions in electrical grid networks, the real power is supplied by the rotating mass inertial response [15], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35] and [36].

As renewable energy sources are being added rapidly to power systems globally, traditional power plants are therefore being displaced by renewable power generation. Gas and steam power production plants are in the same vein being retired and some advancing towards the end of their functional life, power plant owners faces a difficult resolution between refurbishing and dismantling/retiring their plants. Dismantling/retiring a power production unit can decrease a plant's reactive power ability, perhaps resulting in shortfalls that directly have an effect on the local system's reliability. If a unit is dismantled/retired, the challenge will be to keep in good condition grid voltage at or near the plant interconnection point, in order to make sure that there is grid reliability. Nevertheless, there is possibly a more economical and beneficial solution: which is converting existing synchronous generators into synchronous condensers. A recent refurbishment from generator to synchronous condenser has the plant not only stabilizing the grid and keeping the lights on in situations of high demand, but as well keeping the air cleaner in the process. [37], [38], [39], and [40].

Synchronous machines that are designed solely to provide reactive power sustenance are called synchronous condensers. Synchronous condensers have all of the response speed and controllability benefits of generators without the requirement to construct the rest part of the power plant, such as fuel handling equipment and boilers. Because they are rotating machines with moving parts and auxiliary structures, they may need notably more maintenance than static substitutes. They also consume or use-up real power, equivalent to about 3% of the machine's reactive power grading. The synchronous condenser supports voltage regulation, by drawing-up leading current when line voltage sags, which increases generator excitation thereby restoring the electrical power line voltage, this is illustrated in Figure 3, showing the curves with and without (w/o) the synchronous condenser connected to an electrical power line. The ability of a synchronous condenser can be improved by substituting the copper wound iron field rotor with an ironless rotor of high temperature superconducting wire, which have to be cooled to liquid nitrogen boiling point of 77oK (-196oC). Synchronous machines, be it motor or generator with controllable field has reactive power abilities. Active power is the energy made available to run a motor, heat an apartment, or light-up an electric bulb, reactive power provides the main purpose of regulating voltage. If voltage on the system is not adequate, active power cannot be supplied in an electrical grid network. Reactive power is utilized to supply the voltage levels essential for active power to do beneficial tasks. Reactive power is necessary to move active power all through transmission and distribution networks to the electricity consumer. Reactive power (VAR) is a prerequisite to keep in good condition the voltage to convey active power (watts) through electrical transmission lines. Motor loads and other loads need reactive power to convert or change the flow of electrons into beneficial work. When there is not enough reactive power, the voltage sags down and it is not feasible to push the power required by loads through electrical power lines [13], [14], [15], [23], [41] and [42].

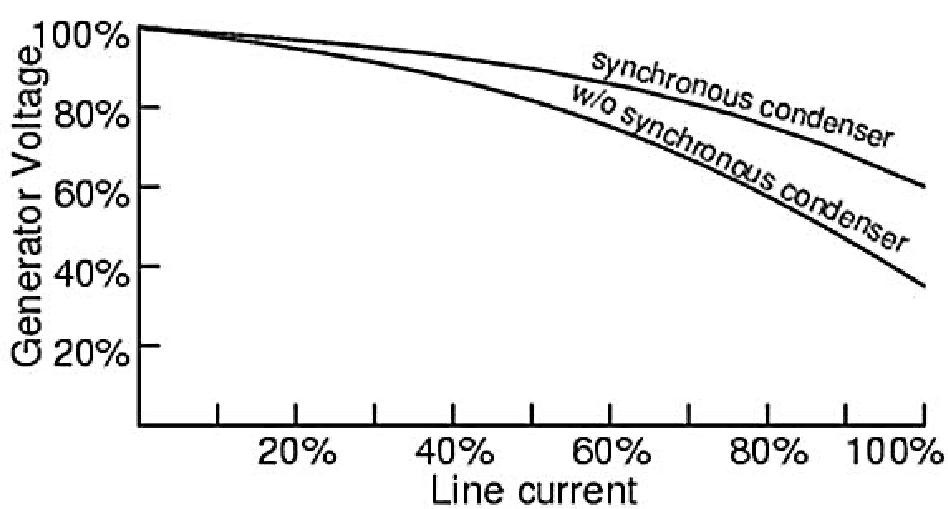

Figure 3 Illustration of the curves obtained with and without (w/o) the synchronous condenser connected to an electrical power line [41].

5. METHODOLOGY

5.1. Description of Method

The research model under study consists of a 132 kV high voltage (HV) alternating current (AC) power supply system source linking a three phase 33 kV medium voltage (MV) power line network with the aid of a 132/33 kV HV/MV transformer. The 33 kV MV power line network is then linked to the MV side of the 132/33 kV HV/MV transformer. Thereafter, a 33 kV 50 Hz load is joined to the three phase 33 kV MV electric-power system, with a synchronous condenser placed at the terminating end of the three-phase power line network via a 33/25 kV MV transformer. The schematic diagram of the proposed model without and with the synchronous condenser installed on the proposed power system network are presented in Figure 4 and Figure 5 respectively.

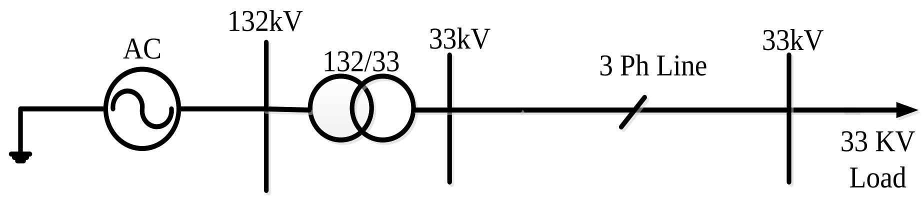

Figure 4 Schematic diagram of the proposed 33 kV MV power system network without the synchronous condenser installed on the network.

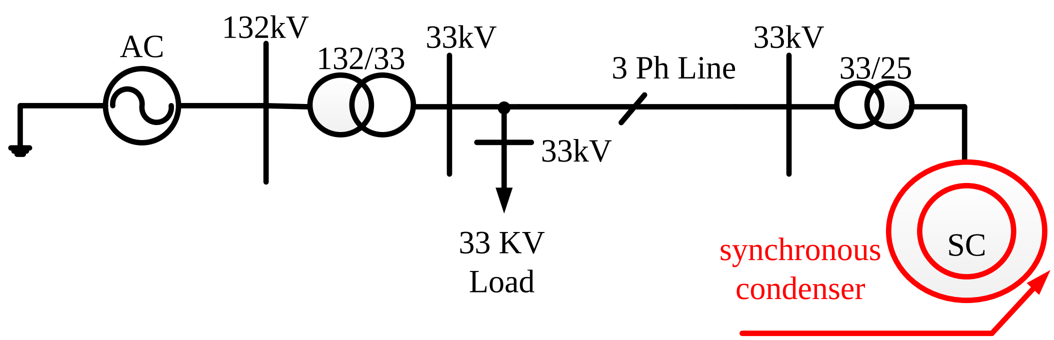

Figure 5 Schematic diagram of the proposed 33 kV MV power system network with the synchronous condenser placed at the extreme end of the network.

To validate the model, three sets of datas have been analyzed, data 1, 2, and 3. With different values of inductive loads of 4, 7 and 10 MVARs, an active power of 30 MW and a capacitive load of 0.5 MVAR joinedto the electric-power system network. The results of both measured and calculated values of the power factor $(\mathrm{Cos}\,\varphi)$ gotten from the network is 0.99, 0.97 and 0.95 for Data 1, 2, and 3 respectively. The power factor of the network is measured and caculated in order to test the validity of the proposed electric-power system network.

5.2. Voltage measurement and direction of power flow

The voltage values measured at the sending and receiving ends of the 33 kV MV electric-power system network for the three sets of data's 1, 2 and 3, with their direction of power flow is obtained. The results of the voltage values obtained and power flow direction observed when the synchronous condenser is switched OFF on the proposed network shows that for data 1 Sending Voltage (U_s) is 32.95, while Receiving Voltage (U_r) is 32.39, therefore Voltage Difference for data 1= 0.56 Volts ;In the same vein for data 2 - Sending Voltage (U_s) is 32.00, while Receiving Voltage (U_r) is 31.70, hence Voltage Difference for data 2 = 0.30 Volts; Also, considering data 3 - Sending Voltage (U_s) is 31.70, while Receiving Voltage (U_r) is 31.30, hence Voltage Difference for data 3 = 0.40 Volts. It can be seen that large voltage differences were gotten from the electric-power system and the direction of power flow observed is positive (+), which means that power flowed from the voltage sending (U_s) end to the voltage receiving (U_r) end of the power line. While the voltage values documented and the power flow directions monitored with the synchronous condenser switched ON for data 1 is Sending Voltage (U_s) is 32.70, and Receiving Voltage (U_r) is 33.10, therefore Voltage Difference for data 1= - 0.40 Volts ; for data 2 - Sending Voltage (U_s) is 32.65, while Receiving Voltage (U_r) is 32,95, hence Voltage Difference for data 2 = - 0.30 Volts; Equally, for data 3 - Sending Voltage (U_s) is 32.20, while Receiving Voltage (U_r) is 32.40, and Voltage Difference for data 3 = - 0.20 Volts, but unlike the previous situation when the synchronous condenser is switched OFF, in this case with the synchronous condenser switched ON, small voltage differences were gotten from the network and the direction of power flow monitored is negative (-), this means that power flows from the receiving(U_r) end to the sending(U_s) end of the proposed 33 kV MV electric-power system network.

6. SIMULATION RESULTS AND DISCUSSION

6.1. Simulation

MATLAB/Simulink software program has been utilized for the simulation of the proposed electric-power system network, two scenarios were considered, first is the Case when the synchronous condenser is switched OFF on the 33 kV MV electric-power system network, which resulted in large voltage differences on the power line. The second scenario is the Case with the synchronous condenser switched ON as regards to the 33 kV MV electric-power line, which gave rise to a small voltage difference on the proposed electric-power system network.

6.2. Results and Analysis

To start with, power factor for data 1, 2, and 3 were measured and thereafter calculated, this has been done as formerly expressed to test the authenticity or validity of the proposed electric-power system under consideration. It was noticed that the measured and calculated values of the power factor gotten were the same for the three sets of data monitored. Simulation model results for the voltage values gotten at the beginning end of the 33 kV medium voltage (MV) electric-power system network with the Synchronous Condenser switched OFF and ON is recorded and a clear and vivid explicit details is presented with a 3D diagram in Figure 6, large voltage differences were noticed on the 33 kV medium voltage (MV) network as compared to the readings recorded at the terminating end of the power line and the direction of power flow is from the voltage sending (U_s) end of the network to the voltage receiving (U_r) end of the power line for data's 1, 2, and 3 monitored. At the beginning end of the electric-power line, results show that the scheme uses up reactive power, when the synchronous condenser is switched OFF. And reactive power is injected into the 33 kV medium voltage (MV) electric-power system network, when the synchronous condenser is switched ON as regards to the proposed network. Also, it is seen that the voltage profile is better when the synchronous condenser is switched ON.

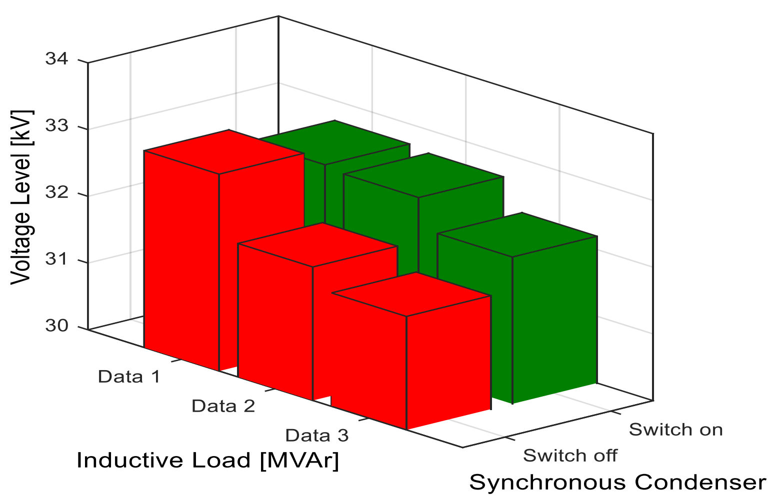

Figure 6 Voltage values at the beginning end of the 33 kV MV electric-power system network when the Synchronous Condenser is swithced OFF and ON

The Synchronous Condenser is equally switched OFF and ONat the terminating end of the line as seen in Figure 7. Results gotten shows that when the synchronous condenser is switched OFF, the electric-power line uses up reactive power. But reactive power is injected onto the 33 kV medium voltage (MV) power line network, when the synchronous condenser is switched ON. Here, the results depict a small voltage difference on the power line as compared to larger values recorded at the starting point of the proposed electric-power system network and the observed power flow direction movement is from the receiving voltage (U_r) end of the proposed electric-power model to the sending voltage (U_s) end of the network. It is also observed that the system experiences drop in voltage values during the whole time when the synchronous condenser was switched OFF, but a better voltage profile is observed when the synchronous condenser is switched ON. This has been illustrated in Figure 7.

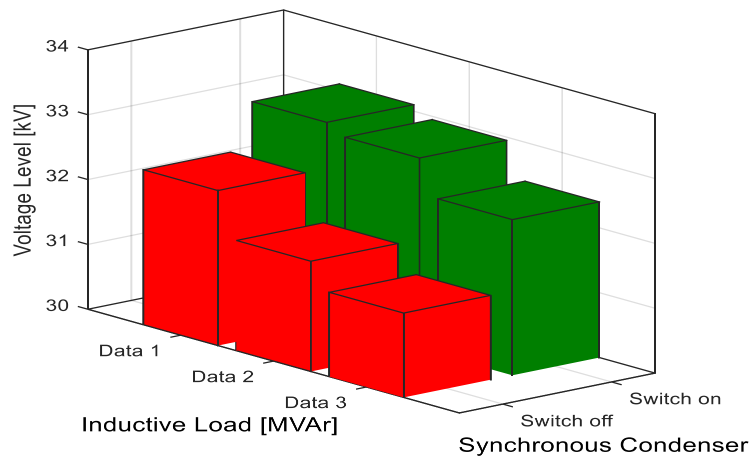

Figure 7 Voltage values at the terminating end of the 33 kV MV electric-power system network with the synchronous condenser swithed OFF and ON

The graphical illustration of the differences in voltage values gotten at the beginning and terminating end of the 33 kV MV electric-power line with the synchronous condenser switched OFF and ON is shown in Figure 8, the noticed directions of power flow for data 1, 2, and 3 is also displayed. Large voltage difference values are noticed and the direction of power flow is from sending voltage (U_s) end to the receiving voltage (U_r) end of the electric-power line, which imply positive (+) direction of power flow for the scenario when the synchronous condenser is switched OFF. Also, the obtained voltage difference values for the observed data's 1, 2 and 3, when the synchronous condenser is switched ON as regards to the electric-power system network is small and the directions of power flow is from the receiving voltage (U_r) terminating ends to the sending voltage (U_s) ends of the proposed network under study, which means that the monitored power flow direction is negative (-). This imply that the case with the synchronous condenser switched ON as regards to the 33 kV medium voltage (MV) electric-power system network gave more favorable result for enhanced voltage stability and power flow control as compared with the scenario when the synchronous condenser is switched OFF. Also, the monitored voltage difference reduces as we observe data 1 through 3 for both switched OFF and ON situations.

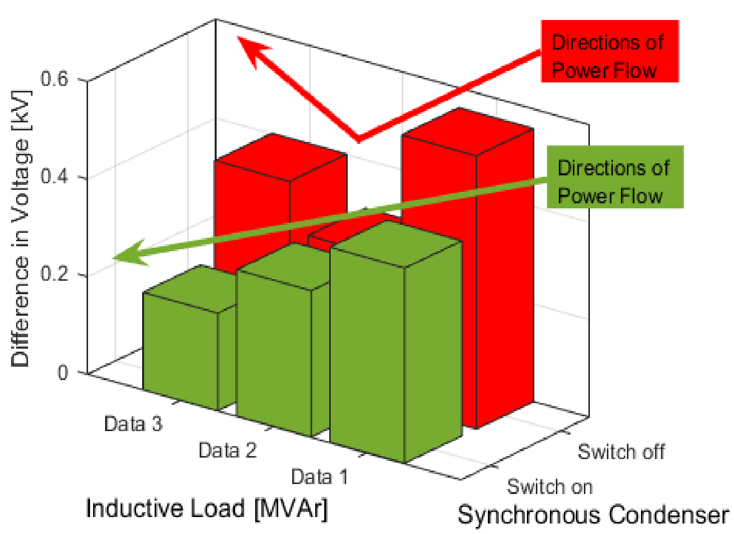

Figure 8 The observed directions of power flow, and the obtained difference in voltage values at the beginning and end terminals of the 33 kV MV power line when the synchronous condenser is swithced OFF and ON.

7. CONCLUSION

Globally, renewable power generating plants are being added continuously to the electricity grid network and many power plants are also getting to the end of their useful operational life time. Thus, electric-power plant utility authorities and other stakeholders in the industry are faced with the difficult decision between dismantling or retiring these plants. The authors of this paper suggest that these rotating synchronous machines should be refurbished to synchronous condensers exclusively for reactive power compensation on the electric-power grid network. The reactive power of a synchronous condenser can be effortlessly regulated by means of its excitation and when placed across electric-power system line, ideally at the receiving terminating end, makes it a good strategy for achieving voltage stability and power flow control in power lines; Synchronous condensers make available active compensation in electric-power lines: the reactive power absorbed or supplied utilizing these devices are by itself with little or no direct human control so as to maintain voltage of the bus bar to which it is connected in an electrical grid network. This research have been able to establish the fact that the synchronous condenser technology allows the regulation or control of reactive power which improves voltage stability and power flow control of electrical power networks. And the authors therefore posit that instead of dismantling and/or retiring power plants, same should be refurbished to synchronous condensers and utilized specifically for reactive power control and probably other applications in electrical power systems; Future research will be;How to sustain stable voltage and ascertain the direction of power flow in a consederably extensive electric-power system network with many branches and also to develop an appropriate control scheme for optimal reactive power compensation in ensuring voltage stability and power flow control in electrical power lines by utilizing the synchronous condenser technology.

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REFERENCE

1. Dictionary.com, Machine [Online]. Available from: http://dictionary.reference.com
2. Merriam-webster Dictionary, Machine, [Online]. Available from: http://www.merriam-webster.com
3. Farlex, The Free Dictionary, Machne, [Online] Available from; http://www.thefreedictionary.com
4. Cambridge English Dictionaries, Machne, [Online]. Available from: http://dictionary.cambridge.org
5. Macmillan Dictionary, Machne, [Online]. Available from: www.macmillandictionary.com
6. Oxford Dictionaries, Machne, [Online]. Available from: www.oxforddictionaries.com
7. Vocabulary.com, Machne, [Online]. Available from: www.vocabulary.com
8. Business Dictionary, Machne, [Online]. Available from: http://www.businessdictionary.com
9. Dictionary.com, Synchronous. [Online]. Available from: http://dictionary.reference.com
10. Merriam-webster Dictionary, Synchronous. [Online]. Available from: http://www.merriamwebster.com
11. G. Heydt, S. Kalsi, and E. Kyriakides, "A Short Course on Synchronous Machines and Synchronous Condensers," American Semiconductor. 2003.
12. P. M. Dusane, M. Q. Dang, F. O. Igbinovia, and G Fandi, "Analysis of the Synchronous Machine in its Operational Modes: Motor, Generator and Compensator," 19th International Student Conference on Electrical Engineering. May 2015. Prague, Czech Republic.
13. T. V. Cutsem, "The Synchronous Machine. Electric Power Systems Analysis and Operation," Universite de Liege. February 2015.
14. Uts.edu, "Synchronous Machines. Electrical Energy Technology," [Online]. Available from: http://services.eng.uts.edu.au
15. F. O. Igbinovia, G. Fandi, J. Švec, Z. Müller, and J. Tlustý. "Comparative review of reactive power compensation technologies," In: IEEE 16th International Scientific Conference on Electric Power Engineering (EPE), Kouty nad Desnou,May 2015. pp. 2-7.
16. Colorado.edu, The Synchronous Machine, Experiment No. 5. [Online]. Available from: http://ecee.colorado.edu
17. EnergyPolicyinDenmark,DanishEnergyAgency,December 2012.
18. Energinet.dkAncillaryServicesStrategy,Energinet.dk,August 2011.
19. System Plan, Energinet.dk, October 2007.
20. Z. H. Rather, Z. Chen, P. Thøgersen, and P. Lund, "Dynamic reactive power compensation of large-scale wind integrated power system," IEEE Transactions on Power Systems. September 2015.vol. 30, no. 5, pp. 2516-2526.
21. A. Deecke, and R. Kawecki, "Usage of existing power plants as synchronous condenser," Przegląd Elektrotechniczny. 2015.vol. 91, no.10, pp. 64-66.
22. G. Klempner and I. Kerszenbaum, "Operation and Maintenance of Large Turbo Generators," John Wiley & Sns, Inc. 2004.

23. T. Chan, Synchronous Machines, “Electrical Engineering – Vol. III. Encyclopaedia of Life Support Systems (EOLSS). [Online]. Available from: http://www.eolss.net
24. General Electric Company, “Synchronous Condenser Systems,” GE Digital Energy 2014. [Online]. Available from: www.gedigitalenergy.com
25. S. T. Nagarajan, and N. Kumar, “Fuzzy logic control of SVS for damping SSR in series compensated power system,” International Transactions on Electrical Energy Systems, 2015. vol. 25, pp. 1860–1874.
26. M. M. Derafshian, and N. Amjady, “A new two-stage framework for voltage stability enhancement incorporating preventive and corrective control actions,” International Transactions on Electrical Energy Systems. August 2015.vol. 25, no. 8, pp. 1492-1521.
27. Y. Miao, H. Cheng, and Y. Yao, “Study of the reactive power control for a real UHVAC power transmission project. International Transactions on Electrical Energy Systems” July 2015.vol. 25, no. 7, pp. 1223-1240.
28. R. Leelaruji, L. Vanfretti, K. Uhlen, and J. O Gjerde, “Computing sensitivities from synchrophasor data for voltage stability monitoring and visualization,” International Transactions on Electrical Energy Systems. June 2015. vol. 25, no. 6, pp. 933-947.
29. H. A. Kojori, S. B. Dewan, and J. D. Lavers, "A large-scale PWM solid-state synchronous condenser," IEEE Transactions on Industry Applications,” January 1992.vol. 28, no. 1, pp. 41-49.
30. S. Ganjefar, and M. Farahani, “Comparing SVC and synchronous condenser performance in mitigating torsional oscillations,” International Transactions on Electrical Energy Systems. November 2015.vol. 25, no. 11, pp. 2819-2830.
31. S. Teleke, T. Abdulahovic, T. Thiringer, and J. Svensson, “Dynamic Performance Comparison of Synchronous Condenser and SVC,” IEEE Transactions on Power Delivery, March 2008.vol. 23, no. 3, pp. 1606-1612.
32. N. Mendis, K. M. Muttaqi, and S. Perera, "Management of battery-supercapacitro hybrid energy storage and synchronous condenser for isolated operation of PMSG-based variable-speed wind turbine generating systems," IEEE Transactions on Smart Grid, March 2014.vol. 5, no. 2, pp. 944-953.
33. P. Hsu, E. Muljadi, Z. Wu, and W. Gao, “Permanent magnet synchronous condenser with solid state excitation,” In: 2015 IEEE Power & Energy Society General Meeting, July 2015. IEEE, pp. 1-5.
34. A. S. Sengar, R. Chhajer, G. Fandi, and F. O. Igbinovia, “Comparison of the Operational Theory and Features of SVC and STATCOM,” 19th International Student Conference on Electrical Engineering. May 2015. Prague, Czech Republic.
35. F. O. Igbinovia, G. Fandi, Z. Müller, J. Švec, and J. Tlustý, “Optimal location of the synchronous condenser in electric-power system networks,” In: IEEE 17th International Scientific Conference on Electric Power Engineering (EPE), Prague, May 2016.
36. F.O. Igbinovia, G. Fandi, Z. Müller, J. Švec, and J. Tlusty, “Cost implication and reactive power generating potential of the synchronous condenser,” In: IEEE 2nd International Conference on Intelligent Green Building and Smart Grid (IGBSG), Prague, June 2016.
37. J. M. Fogarty, and R. M. LeClair, “Converting Existing Synchronous Generators into Synchronous Condensers,” Power Engineering, vol. 115, no. 10, October 2011.
38. General Electric Company, “Synchronous Condenser Conversion, Fact Sheet. Power Generation Services,” 2014. [Online]. Available from: https://powergen.gepower.com
39. Siemens, “Siemens Energy converts U.S. steam turbine generators to synchronous condensers,” August 2013. [Online]. Available from: http://www.siemens.com
40. C. Davidson and W. Wirta, “AES Uses Synchronous Condensers for Grid Balancing. Power,”2014. [Online]. Available from: http://www.powermag.com
41. J. Parmar, “How reactive power is helpful to maintain a system healthy,” Energy and Power. Electrical Engineering Portal. August 2011. [Online]. Available from: http://electrical-engineering-portal.com
42. All about circuits, “Synchronous Condenser,” AC Motors. [Online]. Available from: www.allaboutcircuits.com.