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Dynamic Performance of the Static Var Compensator Enhancement

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***Abstract* —*This paper presents an in-depth investigation of the dynamic performance of the Static Var Compensator SVC theoretically and by exact digital simulation. The major factors of the SVC instability analyzed and a new Automatic Gain Controller AGC proposed to ensure the stable operation of the SVC under various load conditions. The performance of SVC scheme connected to the 230kV grid is evaluated. In addition, all details of the model is implementation, the controls used, and the data for studied system are providing in the paper.*

Keywords — *Automatic gain controller, dynamic performance, Theoretically, Digital simulation, SVC.*

I. INTRODUCTION

Since 1960s, low frequency oscillations have been observed when large power systems are interconnected by relatively weak tie lines. These oscillations may sustain and grow to cause system separation if no adequate damping is available [1-8]. Although Power System Stabilizer's PSS's provide supplementary feedback stabilizing signals, they suffer a drawback of being liable to cause great variations in the voltage profile and they may even result in leading power factor operation under severe disturbances. In this context, Flexible Alternating Current Transmission System FACTS technology, based on modern powerful disturbances. FACTS technology, based on modern powerful semiconductor devices, enables the transmission system to improve its efficiency by regulating the power flow, enlarging the loading capability, increasing the system security and providing greater flexibility, just to enumerate a few benefits.

Particularly, FACTS compensators commanded through proficient control algorithms allow enhancing the stability and transfer capability of present and new transmission lines [8–15] these potentialities come from the faculty of FACTS compensators to act over the interrelated parameters that govern the operation of transmissions systems. Recently, several FACTS devices have been implemented and installed in practical power systems such as SVC, Thyristor Controlled Series Capacitor TCSC, and Thyristor Controlled Phase Shifter TCPS [16-20]. The emergence of FACTS devices and in particular GTO thyristor-based STATCOM has enabled such technology to propose as serious competitive alternatives to conventional SVC.

The thyristor protected series compensation (TPSC), Thyristor Controlled series compensation (TCSC) are those FACTS devices that have a strong influence on the system stability and small or no influence on the voltage quality. The SVC and STATCOM have a strong influence on voltage quality improvement and show medium performance with respect to overall system stability. The unified power flow controllers (UPFC) have shown efficient performance in terms of load flow support, stability and voltage quality. The STATCOM is the best option available for providing efficient voltage quality in the power system [21-25].

The maximum compensating current of the SVC decreases linearly with the ac system voltage and the maximum var output decreases with the square of the voltage. This implies that for the same dynamic performance, a higher rating SVC is required when compared to that of a STATCOM. For an SVC, the maximum transient capacitive current is determined by the size of the capacitor and the magnitude of the ac system voltage. In the case of a STATCOM, the maximum transient capacitive overcurrent capability is determined by the maximum turn-off capability of the power semiconductors employed. [26-31].

This paper investigates the dynamic operation of SVC, and effect of the power system strength on the SVC stability. A new AGC proposed to ensure the stable operation of the SVC under various load conditions. In SVC the total harmonic distortion THD of the output voltage of converter which is very small compared with other low pulse model of voltage source converter currently used to investigate FACTS devices. The complete digital simulation of the SVC within the power system is performed using the Power System Blockset PSB.

II. STATIC VAR COMPENSATOR SVC

The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three Thyristor Switched Capacitor or TSC. Reactors are either switched on-off “Thyristor Switched Reactor or TSR” or phase-controlled “Thyristor Controlled Reactor or TCR”. The control system in Fig. 1 and consists of; voltage regulator that uses the voltage error to determine the SVC susceptance B_{SVC} needed to keep the system voltage constant. A distribution unit that determines the TSC’s “and eventually TSR’s” that must be switched in and out, and computes the firing angle α of TCR’s. A synchronizing system using a Phase Locked Loop PLL synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors [3].

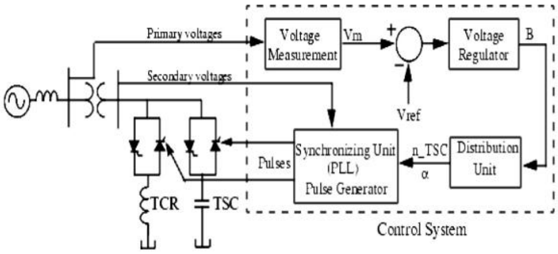


Fig. 1 Single-line diagram of a SVC control system.

The SVC operated in two different modes, voltage regulation mode and in var control mode. When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains, and the system strength Short Circuit Level SCL. An AGC has design to reduce the voltage regulator gain and therefore reduce the oscillations of the SVC in the case of a weak power system. Thus, the voltage regulator gain is set up to give a fast response for a strong system and in the case of a weak power system; the AGC reduces its gain. The designed AGC shown in Fig. 2 shows the SVC block diagram with the AGC.

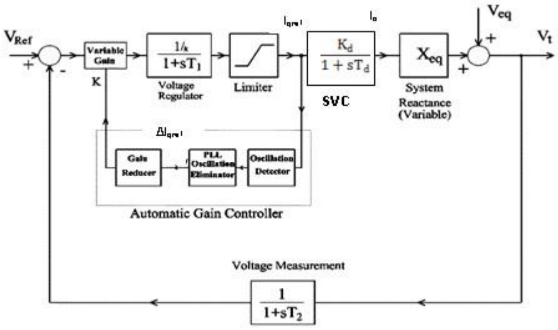


Fig. 2 SVC controller voltage with AGC.

III. STUDIED SYSTEM

To demonstrate the effect of the power system strength on the SVC stability, an exact digital simulation, using the SVC model performed by PSB/Simulink. Figure 3 shows the single line diagram of the simulated power system with the SVC.

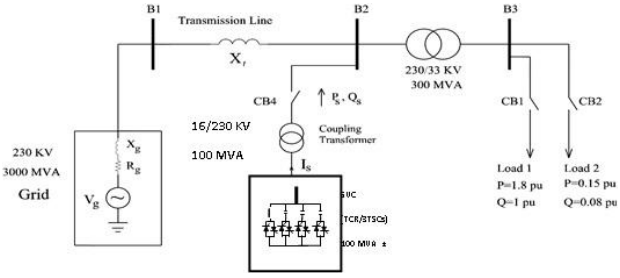


Fig. 3. Single-line diagram of the simulated power system with SVC.

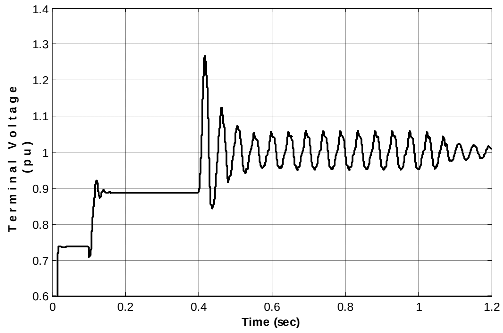
IV. RESULTS AND DISCUSSION

A. *Effect of the SVC on the Power System Strength Stability*

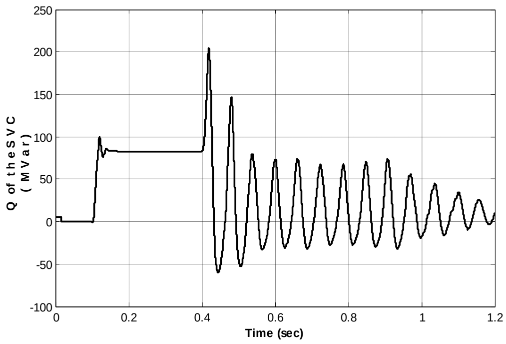
The system reactance X_{eq}, is a part of the feedback loop and it is crucial to note that X_{eq} varies as loads are added to or rejected from the power system or when a transmission line or generator outage occurs. Therefore, the overall closed loop gain and the stability margin of the SVC are greatly affected by X_{eq}, or system strength [18]. If the impedance of the power system increases “weak system”, the amount of voltage changes due to the SVC reactive current increases and the overall system tends to instability. If the power system impedance decreases “strong system”, the system is more stable, although the response is slower than that of the weak system. The digital simulation results are reactive power of the SVC in MVAR, susptance of the SVC B_{svc} in pu, and terminal voltage V_{B2} in pu are discussed, for two cases.

For strong system, the SVC is connected to bus B_2 at t=0.1sec, while both loads are in the power system. It regulates the bus voltage to 0.89pu. While t=0.4sec, load #1 is rejected and only load #2 with low impedance remains. As shown in Fig. 4 reactive power of the SVC, B_{svc} and bus voltages exhibit strong oscillations. Although the SVC has a fast and stable response for the strong system, it exhibits oscillations for the weak power system.

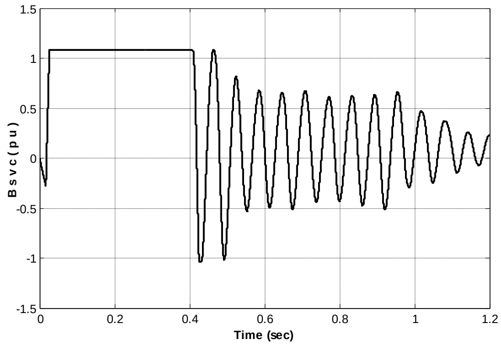
For weak system, the SVC is connected to bus B_2 at t=0.1sec, while load #2 in the power system. While t=0.4sec, load #1 is injected with high impedance. As shown in Fig. 5 the voltage regulates the bus voltage to 0.89pu and therefore the SVC has a fast and stable response for the strong system.



(a) Terminal voltage V_{B2} (pu).

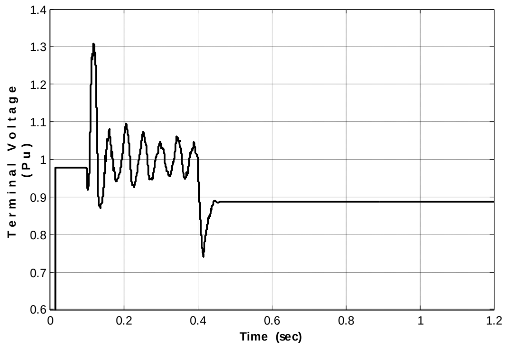


(b) SVC reactive power (MVAR).

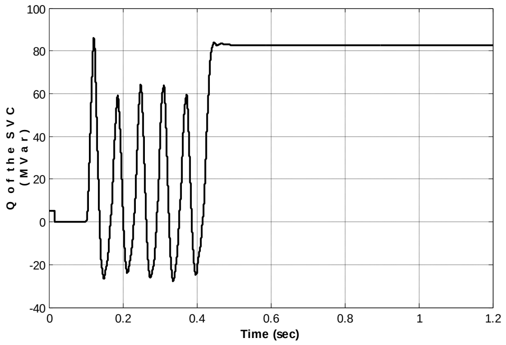


(c) The susptance of the SVC (pu).

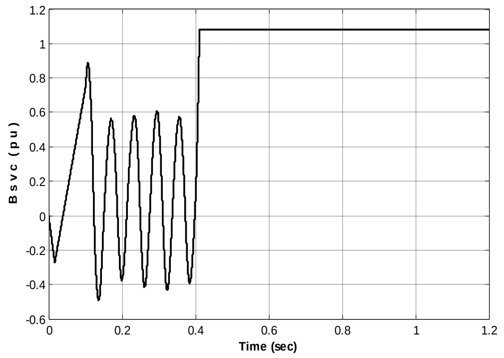
Fig. 4. Effect of the SVC on the power system strength stability for strong system.



(a) Terminal voltage V_{B2} (pu).



(b) SVC reactive power (MVAR).



(c) The susptance of the SVC (pu).

Fig. 5. Effect of the SVC on the power system strength stability for weak system.

B. *Effect of the AGC in SVC on the Power System Stability*

In order to verify the performance of the AGC in stabilization of the SVC, the system of Fig. 6 with the same illustrated loads and same step changes again simulated, while the SVC was equipped with the AGC. The voltage regulator parameters are K_p=3 and K_i=800 and the regulation slope, k=0.9pu. SVC controller voltage with AGC added.

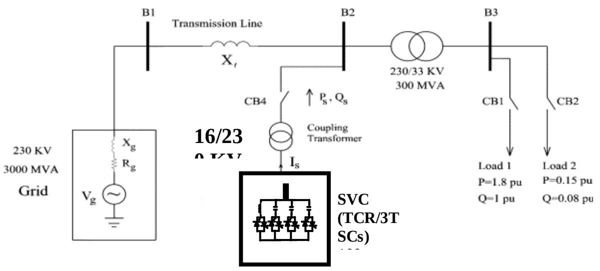
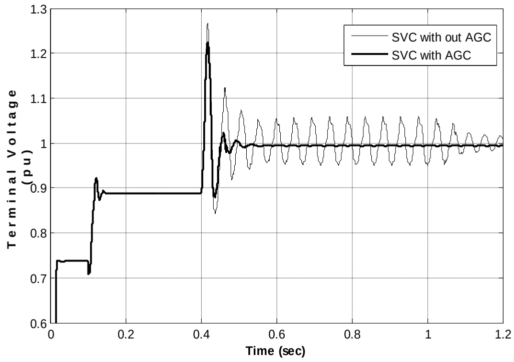
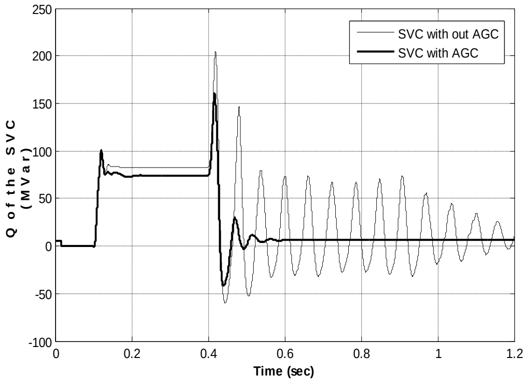


Fig. 6. Single-line diagram of the simulated power system with SVC

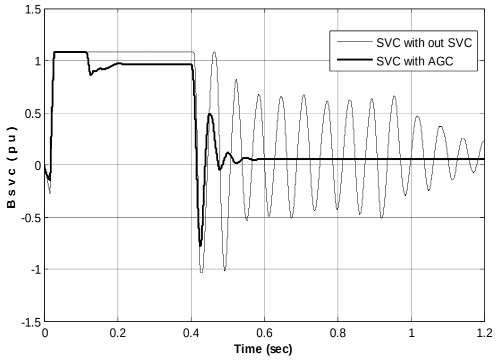
For strong system, the SVC is connected to the power system at t=0.1sec while both loads are in the system and at t=0.4sec, load #1 is rejected. The simulation results are shown in Fig. 7 along with the results of the same system without AGC, to validate the advantage of the AGC. Figure 10a shows that the terminal voltage is stabilized after a few oscillations and as the result, the SVC susptance and reactive power are stabilized, while the system without the AGC is still oscillating at the end of the simulation.



(a) Terminal voltage V_{B2} (pu).



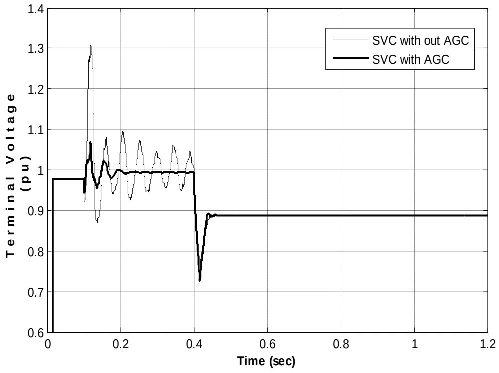
(b) SVC reactive power (MVAR).



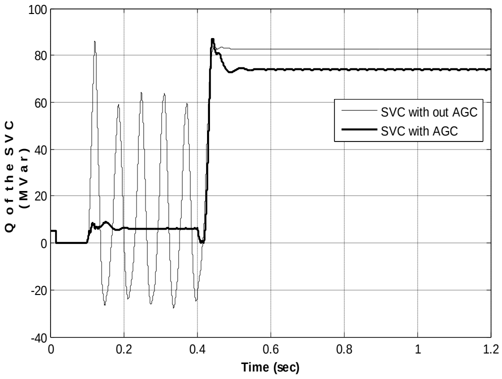
(c) The susptance of the SVC (pu).

Fig. 7. Effect of the AGC in SVC on the power system stability for strong system.

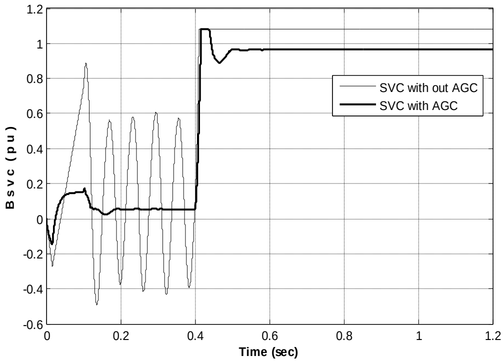
For weak system, the SVC is connected to the power system at t=0.1sec while load #2 in the power system. At t=0.4sec, load #1 is injected with high impedance. The simulation results are reactive power of the SVC, susptance of the SVC, and terminal voltage V_{B2} are shown in Fig. 11 along with the results of the same system without the AGC, to validate the advantage of the AGC. Figure 8 shows that the terminal voltage is stabilized after a few oscillations and as the result, the SVC susptance and reactive power are stabilized, while the system without the AGC is still oscillating at the end of the simulation.



(a) Terminal voltage V_{B2} (pu).



(b) SVC reactive power (MVAR).



(c) The susptance of the SVC (pu).

Fig. 8. Effect of the AGC in SVC on the power system stability for weak system.

V. CONCLUSIONS

The power system strength greatly affects the response time and stability of the SVC, the voltage regulator is set to provide a fast response for a strong system, it may lead to instability for a weak power system, and set to provide a stable response for a weak power system. The response for a strong power system will be very slow and sluggish, as the overall system closed loop gain decreases. The power system greatly affects the response time and stability when added AGC to SVC.

REFERENCES

[1] Kundur, P., "Power System Stability and Control", McGraw-Hill, 1994.

[2] Cai, L.J., Erlich, I., "Simultaneous coordinated tuning of PSS and FACTS damping controller in a large power system", IEEE Trans. Power Syst. Vol. 20, pp.294-300, 2005.

[3] Wang, H.F., "Static Synchronous Series Compensator to Damp Power System Oscillations", Electric Power Systems Research, Vol. 54, pp. 113-119, 2000.

[4] Mithulananthan, N., Canizares, C., Roeeve, J., and Rogers, G., "Comparison of PSS, SVC, and STATCOM for Damping Power System Oscillations", IEEE Transactions on Power Systems, Vol. 18, No. 2, 2003.

[5] Hingorani, N.G., and Gyugyi, L., "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems", IEEE Press, 2000.

[6] Chaudhuri B., Pal B.C., Zolatas A.C., Jaimoukha, I.M., and Green, T.M., "Mixed-Sensitivity Approach to H1 Control of Power System Oscillations Employing Multiple Facts Devices", IEEE Transaction Power System, Vol.18, pp.1149-1156, 2003.

[7] Gabrijel, U., and Mihalic, R., "Direct Methods for Transient Stability Assessment in Power Systems Comprising Controllable Series Devices", IEEE Transaction Power System, Vol.17, pp. 1116-1122, 2003.

[8] Sahoo, N.C., Panigrahi, B.K., Dash, P.K., and Panda, G., "Multivariable Nonlinear Control of STATCOM for Synchronous Generator Stability", Electric Power Energy System, Vol. 26, pp. 37-48, 2004.

[9] Wang, Y.P., Hur, D.R., Chung, H.H., Watson, N.R., Arrillaga, J., and Matair, S.S., "A Genetic Algorithms Approach to Design an Optimal PI Controller for Static VAR Compensator", Proceedings of the Power Conference, Vol. 3, pp. 1557-1562, 2000.

[10] Padiyor, K.R., "Design and Performance Evaluation of Subsynchronous Damping Controller with STATCOM", IEEE Transactions on Power Delivery, Vol. 21, No. 3, pp. 1398-1405, 2006.

[11] Wang, H.F., "Interactions and Multivariable Design of STATCOM ac and dc Voltage Control", Electric Power Energy System, Vol. 25, pp. 387-394, 2003.

[12] Rahim, A.H.M.A., Baiyat, S.A.A., and Acmaghrabi, H.M., "Robust Damping Controller Design for a Static Compensator", Proceeding IEE Vol.149, No. 4, pp. 491-496, 2002.

[13] Xiao, Y., Song, Y.H., and Sun, Y.Z., "Power Flow Control Approach to Power Systems with Embedded FACTS Devices", IEEE Transaction Power System, Vol. 17, pp. 943-950, 2002.

[14] Dong, F., Chowdhury, B.H., Crow, M.L., Acar, L., "Improving Voltage Stability by Reactive Power Reserve Management", IEEE Transaction Power System, Vol. 20, pp. 338-345, 2005.

[15] El-Moursi M.S., Sharaf A.M., "Novel reactive power controllers for the STATCOM and SSSC", Electric Power Systems Research Vol. 76, pp. 228–241, 2006.

[16] Giroux, P., Sybille, G., and Le-Huy, H., "Modeling and Simulation of Distribution STATCOM Using Simulink's Power System Block Set", Proceedings of the 27th Annual Conference of the IEEE Industrial Electronics Society, IECON'01, 2001.

[17] Rodriguez, J., Lai, J.S., and Peng, F.Z., "Multilevel Inverters: A Survey of Topologies, Controls and Applications", IEEE Transaction Industrial Electron, Vol. 49, No. 4, pp. 724-738, 2002.

[18] Mohan, R., and Varma, R.K., "Thyristor-Based FACTS Controllers for Electrical Transmission Systems", IEEE Press, 2002.

[19] Amir H., Norouzi, and Sharaf, A.M., "Two Control Schemes to Enhance the Performance of the STATCOM and SSSC", IEEE Transactions Power Delivery, Vol. 20, No. 1, 2005.

[20] Wenjuan Zhang, "Optimal sizing and location of static and dynamic reactive power compensation," a dissertation submitted to the University of Tennessee, Knoxville, Dec. 2007.

[21] Ahmed Thabet, and Youssef A. Mobarak, "The effect of cost-fewer nanoparticles on the electrical properties of polyvinyl chloride", Electrical Engineering, Vol. 99, Issue 2, pp. 625-631, June 2017.

[22] Hussain M. Bassi, and Youssef Mobarak, "State-Space Modeling and Performance Analysis of Variable-Speed Wind Turbine Based on a Model Predictive Control Approach Engineering, Technology and Applied Science Research, Vol. 7, No. 2, pp. 1436-1443 · January 2017

[23] Youssef A. Mobarak, and Mahmoud M. Hussein "Voltage Instability of Initiation Fault Duration as Influenced by Nodes Short Circuit Levels NSCL with Different Types of Loads", International Journal of Electrical and Computer Engineering (IJECE), Vol. 6, No. 3, pp. 120-129, June 2016.

[24] Youssef A. Mobarak, and Moamen Atef, "Effect of Novel Nanocomposite Materials for Enhancing Performance of Thin Film Transistor TFT Model", International Journal of Advances Applied Siences (IJAAS), Vol. 5, No. 1, pp. 120-129, March 2016.

[25] Youssef A. Mobarak, "Effects of the Droop Speed Governor and Automatic Generation Control AGC on Generator Load Sharing of Power System", International Journal of Applied Power Engineering (IJAPE), Vol. 4, No. 3, pp. 21-30. December 2015.

[26] Youssef Mobarak, Ahmed M. Elnoby, "Improvement of Dynamic Performance of Interconnected Power Systems with Static Synchronous Series Compensator", International Journal of Electrical and Electronics Engineering (IJEEE), Vol. 7, Issue 2, pp. 21-30. July-December 2015.

[27] A. M. Elnoby, Gaber El-Saady, Youssef Mobarak, Mohamed A. A. Wahab, Mohamed, M. Hamada, and Abdel-Moamen M. A, "Robust Technique LFC of Two-Area Power System with Dynamic Performance of Combined SMES and SSSC Control", International Journal of Advances in Engineering & Technology (IJAET), Volume 8 Issue 2, pp. 46-58, Apr. 2015.

[28] Youssef A. Mobarak, "Voltage Collapse Prediction for Egyptian Interconnected Electrical Grid EIEG", International Journal on Electrical Engineering and Informatics, Vol. 7, No.1, pp. 79-88, March 2015.

[29] Ahmed Thabet, and Youssef A. Mobarak, "Experimental Dielectric Measurements for Cost-fewer Polyvinyl Chloride Nanocomposites", International Journal of Electrical and Computer Engineering (IJECE), Vol. 5, No. 1, pp. 13-22, February 2015.

[30] Abdullah Alshehri, Ahmad Hussain, and Youssef A. Mobarak, "Energy-Conversion Measures in the Industries of Saudi Arabia and Development of Methodology for Certification of Energy Personnel in the Kingdom", Energy Policy, Vol. 64, pp. 203-208, 2014.

[31] Youssef A. Mobarak, M. Bassyouni, and M. Almatawa, "Materials Selection, Synthesis, and Dielectrical Properties of PVC Nanocomposites", Advances in Materials Science and Engineering, Vol. 2013, Article ID 149672, 6 pages, 2013.