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Optimum Location and Sizing of FACTS Devices Using Genetic Algorithm

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Abstract

This paper presents a Genetic Algorithm (GA) model for optimum location and sized of Flexible AC Transmission Systems (FACTS) for applied real network. The heuristic methods based on load flow analysis for reading the voltage profile and implementing the perfect location and sized of FACTS devices. Case studies are carried on 380 KV power grid of western region of Saudi Arabia. This research utilizes the steady state model of Unified power flow controller (UPFC)and Static Var Compensator (SVC) which are simulated and done in MATLAB. The obtained result implements the effectiveness of FACTS through employed genetic algorithm to find the best location and appropriate size of device models.

Keywords: FACTS, Genetic Algorithm, Voltage profile, losses, Newton Raphson.

I. INTRODUCTION

Flexible alternative AC systems (FACTS) device is new technological thinking that is based on the substantial incorporation of electronic devices and methods into the high-voltage side of the network, which makes FACT device is electronically controllable and reliable. [2]

The FACTS concept looks at ways of capitalizing on the many breakthroughs taking place in the area of transmission lines and substations in order to increase the control of power flows in the high voltage side of the network during both steady-state and transient condition systems.[3].

Hence, FACTS implementation is very complicated and imposes a specific position with a suitable size in the grid that must be optimal [6-7]. So, the decision to decide which place and size of flexible alternative AC systems are essential and will reflect the system state.

The FACTS controllers can be widely classified as shunt (SVC, STATCOM), series (SSSC, TCSC), and combined series-shunt controller (UPFC).[1] Controllers maybe could be a variable impedance, variable source, or a combination of them.[4] The shunt compensator can enhance the voltage by injecting reactive power at the low voltage bus, while the series controller can be reduced line losses and improved power capability by alleviating the line overloads. [5]

A lot of researches have been written and created in order to use FACTS in the best way regarding the steady-state of the power grid. Some studies are focused on studying a specific type of FACTS or making the comparison between others based on voltage profile, losses, reactive, active power and cost to measure the FACTSs' performance in the grid. [15-19] A significant amount of research has been applied FACTS on alternative energy penetration on the power system, for example, solar photovoltaic (PV), wind, and other renewable energy solutions.[11] Besides, some papers are employed FACTS with distributed generation (DG) for voltage profile enhancement.[12-14] Also, other researches are connected load flow analysis with heuristic methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Evolutionary Algorithms (EA), Evolution strategies (ES), and simulated annealing (SA). [8-10] to employ FACTS model for finding the optimum location, size, and cost parameters.

The main aim of this paper to model FACTS devices in optimum size and location by employing genetic algorithm technique in analyzing the 380 KV grid. The applicable method let FACTSs' work are very effective to enhance voltage profile and line flow results for each bus in the network for a steady-state system. The case study is performed by MATLAB coding, and it is developed and designed based on GA and FACTS.

The Genetic Algorithm optimization techniques have been widely applied in solving the optimal FACTS placement and size problem. The GA is to converge toward the global solution because it, simultaneously evaluates many points in the parameter space. [20]

II. POWER FLOW EQUATION

The power flow problem involves computing the nonlinear algebraic equations for the network that is under steady-state conditions. The Newton-type method is strong convergence characteristics, has proved most successful in solving power flow problems. The power flow equations can be explained, the power flow across the general two-port network elements that are connecting between buses k and m shown in Fig. 1. It is considered, and the following equations are obtained.

The injected active and reactive powers at bus-k ($P_K$and Q_K)

$$P_K = G_{KK} V_K^2 + (G_{KM} cos\delta_{KM} + B_{KM} sin\delta_{KM}) V_K V_M$$

$$Q_K = -B_{KK} V_K^2 + (G_{KM} sin\delta_{KM} - B_{KM} cos\delta_{KM}) V_K V_M$$

$$P_M = G_{MM} V_M^2 + (G_{MK} cos\delta_{MK} + B_{MK} sin\delta_{MK}) V_K V_M$$

$$Q_M = -B_{MM} V_M^2 + (G_{MK} sin\delta_{MK} - B_{MK} cos\delta_{MK}) V_K V_M$$

Where $\delta_{KM} = \delta_K - \delta_M = -\delta_M$, $Y_{KK} = Y_{MM} = G_{KK} + jB_{KK} = Y_K + Y_{KM}$ and $Y_{KM} = Y_{MK} = G_{KM} + jB_{KM} = -Y_{MK}$

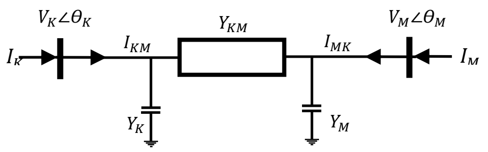

Figure 1: The power flow of two-port network

III. FACTS DEVICES MODELING

The Mathematical models of the FACTS devices are applied and performed to perform the Steady-state research. Therefore, UPFC and SVC are modeled to use the injection power method. The mathematical model of UPFC is integrated into the transmission lines, while the SVC model is incorporated into the bus of sending end as a shunt element of transmission lines. The power-injected method is an effective way for FACTS devices in order to handle them in load flow computation issues. The main benefit of this model is to not destroy the existing impedance matrix Z of the system, so, the FACTS model would be easy to implement in load flow programs. Furthermore, the injected power method through FACTS controllers is convenient and sufficient for improving the electric grid.

A. Static Var Compensator

It is a shunt connected with variable reactance absorbed or generated reactive power to regulate the voltage bus. SVC controller consists of a fixed capacitor (FC) and a thyristor-controlled reactor (TCR). Two models of SVC can be presented, which are firing angle and reactance. The research will focus on practicing SVC as an adjustable reactance with reactance limits. As shown in figure 2, its equivalent circuit is applied to drive the nonlinear power equation of SVC and the linearized equations required by Newton's method.

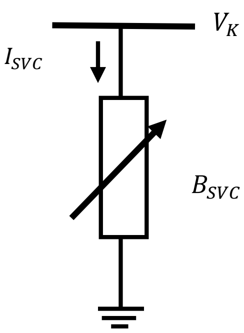

Figure 2: Schematic diagram of SVC

The current (I_{SVC}) formula from the transfer admittance equation that SVC draws is:

$$I_{SVC} = jB_{SVC} V_K$$

While the injective power (Q_{SVC}) equation is:

$$Q_{SVC} = Q_K = -V_K^2 B_{SVC}$$

The linearized equation of SVC is given where the total susceptance B_{SVC} is taken to be the state variable.

$$\begin{bmatrix} \Delta P_K \\ \Delta Q_K \end{bmatrix}^i = \begin{bmatrix} 0 & 0 \\ 0 & Q_K \end{bmatrix}^i \quad \begin{bmatrix} \Delta\theta_K \\ \frac{\Delta B_{SVC}}{B_{SVC}} \end{bmatrix}^i$$

When the iteration is ended (i), the variable susceptance of shunt controller is updated to:

$$B_{SVC}^i = B_{SVC}^{i-1} + \left(\frac{\Delta B_{SVC}}{B_{SVC}}\right)^i B_{SVC}^{i-1}$$

The changing of susceptance value will be presented B_{SVC} to control or maintain the nodal voltage at a limited value.

B. Unified Power Flow Controller

Generally, it consists of two voltage source converters connecting to the network using shunt and series transformers. Both the source converters are employing Gate Turn-off Thyristors (GTOs) and connecting to the capacitor on their DC side. In the figure 3, the equivalent of UPFC is shown the main advantage of two coordinated synchronous voltage sources for the fundamental frequency steady-state analysis. The equation of UPFC voltage sources are:

$$E_{sh} = V_{sh}(cosV_{sh} + jsinV_{sh})$$

$$E_{se} = V_{se}(cosV_{se} + jsinV_{se})$$

Where, $V_{sh}$and V_{sh} are the voltage magnitude and phase angle representing the controllable of shunt source converter. While, V_{se} and □$_{se}$ and are the voltage magnitude and phase angle representing the controllable of the series source converter. The series injected voltage computed the amount of power flow to be controlled. The active and reactive power equations are:

Series converter:

$$\begin{aligned} P_{se} = V_{se}^2 G_{se} + V_K V_{se} [G_{se} \cos(\delta_{se} - \delta_K) \\ + B_{se} \sin(\delta_{se} - \delta_K)] \\ + V_M V_{se} [G_{se} \cos(\delta_{se} - \delta_M) \\ + B_{se} \sin(\delta_{se} - \delta_M)] \end{aligned}$$

$$\begin{aligned} Q_{se} = -V_{se}^2 G_{se} + V_K V_{se} [G_{se} \sin(\delta_{se} - \delta_K) \\ - B_{se} \cos(\delta_{se} - \delta_K) \\ + V_M V_{se} [G_{se} \sin(\delta_{se} - \delta_M) \\ - B_{se} \cos(\delta_{se} - \delta_M)] \end{aligned}$$

Shunt converter:

$$P_{sh} = -V_{sh}^2 G_{sh} + V_K V_{sh}[G_{sh}\cos(\delta_{sh}-\delta_K) + B_{sh}\sin(\delta_{sh}-\delta_K)]$$

$$Q_{sh} = V_{sh}^2 G_{sh} + V_K V_{sh}[G_{sh}\sin(\delta_{sh}-\delta_K) - B_{sh}\cos(\delta_{sh}-\delta_K)]$$

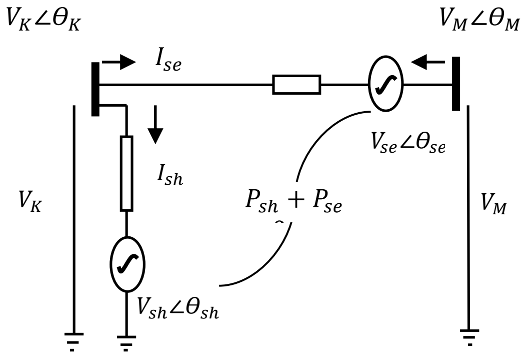

Figure 3: Steady state model of UPFC

IV. GENETIC ALGORITHM

Heuristic methods are applied to solve complex optimization problems that are based on the mechanisms of natural selection and genetics techniques. The techniques of Genetic Algorithms are able to search several possible solutions simultaneously, and they do not require any prior knowledge of the objective function. Also, it is always produced high-quality solutions, and therefore the heuristic method is an excellent technique for the optimal solution in a complex problem. [21] The genetic approach starts with a random generation of the initial population that represents possible solutions to the problem. Then, the fitness of each individual is evaluated by the value of the objective function, which is called the fitness function. The new populations are generated and formed by genetic operators (Reproduction, Crossover, and Mutation) until assigned the maximal number of generations is reached. Figure 4, depicts the Outline of GAs for optimization problems.

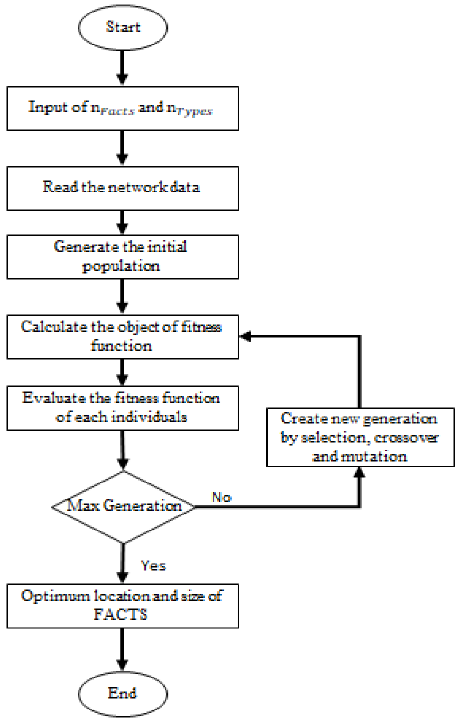

Figure 4: The optimization of GA process

V. PROPOSED GENETIC ALGORITHM METHOD

The main aim of optimization to enhance of voltage profile and reduce the losses by selecting the optimum location and size of SVC and UPFC. The GA is proposed to optimum location and size of a typical 380kV power grid of the western region of Saudi Arabia. The network includes 21 buses, 45 transmission lines, 3 generators, and 18 load buses. Shown in figure 5.

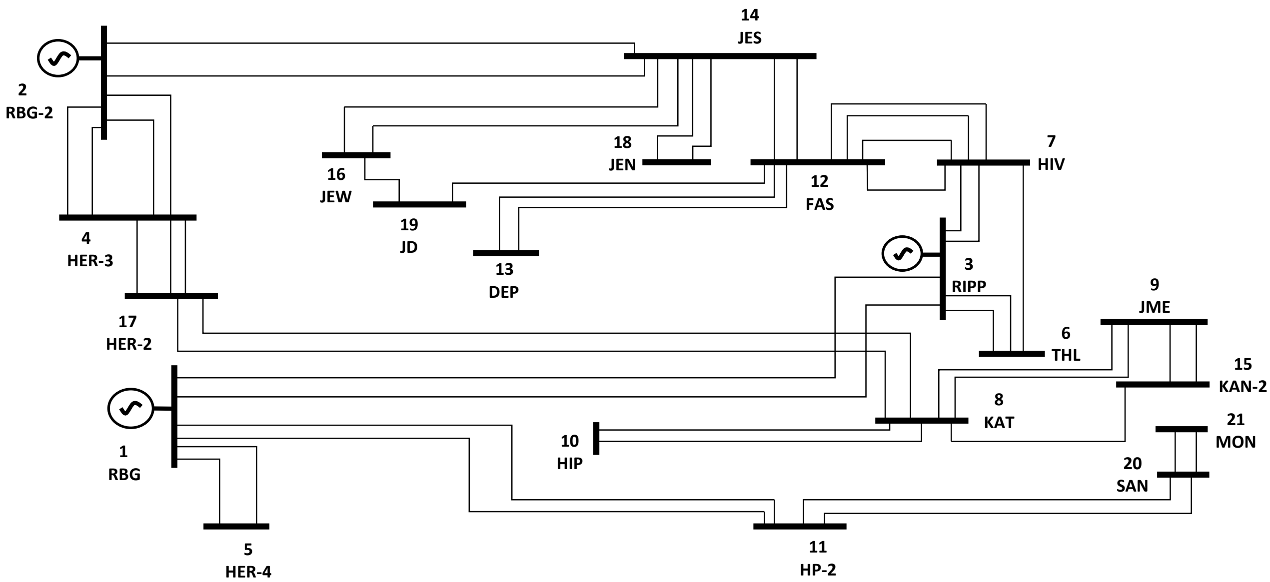

Figure 5: 380 KV of western region

Step 1: For the Test buses, the network of 380 KV of the western region of Saudi Arabia will be collected and considered for this paper.

Step 2: applying Newton Raphson load flow analysis to get the value of voltage bus, angle, real power & reactive power flows, and line losses. Here, the max iteration permitted is 100 & tolerance is 1 e-12 must be specified.

Step 3: through reading the voltage profile data, a genetic algorithm will be initialized and generated to create the population. For GA parameters, population size is considered as 30, and number of generation is 100. At the end of the last generation, GA results in proper compensation range of SVC and UPFC to enhance the voltage profile and reduce the power loss in the system.

Step 4: Now, Newton Raphson's load flow must be carried out. The FACTS devices have already been allocated in the respective lines as considered for the different test systems. By the end of load flow, the results will be developed to get. Step 5: The above steps are repeated for different sizes of FACTS devices under the average loading condition.

VI. RESULTS AND DISCUSSIONS:

A MATLAB coding is developed for genetic algorithms. To verify the effectiveness of the proposed algorithm for the two devices of UPFC and SVC that are applied on the 380 KV network to present the bus and transmission lines results under the normal loading condition.

Table 1: The active and reactive power lines of UPFC results

Line Power		Active Power flow (MW)		Reactive Power (Mvar)		Line Flow (MVA)	
From	To	without FACTS	UPFC	without FACTS	UPFC	without FACTS	UPFC
2	-	2500	2500	-2539.602	-2859.958	3563.647	3798.6
	14	558.704	560.656	4.184	-160.633	558.72	583.214
	4	345.648	344.672	-636.992	-634.673	724.729	722.225
20	-	-370	-370	-151.987	-151.987	400	400
	11	-260.122	-260.19	1194.648	1215.673	1222.64	1243.206
	21	75.122	75.19	-1270.642	-1291.667	1272.861	1293.853

Table 2: The active and reactive power lines of SVC results

Line Power		Power at bus MW		Power at bus Mvar		Line Flow MVA	
From	To	without FACTS	SVC	without FACTS	SVC	without FACTS	SVC
3	-	1200	1189.659	975.577	977.165	1546.529	1539.526
	1	-134.56	-144.612	1514.284	1514.901	1520.251	1521.788
	6	336.611	338.613	-418.482	-418.4	537.06	538.254
	7	397.949	400.828	-608.014	-607.919	726.667	728.168
15	-	-888	-897.659	-364.77	-364.77	960.001	968.943
	8	-410.089	-413.392	-187.526	-187.537	450.931	453.941
	9	-238.956	-242.134	-88.622	-88.616	254.86	257.84

Based on GA that analyzes to select the optimum location of two UPFC devices, which are the lines are 2-14 and 20-21, while the size of controllers is 32.8193 MVA and 7.1807 MVA. On the other hand, the best location of two SVC devices at bus 3 and 15, while their sizes are 10.3406 Mvar and 9.6594 Mvar.

It can be noticed that the UPFC enhanced the active and reactive power lines 2-14 and 20-21, as shown in table 1. Also, the ability of UPFC to control power and reactive let the reliability of the line power flow is increased by 4.38% and 1.65% based on the location. In general, the system's total line flow before and after using the UPFC is 27051.619 MVA and enhance to 27345.106 MVA.

Table 2 illustrates the effectiveness of SVC controller on the transmission lines of buses 3 and 15, which increases the power line flow by 0.15% and 0.85%. Furthermore, the power reactive at bus 3 is 975.577 Mvar without SVC, then after applying FACTS, the value has raised to 977.165 Mvar. Overview, the total line flow of the 380 KV system with SVC is 968.943 MVA which increased 0.93%, than the original value is 960.001 MVA.

It is clearly seen from figure 6 that using FACTS on the applied network has developed the performance of bus voltage (bus 20 and 21) based on the line power flows that are improved. The total losses of 380 KV have become less than 98.963 MW without FACTS, and with using FACTS, the controller is 93.654 MW.

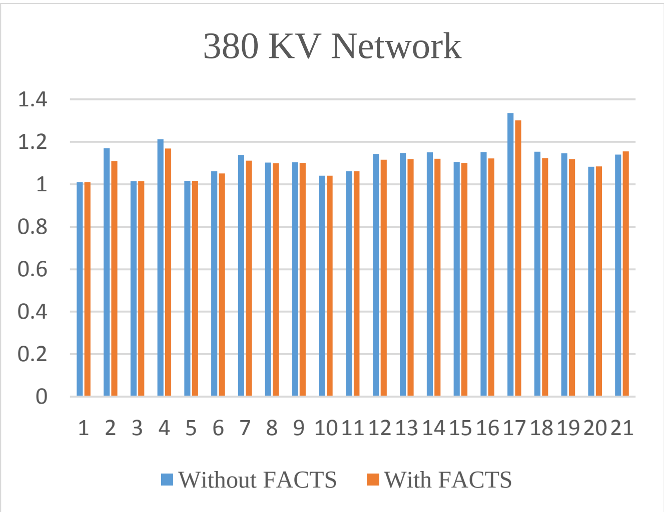

Figure 6: Voltage bus of 380 KV network with using FACTS devices

VII. CONCLUSION

In this paper, the optimal placement and size of FACTS controllers are developed based on a Genetic Algorithm (GA) model for the 380 KV power grid of the western region of Saudi Arabia. UPFC and SVC devices are simulated and selected to improve the performance of the power system of the network. Using the approached method, the individual bus voltages and line power flows are significantly enhanced because of the effectiveness of location and size of FACTS.

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REFERENCES

[1] Narain G. Hingorani, Laszlo Gyugyi, “Understanding FACTS: Concepts and Technology of Flexible ac Transmission Systems”, IEEE Order No. PC571-3, 2000.

[2] Enrique Acha, Claudio R. Fuerte-Esquivel, Hugo Ambriz-Pe´rez, Ce´sar Angeles-Camacho, “FACTS, Modelling and Simulation in Power Networks,” John Wiley & Sons , West Sussex, Pp. 1- 42, 2004.

[3] Yong-Hua Song, “Modern Optimisation Techniques in Power Systems” springer science & business media, 1st adtion1999.

[4] Hingorani NG,” Flexible AC Transmission,” IEEE Spectrum, p. 40-45, April 1993.

[5] A-A. Edris, Chair,“Proposed terms and definitions for flexible AC transmission system (FACTS),” IEEE Transactions on Power Delivery, Vol. 12, No. 4, October 1997.

[6] Rajive Tiwari,K. R. Niazi,Vikas Gupta,“Optimal Location of FACTS Devices for Improving Performance of the Power Systems,” July 2012.

[7] M. Bhandari, S. S. Gurav, “Genetic algorithm based optimal allocation of SVC for reactive power minimization in power systems,” *International Conference on Industrial Instrumentation and Control (ICIC)*, pp.1651-1656, 2015.

[8] Subrata Majumdar,A K Chakraborty,P.K.Chattopadhyay, “Active Power Loss Minimization With FACTS Devices Using (SA/PSO) Techniques,” International Conference on Power Systems, IEEE, pp. 1-5, December 2009.

[9] Arup Ratan Bhowmik, Ajoy Kumar Chakraborty, Priyanath Das, “Optimal Location of UPFC Based on PSO Algorithm Considering Active Power Loss Minimization,” IEEE, Fifth Power India Conference, pp. 1-5, December 2012.

[10] R. Dubey, S. Dixit and G. Agnihotri, “Optimal Placement of Shunt Facts Devices Using Heuristic Optimization Techniques: An Overview,” Fourth International Conference on Communication Systems and Network Technologies, pp. 518-523, 2014.

[11] A. Saberian et al., “Role of FACTS devices in improving

penetration of renewable energy," IEEE 7th International Power Engineering and Optimization Conference (PEOCO), pp. 432-437, 2013.

[12] M. J. Afzal, A. Arshad, S. Ahmed, S. B. Tariq and S. A. A. Kazmi, "A review of DGs and FACTS in power distribution network: Methodologies and objectives," International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), pp. 1-7, 2018.

[13] M. J. Afzal, S. Ahmad, M. A. Arshad and S. A. A. Kazmi, "Voltage improvement of loop configured distribution networks with DGs & FACTS devices,"1st International Conference on Power, Energy and Smart Grid (ICPESG), pp. 1-5, 2018.

[14] P. Yella Reddy, B. Rama Bhupal Reddy,"Losses Minimization In Power Systems Using Unified Power Flow Controller," International Journal of Management, Technology And Engineering, Volume 8, pp 5928-5948 December, 2018.

[15] M. Lakshmikantha Reddy, M. Ramprasad Reddy and Dr. V.C.Veera Reddy, "Analysis of Power System in the Presence of Shunt and Series Facts Devices," International Journal of Engineering Trends and Technology (IJETT).Vol. 33, pp 111-117, March 2016.

[16] S. E. Mubeen, R. K. Nema and G. Agnihotri, "Comparison of Power flow control: TCSC versus UPFC," Joint International Conference on Power System Technology and IEEE Power India Conference, pp. 1-5, 2008.

[17] Aishvarya Narain, S. K. Srivastava,"An Overview of Facts Devices used for Reactive Power Compensation Techniques," International Journal of Engineering Research & Technology (IJERT).Vol.4, Pp. 81-85,December 2015.

[18] V. S. Rao and R. S. Rao, "Comparison of various methods for optimal placement of FACTS devices," 2014 International Conference on Smart Electric Grid (ISEG), Pp. 1-7, 2014.

[19] M. Karami, N. Mariun and M. Z. A. Ab Kadir, "Determining optimal location of Static Var Compensator by means of genetic algorithm,"International Conference on Electrical, Control and Computer Engineering (InECCE). Pp. 172-177, 2011.

[20] P. K. Tiwari and Y. R. Sood, "Optimal location of FACTS devices in power system using Genetic Algorithm," *World Congress on Nature & Biologically Inspired Computing (NaBIC)*, pp.1034-1040, 2009.

[21] Aditya Tiwari, K. K. Swarnkar, S. Wadhwani and A. K. Wadhwani , "Optimal Power Flow with Facts Devices using Genetic Algorithm" International Journal of Power System Operation and Energy Management. Vol.1, Pp.66-72, 2011.