R.Siva Subramanyam Reddy.et.al. Int. Journal of Engineering Research and Applicatiowww.ijera.com
ISSN: 2248-9622, Vol. 7, Issue 9, (Part -3) September 2017, pp.07-12

RESEARCH ARTICLE OPEN ACCESS

Optimal Placement and Sizing of Static Synchronous Series Compensator (SSSC) Using Heuristic Techniques for Electrical Transmission System

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ABSTRACT
The extensive growth of industrial demand and domestic demand will make the power system more expensive. The increase of demands will also leads to the increase of the losses from generation to the distribution level. To achieve the flexible operation of the power system from generation to the distribution along with the exponential growth of load, Flexible alternating currents transmission system(FACTS) devices are used. The inclusion of FACTS devices in the power system will make the system more reliable. With the advancements in the power electronic devices the design of facts devices will also take more advantageous position to operate the power system with more reliable. There are many types of FACTS devices such as series, shunt , series-shunt and shunt-shunt . among these types shunt –shunt FACTS device plays a major role to operate the power system with less power losses and improved voltage profile Static Synchronous Series Compensator (SSSC) is one of the series FACTS device which is used , not only to compensate the inductive reactance of the line and maintain the power system stability at transient conditions also. SSSC is majorly used to improve the voltage profile by reducing the impedance of the line which will reduce the voltage drop across the transmission line. For increasing the voltage profile the placement of the device is so important with the suitable size. So in this paper the a new method is proposed for placing and sizing of the SSSC. By using the optimizing techniques like Genetic algorithm (GA) and particle swarm optimization (PSO) the voltage profile of the system is improved with the placement of the SSSC with suitable sizes.

***Keywords*:** Power systems, Voltage profile, GA, PSO, Losses (KW and MVAR)

Date of Submission: 30-08-2017 Date of acceptance: 09-09-2017

I. INTRODUCTION

Power system is the one of the complex systems which consists of thousands of line and hundreds of buses which are inter connected to each other to satisfy the load conditions. With the exponential increasing of load the sources does not able to satisfy the load conditions which turns into block outs at certain parts of the power system. The losses also play a crucial role to design the generating plants which are connected to the loads to satisfy their need through the transmission lines. The real and reactive behavior of the load will tends to the real and reactive power losses in the power systems. The increase of load does not tend to rising of the generating plants, but the losses are rising with the increase in load conditions. So, by reducing the losses which will improve the voltage profile of the power system. The inclusion of the capacitive effect at the load and at the transmission system will helping in reduction of the losses in the power system. The inclusion of the capacitive effect will provide the leading MVARs to the load and inclusion of the capacitive effect will reduce the inductive nature of the transmission line which reduces overall losses in the power system. With the recent developments in the area of FACTS, the SSSC is one of series connected key FACTS controller used to meet the above problems [1]-[18].

The paper in completely divided in to four parts which are introduction, modeling of SSSC optimizing techniques results and conclusion.

II. POWER FLOW ANALYSIS

The complex systems like power systems are analyzed by using one of the mathematical method analysis which is newton-raphson method to give good convergence. The transmission line in power system can be denoted by a two-bus system "k" and "m" in ordinary form. The active power transmitted between bus nodes k and m is given by:

$$P = \frac{V_k * V_m}{X} \sin(\delta_k - \delta_m) \quad (1)$$

Where δ_k and δ_m are the voltages at the nodes, $(\delta_k - \delta m)$ the angle between the voltages and, the line impedance. The power flow can be controlled by altering the voltages at a node, the impedance between the nodes and the angle between the end voltages. The reactive power is given by:

$$Q = \frac{V_k^2}{X} - \frac{V_m * V_k}{X} \cos(\delta_k - \delta m) \qquad (2)$$

The series compensation of the FACTS device effects the impedance of the transmission line which is connected between any two buses of the transmission system. The reactive nature of the load implies the reactive current from the source ie generating stations of the power system. But the reactive nature of the transmission lines increases the losses of the system.

III. MODELING OF POWER SYSTEMS WITH SSSC

It is acceptable to expect that for the aim of positive sequence power flow analysis the will be represented by a synchronous voltage source with maximum and minimum voltage magnitude limits [4]. The synchronous voltage source stands for the fundamental Fourier series component of the switched voltage waveform at the AC converter terminal of the. The bus at which the is connected is represented as a PV bus, which may change to a PQ bus in the case of limits being violated. In this case, the generated or absorbed reactive power would reach to the maximum limit. The equivalent circuit shown in Figure 1 is used to obtain the mathematical model of the controller for incorporation in power flow algorithms [2].
The power flow equations for the are derived below:

$$E_{vR} = V_{vR}(\cos\delta_{vR} + J\sin\delta_{vR}) \qquad (3)$$

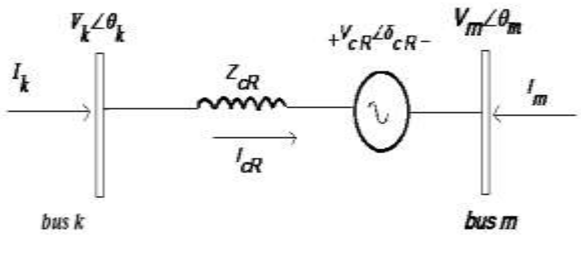

Fig. 1: Equivalent Circuit

$$E_{cR} = V_{cR}(\cos\delta_{cR} + J\sin\delta_{cR}) \qquad (4)$$

The magnitude V_{cR} and phase angle δ_{cR} of the voltage source representing the series converter are controlled between limits $(V_{cRmin} \le V_{cR} \le V_{cRmax})$ and $(0 \le \delta_{cR} \le 2\pi)$ respectively. Based on the equivalent circuit shown in Figure 2 and Equations (11), the active and reactive power equations at bus k are:

$$P_k = V_k^2 G_{kk} + V_k V_m[G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)] + V_k V_{cR}[G_{km}\cos(\theta_k - \delta_{cR}) + B_{km}\sin(\theta_k - \delta_{cR})] \qquad (5)$$

$Q_k = -V_k^2 B_{kk} + V_k V_m[G_{km}\sin(\theta_k - \theta_m) -$
$Bkm\cos\theta k-\theta m+VkVcRGkm\sin\theta k-\delta cR-Bkm\cos$
$\theta k-\delta cR$ *(6)*

And for series converter are:
$P_{cR} = V_{cR}^2 G_{mm} + V_{cR}V_k[G_{km}\cos(\delta_{cR} - \theta_k) +$
$Bkm\sin\delta cR-\theta k+VmVcRGmm\cos\delta cR-\theta m+Bmm$s
in$\delta cR-\theta m$ *(7)*

$$Q_{cR} = -V_{cR}^2 B_{mm} + V_{cR}V_k[G_{km}\sin(\delta_{cR} - \theta_k) - B_{km}\cos(\delta_{cR} - \theta_k)] + V_m V_{cR}[G_{mn}\sin(\delta_{cR} - \theta_m) - Bmm\cos(\delta_{cR} - \theta_m)] \qquad (8)$$

The system of equations is as follows:

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{mk} \\ \Delta Q_{mk} \end{bmatrix} = \begin{bmatrix} \frac{\partial p_k}{\partial\theta_k} & \frac{\partial p_k}{\partial\theta_m} & V_k\frac{\partial p_k}{\partial V_k} & \frac{\partial p_k}{\partial V_m} & \frac{\partial p_k}{\partial\delta_{cr}} & V_{cr}\frac{\partial p_k}{\partial V_{cr}} \\ \frac{\partial p_m}{\partial\theta_k} & \frac{\partial p_m}{\partial\theta_m} & V_k\frac{\partial p_m}{\partial V_k} & \frac{\partial p_m}{\partial V_m} & \frac{\partial p_m}{\partial\delta_{cr}} & V_{cr}\frac{\partial p_m}{\partial V_{cr}} \\ \frac{\partial Q_k}{\partial\theta_k} & \frac{\partial Q_k}{\partial\theta_m} & V_k\frac{\partial Q_k}{\partial V_k} & V_m\frac{\partial Q_k}{\partial V_m} & \frac{\partial Q_k}{\partial\delta_{cr}} & V_{cr}\frac{\partial Q_k}{\partial V_{cr}} \\ \frac{\partial Q_m}{\partial\theta_k} & \frac{\partial Q_m}{\partial\theta_m} & V_k\frac{\partial Q_m}{\partial V_k} & V_m\frac{\partial Q_k}{\partial V_m} & \frac{\partial Q_k}{\partial\delta_{cr}} & V_{cr}\frac{\partial Q_k}{\partial V_{cr}} \\ \frac{\partial p_{mk}}{\partial\theta_k} & \frac{\partial p_{mk}}{\partial\theta_m} & V_k\frac{\partial p_{mk}}{\partial V_k} & V_m\frac{\partial p_{mk}}{\partial V_m} & \frac{\partial p_{mk}}{\partial\delta_{cr}} & V_{cr}\frac{\partial p_{mk}}{\partial V_{cr}} \\ \frac{\partial Q_{mk}}{\partial\theta_k} & \frac{\partial Q_{mk}}{\partial\theta_m} & V_k\frac{\partial Q_{mk}}{\partial V_k} & V_m\frac{\partial Q_{mk}}{\partial V_m} & \frac{\partial Q_{mk}}{\partial\delta_{cr}} & V_{cr}\frac{\partial Q_{mk}}{\partial V_{cr}} \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \Delta\theta_m \\ \frac{\Delta V_K}{V_K} \\ \frac{\Delta V_m}{V_m} \\ \Delta\delta_{cr} \\ \frac{\Delta V_{cr}}{V_{cr}} \end{bmatrix} \qquad (9)$$

IV. PLACEMENT OF FACTS DEVICE USING OPTIMIZING TECHNIQUES

The modeling of the SSSC along with the suitable placements gives fruitful results in the power system network. The losses are reduced by placing the SSSC in the power system network. But by optimal placement of SSSC in the power system network the losses are greatly reduced. The optimal placement of SSSC is carried by using different optimizing techniques like genetic algorithm (GA), particle swarm optimization (PSO) and differential evolution (DE). The total algorithms are used to place the SSSC to reduce the system losses and improve the voltage profile of the buses.

A. Genetic Algorithm (GA)

The basics of the genetic algorithm is given in [6].The population, maximum generations, crossover rate, mutation rate and selection of the genetic algorithm. The population of the genetic algorithm is initialized with branch number and the size of the SSSC. At each generation of the GA, the power system network is incorporated with the SSSC along with the size. The losses at each generation are calculated by using load flow analysis. At each generation the losses are considered as the local minimum losses and if the losses will get lesser than the previous generation. Finally the minimum losses are calculated with optimum location and size of the SSSC. The flowchart of the genetic algorithm with incorporation of the SSSC with the optimum size.

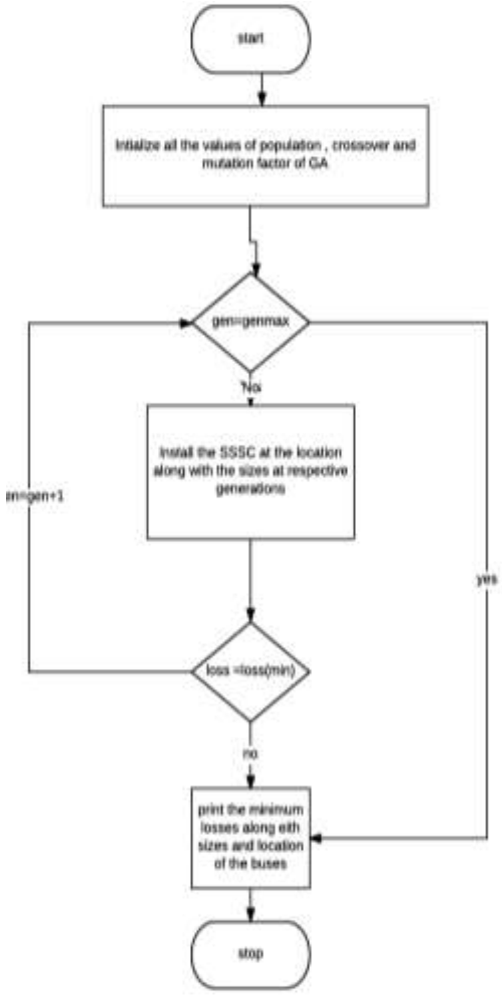

Fig. 2 flowchart of Genetic Algorithm

B. Particle Swarm Optimization (PSO)

Particle swarm optimization is also one of the optimization technique which is mainly used for optimizing the engineering problems. In this paper PSO is used to optimizes the losses of the power system network by placing the SSSC with optimal size. The basics of the PSO are presented in to optimize the many linear and non linear engineering problems. The adoption of PSO with power system by initializing the particles with branch numbers and size of the SSSC. The flowchart of the PSO with placement of SSSC along with size is shown I the fig.3

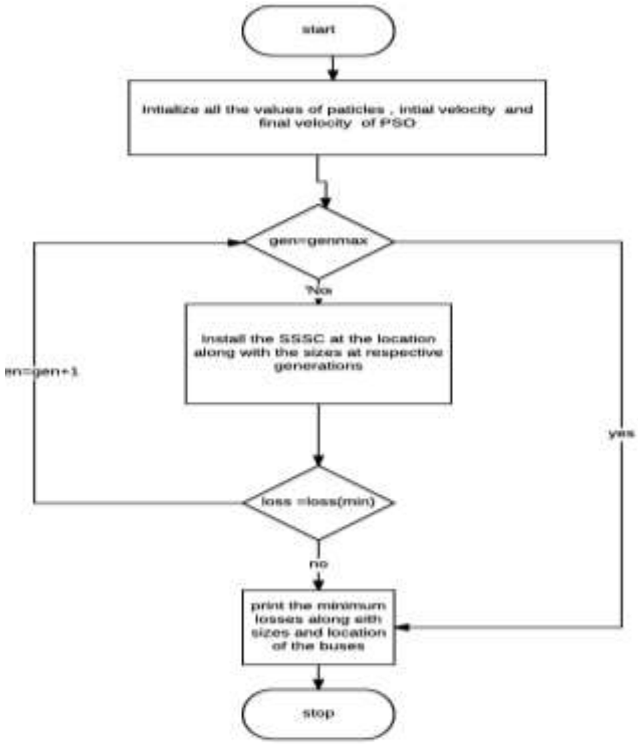

Fig. 3: Flowchart of the PSO with the placement of SSSC

V. RESULTS AND CONCLUSIONS

A. Test case II IEEE 30 Bus system

The proposed method is tested on IEEE 14 bus system. The single line diagram and Voltage profile of respective system is shown in the fig 5 and fig 6 respectively.

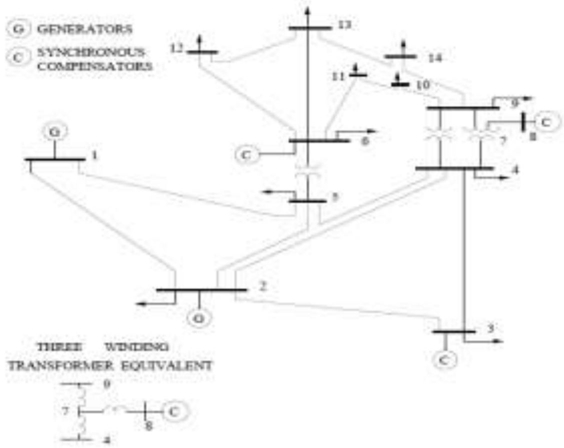

Fig. 4: Single line diagram of IEEE14 bus

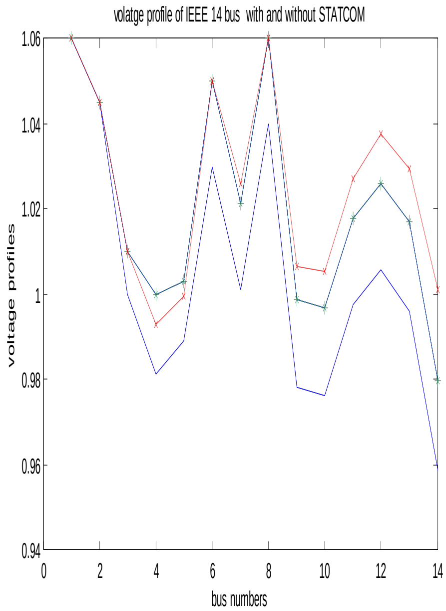

Fig 5: Voltage Profile of the IEEE 14 bus with and without SSSC

Table 2: Comparative analysis of Optimising Techniques by placing SSSC

Method	Min Voltage(p.u) (Bus)	SSSC Placed bus	Real power losses(kW)	Reactive Power losses(KVAR)
Without SSSC	0.9587(14)	———	18.999	84.434
GA	0.9906(4)	6-7	18.16	82.616
PSO	1.0031(4)	5-6	17.591	81.934

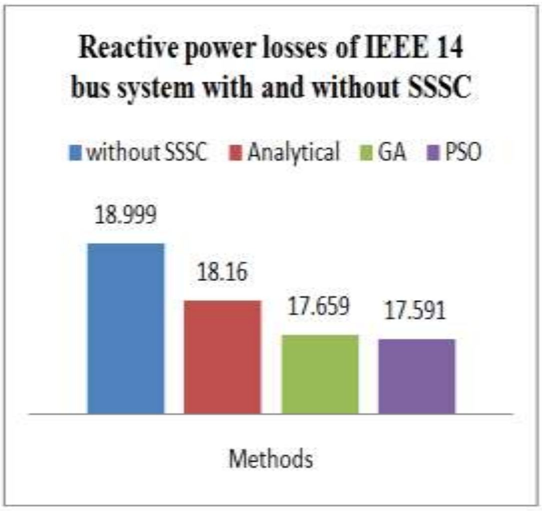

Fig.6 Real power losses of IEEE 14 bus system with and without SSSC

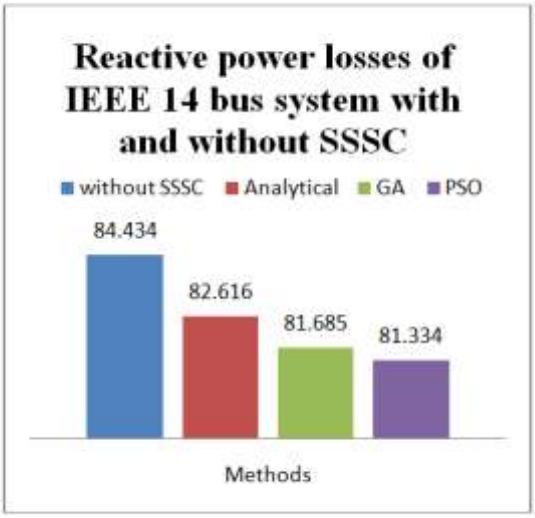

Fig 7. Reacive power losses of IEEE 14 bus system with and without SSSC

The minimum voltage of the IEEE 14 bus system without is 0.9587p.u. The real and reactive power losses of the system are 18.999 kW and 84.434 kVar. The SSSC is placed by using the optimizing techniques. By GA the is placed at the bus the voltage profile is improved which is shown in the figure 3 .The minimum voltage is improved to 0.9906 at 4th bus. The real and reactive power losses are reduced to 18.16 kW and 82.616 kVar which is shown in the table 6. But the voltage injected at 1.024 p.u unlike in GA. The voltage profile and real power losses and reactive power losses are 1.000,17.659 kWand 81.685KVAR.The improved voltage profile by placing SSSC using PSO is shown in the figure 5. The minimum voltage is 1.0031 p.u at 4th bus by placing the SSSC between 5th and 6thbus . The real and reactive power losses are 17.591 kW and 81.934 kVar.

B. Test case II IEEE 30 Bus system

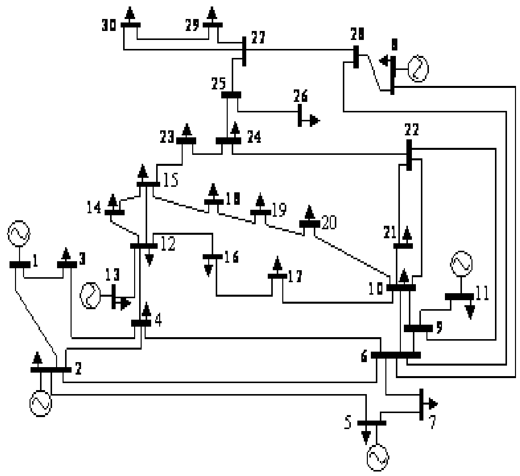

Fig.4 Single line diagram of IEEE 30 bus system.

Table 3: Comparative analysis of IEEE 30 bus system for Optimizing Techniques by placing SSSC

Method	Min Voltage(p.u) (Bus)	SSSC Placed bus	Real power losses(kW)	Reactive Power losses(KVAR)
With out SSSC	0.9828	————	17.759	69.75
GA	0.9982	16-17	17.235	65.434
PSO	1.012	15-16	16.923	65.176

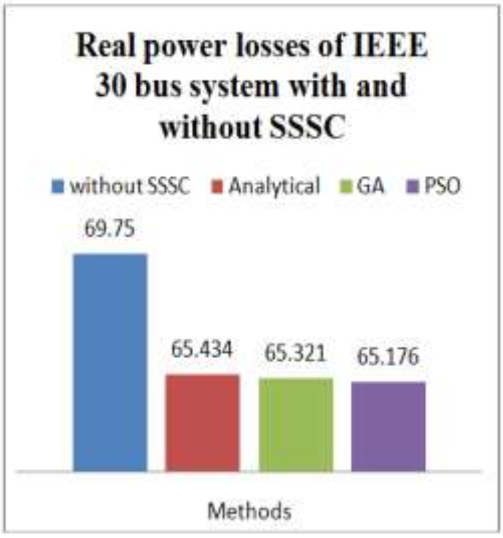

Fig .7 Real power losses of IEEE 30 bus system with and without SSSC

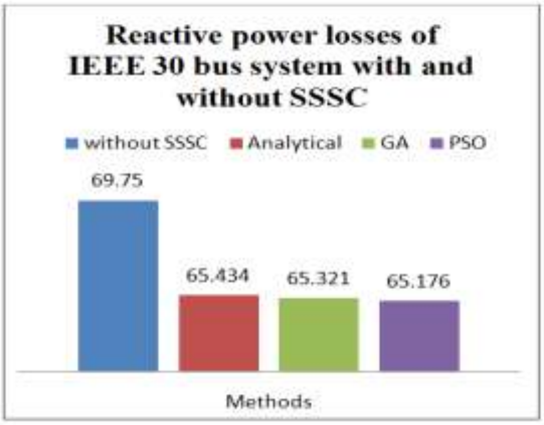

Fig . 8 Reactive power losses of IEEE 30 bus system with and without SSSC

The minimum voltage of the IEEE 30 bus system without is 0.9587p.u. The real and reactive power losses of the system are 17.75 kW and 69.75 kVar. The SSSC is placed by using the optimizing techniques.By GA the is placed at the bus the voltage profile is improved .The minimum voltage is improved to 0.9906. The real and reactive power losses are reduced to 17.235 kW and 65.434 kVar which is shown in the table 6. But the voltage injected at 1.024 p.u unlike in GA. The voltage profile and real power losses and reactive power losses are 0.9982,17.028 kWand 65.321KVAR.The improved voltage profile by placing SSSC using PSO is shown in the figure 5. The minimum voltage is 1.012 p.u at 4th bus by placing the SSSC between 15th and 16thbus. The real and reactive power losses are 16.923 kW and 65.176 kVar.

VI. CONCLUSIONS

By the analysis with the two test cases of incorporating the SSSC at the suitable location. The PSO can select the suitable branches for maintain the voltages at stability condition and reduce the losses at high level. The reduction of the losses will show the great impact on the system to maintain the voltage stability. The size of the device also selects the similar size which will compare with the analytical methods and GA. So finally it is concluded that PSO is the best optimizing technique among GA and analytical methods of placing the SSSC

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International Journal of Engineering Research and Applications (IJERA) is **UGC approved** Journal with Sl. No. 4525, Journal no. 47088. Indexed in Cross Ref, Index Copernicus (ICV 80.82), NASA, Ads, Researcher Id Thomson Reuters. DOAJ.

R.Siva Subramanyam Reddy. “Optimal Placement and Sizing of Static Synchronous Series Compensator (Sssc) Using Heuristic Techniques for Electrical Transmission System.” International Journal of Engineering Research and Applications (IJERA) , vol. 7, no. 9, 2017, pp. 07–12.