International Journal of
Intelligent Systems and Applications in Engineering

ISSN:2147-6799 www.ijisae.org Original Research Paper

Economical and Technical Challenges of a Large Scale Solar Plant

Mustafa YAGCI

Accepted : 11/03/2017 Published: 30/06/2017

Abstract: Turkish government has increased the importance of Konya-Karapınar region by making the area a pilot region for solar energy production. In the near future, the government plans to have a 1 GW solar energy plant in the area. According to this master plan, a pilot solar energy production system was established in the Necmettin Erbakan University campus. A 1000W two-axis tracking and 1000W fixed panels were implemented in this system. In this paper, the performance of these panels are compared and evaluated. 25 years of solar radiation data for Konya is taken from the state meteorology institute, and the produced energy is compared with the predicted values. Tracking panels are found to be approximately 25% more efficient than the fixed panels. However, the maintenance of the tracking panels is observed to be more costly. Moreover periodic cleaning and repairs are found to be very important and another cost factor for both systems. Using the insight from this pilot system, an economic analysis of a large scale 1MW solar energy plant to be established in the campus is performed. For this analysis, fixed panels are considered due to the low investment and maintenance costs and the simplicity of the maintenance work. It is found that the 1MW solar plant will recover the investment cost within 4-5 years and will provide almost 3M$ profit after 20 years.

Keywords: *Economical analysis, Efficiency, Solar photovoltaic (PV) system, Sun tracking system.*

1. Introduction

Due to the shortage of fossil originated fuels, and the global warming problem due to the generation of CO_2 gas, alternative, clean and renewable energy sources are gaining more and more interest [1]. As sun is one of the primary energy sources for our world, generating energy from the sun is very appealing.

Although there are several solar energy generation techniques, photovoltaic based techniques are more popular [2]. In the PV systems, the solar energy is directly converted to electricity using the PV panels.

There are two main types of PV based systems, which are fixed and tracking panels. Fixed panels are positioned to the sun with the best angles (azimuth and zenith angles [3],[4]) to maximize the solar energy generation. As the position of the sun changes during the day and also changes each day depending on the season, these fixed panels cannot provide a perpendicular income angle, and hence the electricity generation efficiency is limited. In the second way, which is to track the sun, and hence change the angles, provides a higher electricity generation efficiency as the income angle can be more perpendicular [4].

The tracking system can be a single axis, changing only one angle, [5],[6],[7], or multi-axis, which changes both angles [8]. The control of the motors which change the angles can be open loop [9], in which a look-up table is used, or closed loop [10],[11],[12]. All these techniques have advantages and disadvantages [13],[14]. When the system becomes more complex, the electric energy generation efficiency increases but the investment and the maintenance costs increase as well.

As Turkey has a great potential in the solar energy generation, Turkish government announced Konya-Karapınar region as a pilot region for solar energy generation. The government plans to generate 1 GW solar energy plant within this area. According to this master plan, a feasibility study is performed within this study to get more insight on the technical and the economic challenges of a large scale solar plant.

First, two small scale solar plants are constructed, which are both 1000W. One of them uses fixed panels, while the other uses dual-axis tracking panels. These plants are operated for a year and the performances of these plants are compared. The tracking panels are observed to be more efficient than the fixed plants, but the investment and the maintenance costs of these panels are more as expected.

In parallel, an intensive economic analysis of a large scale 1MW solar plant using fixed panels is investigated in which maintenance cost and the performance degradation factors are also taken into account. There are examples of such feasibility studies in the literature which are performed for other countries [15],[16], to our knowledge, such economic analyses are not performed yet for Turkey.

2. Estimation of the sun energy

The solar radiation data of Konya for the past 25 years is taken from the state meteorology institute. The date provides the total daily solar radiation in cal/cm^2 for each day. From this data, an estimation of the total solar power production is made.

First, the unit of the solar radiation is converted from cal/cm² to J/m².

$$\frac{1\,cal}{cm^2} = \frac{1\,cal}{cm^2} x \frac{10000\,cm^2}{1\,m^2} x \frac{1\,4{,}184\,J}{1\,cal} = 41840\,\frac{J}{m^2} \quad (1)$$

Then, the unit is further converted from J/m² to kWh/m²

$$\frac{1\,cal}{cm^2} = 41840\frac{J}{m^2} = 41840\frac{W.s}{m^2} x \frac{1\,h}{3600s} x \frac{1\,kW}{1000\,W}$$

[1] *Dep.of Electric and electronic Eng.,Necmettin Erbakan University, Konya-42060, TURKEY*
* *Corresponding Author Email: myagci@konya.edu.tr*

$$= 0{,}01162\ \frac{kWh}{m^2} \qquad (2)$$

Then multiplying this number with efficiency of the panel and the area of the panel gives the total energy production of that panel in one day. By adding the production estimates of each day in a year, the final solar energy estimation for one year can be done.

3. System Information

In the solar energy production systems, two types of panels are commonly used. These are fixed and tracking panels.

Characteristics of solar panels used for electricity generation are given .

PV module specifications;

Cell type	Mono crystalline
Maximum power rating (Pmax)	100 Wp
Open circuit voltage (Voc)	22.6 V
Short circuit current (Isc)	±5.53 A
Voltage at maximum power (Vmp)	19.35 V
Current at maximum power (Imp)	5.17
Production tolerance (%)	±3
Dimensions (mm)	1195* 545*35

The fixed panels are positioned towards the sun movement axis. The sun rays become perpendicular to the panels during a short period of time in the day. This fact reduces the efficiency of the total system. However, the system is cheaper to construct and to maintain compared to the tracking panels.

The tracking panels are again positioned towards the sun movement axis. Moreover, these panels have an automated actuation system which moves the panels during the day to make the angle between the sun rays and the panels as perpendicular as possible throughout the day. This way, the efficiency of the system is greatly increased. However, the construction and the maintenance cost are significantly more compared to the fixed panels.

The movement of the panels is generally controlled by a look-up table calculation according to the global position of the area. The position of the sun is calculated by the controller unit and the angle of the panels is arranged according to this calculation. However, in some systems, an intelligent sun tracking system is implemented which detects the position of the sun by the sensors mounted on the panels, and moves the panels according to the sensor data.

The tracking system can be single-axis or dual-axis. The single-axis panels have fixed angles but can move in one axis and follow the sun as sun moves. The dual-axis panels do not have a fixed angle. The angle of the panel can be adjusted according to the season by moving the panels along the first axis. In addition the panels can follow the sun during the day by moving along their second axis.

Figure 1 shows the block diagram of our pilot solar energy production system which includes both fixed panels and dual-axis tracking panels.

In this pilot system, the generated energy is not provided to the grid, but stored in batteries. Because of this reason, according to the battery voltage level, the solar controller let panels provide the energy to the batteries, and charge them, or isolate the batteries from the panels. The inverter converts the DC voltage on the batteries to AC voltage, and provides this voltage to the loads.

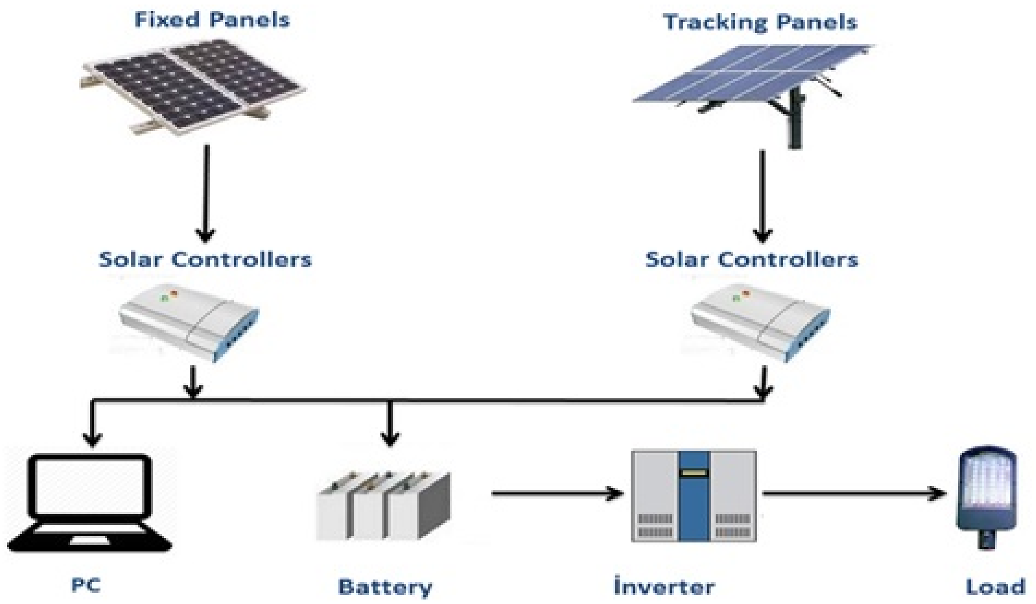

Figure 1. The block diagram of the constructed pilot solar energy production system which includes both fixed panels and dual-axis tracking panels.

In our pilot system, 400 m² area is allocated in the Necmettin Erbakan University campus. Figure 2 shows the 1000 W fixed panel system constructed using 1000 W fixed panels in the campus area. These panels are tilted 33° towards the south in Turkey-Konya to get the maximum energy efficiency both in summer and in winter.

Figure 3 shows the dual-axis 1000 W tracking panels constructed in the campus area close to the fixed panels. The panels are controlled by two step motors, one tilting them in the horizontal axis and the other in the vertical axis. The motors are driven by a controller unit which includes a microcontroller and motor driver circuits. The solar movement for Konya for 365 days is stored in a look-up table and the microcontroller computes the necessary pulses to drive the motors in order to keep the track of the sun.

Figure 2. 1000 W fixed panels constructed in the Necmettin Erbakan University campus.

Figure 3. The dual-axis 1000W tracking panels constructed in the campus area

Figure 4 shows the load, which are 8 streetlights having two 45 W LED lambs to generate a total of 720 W load. The lambs are controlled by a timer to turn them on even during the day time to ensure that the batteries are neither completely full nor completely empty.

Figure 4. The streetlights used as a load

4. Measurements

First, last 25 years of sun radiation data is taken from the state meteorology institute. Then, average electric energy generation estimation is made for 1000 W panels according to the calculations provided in the above section. The solar panels constructed in the campus area generated electric energy from June 2013 till June 2014. The generated energy values are recorded for each 10 minutes during this period. Figure 5 shows the generated energy for the both type of panels and the estimated energy which are in good correlation.

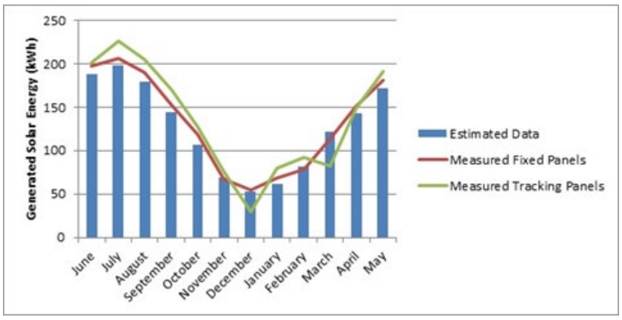

Figure 5. The generated energy (kWh) for the both type of panels and the estimated energy are in good correlation.

In Figure 5, it can be observed that the tracking system energy generation has a drop in December 2013 and March 2014. During March 2014, due to seasonal strong winds, the motors driving the tracking system have been broken and it took 14 days to repair and maintain the system. During this period, the system was down. Figure 6 shows the energy generation during this period. Hence, the total energy generation for the tracking system in March became less than the fixed system.

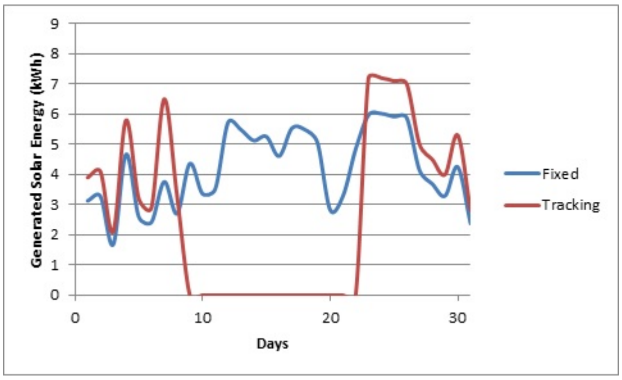

Figure 6. The generated energy (kWh) for the fixed and tracking systems in March 2013.

Similarly, during December 2013, the motor systems driving the tracking system was down for a week and hence the generated energy became less for the tracking system.
Similar technical problems that can cause the tracking system to be down for some periods during the year decrease the total efficiency of the tracking system but still. Moreover, the additional construction cost (approximately 1500 $ for our system) plus the maintenance costs makes the tracking system more costly. However, still the overall efficiency of the tracking system is found to be more for the tracking system than the fixed system.
One additional effect observed during the whole period is the dirtiness of the panels. It is observed that the voltage generated by the panels tend to decrease due to the accumulated dirt. The clean fixed panels could generate around 13 V (which corresponds to around 800 W for our system) during the midday times (around 12:30), yet the same panels could generate only around 3.5 V (which corresponds to around 200 W for our system) just before the cleaning. To maximize the efficiency, the panels need to be cleaned regularly.

Another problem we faced during this whole period is that our system is not connected to the grid. Hence, the generated energy is stored in the batteries. Here, the problem we faced is that when the battery voltage is high, then the batteries do not store the energy anymore and so the generated energy is seen to be low. To overcome this problem, the load streetlights are turned on regularly using time controlled switches for certain periods even during the day times so that the batteries are not fully charged. Although we have overcome this problem, we realize that it is more practical to connect the panels to the grid from the beginning.

5. Economic Analysis of The 1 MW Solar Plant

Turkish government has increased the importance of Konya-Karapinar region by making the area a pilot region for solar energy production, and has planned to establish a 1GW solar energy plant in the area. According to the master plan, Necmettin Erbakan University plans to establish a large scale 1 MW solar plant in its campus. In this study, we wanted to get more insight on the technical and economic challenges and benefits of this large scale 1 MW solar plant by researching on our 1000 W pilot solar panels.
In addition to technical insights provided in the above section, an economic analysis of a 1 MW solar plant is also studied. The plant is planned to have all fixed panels because of the small investment and maintenance costs.
The plant is planned to be constructed in the Konya Necmettin Erbakan University campus. The total area planned for this plant is 15000 m² and the total active panel area will be 6776 m² using 4160 panels which are 240 W each. The investment cost for this plant is estimated to be 1,2 M$.
Table 2 summarizes the economic analysis for this plant. The lifetime of the plant is estimated to be 20 years at least, and so the economic analysis is provided for 20 years. In Table 1, the rightmost column shows the total profit, which is -1,2 M$ in the beginning, and keeps increasing each year due to the sales of the generated electricity. During the calculation of the sales, the price of the electricity (0,1806 $/kWh) is kept constant, because in Turkey the price is fixed at this value in USD.

Table 1. The summary of the economic analysis for 1 MW solar plant

Electricity Price ($/kWh)	Long term efficiency degradation factor	Generated electric energy (kWh)	Yearly Sale ($)	Maintanence cost ($)	Yearly Profit ($)	Total Profit ($)
-	-	-	-	-	-	-1200000
0,1806	1	1354253,217	244578,131	1000	243578,131	-956421,869
0,1806	1	1354253,217	244578,131	1070	243508,131	-712913,738
0,1806	1	1354253,217	244578,131	1144,9	243433,231	-469480,5069
0,1806	1	1354253,217	244578,131	1225,043	243353,088	-226127,4189
0,1806	1	1354253,217	244578,131	1310,79601	243267,335	17139,91608
0,1806	0,994	1346127,698	243110,6622	1402,551731	241708,1105	258848,0266
0,1806	0,988	1338002,179	241643,1934	1500,730352	240142,4631	498990,4897
0,1806	0,982	1329876,659	240175,7247	1605,781476	238569,9432	737560,4329
0,1806	0,976	1321751,14	238708,2559	1718,18618	236990,0697	974550,5025
0,1806	0,97	1313625,621	237240,7871	1838,459212	235402,3279	1209952,83
0,1806	0,964	1305500,101	235773,3183	1967,151357	233806,1669	1443758,997
0,1806	0,958	1297374,582	234305,8495	2104,851952	232200,9976	1675959,995
0,1806	0,952	1289249,063	232838,3807	2252,191589	230586,1891	1906546,184
0,1806	0,946	1281123,543	231370,9119	2409,845	228961,0669	2135507,251
0,1806	0,94	1272998,024	229903,4432	2578,53415	227324,909	2362832,16
0,1806	0,934	1264872,505	228435,9744	2759,031541	225676,9428	2588509,103
0,1806	0,928	1256746,986	226968,5056	2952,163749	224016,3418	2812525,445
0,1806	0,922	1248621,466	225501,0368	3158,815211	222342,2216	3034867,666
0,1806	0,916	1240495,947	224033,568	3379,932276	220653,6357	3255521,302
0,1806	0,91	1232370,428	222566,0992	3616,527535	218949,5717	3474470,874

The third column from the left in Table 1 shows the estimation of long term efficiency degradation factor. The panels will operate at maximum efficiency in the beginning (14%) but this value will degrade by time according to the manufacturer's specifications (approximately 12.5% after 20 years) [16]. The generated electricity is calculated according to this degradation factor. Moreover, although the efficiency in the beginning is 14% according to the datasheets, in the calculations in Table 1, the efficiency is taken as 12% in the beginning. The reason for this drop is the environmental effects like dirt accumulation on the panels [17]. So, in the estimations, the actual panel efficiency begins from 12% and keeps degrading till approximately 10.5% after 20 years.

The maintenance cost for the fixed panels are mainly due to the regular cleaning work of the panels. For this work, 1000 $ cleaning cost is estimated [18],[19]. This cost will increase each year due to the inflation factor, which is taken as 7%.
It is important to mention here that there is an optimization between to the maintenance cost and drop of the efficiency due to the dirt accumulation. If the maintenance cost is increased and the panels are cleaned more frequently, the efficiency drop due to the dirt accumulation will be smaller, and hence the costs will increase but the income as well. This optimization depends on the location of the plant (how easy and low cost it is to provide water to clean the panels), the man power or automated cleaning procedure costs. Figure 7 shows the total estimated profit over the years after the plant is constructed. According to the calculations in Table 2, it is estimated that the plant will recover the investment cost in 4-5 years and will provide almost 3 M$ profit after 20 years.

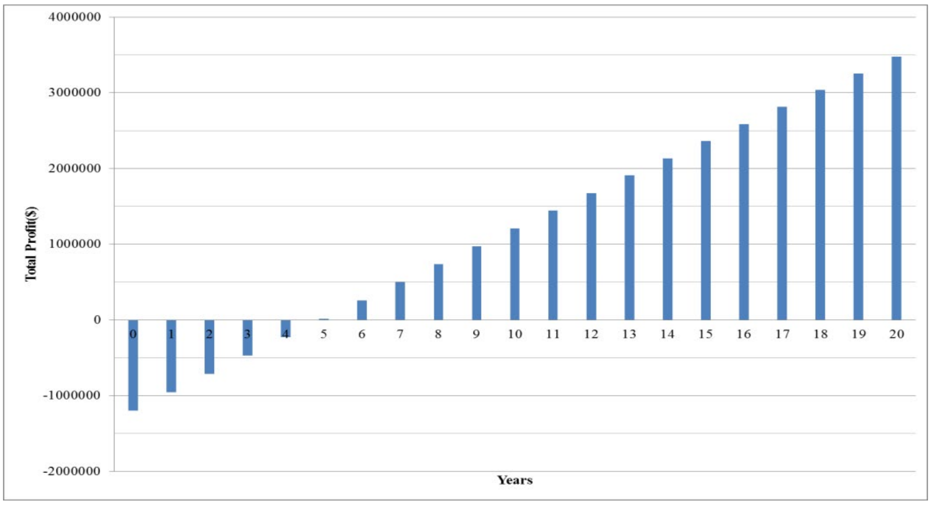

Figure 7. The total estimated profit over the years after the plant is constructed

6. Conclusion

As Konya-Karapinar region has been gaining importance in solar energy production, a study to get more insight on the technical and economic challenges of solar energy generation is performed within this work. First, a small scale, 1000W fixed and tracking panels are constructed in the Necmettin Erbakan University campus, and the performances of these panels are studied for a year. It is observed that the tracking panels provide more efficient solar energy generation, but the investment and maintenance costs are higher. Second, an economic analysis of a large scale 1 MW solar energy plant was performed. In this analysis, fixed panels are considered because of the low investment and maintenance costs and also simplicity of the maintenance work.
It is found that, a 1 MW fixed panel solar plant will recover the investment cost within 5 years. Moreover, it will generate almost 3 M$ profit after 20 years. If the lifetime of the plant becomes more than 20 years, then the total profit will be even higher. One more observation is the effect of the dirt accumulation on the panel performances. In the literature, there are several studies mentioning this fact, and within this study this effect is clearly observed. An intensive study is needed to optimize the amount of maintenance cost to clean the panels so that the efficiency drop due to dirt accumulation is overcome by the good maintenance.

References

[1] O. Ekren, B.Y. Ekren and B. Ozerdem (2009) Break-even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage – a case study. Applied Energy. Vol.Pages. 1043–54.
[2] Alata, M. Al-Nimr and M.A. Qaroush, Y (2005). Developing a multipurpose sun tracking system using fuzzy control. Energy Conversion and Management. Vol. 46, Pages.1229–45.
[3] I.Sefa, M.Demirtas, and I.Çolak (2009). Application of one-axis sun tracking system. Energy Conversion and Management. Vol.50, Pages. 2709–2718.
[4] S.A. Kalogirou (1996). Design and construction of a one-axis sun-tracking system. Solar Energy, Vol.57 Pages.465–469
[5] M. Abouzeid (2001). Use of a reluctance stepper motor for solar tracking based on a programmable logic array (PLA) controller. Renewable Energy Vol. 23 Pages. 551-560.
[6] M.M. Abu-Khader, O.O. Badran, S. Abdallah (2008). Evaluating multi-axes sun-tracking system at different modes of operation in Jordan. Renew Sustain Energy Rev.Vol.12Pages.864-873
[7] G.C. Bakos (2006). Design and construction of a two-axis sun tracking system for parabolic trough collector (PTC) efficiency improvement. Renewable Energy. Vol. 31, Pages.2411–21.
[8] V. Poulek and M.A. Libra (2000). Very simple solar tracker for space and terrestrial applications. Solar Energy

Mater Solar Cells. Vol. 60. Pages.99–103.

[9] S. Abdallah and N. Salem (2004). Two axes sun tracking system with PLC control. Energy Conversion and Management. Vol.45. Pages.1931–1939.

[10] P. Roth, A. Georgiev and H. Boudinov (2004). Design and construction of a system for sun tracking. Renewable Energy. Vol. 29. Pages.393–402.

[11] W. Batayneh, A. Owais and M. Nairoukh (2013). An intelligent fuzzy based tracking controller for a dual-axis solar PV system. Automation Construction.Vol. 29.Pages.100- 106.

[12] Barakat, B. Rahab, H. Mohmedi, B. Naiit, N, (2001). Design of a tracking system to be used with photovoltaic panels. 4th Jordanian International Mechanical Engineering Conference, Amman, Jordan. Pages. 471–488.

[13] Y. Yao, Y. Hu, S. Gao, G. Yang and J. Du (2014). A multipurpose dual-axis solar tracker with two tracking strategies.Renewable Energy.Vol. 72.Pages. 88-89.

[14] P. Roth, A. Georgiev and H. Boudinov (2004). Design and construction of a system for sun tracking. Renewable Energy. Vol.29 Pages.393–402.

[15] A.M. Paudel and H. Sarper (2013). Economic analysis of a grid-connected commercial photovoltaic system at Colorado State University-Pueblo. Energy. Vol.52.Pages.289-296.

[16] J.Y. Kim, G.Y. Jeon, and W.H. Hong (2009). The performance and economical analysis of grid-connected photovoltaic systems in Daegu, Korea.Applied Energy. Vol. 86.Pages. 265-72.

[17] M., Özcan, M.S. Endiz and F. Sadikoğlu (2016) Techno Economic Study of 1 MW Grid Connected Photovoltaic Power Plant in Konya Organized Industrial Zone. International Conference on Machine Learning, Electrical and Electronics Engineering, Antalya, Turkey. Pages.64-70.

[18] M.Yagci, Ş. Erel and M. Özcan (2016). Smart Cleaner Implementation for Solar Photovoltaic Panels. 2nd International Conference on Engineering and Natural Sciences, Sarajevo, Bosnia and Herzegovina.Pages.225-30.

[19] F. Sadıkoğlu and M. Özcan (2016).2 MW Feasibility Study for Solar Energy Power Plant Implementation . Electrical-Electronics and Computer Symposium, Tokat,Turkey.Pages.149-157