A CASE STUDY OF SHE (SOLAR-HYDROELECTRIC) IN TURKEY

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Abstract: Nowadays, energy and source requirements are significant issues, as in the past. Besides, renewable energy sources that especially hybrid energy systems and their usages have been very popular in recent years because of a lot of reasons. In this study, efficiency of solar-Hydro Electric (SHE) is compared with hydro energy and solar energy systems and a case situation is computed with real data and it is clarified the efficiency, generation, cost and available credibility items of system in Turkey. Energy efficiency, systems cost, investment repayment period, operation expenditures, available energy credibility and optimum energy costs are computed and shown in study. Electricity generation of solar is calculated by PVsyst program. Generation and capacity utilization rates of systems are shown in graphics.

Keywords: SHE (Solar-Hydroelectric), Energy Efficiency, Energy Credibility, Distributed Energy Systems

Introduction

Nowadays, energy and source requirements are significant issues, as in the past. It is a usual application that restriction of the transformer capacity as 30% for renewable energy in most countries. It has become a necessity for supplying system stability and quality. But this situation is limited for renewable energy investments. A new transformer building and its infrastructure costs are very expensive. So, productive usage of transformer is more effective than build a new one. Hybrid systems like SHE (Solar-Hydroelectric) is aim to provide this efficiency. Despite a lot of scientific studies can be finds about hybrid energy systems, there are a few studies about SHE (solar-Hydro Electric) in literature. Hybrid system applications are steadily increased in Turkey, but there is no SHE application. So, in this study, a case situation is computed with real data and it is clarified the efficiency, generation, cost and available credibility items of system in Turkey.

Most of the researches are about water pumping which using solar energy for irrigation. One of them was released by Dursun and Özden (2014). Also, most of them are about off grid systems and generally solar and wind energy is used as integrated system for hybrid systems. Some SHE (Solar-Hydroelectric) studies in recent years is started all over the World. It could not have done yet at any project in Turkey.

It is mentioned in many articles about solar and Hydro Electric, in recent years. Some of them are Glasnovic and Margeta (2009), called their Project as SHE (Solar-Hydroelectric) which is tested in Croatia. They have explained that the system is not only an applicable project but also a complementary system. Bekele and Tadesse (2012) studied hydro-wind-solar in 6 different area of Ethiopia and published their article. Glasnovic and Margeta (2010), studied about solar-hydroelectric system for Europe. They offered a mathematical model for finding the optimum point of system's installed capacity. It is stated in their study that solar-hydroelectric is a good approach for management of electric generation due to their generation time. Kusakana and Jimoh (2009) stated that solar-hydroelectric systems are low-cost type project and it is so useful for rural zone. And solar-hydroelectric systems are compared with other renewable energy systems. Meshram and et. al (2013), analyzed on grid solar-hydroelectric system performance. It is stated in study that solar-hydroelectric system is reducing the complexity and cost. Sirasani and Kamdi (2013), studied about hybrid system which is occurred wind, solar and hydroelectric. It is investigated multiple effects on systems like social, environmental, affordability and efficiency. It is offered in study that solar-hydroelectric systems should be extended. A solution is searched in Afify's (2014) study by using solar and hydroelectric system for Qattara zone of Egypt.

There are a lot of methods for supplying lack of energy. The solar-hydro is one of them and it has been examined since 2000. But, these studies are about separate energy system for hydro and solar. It is stated in these studies, solar and hydroelectric systems are located in different places, but use same infrastructure for on grid. There are a few applications which using hydro energy structures to establish SPP. Generally reservoir area of HEPP is used for SPP plants.

Materials and Methods

Turkey is not a rich country in term of water resources. Most of the water resources of Turkey are depended to rainfall. The capacity utilization rate of HEPP (hydroelectric power plant) is between 25-40% in Turkey. Generally, electric generation of HEPP is more than average in spring and less than average in summer time in Turkey. According to the January 2016 data, 559 HEPPs in operation and total installed capacity is 26,136 MW. Average electric generation of Hydro Electric is 70,000 GWh and capacity utilization rate is about 35%. Turkey is located in a relatively advantageous geographical situation about solar radiation. Capacity utilization rate of SPP (solar power plant) is between 15-20% in Turkey. Generally, electric generation of SPP is more than average in summer time. Approved and commissioned SPP projects by TEDAŞ-TEDC (Turkish Electricity Distribution Corporation-until January 2016) are given in Table 1.

Table 1: Approved and commissioned SPP projects by TEDAŞ-TEDC

	Quantity	Installed Capacity (kW)
Approved SPP	2,748	2,544,816
Commissioned SPP	384	259,748

Allocated transformer capacity is limited for renewable energy in Turkey. Individually capacities are allocated for hydro and solar energy. Most of the investors wanted to enterprise renewable energy. But they cannot do it, because there is no suitable transformer capacity. Indeed hydro energy and solar energy are complemented each other, because of natural generation time. HEPP is not generated more electricity in summer. On the contrary summer time is the highest electricity generation time of SPP. So, they are complemented each other naturally and they do not need to a separate transformer capacity. Same transformer utilization can be possible for SHE (Solar-Hydroelectric) systems. It is a natural compensation for electricity generation and it is an efficiency system. Generation, cost, efficiency and credibility items are examined in this study.

A HEPP project is chosen for case study which is located in Siirt province of Turkey. In this study, cost, generation, capacity utilization rate and credibility items of solar system, hydroelectric system and solar-hydroelectric system are compared with each other. It is shown that solar-hydroelectric system is the best offer for the matter in hand.

HEPP Project characteristics are given in Table 2.

Table 2: Project characteristics

Project Characteristics	
Installed Capacity	12.78 MW
Turbines Type	Francis–horizontal axis
Gross Height	41.26 m
Net Height	40.85 m
Drainage Area	1,077.6 km^2
Dam Volume	1 hm^3
Project Flow	36 m^3/s
Average Flow	12.42 m^3/s
Canal Type	Trapeze
Base-Width of Canal	5 m
Height of Canal	3 m
Long of Canal	8,200 m

HEPP project has 12.78 MW transformer capacities that had been given permission by authorities. So, a system is planned to design that under limit of transformer and used same infrastructure. 100 Wp First Solar FS-3100-PLUS model solar panel and SMA Sunny Central 850 CP XT model inverter are used in design. 14.80 MW SPP can be assembled on canal which is 8,200 m length and 11 m surface width. SPP and HEPP can be using same infrastructure of grid and transformer. This is the main aim of solar-hydroelectric system. So, solar-hydroelectric system offers energy efficiency and transformer capacity and do not need a new ones. 14.80 MWdc and 12.75 MWac is planned to installed capacity of SPP. 12.75 MWac is preferred as installed capacity, because of HEPP's 12.78 MW transformer capacity. It is allocated to the HEPP by Electricity Distribution Corporation.

The credibility, cost, electric generation and capacity utilization rate of SPP, HEPP and SHE (solar-hydroelectric) was calculated in this study. HEPP's electric generation is calculated from formula and SPP's electric generation was calculated by PVsyst energy program. Acceptances of SPP, HEPP and SHE Project is given below;

- 1 USD = 3 Turkish Liras
- Ignore the promotion of deductible VAT, accounting ETL(energy transmission line) and the other promotions which are accepted by Turkish Government
- Same balance-sheet and financial data are accepted for SPP, HEPP and SHE projects
- Canal is covered by solar panels which is 8,200 m lengthy
- No land acquisition, ETL and on grid system infrastructure is accepted to solar part of SHE system. All infrastructure and land is common in SHE project
- SPP's electric generation is calculated by PVsyst program
- 39 years flow data are used in HEPP's electric generation calculation which is obtained in 1972-2010
- 0.073 USD is accepted for SPP and 0.133 USD is accepted for HEPP as unit price of revenue
- Annual 5% interest rate, 1.1 solvency, 2 years nonpayment and 10 years loan term are accepted as criteria of credibility for systems

Transform of Solar radiation to electric is termed as photovoltaic effect. Photovoltaic cell is the main equipment of SPP. The photovoltaic module is a form of cell series. And the photovoltaic array is a form of series-parallel combination (Ayyoubi, 2009, Said, 2003, İbrahim, 2009). A solar cell can be represented as a current model as simplified equivalent circuit of photovoltaic cell shown in Figure 1.

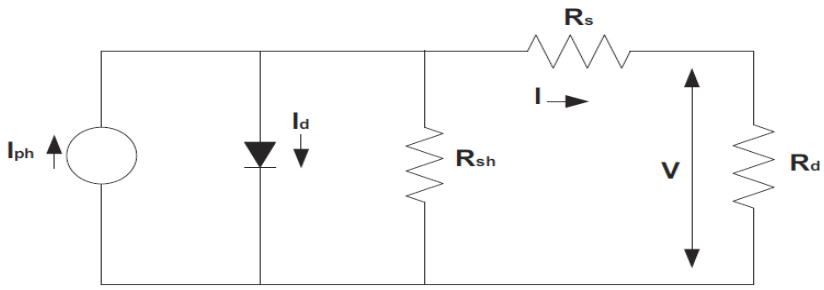

Figure 1. Simplified equivalent circuit of photovoltaic cell

The typical I-V characteristic of a PV array is given by the following in Equation 1. (Hussein, 1995);

$$I = Np.Iph - Np.Id.e^{\left(\frac{q}{kTA}X\frac{V}{Ns}\right)-1} \qquad (1)$$

where, I is the photovoltaic array output current (A), Iph is the photo current, Np is the number of modules connected in parallel, Id is the cell reverse saturation current, q is the charge of an electron, V is the photovoltaic array output voltage (V), k is the Boltzman's constant, T is the cell temperature, A is the pn junction ideality factor, Ns is the number of cells connected in series, The factor 'A' determines the cell deviation from the ideal pn junction characteristic; it ranges from 1 to 5, 1 being the ideal value (Khallat, 1986).

The cell reverse saturation current I_d versus to temperature was given by in Equation 2. (Vachtsevanos, 1987);

$$Id = Ic.[\frac{T}{Tc}]^3.e^{\left(\frac{qEg}{kA}[\frac{1}{Tc}-\frac{1}{T}]\right)} \qquad (2)$$

where, Ic is the reverse saturation, Tc is the cell reference temperature, current at Tc, and Eg is the band gap energy of the semiconductor used in the cell. The photo current Iph depends on the solar radiation and the cell temperature as given by in Equation 3.

$$Iph = [Iscr + Ki.(T - Tc)].\frac{S}{100} \qquad (3)$$

where Iscr is the cell short circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm^2. The PV array power can be calculated by Equation 4.

$$P = I \,.\, V \tag{4}$$

$$P = V.Np.(Iph - Id).e^{\left(\frac{q}{kTA}x\frac{V}{Ns}\right)-1} \tag{5}$$

Hydroelectric energy generation formulas are given in below Equation 6.

$$N = \varrho \,.\, g \,.\, \mu \,.\, Q \,.\, H \tag{6}$$

where, N is the power (MW), ϱ is the water density (1000 kg/m^3), g is the gravity (9.81 m/s^2), μ is the efficiency of plant (multiplications of turbine, generator and transformer's efficiencies), Q is the project flow (m^3/s), H is the height of project (m).

Results and Discussion

HEPP transformer capacity (power) is 12.78 MW. Capacity Utilization Rate of HEPP is 33.37%. Capacity Utilization Rate of SPP is 22%. And Capacity Utilization Rate of SHE is 55.23%. So, most part of transformer capacity is useless in HEPP and SPP projects. SHE system is more effective than HEPP and SPP.

SPP and HEPP Projects have to use 2 separate transformer to connect grid. But a transformer is adequate in SHE system. New transformer investment is unnecessary in SHE systems. So, SHE systems can be called as efficient projects. Tables and graphics are obtained from studies is given below.

Table 3: Monthly electric generation summary table for three different position (kWh)

	Electric Generation (kWh)			
Months	**HEPP**	**SPP**	**SHE**	**Installed Cap.-12.78 MW**
Oct.	2,172,229	2,076,000	4,248,229	9,329,400
Nov.	2,177,983	1,679,000	3,856,983	9,329,400
Dec.	2,331,823	1,274,000	3,605,823	9,329,400
Jan.	2,328,107	1,351,000	3,679,107	9,329,400
Feb.	2,534,302	1,428,000	3,962,302	9,329,400
March	3,633,352	1,927,000	5,560,352	9,329,400
April	6,185,870	2,119,000	8,304,870	9,329,400
May	6,327,884	2,258,000	8,585,884	9,329,400
June	2,970,089	2,591,000	5,561,089	9,329,400
July	2,275,366	2,694,000	4,969,366	9,329,400
Aug.	2,176,311	2,687,000	4,863,311	9,329,400
Sept.	2,136,685	2,492,000	4,628,685	9,329,400

Table 4: Average capacity utilization of 3 different position obtained from electricity generation (MW)

	Average Capacity Utilization(MW)			
Months	**HEPP**	**SPP**	**SHE**	**Installed Cap.**
Oct	3.02	2.88	5.90	12.78
Nov.	3.02	2.33	5.36	12.78
Dec.	3.24	1.77	5.01	12.78
Jan.	3.23	1.88	5.11	12.78
Feb.	3.52	1.98	5.50	12.78
March	5.05	2.68	7.72	12.78
April	8.59	2.94	11.53	12.78
May	8.79	3.14	11.92	12.78
June	4.13	3.60	7.72	12.78
July	3.16	3.74	6.90	12.78
Aug.	3.02	3.73	6.75	12.78
Sept.	2.97	3.46	6.43	12.78

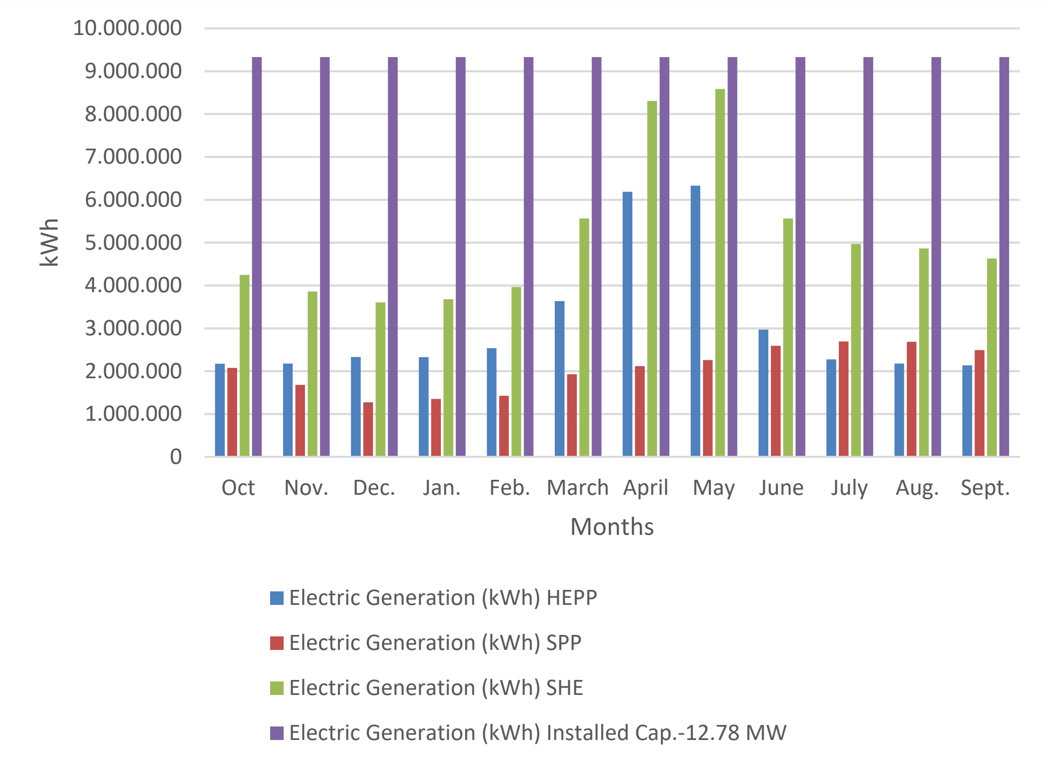

Figure 2: Monthly electric generation summary graphic of 3 different position (kWh)

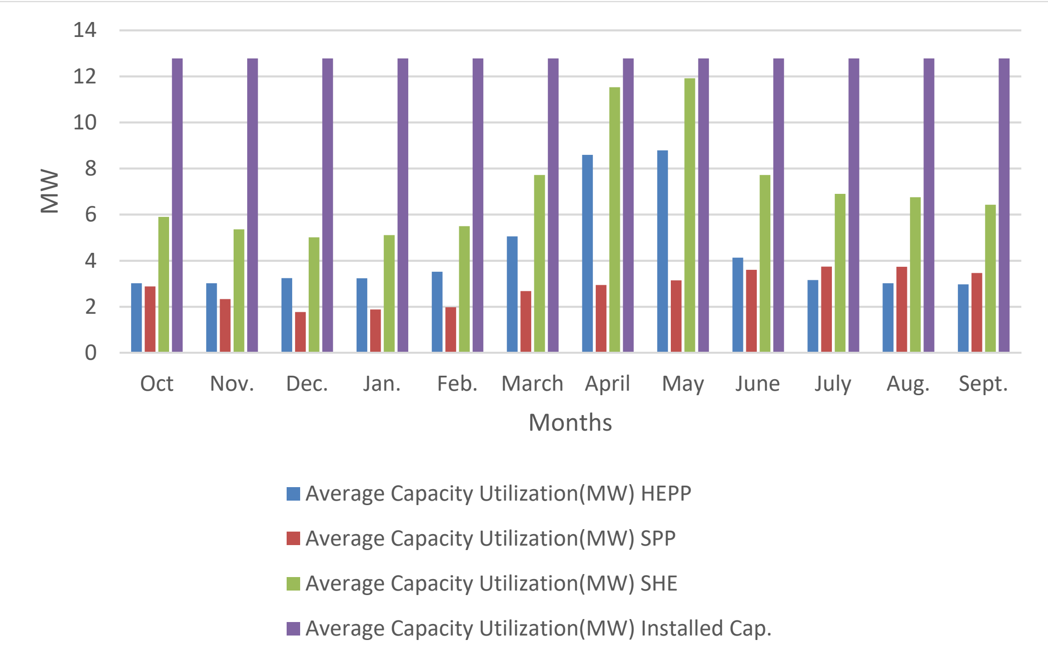

Figure 3: Average capacity utilization of 3 different position obtained from electricity generation (MW)

Reservoir area of HEPP and 8,200 m length storage capacity is about 8 hours in case study. Seasonal electricity generation discrepancy can be monitored in HEPP system because of rainfall dependence. Energy can be managed in SHE systems. Solar part of SHE system is generates electric only daytime. HEPP has enough storage capacity for interrupted electricity generation. The main idea of SHE system is efficiency usage of transformer capacity and interrupted electricity generation. A sample energy management of SHE system is given Figure 4 for a day.

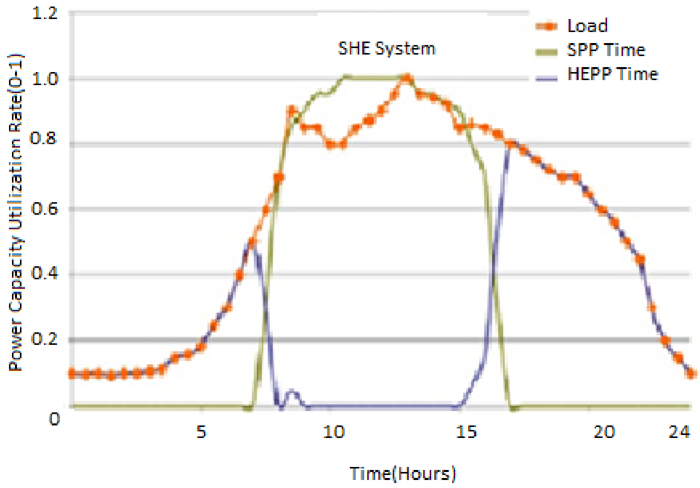

Figure 4: A Sample energy management of she for a day (Sunengy diagram)

Conclusion

Summary of SHE system is given in Table 5;

Table 5: Summary of case study

Items/Plants	HEPP	SPP	SHE
Electricity Generation (kWh)	37,250,000	24,576,000	61,826,000
Power Capacity Utilization Rate (%)	33.37	22	55.23
Total Fixed İnvestment Cost (USD)	16,600,000	17,750,000	33,460,000
General Investment Cost (USD)	17,781,072	18,324,991	35,170,538
Annual Operation Income (USD)	2,719,250	3,268,608	5,987,858
Annual Operation Expenditure (USD)	515,000	485,000	715,000
Project Credit Amount (USD)	10,750,000	15,750,000	31,000,000
Credibility - (%)	60.46	85.95	88.14
Recycling Period (years)	8.07	6.58	6.66

As a result of this study it can be concluded below;

- It is a usual application that restricts the transformer capacity as 30% for renewable energy in most countries. It has become a necessity for supplying system stability and quality. But this situation is limited the renewable investments. Transformer capacity is vital for renewable energy investments. An average capacity utilization rate of HEPP is 25-40% and capacity utilization rate of SPP is 15-20%. So, great part of transformer capacity is useless in single-handed energy transformer capacity like HEPP or SPP. HEPP and SPP are complementary systems actually, because of electricity generation time period. Solar part of SHE systems can be generated more energy in summer when hydroelectric generation is so limited and contrary to this hydroelectric part of SHE systems can be generated more energy in spring when SPP's electricity generation is so limited. And if a HEPP has got enough storage flow capacity, it can generate energy at night when generation is impossible for SPP. So, efficiency transformer capacity and interrupted energy generation can be supplied by SHE systems. With correct energy management capacity utilization rate of SHE can be between the ranges of 40-60%.
- SPP projects use 20,000 m^2 land for per 1 MW installed capacity. In addition, investor has to get dry marginal agricultural land permission. In SHE system, investors do not need to extra land and permission for activating the plant. It is time and Money saving part of SHE systems.
- Separately plants like HEPP or SPP is more expensive than SHE systems. SHE systems offered low-cost investment and operation expenditures because of common usages.
- There is a lot of credit loan about renewable energy. Generally International Banks like World Bank is evaluated this system with suitable lines. So, credibility of efficiency SHE system is higher than separately plants like HEPP or SPP.
- Equity is the most important part of investments. Many investors avoid from high equity investments. It is clear from table 5 that SHE systems offer minimum equity and maximum credibility. An investor can

spend more money to HEPP, than SHE system. So, it is understood that SHE system is the smartest choice for investors.

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