doi: 10.17221/12/2016-RAE

Investigation of solar-powered drip irrigation: The case study of the Jordan Valley – Short Communication

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Abstract

Perakis C., Kyriakarakos G., Bani Hani N., Hammad S., Damasiotis M. (2017): Investigation of solar-powered drip irrigation: The case study of the Jordan Valley. Res. Agr. Eng., 63: 168–171.

Agriculture is the sector that consumes by far most water globally. Much research efforts aim at minimizing losses through the use of drip irrigation. Rural agricultural areas often do not have access to a main electrical grid to power the pumps needed for drip irrigation; it reduces the options in paying for a grid extension, getting a diesel generator or investing in an off-grid renewable energy system. In this paper, these alternatives are assessed technically and economically under real world conditions through the Jordan Valley case study. The results show that the autonomous photovoltaic (PV)-battery system is preferable to the use of a diesel generator, as well as it is preferable to the main grid extension in many cases depending on the cost of grid electricity and distance from the grid. For current subsidized grid electricity retail price to farmers, the PV-battery system becomes more attractive above a 300 m distance from the grid, while if the actual cost of electricity production in Jordan is taken into account, then it breaks even to 128 m.

Keywords: photovoltaics; batteries; conventional fuels; pumping; net present cost

Agriculture is the sector that consumes most water globally, reaching 69% of the total withdrawn water. The irrigation water far exceeds the consumptive use of irrigation (FAO 2015). Much research effort has taken place in order to minimize the losses of irrigation water. Drip irrigation is the irrigation method that presents the lowest water losses and needs the least amount of water in order to sufficiently irrigate a plantation. This is the reason drip irrigation adoption has been increasing in areas where water scarcity exists or the climatological conditions lead to high losses when using other irrigation methods (Karlberg et al. 2007). The drippers used in a drip irrigation system need a minimum feed pressure to be able to supply their nominal flow. This leads to the need of a pump to increase the pressure of the feed water, even in the cases where access to an irrigation canal or other surface water source is available. In rural agricultural areas, there is often no direct access to an electrical grid. If the farmer needs to operate a pump, the most common options that arise is to pay for a grid extension, get a diesel generator or invest in an off-grid renewable energy system (Carroquino et al. 2015).

Supported partly by the European Union Seventh Framework Programme (FP7/2007-2013) under Grant No. 609554.

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In this study, the application of solar pumping technology to drip irrigation has been examined. The case study of the Jordan Valley is chosen as means to compare solar pumping cost effectiveness to conventional pumping systems currently used by farmers, namely grid-electricity and diesel pumping systems, using the real world data.

MATERIAL AND METHODS

In this paper, drip irrigation of a typical 3 × 10^4 m^2 (300 m × 100 m) date palm plantation in Deir Alla in the Jordan Valley has been examined. Water is pumped from a water pond to the plantation. Spacing within and between tree rows is 10 m, resulting in 30 tree rows and 300 trees in total.

Irrigation requirements were calculated according to the modified Penman-Monteith equation, using typical climate data from the meteorological station at the Deir Alla agricultural station. Annual net irrigation requirements were estimated at 28,071 m^3.

The investigated drip irrigation system was designed based on the calculated daily maximum of 122 m^3/day during the summer period. For the purpose of minimizing energy requirements, the plantation was divided into three equal plots of 100 × 100 m that were irrigated successively within the same day, while the plantation was irrigated on a daily basis and in accordance with local farmers' habits. This was decided after investigating different plot configuration in relation to the resulting power needs of the pump. Water velocity in the piping system should be kept at least 1.5 m/s, to avoid sedimentation of suspended solids and drippers clogging. Pressure drop in the pipes was calculated using the Hazen-Williams equation. A commonly used typical centrifugal pump was considered.

Table 1. Drip irrigation system parameters per irrigation plot (10^4 m^2)

Parameter	Value
Minimum pressure at drippers (Pa)	10^5
Flow rate in laterals (m^3/h)	2
Head loss in laterals (m)	13.1
Pumping lift from pond to irrigation system (m)	5
Flow rate in main line (m^3/h)	20
Total dynamic head (m)	31.7
Pump and motor efficiency	40%
Pump power (kW)	4.3

The basic parameters of the drip irrigation system for each of the three plots are shown in Table 1. The results show that the 3 × 10^4 m^2 date palm plantation can be irrigated by a 4.3 kW pump that pumps water at a rate of 20 m^3/h.

Based on the data above, the drip irrigation system is fed by a 4.3 kW electric pump that annually pumps 28,071 m^3 of water and consumes 6,063 kWh_{EL}. In order to calculate the Net Present Cost (NPC) of the system over a period of 20 years, the parameters shown in Table 2 were considered. Costs are based on the local market prices, while electricity cost was provided by the National Electric Power Company (NEPCO), Jordan. For converting JOD to EUR, the average exchange rate (1 JOD = 1.115 €) for the period 1/4/2014–1/4/2015 was taken into account. The grid extension and connection costs used were provided by the Electricity Distribution Company, while distance between electricity poles was assumed at 30 m. The NPC ranges from 7,531 € without grid extension to 59,780 € for farms located 1.5 km away from the nearest electricity distribution line.

In the case of a diesel-pumping system, a pump was coupled to a diesel generator. Assuming a specific diesel consumption of 0.4 l/kWh and a price for diesel equal to 0.506 €/l, the annual cost for diesel is 1,228 €. The cost of the diesel pump is 3,000 € with an annual maintenance cost of 600 € and a replacement cycle of 10 years (the high maintenance cost includes the periodic replacement of the diesel generator) (Table 2). NPC is calculated as a function of diesel price and ranges from 28,084 € for the current diesel price in Jordan (0.506 €/l) to 43,293 € for a diesel price equal to 1.00 €.

The photovoltaic (PV) pumping system considered comprises a PV array, an Maximum Power Point Tracking (MPPT)/charge controller and a battery bank. Since the sizes of the PV array and the battery bank are related, a techno-economic optimization approach is used. Two software suites were used, namely TRNSYS (TESS, USA) and GenOPT (BerkleyLab, USA). TRNSYS is the main simulation program and GenOPT is the optimization suite. Typical crystalline PVs and OPzS batteries are considered. Particle Swarm Optimization (PSO) was used, since it is able to optimize discrete variables and gives good results for energy systems (Boonbumroong et al. 2011). The optimal sys-

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Table 2. Parameters related to the calculation of net present cost (NPC) of the studied systems

Parameter	Electric grid	Diesel	PV
Cost of pump (€)	500	3,000	500
Pump replacement (years)	15	10	15
Annual maintenance costs (€)	80	600	125
PV panels (€/Wp)			0.70
Batteries (€/Wh) (a 7 year replacement period is considered)			0.20
PV and battery inverters (€)			6,000
Support structure and electrical equipment (€)			1,700
Installation and commissioning (€)			1,000
Specific consumption of diesel generator (l/kWh)		0.4	
Electricity cost for farmers (€/kWh)	0.075		
Cost per pole (€)	106		
Cost of cable (€/m)	31		
Line connection cost (€)	449		
Real interest rate		5.4% (2014 World Bank)	

PV – photovoltaic

tem is the one that presents the lowest NPC over a 20-year investment period and at the same time can fulfill certain technical constraints. The only constraint used was that the battery bank State of Charge does not drop below 25%, which ensures that the load is always met and the battery bank never gets deep discharged leading to early aging. The optimization variables along with the optimal values for the PVs, batteries and accessories are presented in Table 3. The PV array is sized at 7.56 kWp and the battery bank consists of 12 batteries rated at 200 Ah/2 V each (24 V bus). The NPC is 18,464 €.

RESULTS AND DISCUSSION

The summarized results are presented in Fig 1. The use of a diesel pump is the least favourable option from an economical point of view, since it exhibits high operation costs, even with diesel prices as low as 0.5 €/l, which are expected to rise in the future.

PV pumping system compares well to grid electricity for distances above ~300 m from the grid. For shorter distances, grid electricity is cheaper. Grid parity for the PV pumping system is achieved for a retail price of electricity equal to 0.22 €/kWh, with the current price at 0.075 €/kWh. However, for larger distances from the grid, PV pumping becomes more favourable. Grid parity is achieved at 0.17 and 0.08 €/kWh at a distance of 100 and 300 m from the grid, respectively.

Moreover, for a comprehensive comparison, the actual production cost of grid electricity is taken into account, since retail electricity to farmers is heavily subsidized. The production cost of grid electricity in Jordan (2013) was 0.154 €/kWh (NEPCO 2013). In this case, the PV-pumping becomes preferable for distances larger than 128 m from the electric grid. The above data are in agreement with findings published elsewhere, which identify PV pumping

Table 3. Optimization variables and results

System components	Lowest value	Highest value	Step	Optimal value
Typical crystalline modules rated at 280 Wp	10	40	1	27
DC Bus Voltage (V)		12, 24, 48		24
Capacity rating of each of the 2 V batteries (Wh)		200, 400, 600, 800, 1000, 1200, 1500		400

DC – direct current

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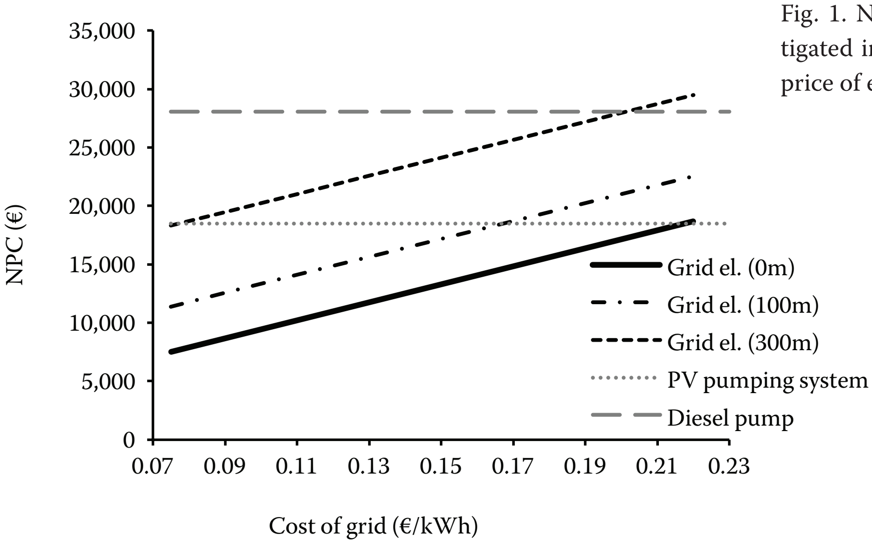

Fig. 1. NPCs for the three different investigated irrigation options in relation to the price of electricity

systems as the most favourable option compared to grid extension and diesel powered systems for rural areas (Al-Smairan 2012; Chandel et al. 2015).

CONCLUSION

In this paper, a direct comparison through a case study was performed of grid extension, diesel generator and PV-battery alternatives for drip irrigation. An autonomous PV-battery system can cover the drip-irrigation needs throughout the year adequately. The diesel generator alternative proves to be the worst option techno-economically. The PV-battery alternative is break-even point in relation to the grid-extension is 300 m. If the production cost of electrical energy is used instead of the subsidized market price for agricultural use, the PV-battery alternative is more preferable in economic terms for distances greater than 128 m. These results show that for current market prices, in many cases an autonomous renewable energy drip-irrigation system can present an attractive and preferable techno-economically wise solution.

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Received for publication February 12, 2016
Accepted after corrections November 16, 2016