Effect of Optimum Sized Solar PV Inverter on Energy Injected to AC Grid and Energy Loss in Pakistan

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Abstract

Objective: To analyze the effect of optimized size inverter for Nawabshah Sindh Pakistan on the annual energy injected to ac grid and energy loss. **Methods:** Using the optimized sizing ratio of 1.4664, which is the ratio of rated photovoltaic system to the rated inverter size the simulations are carried out in MATLAB for 3 kW and 50 kW photovoltaic systems. A comparison between the conventional sized system that is the photovoltaic system and inverter of the same size and optimized system where the photovoltaic inverter is connected with respect to the sizing ratio are taken and simulations are carried out using real time data of solar irradiation and ambient temperature of Nawabshah Sindh Pakistan in MATLAB for one year. **Findings:** It is seen that 5830 kWh and 97,162 kWh energy is annually injected to the utility grid or load and annual power loss of 274 kWh and 4568 kWh from conventional sized 3 kW and 50 kW PV systems, respectively. While the annual energy injected to the ac grid is 5852 kWh and 97,529 kWh and annual power loss of 252 kWh and 4201 kWh from optimized sized 3 kW and 50 kW PV systems, respectively. **Novelty:** Thus, we can say that the optimized system not only reduces the size of the inverter but also improves the system efficiency and reduces the losses which eventually decreases the capital cost of the PV system and energy production.

Keywords: Distributed Generation, PV System, Energy Loss, PV Integration, Inverter sizing Ratio.

1. Introduction

In the socioeconomic development of any country, a vital role of electrical energy is seen. A continuous increase in the electrical energy utilization is seen due to an increase in the population, advanced technology usage, etc. [1–2]. Since last two decades, a load shading

of 10–12 h/day is faced by the peoples of Pakistan due to a shortfall of electrical energy even though at about 43% population is living without electricity and about 50,000 small villages are far away from the excess to national grid [3–4]. A major share of electricity in Pakistan is produced from conventional sources such as oil, gas, coal, etc., which are imported thus an increase in the fuel price directly affects the cost of the electricity [5–6]. An increase in the energy demand and dependency on conventional sources is a great concern the world is facing nowadays. These sources result in environmental pollution and contributing to global warming by releasing carbon dioxide to the atmosphere [7–8]. In order to decrease the dependency on conventional energy sources and difference between supply and demand of energy, it is the need of the present era to alter the conventional energy sources to renewable energy sources such as wind, solar, biomass, etc. with low cost and zero carbon emission [9–10]. Nowadays, the capacity of PV power generation has increased from kW to MW in various countries around the world, a 303 GW solar power production is expected by 2020 in the global power production [11–12]. Photovoltaic generating units require low maintenance cost; noise-free and without a rotating part compared to the fossil fuel energy generating units [13]. A massive initial cost of photovoltaic system is one of the key concerns although it is a clean, environmental friendly and secure energy source [14–16]. The power produced by PV panel is intermittent, uncertain, and random in nature as it depends on the meteorological data of the site, such as irradiation and ambient temperature because PV panels are designed under standard test conditions of 1000 W/m^2 irradiations and 25 ºC ambient temperature [17]. The Solar Photovoltaic System is the best solution for the distributed power generation as the sunlight is freely available. Without affecting the environment dc power is produced by SPV system when photo energy strikes on it. SPV system can be operated in standalone and grid-tied mode. Generally standalone SPV systems are used in rural areas which are far away from the national grid and grid-connected systems are used in urban areas in order to supply the excess energy produced by SPV systems to the national grid and receive the energy in case of shortage or any fault [18–19]. In order to connect the photovoltaic system to the distribution grid a voltage source inverter is used, which converts the dc power generated from PV system to ac power injected to the utility grid [8–20]. TypicallyPV system and inverter of same size are used, but it is seen that the irradiations and ambient temperature of the sites are below the standard test conditions hence the power generated by photovoltaic system is always under the designed capacity. Therefore the size of the inverter must be optimized in order to supply the power reliably and efficiently [14, 21–22]. A major portion of capital cost is utilized on the inverter purchase therefore the optimized size inverter also reduces the cost of the photovoltaic system.

The single line diagram of the proposed research work with the integration of solar panels is developed in Dig SILENT power factory software using real time data is shown in Figure 1.

To optimize the inverter size, the load of one of the class of electrical engineering department QUEST Nawabshah is calculated and is shown in Table 1. In order to supply a 2.5 kW load, an inverter of 3 kVA is chosen, whose specifications [23] are shown in Table 2 and the characteristics of PV panels [24] utilized at the site are shown in Table 3.
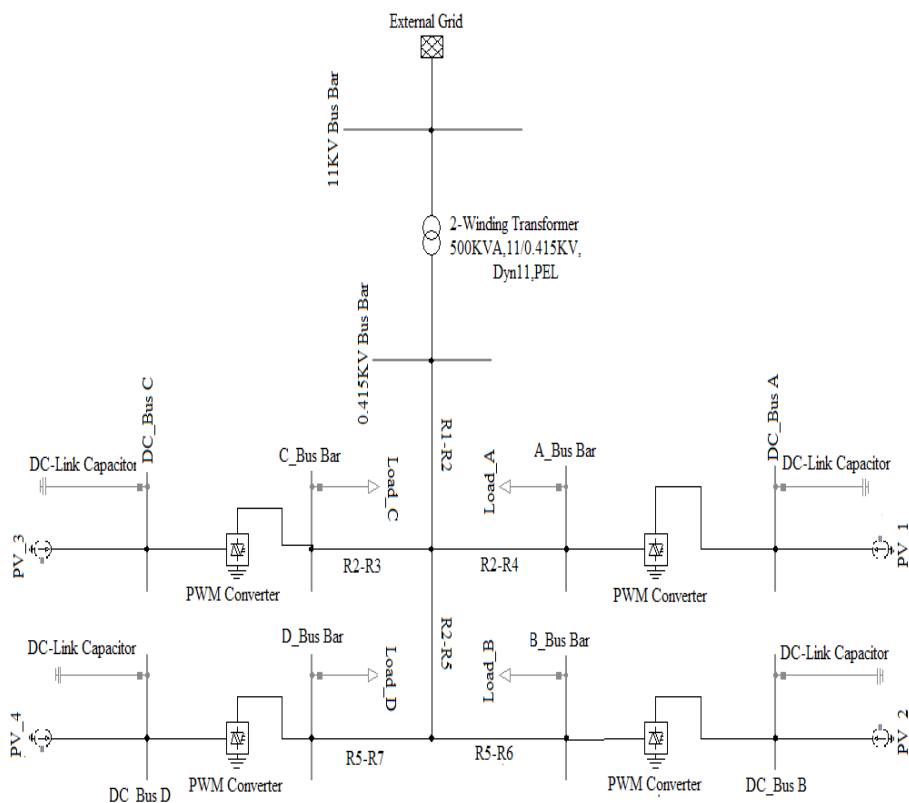
FIGURE 1. Model of distribution system with the integration of solar panels.

TABLE 1. Load of final year class of electrical engineering department

S. no.	Load name with power rating	Quantity	Total power
1	Electric tube lights (40 W)	16	640
2	Electric fans (80 W)	12	960
3	Multimedia and speakers (900 W)	01	900
Total load of class			2500 Watt

TABLE 2. 3 kVA inverter stipulations

|	
Type	Hybrid
Power rating	3 kW
Input direct current	
Minimum input direct current voltage	360 V
Peak input direct current voltage	500 V
Start-up voltage	116 V DC/150 V
Maximum power point voltage	250 V DC to 450 V
Peak input current	13 A

Inverter AC output

Minimum voltage	208, 220, 230, 240 V
Frequency range	47.5 to 50.2 Hz
Minimum current	13.6 A
Power factor	Greater than 0.99

TABLE 3. Characteristics of solar module

Nominal output power (Pmpp)	250 W
Cell type	Poly-crystalline silicon cell
Open circuit voltage (V)	37.4
Short circuit current (A)	8.7
Maximum power point voltage (V)	30.9
Maximum power point current (A)	8.1
Module efficiency (%)	15.3
Temperature co-efficient of maximum power (%/°C)	−0.41
Temperature co-efficient of open circuit Voltage (%/°C)	−0.31
Temperature co-efficient of short circuit current (%/°C)	0.039
Nominal operating cell temperature (°C)	46 ± 2
Operating temperature (°C)	−40 to 85

Figures 2 and 3 shows the annual hourly average solar irradiance and ambient temperature data [25] of site (QUEST Nawabshah) where the photovoltaic system is installed. The aim of this paper is to compare the effect of optimum sized inverter on the annual energy injected to ac grid and its effect on annual energy loss with respect to the conventional sized inverter.
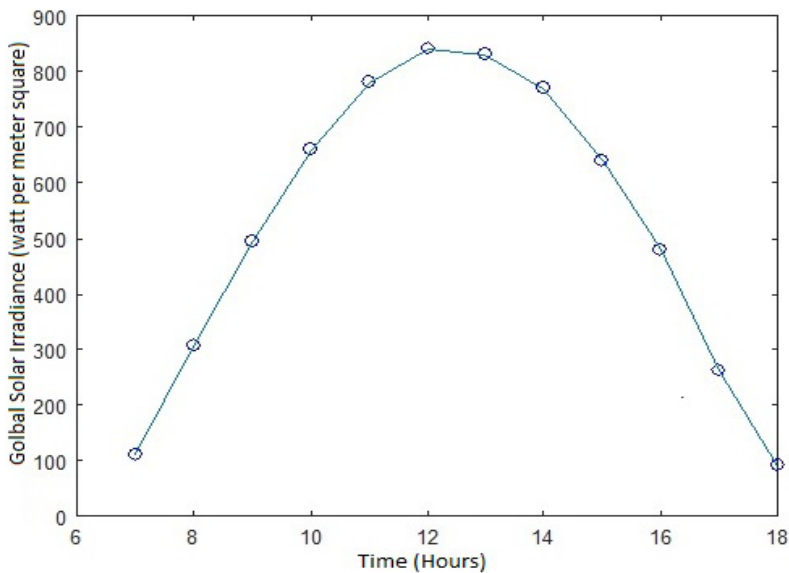
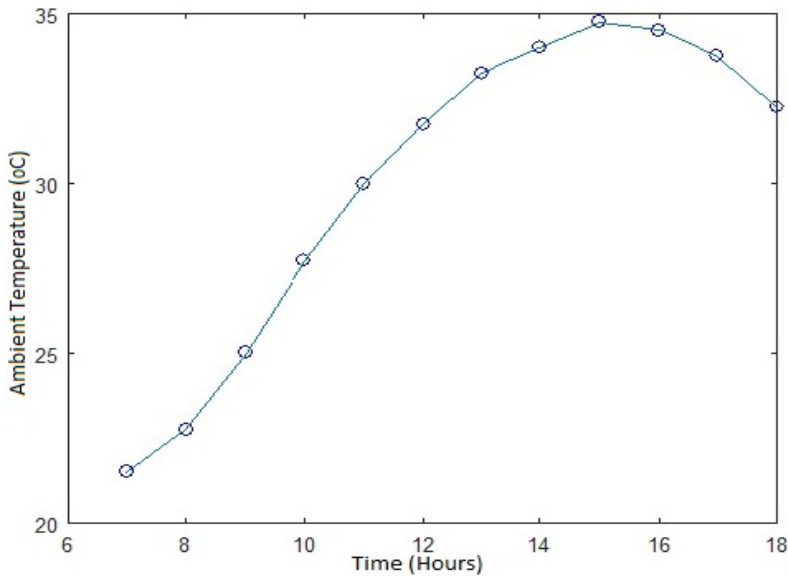**FIGURE 2.** Global solar radiations data at quest.

FIGURE 3. Ambient temperature data at quest.

2. PV Array Output Power

The electrical power of photovoltaic panels depends on the irradiance and cell temperature [26]. A linear relationship with irradiance and non-linear relationship with cell temperature of PV panel power output is seen beyond the standard test conditions. The PV panel output power can be calculated by using Equation (1),

$$P_{pv(out)(t)} = Ppeak\left(\frac{G(t)}{Gs\tan dard}\right)[1-\alpha(Tc-25] \tag{1}$$

where $P_{pv(out)(t)}$, $G(t)$, and Tc are the instantaneous output power of solar panel, irradiance, and cell temperature, respectively, $Ppeak$ is maximum expected output power of solar panel at standard test conditions i.e. 1000 W/m² irradiance and 25 °C cell temperature and α is the temperature coefficient of power which is −0.41%/°C taken from polycrystalline PV panel datasheet.

Therefore, in order to determine the output power, the instantaneous cell temperature of photovoltaic modules can be calculated using Equation (2),

$$Tc = Ta + \left[\frac{(\text{NOCT}-20)}{800}\right]*G(t) \tag{2}$$

where Ta and NOCT are the instantaneous ambient temperature and normal operating cell temperature taken from solar panel data sheet.

Using MATLAB Simulink the instantaneous cell temperature and output power of 3 kW photovoltaic system is simulated and is shown in Figures 4 and 5, respectively.
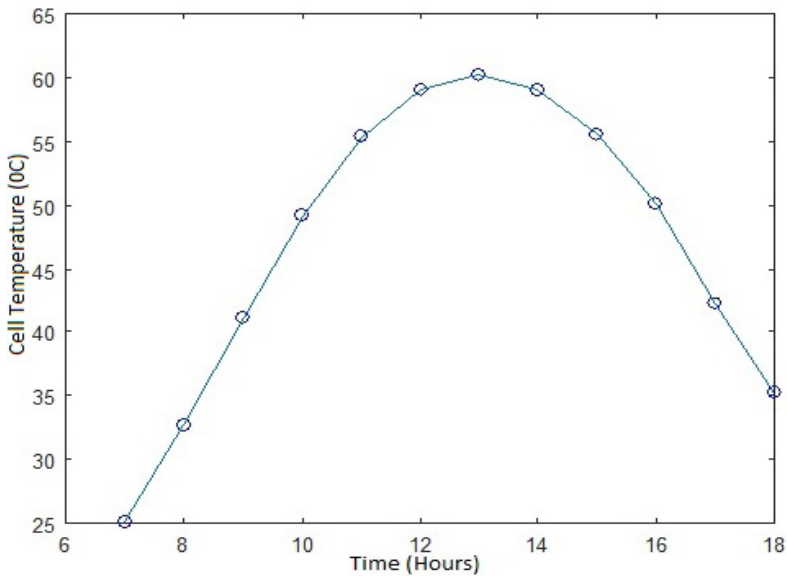
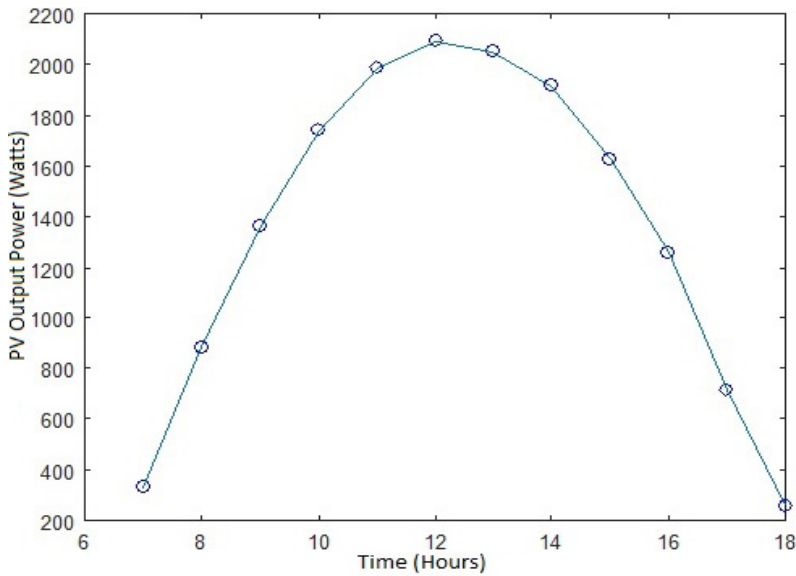**FIGURE 4.**   Cell temperature of PV panel installed at the site.

FIGURE. 5.   Output power of solar system installed at the site.

3. Inverter Efficiency Curve and Its Optimization

The efficiency of photovoltaic inverter [26] may be defined as the ratio of ac output power injected to ac grid to the dc power produced by PV panels input to the inverter as in Equation (3),

$$\eta_{inv} = \frac{P\_ac(t)}{P\_dc(t)} = \left(\frac{P_{dc(t)} - P_{loss(t)}}{P_{dc(t)}} \right) \tag{3}$$

where $P\_dc(t)$, $P\_ac(t)$, and $P\_loss(t)$ are the instantaneous direct current output power of PV system, the alternating current power supplied to the load/utility grid, and conversion power loss respectively.

Using MATLAB Simulink the inverter efficiency curve is developed as shown in Figure 6, using the inverter model presented in Equation (4) developed by [15, 26] in terms of inverter input power to output power.
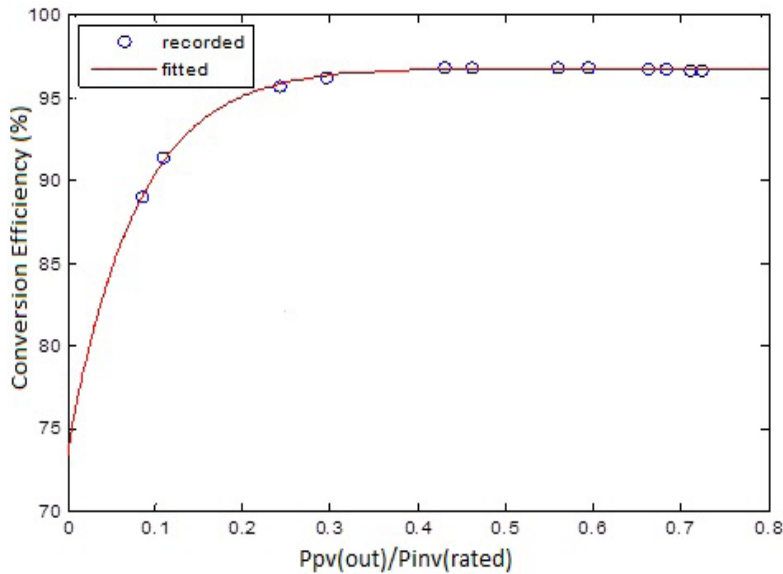

FIGURE 6. Efficiency curve of the inverter installed at site.

$$\eta_{inv} = 100.583 - \left(\text{Pratio} \times 3.611 \right) - \left(\frac{0.972}{\text{Pratio}} \right) \tag{4}$$

Where,

$$\text{Pratio} = \frac{P_{pv(out)(t)}}{Pinv(rated)} \tag{5}$$

The efficiency curve shown in Figure 6 is described by an exponential function as follows.

$$\eta_{inv} = a_e^{bx} + c_e^{dx} \quad \text{when } x > 0$$

$$\eta_{inv} = 0 \quad \text{when } x = 0$$

where $x = \dfrac{P_{pv(out)(t)}}{Pinv(rated)}$ and a, b, c, and d are the model coefficients.

Using MATLAB fitting tool, the developed inverter model coefficients are determined and are described as in Table 4.

TABLE 4. Inverter model co-efficient

Inverter rating	A	B	C	D
3 kW	96.97	−0.003816	−23.55	−12.79

The sizing ratio [15, 26] may be defined as the ratio between photovoltaic systems rated power to the inverter rated power and can be expressed as in Equation (6);

$$Rs = \frac{Ppeak}{Pinv(rated)} \tag{6}$$

When $0 < Rs < 1$, it means that the oversized inverter is used and when $Rs > 1$ it means that the undersized inverter is used. As the aim of the inverter size optimization is to obtain the average possible maximum annual efficiency from inverter which is given as in Equation (7),

$$\varsigma_{Max:annual\ Avrg} = \sum_{i=1}^{366} \frac{\varsigma_{daily\ avrg}}{366} \tag{7}$$

Figure 7 shows the flow chart of the program and outcomes. An iterative loop is used with a set of Rs values from 0.5 to 5 with a gap of 0.01. The loop is repeated iteratively
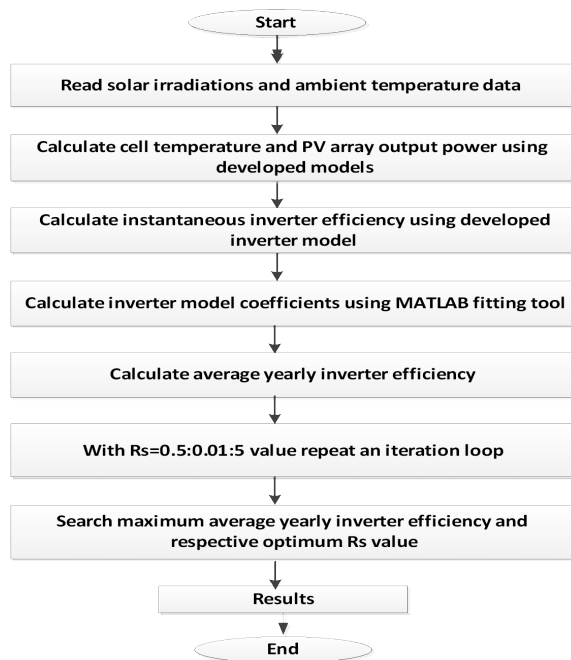

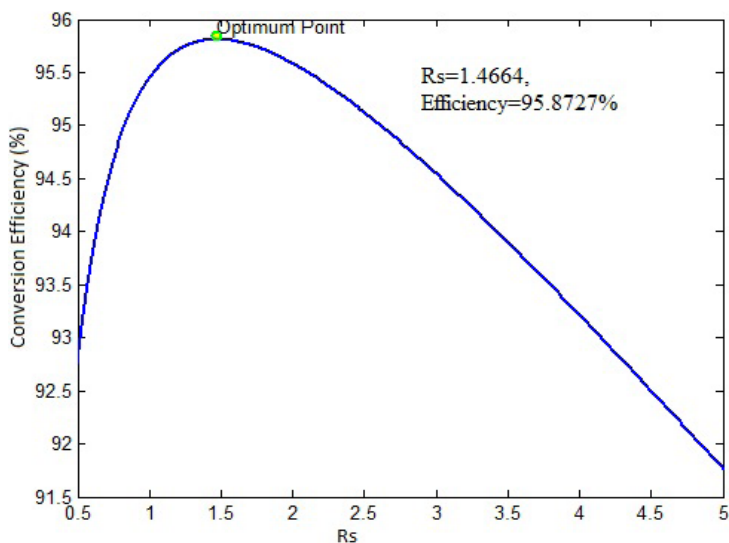**FIGURE 7.** Flow chart of the program and outcomes.

FIGURE 8. Optimal inverter size and maximum average annual efficiency for Nawabshah Sindh Pakistan.

until the sizing ratio reaches its peak value than a search is done in order to determine the maximum annual average efficiency and the optimum sizing ratio which is 95.8727% with a sizing ratio of 1.4664. Figure 8 shows the optimal inverter size and maximum average annual efficiency for Nawabshah Sindh Pakistan.

4. Comparison Between the Conventional and Proposed System

In order to validate the proposed optimization a 3 kW and 50 kW PV systems are taken and comparison between conventional sized inverter and optimized one is simulated in MATLAB and the results are tabulated in Table 5.

TABLE 5. Comparison between conventional and optimized PV system

	Conventional sized system		Optimized system	
PV system rated power (kW)	3	50	3	50
Inverter rated power (kVA)	3	50	2.046	34.10
Sizing ratio Rs	1	1	1.4664	1.466
%age of inverter size w.r.to PV system	100	100	68.2	68.2
Average annual output energy from PV system (kWh)	6104	101730	6104	101730
Annual average conversion efficiency	95.51%	95.51%	95.87%	95.87%
Average annual energy injected to grid (kWh)	5830	97162	5852	97529
Annual power loss (kWh)	274	4568	252	4201

5. Conclusion

It is concluded that the optimized system's performance is better than conventional sized system. As the average annual energy injected to the ac grid is 5830 kWh and 97,162 kWh and annual power loss of 274 kWh and 4568 kWh from conventional sized 3 kW and 50 kW PV systems, respectively. While the average annual energy injected to the ac grid is 5852 kWh and 97,529 kWh and annual power loss of 252 kWh and 4201 kWh from optimized sized 3 kW and 50 kW PV systems, respectively. Thus we can say that the optimized system not only decreases the inverter size but also enhances the efficiency of the system and reduces the losses which eventually decreases the capital cost of the PV system and energy production.

Acknowledgement

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