APPLICATIONS OF
MODELLING AND SIMULATION
ARQII Publication
http://arqiipubl.com/ams eISSN 2600-8084 VOL 5, 2021, 1-6

Development Model of the Inverter Size for the GCC Countries

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Submitted 03 June 2020; Revised 08 July 2020; Accepted 10 July 2020.

Abstract: It is important to develop a suitable model to find the suitable design of inverter based on a required specification that needed to calculate the number of units per day requested by the house holders or companies. The present study deals with the required design using a developed Adaptive Neuro-Fuzzy Inference System (ANFIS) method and based on the calculated results the curve fitting is applied to form the suitable formula. The model is formulated as a function of number of units per day for the Gulf Cooperation Council (GCC) region. In general, the GCC region has high-energy consumption influenced by several factors. Therefore, the solar energy is helping to reduce the use of gas or other fuels to generate power. This means that the obtained results will encourage the GCC through the energy field development and setting the future for it to increase the use of solar energy production. The novelty of the present study is to avoid an increase in generation capacity using the gas to produce the electricity. In addition, it will help the GCC countries to avoid load shedding and meet the energy demands in different sectors. Furthermore, the developed model will help the economic development of the GCC countries. These results reduce capital investment, limiting the equipment installed and the expected load needed in the region.

Keywords: ANFIS; Curve fitting; Panel generation factor; Photovoltaic.

1. INTRODUCTION

Now a days the global warming is a very important issue. That climate change which is caused by human actions affects the environment, where the climate change seriously threatens the nature of the world [1]. Without ambitious mitigation efforts, global temperatures will rise at this time. In the recent years, countries around the world have developed their own vision to orient it towards clean and renewable energy. The reason behind that is clean energy which avoids the consequences of global warming. One of these energies is the solar energy, where the idea of solar energy was taken to improve the sustainability standards of countries and energy sectors [1]. The decision to develop the countries came with the work of renewable energy projects. Furthermore, the solar energy plans have gained importance in recent years [1]. Therefore, the photovoltaic (PV) must be connected to the network to reduce the demand for authority, thereby reducing the load flow. Electricity generation as solar energy increases where the intensity of the sun is collected.

Qamber and Al-Hamad [1] highlights in their article on the PV production which is very dependent on weather conditions. This means that the solar irradiation influences the behavior of PV generation. In addition, this means that it will be an important tool for predicting solar energy to obtain the best economic distribution from the electricity grid. They proposes the artificial innovation method for the calculation of solar panels necessary for the estimation of the daily electricity consumption estimated in five countries. These countries are the Kingdom of Bahrain, Egypt, India, Thailand, and the United Kingdom. Robotics has played an important role in the design and forecasting of renewable energies. It should be noted that the main objective of the article is to design a photovoltaic panel that helps reduce CO2 emissions, where these panels are connected to the national grid. This grid supplies too much electricity generated by the solar energy machine. In this case, the power plant is more efficient than the integrated bicycle system. At the same time, modeling and forecasting in renewable energy engineering helps engineers predict the future of the estimated load required.

Mitoa *et al.* [2] in their research highlight on several studies, which have focused on the use of nature renewable energy sources. Energy and solar are such sources of photovoltaic energy. The renewable energy source used for small reverse osmosis plants. The direct connection of the reverse osmosis plant to renewable energy sources must operate at variable speeds and / or modular operation to match the demand required with the power available in the network. In their article, they studied using both wind and solar PV energies to drive reverse osmosis through the plant configuration, the operating strategy, the control system and the procedures followed to satisfy the selection of the factory with renewable energy sources. Member performance helps wind and solar activities to become economically critical in determining renewable energy reverse osmosis plants.

Qamber and Al-Hamad [3] in their study take in consideration the PV which has today become a new competitive energy resource. The top six locations for solar power are the six countries of the Gulf Cooperation Council (GCC). Here are six countries from the Middle East: Kingdom of Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Kingdom of Bahrain, and Oman with intense solar radiation. GCC countries are well positioned for solar energy. PV is the new competitive source of energy on the planet and can be used in circulation and transmission systems. Qamber and Al-Hamad [3] in their study, the solar cell design model was discovered in five countries with the same household designations. The Panel Generation Factor (PGF) assessed the specificity of climate-dependent cells. The study carried out on five countries, the UK, Thailand, India, Bahrain and finally Egypt. The total number of kilo peak Watt (kWp) of the capacity of the photovoltaic panels, the number of photovoltaic panels required to design the 110 Wp photovoltaic module and the rate of the administrator of the solar by PGF of each country are calculated.

Albadi *et al.* [4] addressed in their study a PV system question in the network of electrical circuits. The target of their study is a case of investigation to reduce system losses. In addition, their study examined the circulation system of Masirah Island in Oman. Their study shows the losses represent 2.1% of the total load. The authors state that distributed production units are renewable, which they consider small. MATLAB is used for the modeling and simulation. The optimal size and location in his study focuses on optimizing the solar bone and using genetic algorithms.

Qamber and Al-Hamad [5] in their study take in consideration the target to engage the PV technology in a way to lower the overloaded equipment and increases the electricity generated at consumer’s side. In their study, they conclude that solar tariffs are proving to be more economical than the conventional sources of power generation. Finally, they conclude that the investment in the GCC smart grid utilizes the budget reduction expected from reinforcement schemes to build a PV system in the residential areas. Marchena *et al.* [6] in their research study and evaluation program for several dispersed solar power plants developed as a practical case study. Analysis of the findings describes the framework that helped improve the monitoring of assets.

By comparing with other work, this paper makes possible to avoid load shedding such as avoiding great future generation capacity for all sectors and / or households.

2. MODEL DEVELOPMENT

In the present study the multi-layer presented in this section is used as a rule-based neural network structure [7-9]. By minimizing the neuro-fuzzy weight, updating vector is needed to be found as:

$$w^x = \frac{w_r}{\sum_{i=0}^{m} w_i} \quad (1)$$

where w^x is known as firing strengths of the fuzzy rules.

The popular truncated method is the Newton algorithm. This method is to obtain a step size and direction in weight space. The step size and direction in weight space help in to find the cost function J_N (.) towards its minimum. The Taylor’s expansion is used, where the cost function can be approximated by the quadratic function:

$$J_N(w + \Delta w) = J_N(w) + \Delta w \frac{dJ_N(w)}{dw} + \frac{1}{2} \Delta w^T \frac{d^2 J_N(w)}{dw^2} \Delta w \quad (2)$$

where w is the weight vector and Δw is the updated weight vector.
To minimize Equation (2), the differentiation of the equation found and set equal to zero to get the following result:

$$\frac{dJ_N(w)}{dw} = \frac{d^2 J_N(w)}{dw^2} \Delta w \quad (3)$$

$$g = -H \,.\, \Delta w \quad (4)$$

where g and H represent the gradient and Hessian of $J_N(w_k)$, respectively.

To find the solution of Newton's equation, the conjugate gradient algorithm is truncated. The algorithm is summarized in the following points:

i) $k = 0$.
ii) w_k the initial weight vector.
iii) $g(w_k)$ and $\boldsymbol{H}(w_k)$ are the gradient and Hessian, respectively.
iv) The termination of $\|g(w_k)\|$ will be applied in the condition that it will be less than $\in$.
v) In case of $\|w_{k+1}\| \leq D_k$, then solving $\boldsymbol{H}(w_k)\Delta w_k + g(w_k)$ using a conjugate gradient.
vi) Calculating λ_k under the condition $w_{k+1} = w_k + \lambda_k \Delta w_k$. Starting with $\lambda_k = 1$.

The trust region radius, D_{k+1} is adjusted with the following heuristic:

$$D_{k+1} = \begin{cases} 2D_k & if \quad \lambda_k \geq 1 \\ \frac{D_k}{3} & if \quad \lambda_k < 1 \end{cases} \quad (5)$$

vii) Back to step (iv).

Both the gradient and Hessian are needed to the cost function $J_N(w_k)$. Then, considering the weight vector **w** and both first and second derivatives of the cost function $J_N(w_k)$ can be obtained as:

$$\frac{\partial J_N(w)}{\partial w_p} = \frac{1}{N}\sum_{k=1}^{N} 2\frac{\partial \hat{y}(w(k),w)}{\partial w_p}\left[y(k) - \hat{y}(w(k),w)\right] \tag{6}$$

$$\frac{\partial^2 J_N(w)}{\partial w_p \partial w_q} = \frac{1}{N}\sum_{k=1}^{N}\left[2\frac{\partial^2 \hat{y}(y(k),w)}{\partial w_p \partial w_q} y(k) - \hat{y}(w(k),w) + 2\frac{\partial \hat{y}(w(k),w)}{\partial w_p}\frac{\partial \hat{y}(w(k),w)}{\partial w_q}\right] \tag{7}$$

Finally, finding the gradient of the model output with respect to the weights:

$$\frac{\partial \hat{y}(x,w)}{\partial w_p} = \begin{cases} \mu_{A^i}^{u} \\ \left[\prod_{u=1,u\neq k}^{U}\sum_{i=1}^{P_u}\mu_{A^i}^{u} w_i^{u}\right]\mu_{A^j}^{k} \end{cases} \tag{8}$$

w_p refers to the i-th weight of the u-th tensor model and w_q refers to the j-th weight of the k-th tensor model.

$$\frac{\partial^2 \hat{y}(x,w)}{\partial w_p \partial w_q} = \begin{cases} \left[\prod_{u=1,u\neq m\neq k}^{U}\sum_{i=1}^{P_u}\mu_{A^i}^{u} w_i^{u}\right]\mu_{A^j}^{k}\mu_{A^l}^{m} \\ 0 \end{cases} \tag{9}$$

where $\mu_{A^i}^{u}$ on the input vector x_i has been dropped to reduce the notation.

The considered inverter size is in the range of 25-30% bigger size for safety purpose. Also, it is recommended to have a battery size through calculating several factors. The factors are the total Watt-hours per day, the expected loss for the battery, which is approximately 0.85, the depth of discharge is considered as 0.6, the nominal battery voltage is 12 Volt V_{dc}. The autonomy's days is 3 days. It should be noted that these days are the number of days that needed for the system to operate when there is no power produced by the PV panels. The Battery capacity calculated as [10]:

$$\text{Battery Capacity (Ahr)} = \frac{\text{(Total Watt−hr per day used by Appliances)} \times \text{Days of autonomy}}{(0.85 \times 0.6 \times \text{Nominal Battery Voltage})} \tag{10}$$

The Solar Charge Controller Sizing needed is typically rated versus Ampere and Voltage capacities. The solar charge controller is required to match the voltage of PV array and batteries. The size of Solar Charge Controller Rating calculated as [10]:

$$Solar\ Charge\ Controller\ Rating = Total\ Short\ Circuit\ Current\ of\ PV\ Array \times 1.3 \tag{11}$$

The ANFIS system applies the artificial neural network to find the suitable Fuzzy Inference System (FIS) structure and parameters. The fuzzy system with its structure identifies the considered fuzzy rules to find the targeted results. The considered architecture of the ANFIS structure has six layers as shown in the Figure 1 which is the developed model in this study.

The fuzzy sets are initialized according to the known data of fuzzy variables in the first layer, where the weights (w) representing the truth-values of the rules in layer (2). The firing strengths of the fuzzy rules are normalized according to Equation (1) and represented in layers (3) and (4). The quadratic function represented by Equation (2) and derived from Newton Algorithm using Taylor's expansion to find the Neuro-fuzzy weight update vector. The result of differentiating Equation (2) is set to zero to minimize Equation (3). Both Equations (8) and (9) represent the model's output with respect to the weights and represented in layers (5) and (6).

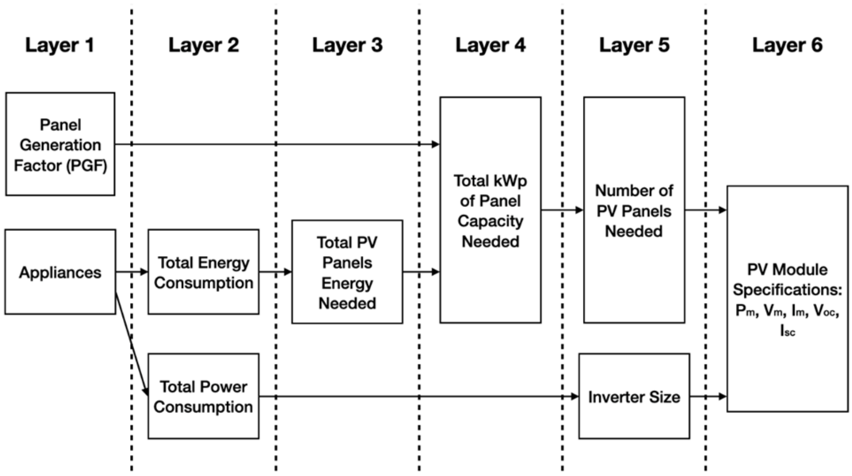

Figure 1. ANFIS developed model of the PV module

With reference to the solar charge controlling, the Fuzzy Inference System (FIS) is applied. Two inputs are shown in layer (1) which are the Panel Generation Factor (PGF) and the Appliances with their Specifications. The output of the model (Layer 6) is the PV module specifications, $P_{max}, V_{max}, I_{max}, V_{oc}$ and I_{sc}. The obtained results in Layer 5 are obtained under the PV module specifications required which is called defuzzification. This process of converting an output fuzzy set for a solution variable into a single value known as output. This output is the PV module which contains the required number of PV panels and inverter size. These information as mentioned earlier forming the PV module with the required specifications.

3. RESULTS AND DISCUSSION

The study started by assigning the PGF of the targeted country under study and the common appliances available in the houses with their ratings and the running period of each appliance. Figure 2 represents the system under study. The targeted module are PV module's specification, number of PV panels and inverter size. The considered appliances in the present study calculate the power and energy of each appliance, where the total power and total energy are calculated. The total kWp of the panel capacity required is calculated for the targeted PV panel's module.

Based on the assumptions made and considered, the results are obtained and discussed. Five different cases are considered in the present study. These cases targeting the model of PV panels. A house with several appliances is assumed in the present study with the five cases. The appliances are running with assumptions of power ratings and a running period. The considered appliances with their running of each appliance depends on the need at that time of running. These appliances are Fluorescent, Lamp Saver, LED Lamp, Fan, Split Units AC with three different number of ton, Window Unit AC, Deep Freezer, Refrigerator, Dry Iron, Steam Iron, Water Heater, Washing machine, Vacuum Cleaner, Water Pump, Kettle, and Microwave. Each appliance is one or more piece(s). For example, the AC is taken in consideration and is assumed that 60% of the total time its compressor unit is running.

The application of the study started with the appliances used in the present study and the results are summarized in Table 1 for the five different cases. The Panel Generation Factor (PGF) of the six GCC countries (Bahrain, Kuwait, KSA, Oman, Qatar, UAE) is 5.84. The PV module's specifications targeted are the same. These targeted specifications are PGF $= 5.84, P_m = 110$ W, $V_m = 16.7$ $V_{dc}, I_m = 6.6$ A, $V_{oc} = 20.7$ V and $I_{sc} = 7.5$ A.

The relationships of the total number of Units per Day versus the considered five cases is shown in Figure 2, the variation of the PV Panels for the five cases considered is shown in Figure 3, and the variation of the Inverter Size for the same five cases illustrated in Figure 4.

Table 1. Results of five cases under study for the GCC

Case #	PGF	Appliances Rating (kW)	Total No. of Units per Day (kWhr/Day)	No. of PV Panels	Inverter Size (kW)
1	5.84	49.763	240.479	487	64691.9
2	5.84	58.717	267.977	543	76332.1
3	5.84	66.211	290.915	589	86074.3
4	5.84	79.585	331.583	671	103460.5
5	5.84	92.977	372.251	754	120870.1

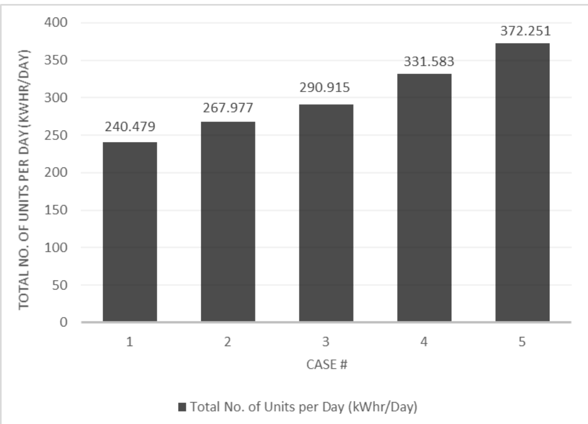

Figure 2. Variation of the total number of units per day for five cases

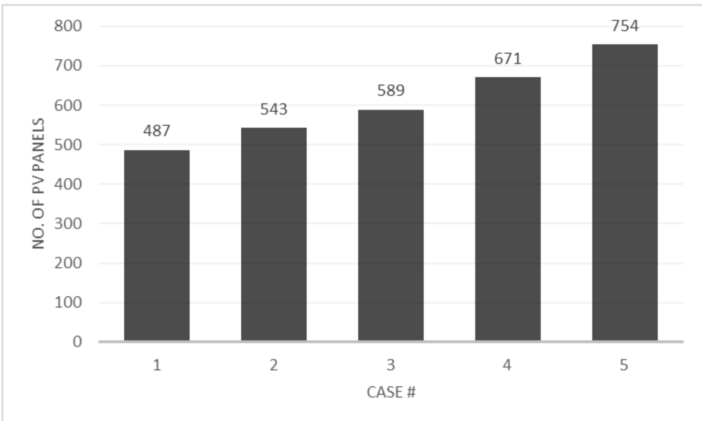

Figure 3. Variation of the PV panels for five cases

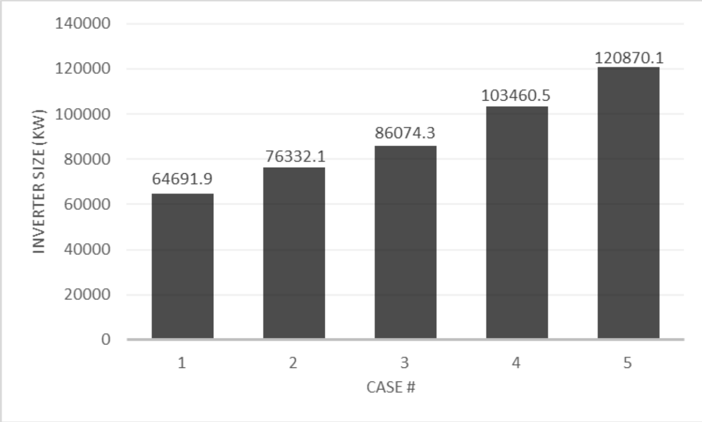

Figure 4. Variation of the inverter size for five cases

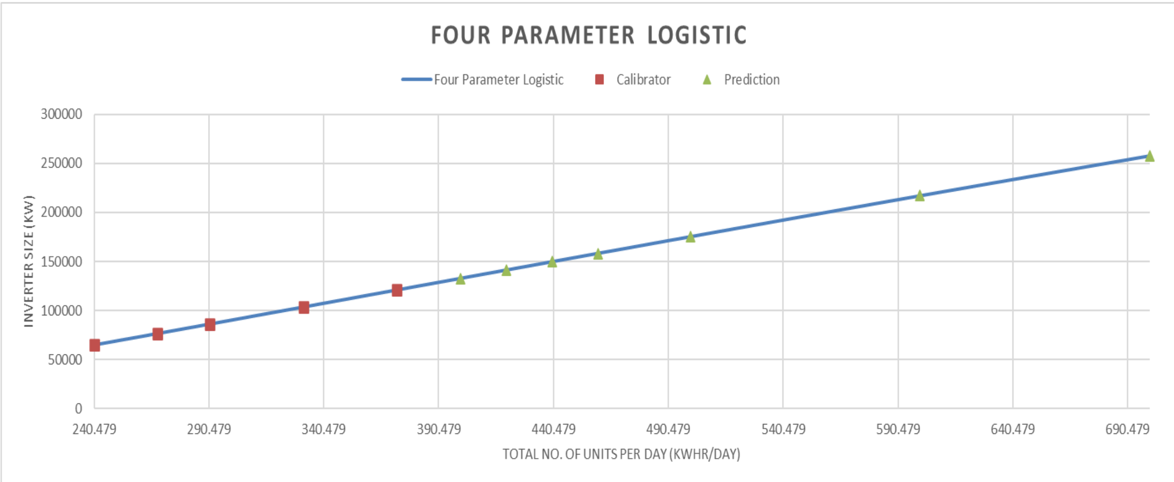

Figure 5. Relationship of the inverter size versus total number of units per day

Applying the curve fitting technique using MyCurveFit (Online Curve Fitting) on the relationship between the inverter size and the total number of units per day results Figure 5. This curve is helping to find the future design for building the required project based on the given data which are given in Table 2. The fitting equation of this relationship becomes:

$$Inverter\ Size = d + (a-d)/[1 + \left(\frac{Total\ number\ of\ units\ per\ day}{c}\right) b] \tag{12}$$

where

$$a = -24021.6824740728$$

$$b = 1.20853630842455$$

$$c = 2532.68899178868$$

$$d = 1591319.41645542$$

This relationship concludes that based on the maximum required number of units per day, the design of the inverter size will be calculated. The area that forms the basis of the solar panel's measurement design of module is known as the project Surface Area illustrated in Figure 6. The relationship between the three variables (total number of units per day, number of PV panels and case number) illustrated is the area that makes the basis of the solar panel's measurement design of module. The surface area is recommended based on the obtained results.

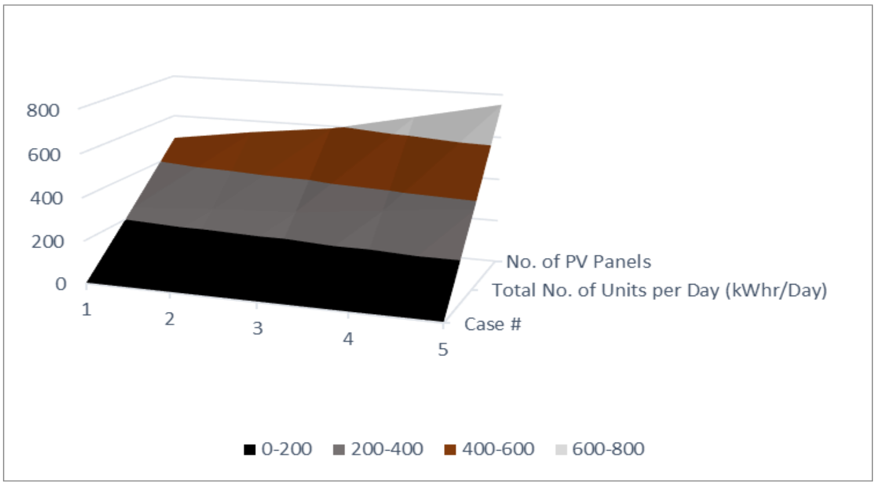

Figure 6. Variation of the inverter size for five cases

4. CONCLUSION

The developed model presents the relationship between the inverter size versus the total number of units per day using ANFIS method. The results demonstrate clearly that the obtained model effectively help in finding the most suitable inverter size based on the required units per day. In addition, the present study indicates the most reliable model of the Neuro-Fuzzy for the most suitable values. The present study forms model for estimated values of the targeted total number of units to be generated using the solar energy. Finally, the developed model of the GCC countries is close to the real required values. In addition, the present study helps avoiding the huge generation capacity in the coming future for the housed and/or sectors. Furthermore, this means that the GCC countries will avoid load shedding and meet the energy demand in the different sector(s). Finally, the developed model helps in the economic development of the GCC countries.

ACKNOWLEDGMENT

The author would like to thank Ms. Aysha Isa Qamber for the great help during the preparation of this paper.

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