Design and Cost Evaluation of a Distribution Feeder Connected Solar System

Sara Ashfaq, Nisma Saleem and Dr. Tahir Mahmood

Abstract

A distribution grid connected photovoltaic (PV) system faces the problem of reactive power imbalance. In view of this problem, a three-phase single-stage distribution grid connected with PV inverter can be incorporated with Var compensation. To obtain the accurate amount of real power insertion, as well as the voltage and var control.

This paper proposes an improved structure of a distribution feeder of UET Taxila for the grid integration of PV solar systems with static var compensation (SVC). The employed scheme consists of a 3 phase bridge inverter which allows the efficient, flexible and reliable generation of PV array. Cost evaluation of project is also carried out on basic level. The validation of proposed models is carried out through digital simulations using the MATLAB/Simulink.

Index terms: Photovoltaic (PV), Static var compensation (SVC), Distributed generation (DG), Maximum Power Point Tracker (MPPT)

1. Introduction

PV systems generate energy with minimal environmental impact. However, a simple photovoltaic system with no storage capacity provides electricity with the sun shine only. It does not provide power in the evening time when loads can be greater, and the output from a PV system can increase or decrease rapidly. [1]

The grids having residential and commercial load have the following characteristics:[3]

1. The Photovoltaic system with the inverter are connected to the electricity grid in parallel with the loads.
   - The load will be served whenever the grid is available.
   - Energy produced by the Photovoltaic system decreases the load
   - The Photovoltaic system is without storage and cannot provide power in the absence of the grid.

2. The inverter of the system meets the IEEE 1547-2005 requirements. [2]
   - There is no direct communication medium and control between the utility grid and the inverter.
   - If the inverter senses that utility grid service has fallen out against the set boundaries for voltage and frequency, the inverter will disconnect itself from the utility grid until normal condition occurs. The load of the grid remains connected to the utility.

3. For residential and small scale commercial systems, the grid interconnection are metered at a flat rate.
   - The price of energy will be constant throughout the day.
   - When there will be excess energy, the meter will spin backward.
Energy will be sold and bought at the same price.
Over the period of a month or a year, if the energy produced goes above the level of energy used, the utility will not pay for the extra amount used. [5]

4. For large scale commercial systems, the rate structures will be more complex.

1.1 Solar Power- Basics

Figure 1 shows the basic components associated with the utilization of solar power in our existing system. These components include:[4]

- Solar panels
- Solar tracker
- Solar battery storage
- Inverters
- Charge controller

![Figure 1: Basic components of a solar power system](image)

I. Solar panels

Two types of solar panels are in common use i.e. Multi-crystalline (poly crystalline) solar panels and mono-crystalline solar panels. A polycrystalline cell consists of many crystals. It has similar life time to the mono crystalline cell type, but with less efficiency and cost. A mono crystalline cell is constructed only with a single crystal. Mono crystalline solar panels are highly efficient.

![Figure 2: a) Mono crystalline b) Multi crystalline](image)
II. Solar Tracker

Solar tracker (Sun tracker) is used to change orientation of solar panel. Solar tracker changes direction of panels automatically to where sunshine is highest. Solar tracker is recommended for higher installations. Because without existence of solar tracker solar panels remains on one direction but as sun light changes its direction. Hence it does not shine 100% on panels.[7-10] Sun trackers are expensive due to its complex assembly.

![Solar Tracker Image]

Figure 3: solar tracker

III. Solar Battery Storage

a. Normal Batteries

Batteries are very important storage medium in solar power system to store the power. Normal batteries are good & cheap. Normal car batteries require maintenance. But there is need of mineral free water after appropriate time duration. [11]

The checking of battery after each six months is necessary for level of distilled water. The connections of cables should be clean and tightened. Dirty and loose connections cause many problems.

![Battery Images]

Figure 4: battery storage for solar system

b. Maintenance Free Batteries

There is no requirement of acids filling in Maintenance free batteries. They have life time of 1000 charges or more. So the battery will be replaced after this time period. [12-13]
Battery storage:

It depends on the size of battery and its capacity (Ampere hour). Example: if a battery is 6Ah so it can store 780W. A battery is 12v and capacity is 65Ah. So, \( P = E \times I = 12\text{v} \times 65 = 780\text{W} \).

Battery capacity:

In parallel connection the capacity of battery increases. As shown below.

\[ \text{Figure 5: Battery connection} \]

IV. Inverters

Inverters are used to convert DC volt system to AC volt at 50Hz. There are two types of inverters

- Modified sine wave
- True sine wave

Modified sine wave inverters are cheap and are commonly available. Devices that require true sine wave inverter will not operate on modified sine wave inverter. True sine wave inverters are expensive. [14-16]

V. Charge Controller

Charge controller is used to charge the solar storage batteries. Solar panels normally provide 15 to 17 volts and charge controller converts it into 12 to 14 volt. Battery often requires a higher voltage than it already has, to charge the battery. [17] Charge controller prevents the batteries to be over charged. It will give a longer life to the battery. Blocking diode is also replacement of charge controller but there are some negative effects.

The charge controllers automatically disconnect the battery if it is going to be empty. Maximum Power Point Tracker at charge controllers are used with higher power ratings. [19] They can save considerable amount of money on larger systems.
2. Optimal design of PV system components for UET Taxila:

2.1 System configuration and operation

The proposed solar (PV) power system consists of the following necessary components:

- PV system
- Storage Battery
- Bi-directional Power Converter
- Charge Controller unit
- DG set as a standby source

The block diagram with the control system of the proposed scheme is shown below.

2.2 Mode of system operation

a. During day time

During day timing, in suggested approach, solar energy is the first choice and it is the only source of energy while the generator is shut down. Solar DC power is converted into AC power by converter for the load. And simultaneously charges the other battery. Figure shows the proposed configuration during the day time.

![Block Diagram and PV control system](image-url)
b. **During night time**

During night time, solar energy stored in battery is the only source of energy. While the generator is off. The converter converts DC energy by selecting either pre saved charged battery or the energy stored by battery during day, to AC power for the load demand. The battery will continue supplying energy to the load to its maximum discharge level. Figure 8 shows the configuration during night time.

c. **During shortfall period**

Shortfall can occur at low sun radiation or on excess load demand of power resulting in low charging of battery. And thus system may suffer a problem during end of day or at night time to meet the balance load power requirement of the whole day. During shortfall of supply, the battery achieves its maximum discharge level and therefore, the generator is turned on.
The battery charge rate is adjusted to maintain the generator output. The operations, which activate or deactivate Gen-set and charging or discharging battery are managed and done by controller unit. The built in DC and AC switching module of controller units monitor and manage the load demand and energy.

### 2.3 PERFORMANCE AND COST EVALUATION OF SYSTEM

#### PV sizing

The formula of sizing is based on energy balance equation. It is used to compute the optimal size of Photovoltaic solar module for critical load as given below: [21]

\[
\text{Photovoltaic Cell Rating (PPV)} = \frac{(PTL \times \text{S.F})}{\text{sun hour}} \text{ watt}
\]

Where:
- Sun hour = 6.2 hours for specific area
- Safety Factor (S.F) = 1.5 (for cloudy weather/low sun radiation)
- PTL is described by total load energy in watt-hours.

\[
P_{TL}(Wh) = \sum_{0h}^{24h} P_L \text{ Watt – Hours}
\]

The optimal number of PV panel = PPV / Standard PV module rating

#### Battery Sizing

The battery stores the electrical energy to a maximum value as requirement.

\[
\text{Battery Capacity (Ah)} = \frac{PTL}{12V \times \text{SOC}}
\]

Where:
- State of Charge of Battery (SOC) = 50%

#### Quality of Power

The analysis of the output waveform is simulated by the MATLAB program.


- **Efficiency of Converter system**

  The efficiency of the converter was found to be almost constant value. (In the range of 96%) [24]

- **Cost Evaluation**

  The cost of consumption of energy can be evaluated for a given PV system. It is clear that the payback period of the PV system in the scheme is less than two years only, against the fuel consumption and maintenance of DG sets.

  \[
  \text{Payback Period} = \frac{\text{Total Cost of Photovoltaic system}}{\text{(Fuel consumption + Maintenance)}} \quad (5) \\
  = 2 \text{ years (Max)}
  \]

2.4 **Required solar power calculations for proposed system**

*For UET Taxila*

**At day timing:**

We need 400 Kwatt *6hour= 2400 Kwatt hour  
Sun shine=9.5 hours

**At night timing:**

We have only 20% of peak load which is 80 KW.  
80Kw*18hours=1440 Kwatt hour  
2400 KWh+1440 Kwh=3840 KWh  
Solar hours=9.5  
3840 Watt hour/9.5=405 k watt hour  
But it is recommended that always choose a panel some bigger than the requirement. Because when solar unit charges the battery, so some power is wasted on charging too.  
So we will choose 486 KWh panel.

2.5 **Quality of solar panels**

Solar panels are recommended to be of good quality. If we are really looking for panels that can be used in 20-25 years without have massive loss we should buy quality solar panels. Because solar panels of average quality have about 1% (or less) yearly loss of energy, it means if we use them for 20 years they will give a loss of 20%.

So a 100 Watt panel will produce 20% less power then what it produced when it was new.

[25-27] After 20 year’s usage of panel in direct sun shine a solar panel will produce 80 watt instead of 100W. Hence, the quality of solar panel being used is one of the key concerns.
2.6 Cost evaluation:

### Solar unit Mono Crystalline

<table>
<thead>
<tr>
<th>Solar Panels</th>
<th>Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>25Watt</td>
<td>7125,- RS</td>
</tr>
<tr>
<td>50Watt</td>
<td>14250,- RS</td>
</tr>
<tr>
<td>100Watt</td>
<td>28500,- RS</td>
</tr>
<tr>
<td>486KWatt</td>
<td>138510000 RS</td>
</tr>
</tbody>
</table>

Table 1: Solar panel cost evaluation

<table>
<thead>
<tr>
<th>Charge controller</th>
<th>Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellsee 20A 12/24v</td>
<td>8200-RS</td>
</tr>
<tr>
<td>Wellsee 30A 12/24v</td>
<td>8600-RS</td>
</tr>
<tr>
<td>Wellsee 50A 12/24v</td>
<td>10000-RS</td>
</tr>
<tr>
<td>Wellsee 75A 12/24v</td>
<td>15000-RS</td>
</tr>
<tr>
<td>Wellsee 2000A 12/24v</td>
<td>720000-RS</td>
</tr>
</tbody>
</table>

Table 2: Charge controller cost

<table>
<thead>
<tr>
<th>Inverter</th>
<th>Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>500W 12v</td>
<td>2599,- RS</td>
</tr>
<tr>
<td>1000W12v</td>
<td>4900,- RS</td>
</tr>
<tr>
<td>486 KW</td>
<td>2430000 RS</td>
</tr>
</tbody>
</table>

Table 3: Inverter Prices

<table>
<thead>
<tr>
<th>Battery</th>
<th>Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000Ah</td>
<td>9000 RS</td>
</tr>
<tr>
<td>2000Ah</td>
<td>18000RS</td>
</tr>
<tr>
<td>5000Ah for 1KW</td>
<td>45000Rs</td>
</tr>
<tr>
<td>For 486Kw</td>
<td>24300000 RS</td>
</tr>
</tbody>
</table>

Table 4: Cost of Battery

Total cost for 486KW:

16 to 18 crore PKR
Field task installations are given in Appendix A.
2.7 MATLAB Simulation and Results:

Figure 10: Matlab Simulink Design of UET Taxila

Results:

Inverter output:

Figure 11: Inverter output
Active and Reactive power

![Graph of Active and Reactive power of system](image1)

Figure 12: Active and reactive power of system

Voltage and current

![Graph of Voltage and current outputs without compensation](image2)

Figure 13: Voltage and current outputs without compensation
Voltage and current

![Figure 14: Voltage and current outputs](image)

3. Conclusion

Design of a distribution grid with solar panels and var compensation is proposed in this work. The fluctuation of reactive power caused by solar integration is improved by incorporating var compensation. The test system used is distribution feeder of UET Taxila (Pakistan). The cost benefit analysis of proposed design is also carried out on root level. And payback period proves the worth of strategy. Simulation tool used is MATLAB/Simulink.

By analysis of the simulation results in different timing situations, we can come to conclusions that the given designed scheme has obvious advantages to achieve a stable voltage with economic benefits of solar implementation.

References

[14] Fei Ding, Peng Li, Bibin Huang, Fei Gao, Chengdi Ding and Chengshan Wang, "Modeling and Simulation of Grid-connected Hybrid Photovoltaic/Battery Distributed Generation System", in Proc.Electricity Distribution China International Conference CICED, PP.1-10 , 2010

Authors

Tahir Mahmood is an associate professor of electrical power engineering at University of Engineering & Technology; Taxila, Pakistan. He has obtained his B.sc.(Hons) and M.sc. degree in electrical engineering from University of Engineering & Technology, Lahore, Pakistan. He has obtained his PhD. Degree from University of Engineering & Technology, Taxila (Pakistan). He has also worked for Pakistan Atomic Energy Commission. His research interests are simulation and Modeling of Power Electronic Components, Electric Power Quality and Reliability, Electric Power Distribution Control & Automation, Distribution System Planning.
Sara Ashfaq is a post graduate researcher in the Electrical Engineering Department at University of Engineering & Technology, Taxila, Pakistan. She has graduated from University of Engineering & Technology, Taxila (Pakistan) at electrical power engineering. Her research interest focus on the load flow analysis in the environment of Smart grid and distribution control and automation.

Nisma Saleem is a post graduate researcher in the Electrical Engineering Department at University of Engineering & Technology, Taxila (Pakistan). She has graduated from University of Engineering & Technology, Lahore (Pakistan) at electrical power engineering. Her research interest focus on the unit commitment in the environment of Smart grid and GSM based monitoring of transmission and distribution system.

Appendix: A

<table>
<thead>
<tr>
<th>Major field task: Before integrating Sub array</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Electrical design</td>
</tr>
<tr>
<td>2. Mechanical and structural design</td>
</tr>
<tr>
<td>3. Site mobilization</td>
</tr>
<tr>
<td>4. Site preparation</td>
</tr>
<tr>
<td>5. Support pole</td>
</tr>
<tr>
<td>6. Support pole installation</td>
</tr>
<tr>
<td>7. Install conduit junction boxes</td>
</tr>
<tr>
<td>8. Install AC tracker motor junction box</td>
</tr>
<tr>
<td>9. Conduit trenching</td>
</tr>
<tr>
<td>10. Electrical equipment concrete pad excavation</td>
</tr>
<tr>
<td>11. Electrical equipment concrete pad form</td>
</tr>
<tr>
<td>12. Lay conduit</td>
</tr>
<tr>
<td>13. Backfill and compact conduit trenches</td>
</tr>
<tr>
<td>14. Pour concrete electrical equipment pad</td>
</tr>
<tr>
<td>15. Drill torque tube bearing plate mounting holes</td>
</tr>
<tr>
<td>16. Drill tracker assembly mounting holes</td>
</tr>
<tr>
<td>17. Install torque tube bearing plates</td>
</tr>
<tr>
<td>18. Install tracker drive assemblies</td>
</tr>
<tr>
<td>19. Install torque tubes</td>
</tr>
<tr>
<td>20. Install struts</td>
</tr>
<tr>
<td>21. Install PV module rails</td>
</tr>
<tr>
<td>22. Install PV modules</td>
</tr>
<tr>
<td>23. Install row junction boxes</td>
</tr>
<tr>
<td>24. Install inverter</td>
</tr>
<tr>
<td>25. Install transformer</td>
</tr>
<tr>
<td>26. Install DC inverter</td>
</tr>
<tr>
<td>27. Install DC interface enclosure</td>
</tr>
<tr>
<td>28. Test source circuits</td>
</tr>
<tr>
<td>29. Test sub arrays</td>
</tr>
<tr>
<td>30. Test inverter</td>
</tr>
<tr>
<td>31. Array start up</td>
</tr>
<tr>
<td>32. Connect all wires</td>
</tr>
<tr>
<td>After integrating sub array development</td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13</td>
</tr>
</tbody>
</table>