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 photo voltic 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 Photo voltic 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 Photo voltic system decreases the load
- The Photo voltic 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

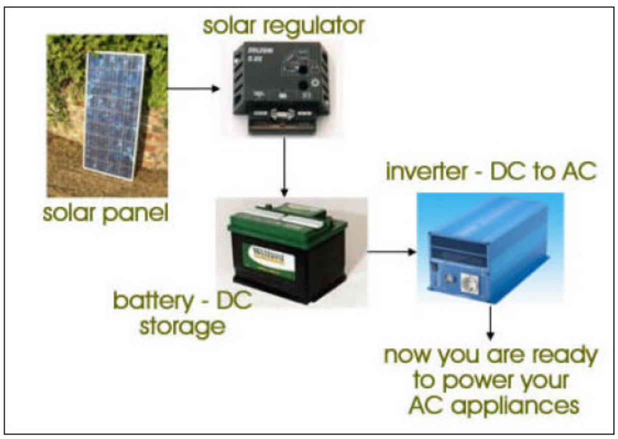

Figure-1 Basic components of a solar power system

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.

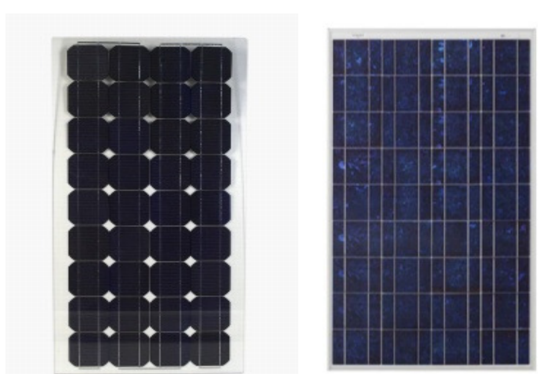

Figure 2: a) Mono crystalline b) Multi crystalline

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.

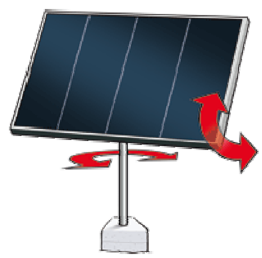

Figure 3: solar tracker

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.

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 * I = 12v * 65 = 780W.

Battery capacity:

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

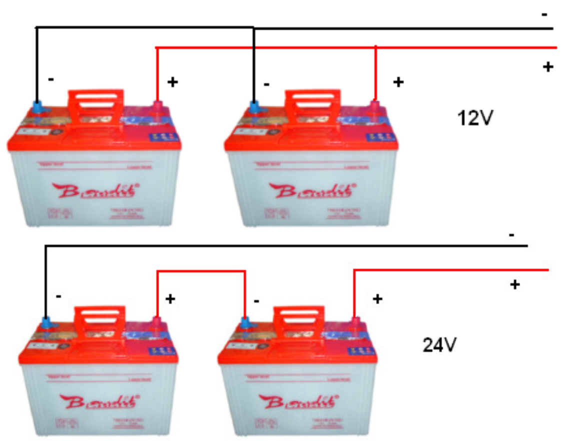

Figure 5: Battery connection

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.

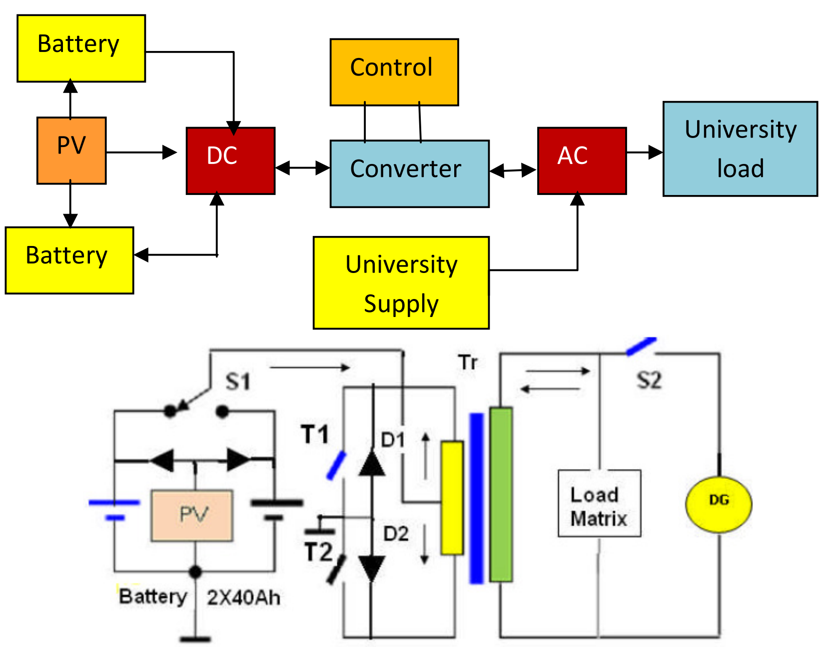

Figure 6: a) Block Diagram b) PV control system

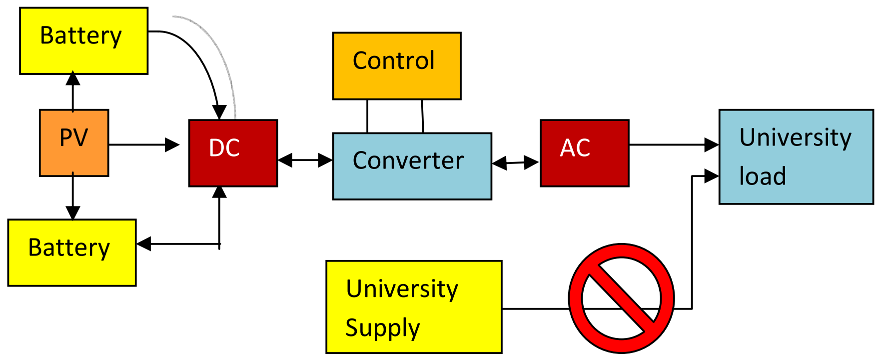

Figure 7: System configuration during day time

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.

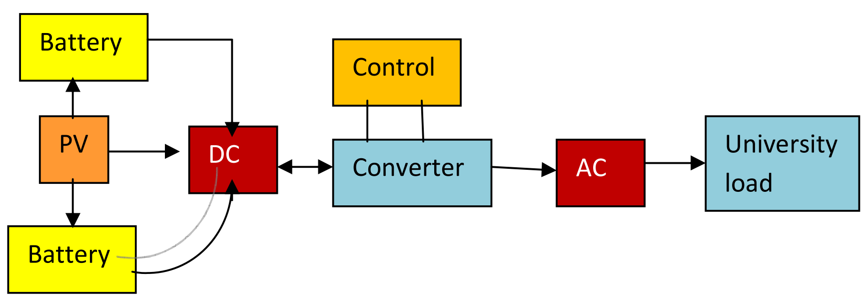

Figure 8: System configuration during night time

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.

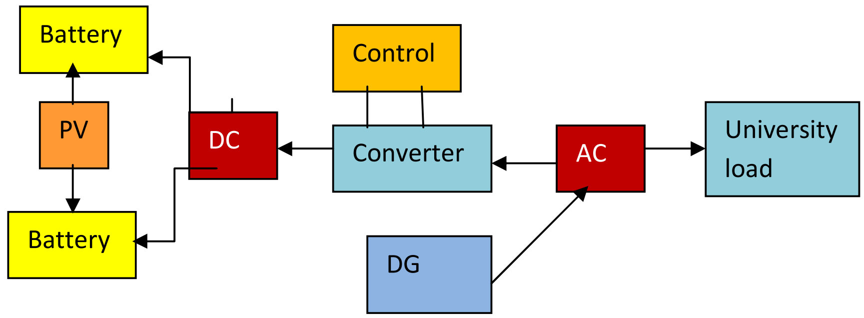

Figure 9: System configuration during shortfall

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]
Photovoltaic Cell Rating (PPV) = {(PTL * S.F) / sun hour} 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.

$$P_{TL}(Wh) = \sum_{0h}^{24h} (P_L) \quad Watt - Hours$$

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.
Battery Capacity (Ah) = PTL / (12V * 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.

Payback Period = Total Cost of Photovoltaic system / (Fuel consumption +Maintenance) (5)
= 2 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

Solar Panels	Prices
25Watt	7125,- RS
50Watt	14250,- RS
100Watt	28500,- RS
486KWatt	138510000 RS

Table 1: Solar panel cost evaluation

Charge controller	Prices
Wellsee 20A 12/24v	8200-RS
Wellsee 30A 12/24v	8600-RS
Wellsee 50A 12/24v	10000-RS
Wellsee 75A 12/24v	15000-RS
Wellsee 2000A 12/24v	720000-RS

Table 2: Charge controller cost

Inverter	Prices
500W 12v	2599,- RS
1000W12v	4900,- RS
486 KW	2430000 RS

Table 3: Inverter Prices

Battery	Prices
1000Ah	9000 RS
2000Ah	18000RS
5000Ah for 1KW	45000Rs
For 486Kw	24300000 RS

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:

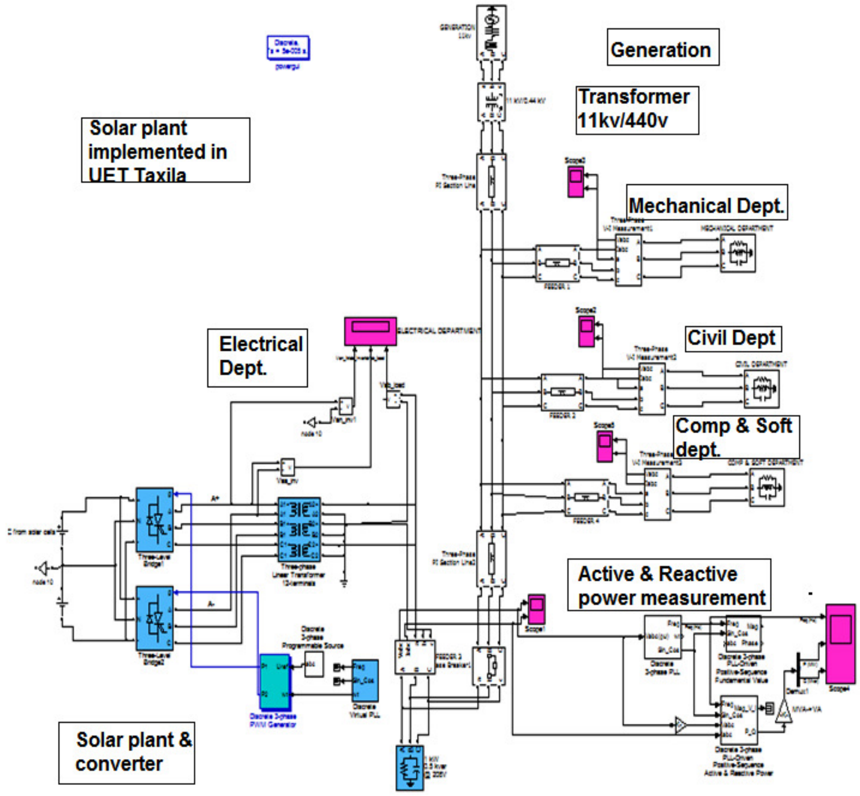

Figure 10: Matlab Simulink Design of UET Taxila

Results:

Inverter output:

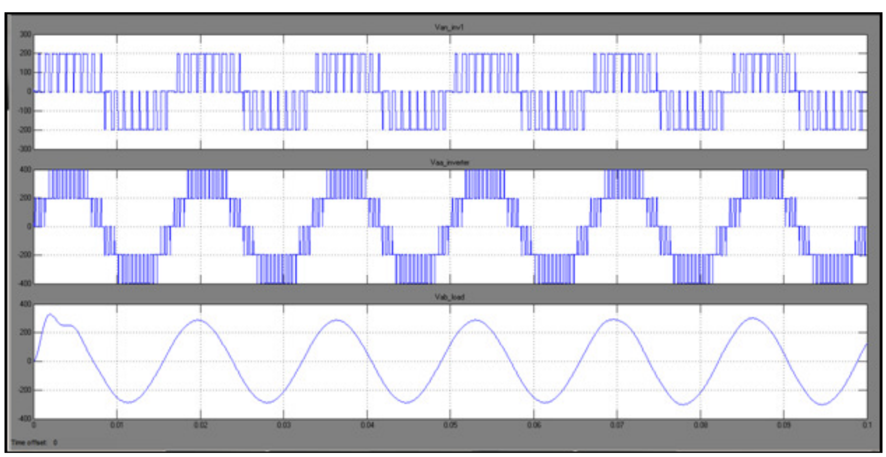

Figure 11: Inverter output

Active and Reactive power

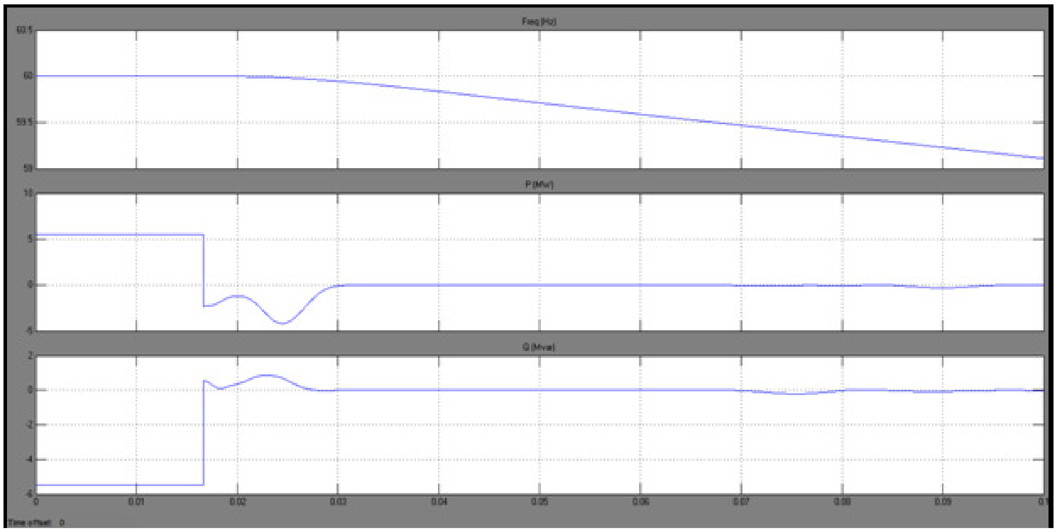

Figure 12: Active and reactive power of system

Voltage and current

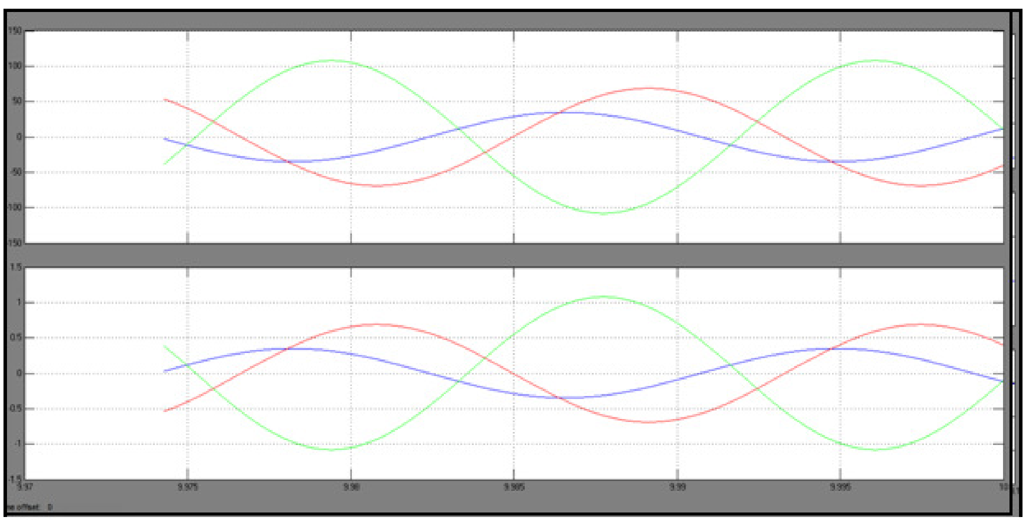

Figure 13: Voltage and current outputs without compensation

Voltage and current

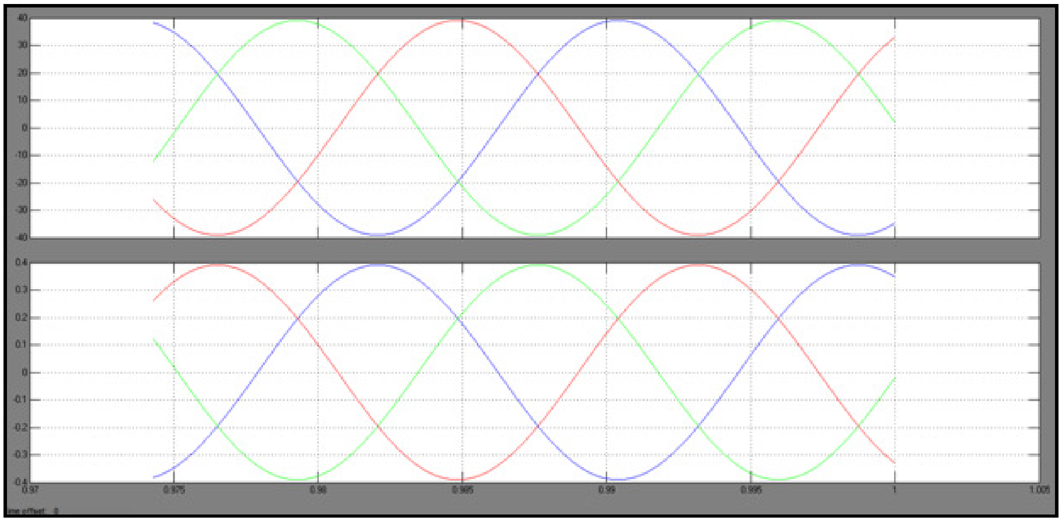

Figure 14: Voltage and current outputs

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

[1] Woyte A, Van den Keybus J, Belmans R, et al. Grid-conneeted photovoltaics in the urban environnlent-an experimental approach to system optimization [C].Power Electronics and Variable Speed Drives 2000 Eighth International Conference, London, UK, 2000.
[2] Wang Haining, Su Jianhui, Ding Ming, Zhang Guorong, Photovoltaic Power Conditioning System, Proceedings of the CSEE, Vol.27 No.2 Jan 2007
[3] PVPS 2011 'The role of Energy Storage for Mini-grid stabilization", lEA PVPS Task II, July 2011
[4] Wang Xifan, et al. Modern Power System Analysis. Science Press.2009.1.244-245
[5] Gao Xiuhang, The Research of Control Method of the Dynamic Reactive Compensation of Distributed Power System, Master's Thesis of Tianjin University
[6] Akagi H, Kanazawa Y, Nabae A. Generalized theory of the instantaneous reactive power in three –phase circuits [A].Proceedings IPEC[C]. Piscataway,USA:IEEE Inc,1983.1375-1386.
[7] Wang Zhaoan, Yang Jun, Liu Jinjun. Harmonic Suppression and Reactive Power Compensation. Machinery Industry Press, 1998.9
[8] Wang Haining, Su Jianhui , Ding Ming , et al. Photovoltaic grid connected power conditioner system[J].Proceedings of the CSEE 2007 , 27(2):75－79.(in Chinese with English abstract)
[9] Zheng Shicheng, Xia Wei, Study on control strategy of three phase photovoltaic grid-connected system[J]. Electrical Engineering,2007,(3):43－46.(in Chinese with English abstract)

[10] H. Ries, J.M. Gordon, M. Lasken, “High-flux photovoltaic solar concentrators with kaleidoscope-based optical designs”, Solar Energy 1997, 60, No.1, pp.11-16

[11] M.S. Moghaddam an d A Hajizadeh, "Control o f Hybrid PV/Fuel Cell/Battery Power Systems" in Proc. Power Electronics, Drives and Energy Systems (PEDES) Conference, PP.I-7, 2010

[12] S. Bando, H. Asano, T. Tokumoto, T. Tsukada and T. Ogata "Optimal Operation Planning of a Photovoltaic•Cogeneration-Battery Hybrid System" in Proc. Power System Technology, 2006. PowerCon 2006.

[13] C. Bingham et al., “Concentrating Photovoltaic Module Testing at NREL's Concentrating Solar Radiation Users Facility”, NCPV and Solar Program Review Meeting 2003, NREL/CD-520-33588, pp. 218-220

[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.I-10 , 2010

[15] AI Bratcu, LMunteanu, S.Bacha, D.Picault and B. Raison "Cascaded DC-DC Converter Photovoltaic Systems: Power Optimization Issues" in Proc. Industrial Electronics, IEEE Transaction, vol58, pp 403•411,2011

[18] P. Tsao "Simulation of PV systems with power optimizers and distributed power electronics", 35th IEEE Photovoltaic Specialists Conference (PVSC) IEEE conference on, pp.389 - 393, June 2010.

[19] P.Tsao, S.Sarhan and LJorio, "Distributed max power point tracking for photovoltaic arrays", 34th Photovoltaic Specialists Conference (PVSC) IEEE conference 2009, pp. 2293-22 98, June 2009

[20]Yang Du and Dylan Dah-Chuan Lu, "Analysis of a Battery•lntegrated Boost Converter for Module-Based Series Connected Photovoltaic System", IEEE conf. 2010 International Conference on Power Electronics, pp.694 - 698, June 2010 . .

[21] D. H . .lang, S.k . .Ii, C. W. Roh, S.S. Hong and S.K. Han "High Power Density and Low Cost Photovoltaic Power Conditioning System with Energy Storage" IEEE conf. 2010 International Conference on IPEC,pp.235 - 240, Oct. 2010 1348

[22] A. Rosenthal et al., “A Ten Year Review of Performance of Photovoltaic Systems”, Twenty Third /€€E PVSC, 1993, pp. 1289-1 291.

[23] D.T. Rizy, Huijuan Li, Fangxing Li, Yan Xu; S. Adhikari and P. Irminger, “Impacts of varying penetration of distributed resources with & without volt/var control: case study of varying load types,” Proc., IEEE Power and Energy Society General Meeting, Detroit, MI, 2011

[24] H. Ribeiro, F. Silva, S. Pinto and B. Borges, “Single-stage inverter for PV applications with one cycle sampling technique in MPPT algorithm,” in Proc., 35th Annual IEEE Cof. on Industrial Electronics (IECON), Porto, Portugal, 2009.

[25] Riad Kadri, Jean-Paul Gaubert, “An improved maximum power point tracking for photovoltaic grid-connected inverter based on voltage oriented control,” IEEE Transactions on Industrial Electronics, vol.58, no.1, pp.66-75, Jan. 2011.

[26] Trisham Esram and Patrick L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Transactions on Energy Conversion, vol.22, no,2, pp.439-449, June 2007.

[27] Libo Wu, Zhengming Zhao and Jianzheng Liu, “A single-stage threephase grid-connected photovoltaic system with modified MPPT method and reactive power compensation,” IEEE Transactions on Energy Conversion, vol. 22, no. 4, pp.881-886, December 2007.

[28] Felix A Farret and M. Godoy Simoes, “Integration of alternative sources of energy,” A Wiley-Interscience Publication.

[29] Marcelo Gradella Villalva, Jonas Rafael Gazoli and Ernesto Ruppert Filho, “Comprehensive approach to modeling and simulation of photovoltaic arrays,” IEEE Transactions on Power Electronics, vol.24, no.5, pp.1198-1208, May. 2009.

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Appendix: A

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

	After integrating sub array development
1	Modular design package
2	Site mobilization
3	Site preparation
4	Support pole hole auguring
5	Support pole installation
6	Drill tracker mounting assembly holes
7	Drill torque tubes
8	Install torque tube bearing plates
9	Install IPPU assemblies
10	Conduit trenching
11	Test IPPU
12	Array start up
13	Set pre cast transformer