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Effect of PV embedded generation on the radial distribution network

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Abstract. Power distribution system in the country is characterized by high power losses, poor reliability of supply, frequent equipment burnouts etc. The traditional approach in electric power generation is to have centralized plants distributing electricity through an extensive transmission & distribution network. Distribution generation (dg) provides electric power at a site closer to the customer, eliminating the unnecessary transmission and distribution costs. This paper described a study of several control strategies associated with the design of active distribution network intended to increase the level of penetration of embedded generation (eg) in distribution networks. By allowing the embedded generator to take part in voltage regulation, larger capacities of embedded generation to be accommodated in the existing distribution network. The load flow study of radial distribution with embedded generation has been carried out. The results being verified by using both PSB and MATLAB code also.

Keywords: distribution generation, PV, embedded generation

1 Introduction

The direction of power flow in the distribution networks was almost always from higher to the lower voltage levels. This system architecture was a technical and economic choice, and with a new technology and changed economic and commercial environment, the power system is now beginning to be modified by the reintroduction of generation connected the distribution networks. The renewed interest in embedded generation has been simulated by a number of technical and environmental factors looking further in to the future, the increased use of fuel cells using skirling engines and photovoltaic devices integrated in to the fabric of buildings may all be anticipated as possible sources of power for embedded generation (N. Jenkins, 'Embedded generation', IEE)[15]. Embedded generation is electricity generation which is connected to the Distribution network rather than to the high voltage National Grid. Embedded generation is typically smaller generation such as Combined Heat and Power (CHP) or renewable generation: small hydro, wind or solar power.

2 Connection of embedded generator to the distribution network

The introduction of embedded generation presents a new set of conditions to networks both with respect to the direction of real and reactive power flows, but also with the quantity of power needed to be transported. Modern distribution systems were designed to accept bulk power at the grid supply points and to distribute it to customers. Thus the flow of both real power (P) and reactive power (Q) was always from the higher to the lower voltage levels. With the significant penetration of embedded generation the power flow may become reversed and the distribution network is no longer a passive circuit supplying loads but an active system with

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power flows and voltages determined by the generation as well as the loads. If the output from an embedded generator is absorbed locally by an adjacent load then the impact on the distribution network then increased losses may occur and steady state voltage variations may become excessive[7, 10]. The figure corresponding to this is shown if Fig. 1.

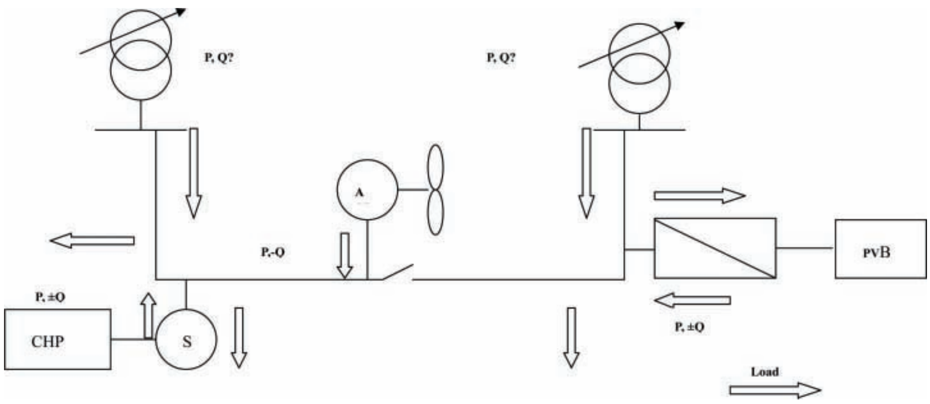

Fig. 1. Distribution network with embedded generation: Photovoltaic system

In general, only small generators may be connected to low voltage networks which supply customers as, at times of low customer demand, the out put of the generator must be feed back through the network. Operating the generator at a leading power factor (absorbing reactive power) acts to reduce the voltage rise but at the expense of increased network losses. On a lightly loaded radial circuit, with all value in per unit and assuming V1 is close to unity, the voltage rise along the circuit is given approximately by [14]: $VI - VO = PR - XQ$.

The reactive power drawn by the generator is effective in reducing the voltage rise, but higher real power losses are incurred in the circuit. Power flow in radial circuit can be explained through the figure shown in Fig. 2.

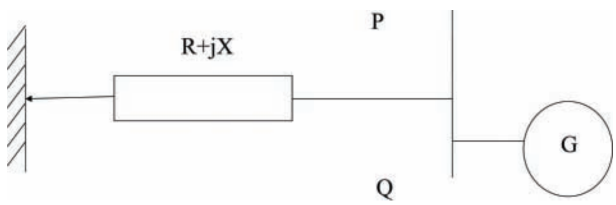

Fig. 2. Power flow in a radial circuit

3 Power quality

Embedded generation will influence the power quality of distribution networks. The usual causes of concern are transient network voltage disturbance, referred to as ‘flicker’ because of its effect on lighting, and harmonic distortion of the voltage waveform. Voltage flicker may be caused either by the connection and disconnection of generators or by transient torque pulsations from the prime mover being translated in to network voltage variations. Harmonic distortion of the network voltage is generally caused by the power electronic interfaces which are being used increasingly for the connection of embedded generators, although directly connected generators may also have an effect[4, 5]. Standards are in place to control the connection of loads likely to degrade the power quality of the distribution network, and these are also applied to embedded generation The prediction voltage flickers from operating embedded generation plant remains more difficult and either data is required from installations already in service or very detailed simulation modeling of the entire generator system is necessary. Surprisingly, the connection of rotating embedded generators may then act to improve the power quality of the network by increasing the fault level and so reducing the transient voltage variations. Embedded generation may also balance the voltage of unbalanced network but then additional negative phase sequence current flow can lead to the possibility of overheating of the generator. Convertors, for stand alone, shunt connection are now being offered for power quality improvement of industrial or commercial loads and it is likely that some type of embedded generation plant offer active power quality improvement facilities in the future.

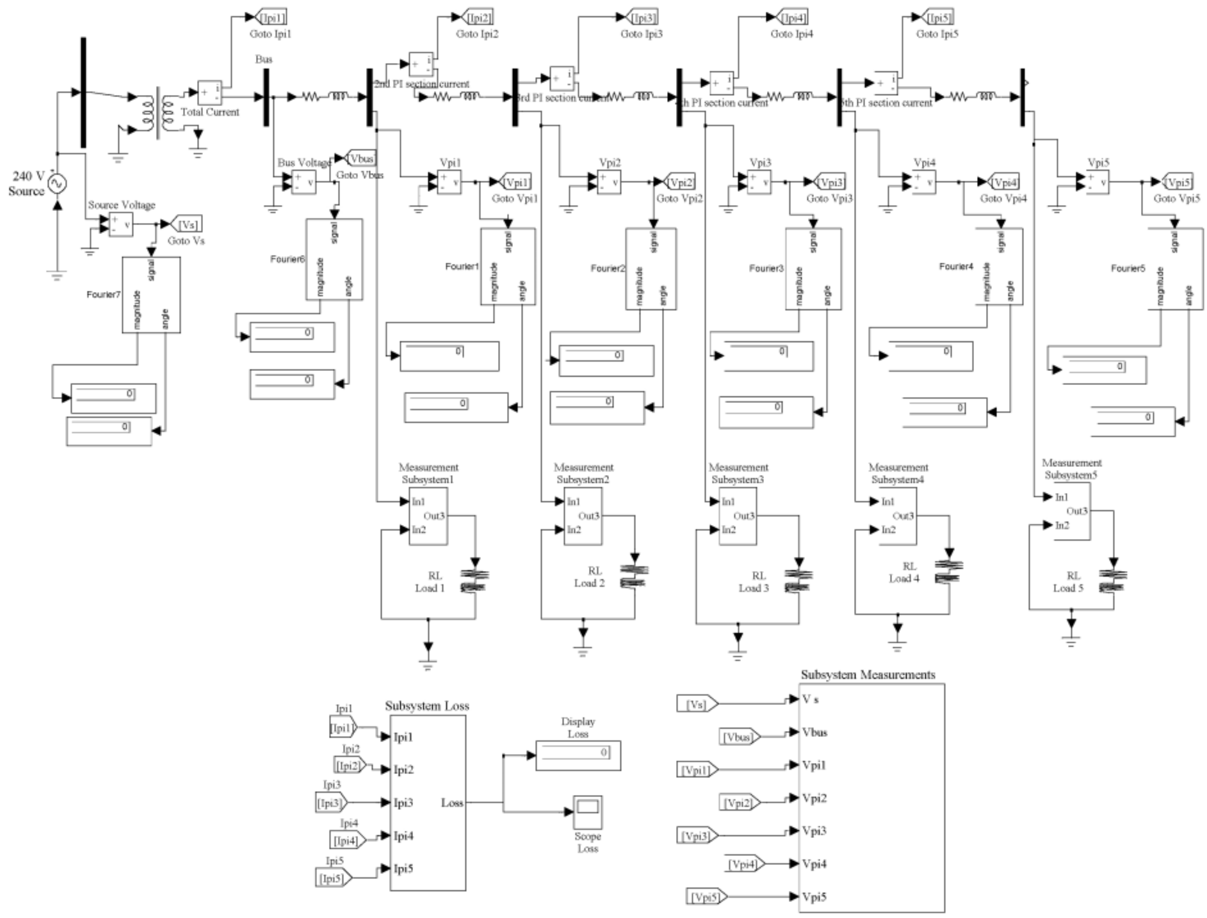

Fig. 3. PSB model for radial distribution system

4 Development of radial distribution system model in PSB

The typical layout radial distribution system is shown in fig has been considered to model the radial distribution system in PSB. Since the distribution line and associated equipment be spread around the few ten kilometers. From the primary distribution systems to secondary distribution transformer are modeled as 240 V source. Loads are tapped from the line. Loads are modeled by equally distributed load in all the taps. The developed PSB model is presented in the figure. To measure loss of radial line in each current is measured and passed to SIMULINK function in order to find out loss of the line. Loss measurement, voltage measurement and load measurement subsystems for developed model are shown in Fig. 3 further results for the developed radial distribution are presented[8, 11, 17]. The developed PSB model for the radial distribution line has been simulated. The load on the each tap is considered to be equally distributed along the line. By simulating the distribution network, the voltage on each load tapping point, bus voltage and source voltages are measured. The power loss in the line has been calculated from section currents. Power absorbed by each of the load s has been measured by using power measurement block. The diagram corresponding to this is shown in Fig. 3. The results correspond to Radial distribution model are presented in Tab. 1 ∼ Tab. 3 respectively. PSB models of distribution system for radial line have been developed and simulation results are presented. The developed model has been employed to study the variations of the voltages and losses at various tapping points of distribution network[1].

Table 1. Volatge at various sections in radial line

Voltage at load tap (r.m.s)						
V_s	V_{bus}	V_1	V_2	V_3	V_4	V_5
239.6	239.4	232.8	227.6	223.9	221.5	220.4

Table 2. Currents in various section of radial line

Voltage at load tap (r.m.s)						
V_s	V_{bus}	V_1	V_2	V_3	V_4	V_5
239.6	239.4	232.8	227.6	223.9	221.5	220.4

Table 3. Load currents in the radial line

Load Currents				
IL1	IL2	IL3	IL4	IL5
83.8	79.1	77.4	75.8	74.7

5 Embedded generation scheme

The PV source is integrated with secondary distribution network through the single phase inverter. General layouts are presented in Fig. 4 and Fig. 5 respectively. To model the secondary distribution network, distribution transformers are represented as voltage source; the secondary feeders are modeled as lumped parameter line and the consumers are modeled as load. The inverter powered from the PV source (modeled as battery) is integrated at each load tapping point of the secondary distribution system and the study on the effect of this embedded generation has been carried out[18].

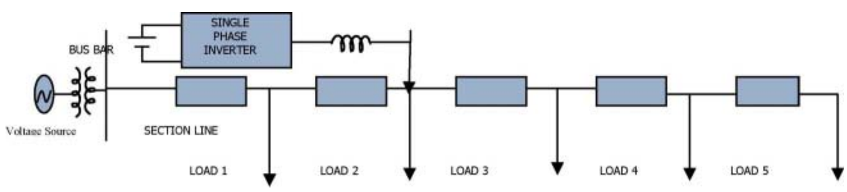

Fig. 4. General layout of radial embedded generation scheme

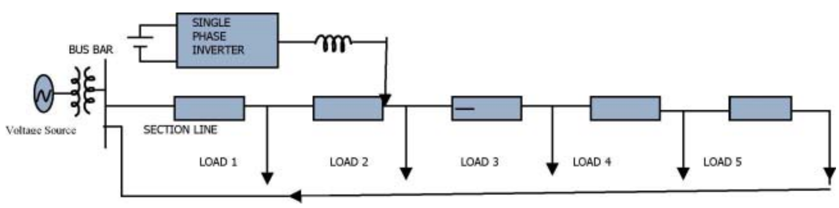

Fig. 5. General layout of ring embedded generation scheme

6 Development of proposed embedded generation scheme in PSB

PSB model of proposed embedded generation scheme has been modeled. This embedded generation scheme consists of distribution system and Inverter powered from PV source. PSB model for grid connected inverter systems and distribution systems are modeled and simulated. To study the effect of PV source on the distribution systems, Inverter is connected in each load tapping and the simulation results are observed. The studies have been carried out by considering the variations in the voltage on the distribution line, power loss and power absorbed in each load. PSB models with masked sub systems are only shown because the inverter inner subsystems to measure total line losses, line voltage subsystem, and load measurement subsystem has been explained[19].

7 Effect PV embedded source on the distribution network

7.1 Effect on voltage

Voltage on the distribution line each tapping point of the load has been taken in to account for this study. Sufficient improvement in voltage on radial distribution line has been obtained by the integration of the embedded generation. The voltage at the load tap points is found to have improved with embedded generation. The improvement in voltage at a particular load tap will become constant when the point of integration of the PV source shifted away from the load tap[13]. The end point voltage will keep on improving and would be best improved when the PV source is integrated in the last tap and in this case, all the tap voltages experiences an improvement in voltage as compared to the other cases[12].

7.2 Effect on power loss

The integration of the embedded generator has also reduces the power loss in the radial distribution line due to the resistance. Power loss and the loss minimized characteristics, it is evident that the optimum point of integration of PV source on radial distribution line to obtain minimum loss will be the end load tap in the line[16].

7.3 Effect on load absorbed power

The power absorbed by the loads is found to be improved by the integration of embedded generation on the distribution line. Power absorbed by the load at a particular point will be improved when the load tap is integrated with embedded generator. The improvement in the absorbed power at a particular load tap will become constant when the point of integration is shifted away from the load tap. The end load tap absorbed power increases and it is found to be maximum when the PV source is integrated in the last load tap in the line. The PSB model[3, 6, 9] and its sub system corresponding to radial distribution system with embedded Generation are shown in the following figures i.e. Fig. 6 $\sim$ Fig. 9 respectively. The readings corresponding to simulation are presented in Tab. 4. The load flow solution provides the steady state condition of power system. For efficient and reliable operations, it is very essential to know the system steady state conditions for various load demands. The load flow problem of such a simple system can be solved through a set of recursive equations called “Dist flow branch equations”. These equations are derived from Kerchief’s voltage and current laws. The recursive equations have excellent convergence pattern and can handle wide range of R and X values of branches. The distribution system having multiple feeding sources and mesh configuration is first converted to an equivalent single source radial system so that the recursive equations can be used[2].

7.4 Steps followed in algorithm and Matlab code

(1) Read the system data. Obtain an equivalent single source radial system and construct the tree of equivalent system.

(2) Set the initial voltage of all busses to V_0 (voltage at the root bus) and the initial injected power at all break points to zero.

(3) Compute the active and reactive power flow at the sending end of each branch.

(4) Compute the voltage magnitude and phase angle at the receiving end of each branch.

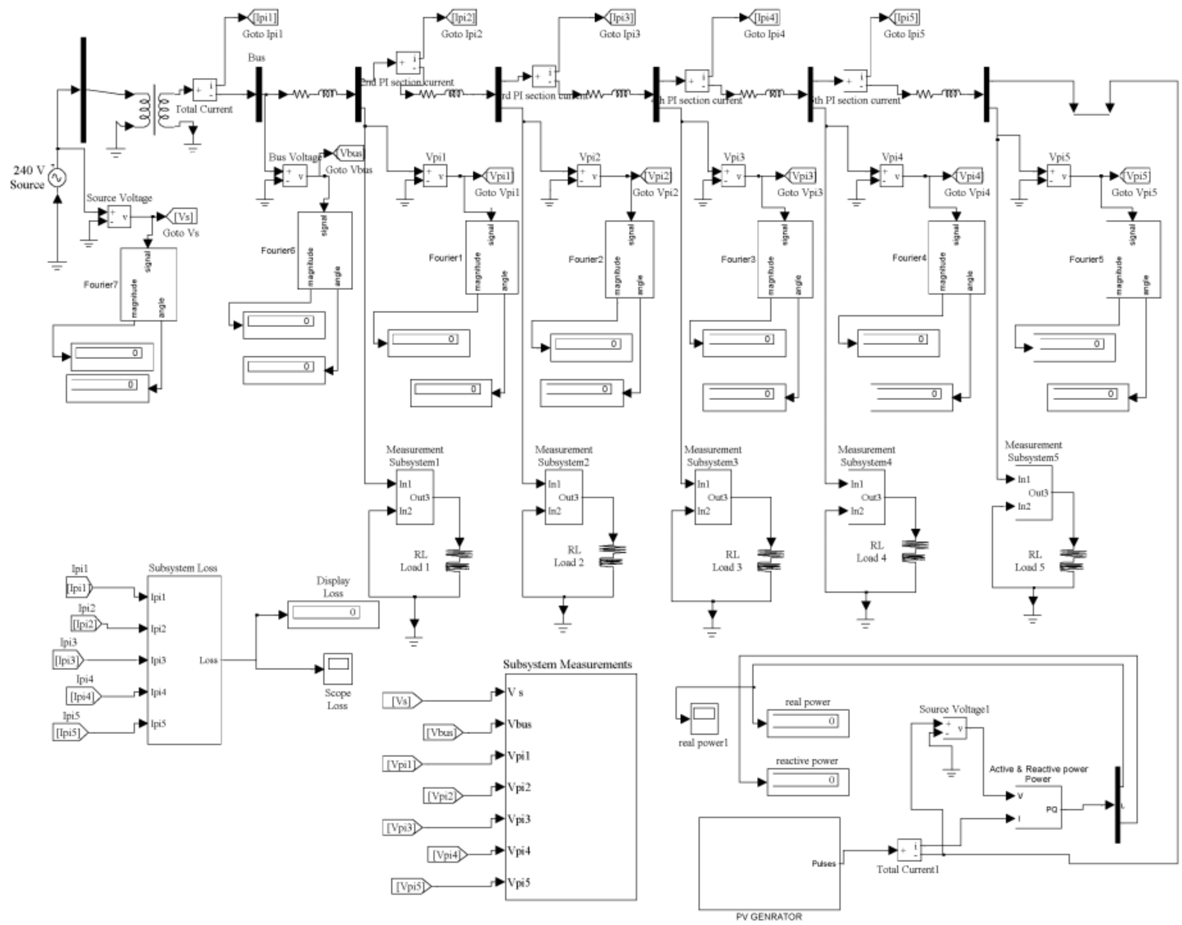

Fig. 6. PSB model for Radial Embedded Generation Scheme

Table 4. Radial distribution line voltages with eg

Condition	Voltage V (rms)						
	V_s	V_{bus}	V_1	V_2	V_3	V_4	V_5
With out EG	239.6	239.4	232.8	227.6	223.9	221.5	220.4
EG in 0^{th} tap	239.6	239.5	232.8	227.7	224	221.4	220.4
EG in 0^{th} tap	239.6	239.5	234.5	229.3	225.4	223.4	222
EG in 0^{th} tap	239.6	239.5	234.4	230.4	227.4	224.6	223.4
EG in 0^{th} tap	239.6	239.5	234.4	230.8	228.2	226.3	225.1
EG in 0^{th} tap	239.6	239.5	234.4	230.9	228.4	228	226.7
EG in 0^{th} tap	239.6	239.5	234.4	230.9	228.7	228.8	228.4

(5) Find the incremental power injection required at the break points using derivations of voltage magnitudes and angles found at the break points.

(6) Repeat steps 3-5 until the algorithm converges with an appropriate tolerance.

PSB model for the proposed radial and ring distributors with embedded generation schemes have been successfully developed. The effect of the integration of PV generation on the distribution network has been presented. It has been observed from the simulation results that there is a considerable decrease in the distribution losses and improvement in the voltage profile with such integration. By using MATLAB we wrote a program in such a way to find out the voltages at various nodes with out embedded generation and with embedded generation. The results obtained were found be tallied with PSB results[1].

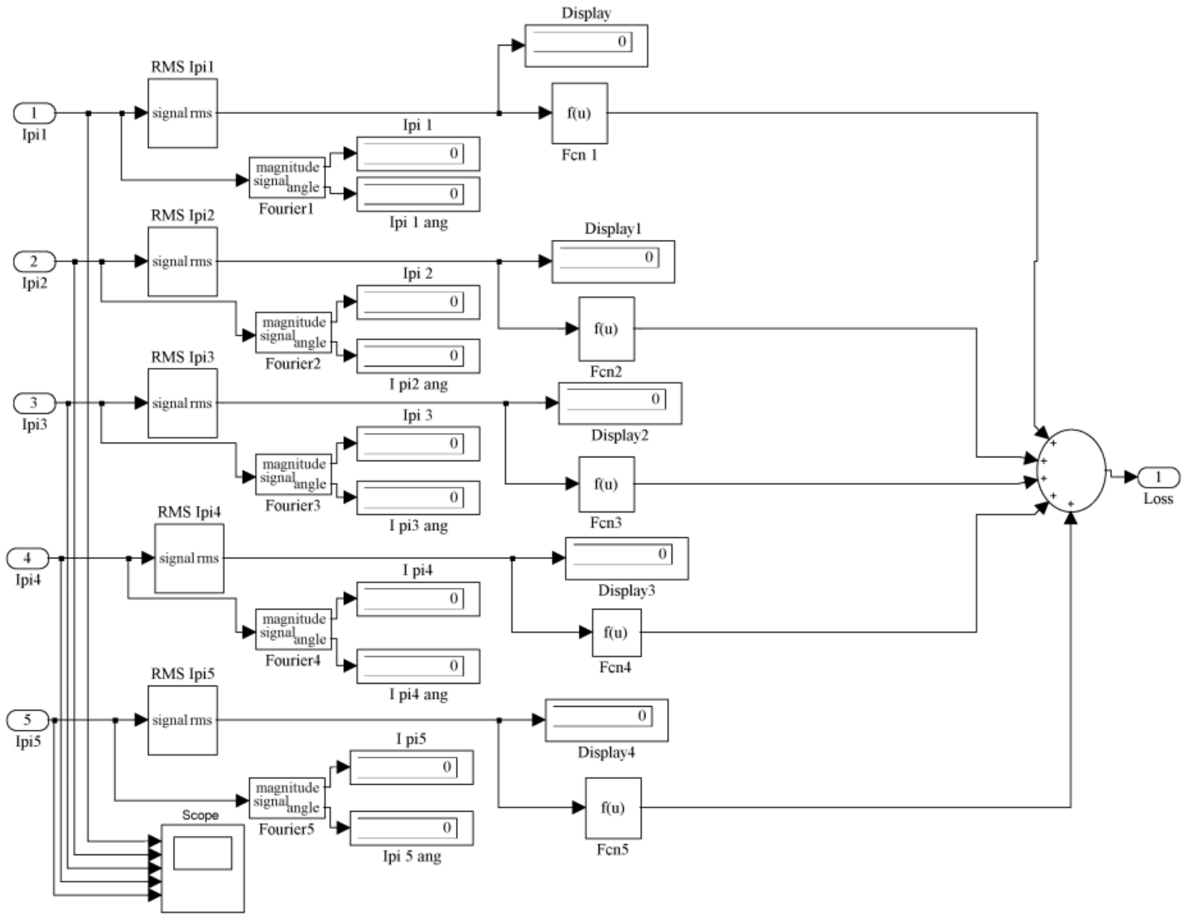

Fig. 7. Current measurement subsystem

8 The future of distributed PV generation and developments

The entire field of distributed generation is undergoing a significant evolution that will affect the development of PV. Industry restructuring in several states is opening electricity markets to new energy companies, including those dedicated to making and marketing green power. Developers don't plan for it, architects and engineers don't include it in their designs and construction, contractors haven't learned how to install and integrate it with standard wiring and metering schemes, and customers don't think to demand it. Many past PV installations have been promoted as "experimental" or "demonstration" projects, leaving the impression that PV is exotic, complicated, and risky. As more PV is put into service, familiarity and demand will increase. And, as PV is attractively or even invisibly incorporated into building materials, builders will design projects to accommodate it. It is likely that embedded generation will, over the coming years, assume an increasingly prominent role in the production of electricity. A number of attractive new technologies are under development including micro CMP, photovoltaic and fuel cells. As the use of embedded generators increases, power engineers will no longer able to consider the distribution network as a passive system, which is well developed and understood, but must address the rather more interesting behavior of active distribution networks serving both loads and generation.

9 Conclusion

The thesis investigates the development of suitable power electronic interface for a PV source to integrate it with utility network. Current controlled voltage source inverter without transformer has been as a PV interface with utility. Proportional integral and average current mode control regulators have been successfully

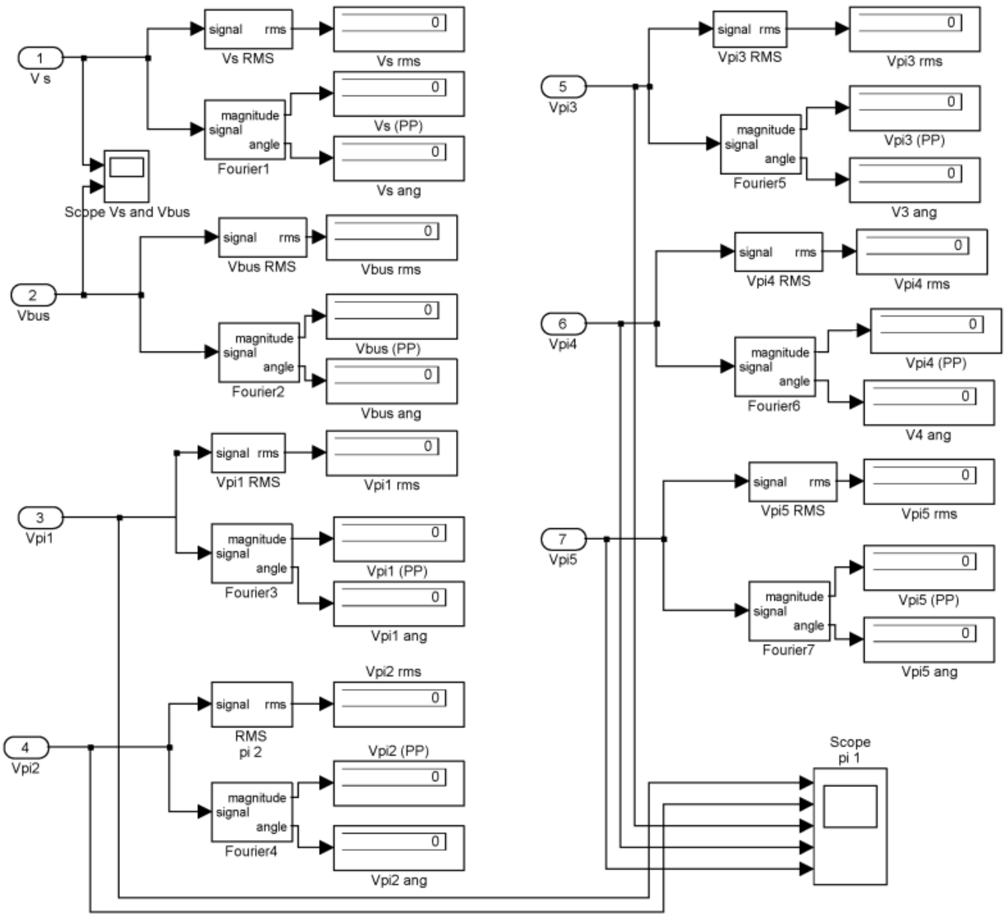

Fig. 8. Voltage measurement subsystem

designed and developed for PV fed inverter. The developed interface has been operated as a real and reactive power source. A model of proposed scheme has also been developed and the simulation results confirm the utility of proposed technique in grid connected PV systems.

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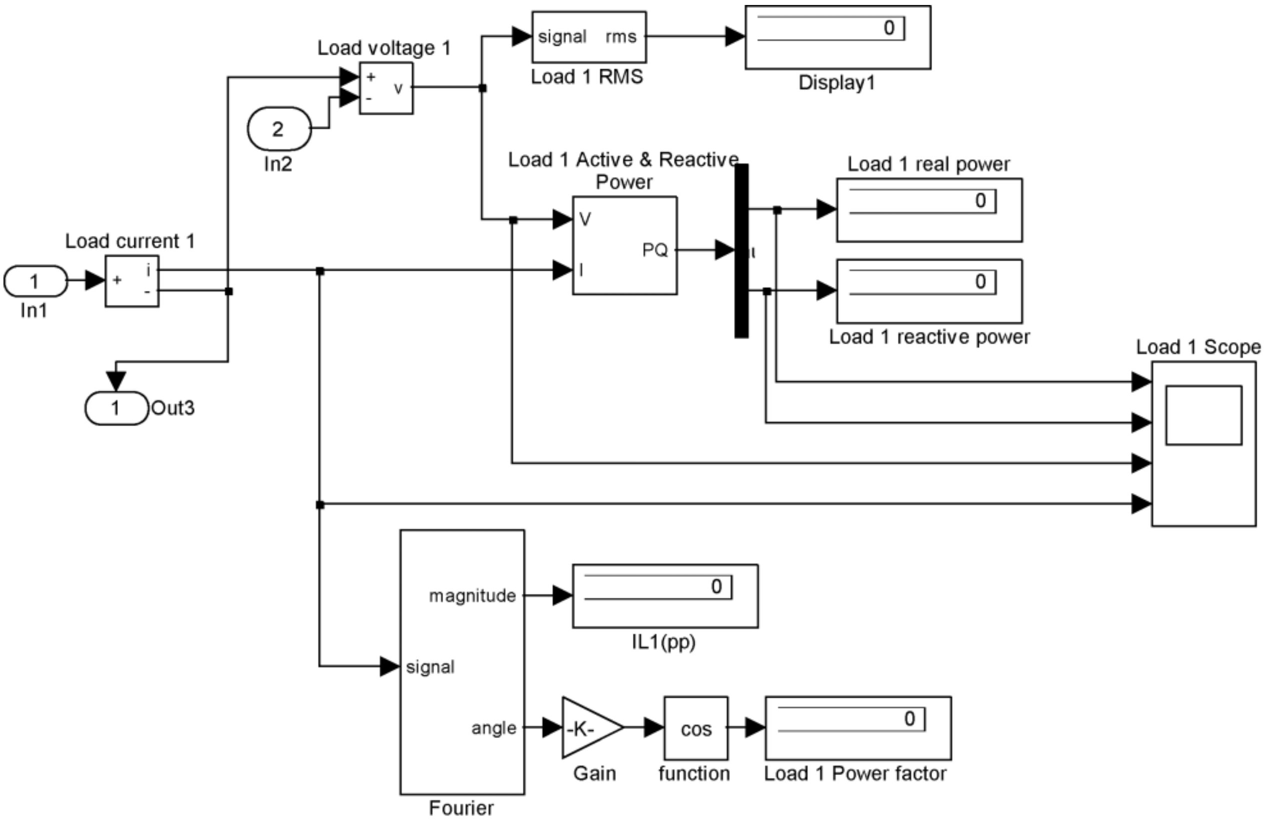

Fig. 9. Load measurement subsystem

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