POWER LOSS REDUCTION IN A DISTRIBUTION SYSTEM BY PHOTOVOLTAIC INVERTER USING PSO

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Abstract - The aim of this paper is to reduce the real power loss and to improve the voltage profile by increasing the number of photovoltaic (PV) generators in a distribution system. This paper utilizes the applicated MATPOWER techniques and the particle swarm optimization (PSO) algorithm to solve the problem in the distribution system. The paper provides an analysis of PV inverters generation in reactive power control modes. The results show that the implementation of PV inverters in the distribution system can improve the voltage profile and reduce the power losses.

Index terms - Distribution system, Photovoltaic inverter, Reactive power control, MATPOWER, Particle Swarm Optimization (PSO).

I. INTRODUCTION

The installation of PV systems in the low voltage (LV) distribution networks can reduce losses on transmission and distribution [1]. But voltage related issues are the most critical among all the problems of an interconnected PV systems to the LV distribution networks. This paper analyzes on the voltage profile and power loss in the distribution system. In addition, high PV generator is to lead the overvoltage problem. In the real power production is low, the potential dangers overvoltage problems in the system [2]. In practice, utility power products protect to reverse on the voltage rise in distribution system. There is limit the number of PV inverters to approve reactive power absorption [3]. However, the reactive power control modes of PV inverters can control voltage (volt-var) mode by coordinating the voltage limit and reactive power control equipment. The scenario is changed according to revised IEEE 1547 standard [4].

From the increasing of PV systems on the LV distribution systems. It is leading to the overvoltage problem, especially during high production and low consumption periods. Different local reactive power control methods will be comparedby PV inverters which can reduces loss and can improves voltage profile in the system. The analysis method is proven by process of load flow calculation results from MATPOWER toolbox and MATLAB program [5]. In this study, the following suppliedreactive power methods as unity power factor, fixed power factor, power factor as cosφ (P),and reactive power Q(V). Therefore, this paper analyzes assess definitions of the optimal approach to supply reactive power control modes by PV inverters. In mode various of inverter operations which PV inverters are used as entire rate to supply or absorb reactive power, if no active power is generated to absorb reactive power from systems [6].The maximum reactive power of PV penetration limit show that in fig.1. Section II presents problem formulation results in a set of nonlinear simultaneous equations between bus i and bus j in the system.

II. PROBLEM FORMULATION

The real power loss in the system equals the sum of all power losses with each branch as follows:

$$P_{loss} = \sum_{j=1}^{N} g_{ij}(V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) \qquad (1)$$

The equality constraints are the power balance equations, which can be described by the equations:

$$P_{gi} - P_{di} - V_i = \sum V_j(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) = 0 \qquad (2)$$

$$Q_{gi} - Q_{di} - V_i = \sum V_j(G_{ij}\cos\theta_{ij} - B_{ij}\sin\theta_{ij}) = 0 \qquad (3)$$

Where N is number at the branch

g_{ij} is conductance of the branch at node bus iand bus j

V_i is voltage magnitude at bus i

V_j is voltage magnitude at bus j

θ_{ij} is the difference of phase angle between bus iand bus j

P_{gi} is real power generation at bus i

Q_{gi} is reactive power generation at bus i

P_{di} is real power demand at bus i

Q_{di} is reactive power demand at bus i

The commonly used method to manage the discrete values is viewing them as continuous values at the beginning of the optimization as following:

$$V_i^{min} \le V_i \le V_i^{max} \qquad (4)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \qquad (5)$$

Based on the original parameters in IEEE 33 bus radial distribution system. For the voltage magnitude in this paper set from 0.9 p.u. to 1.10 p.u., and the reactive power injection is defined to the active power for the PV generator in the distribution system.

III. PV GENERATOR REACTIVE POWER CONTROL MODES

The paper proposed local reactive power control methods are regulated power supplyto reverse power flow in the grid limits on the distribution system. In practice, the voltage profile problems by increasing the high PV inverter capacity in distribution systems. The fast response speed helps in the inverter can inject or absorb because of the reactive power in case of voltage change quickly. when the PV inverter is a work indictive side (absorb Q)in operate of active power injected by PV inverters. Therefore, the increasing of PV generations can be defined to the demand value suitable in the system. The PV generator is defined to set at least a power factor (leading and lagging), see fig. 1 operate with fixed cosφ control [3]. This paper presented four methods in reactive power control modes are the following:

- Mode 1 unity power factor (PF = 1.0 p.u.)
- Mode 2 fixed power factor (PF = 0.9 p.u.)
- Mode 3 power factor as cosφ(P)
- Mode 4 reactive power Q(V)

In this case,PV inverters can implementby the reactive power control modeswith four methods as follows:

A. Unity power factor

Unity power factor is the goal of the more electric utility company. If the PV generator operation in mode unity power factor PF = 1.0 p.u., Q = 0, the active power injection.

B. Fixed power factor

The fixed power factor characteristic (cosφ) method, the PV inverter is operated at a static power. The generated reactive power is relatively to the active power (see fig.1). The PV inverter is controlled to work of the system with the fixed cosφ method.

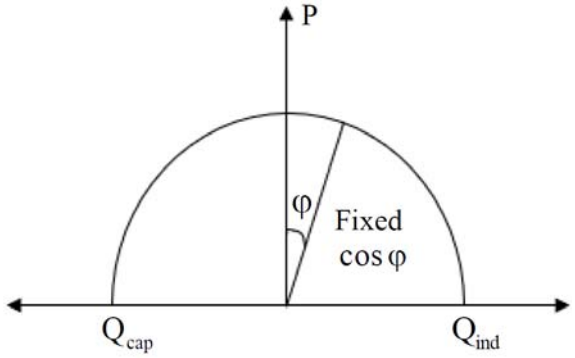


Figure 1: Operate with fixedcosφcontrol [7]

When the operating within a power factor range (PF = 0.9 p.u.), the phase displacement power factor is the same as the apparent power factor.

C. Power factor as cosφ(P)

The power factor as cosφ(P) depend on the power output of PV generators. The method is calculating the reactive power compensation. if the power output value is less than 50 percent of rated power. When PV inverterreachescertain value of the PV operation show that in fig.2.

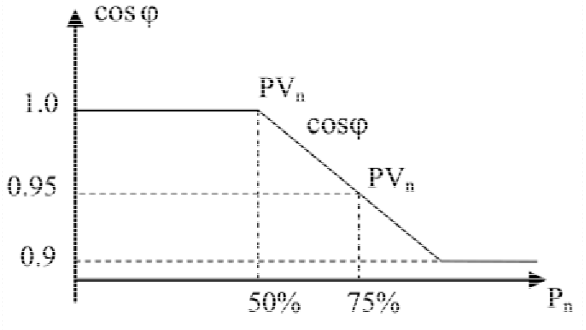


Figure 2: Droop characteristic of cosφ (P) method [3]

When the PV generator supplies more than power factor0.9p.u. and reactive power is forced to absorb in condition of power factor a cosφ(P) droop characteristic.

The reactive power can be expressed as:

$$Q_{pv} = \tan(\arccos\varphi) \cdot P_{pv} \qquad (6)$$

D. Reactive power Q(V)

The Q(V) strategy is calculating the reactive power of each PV inverter on the voltage magnitude in the system. In practice, the PV inverter at end of feeder will begin to inject or absorb reactive power. In practice, the cosφ (P) and Q(V) methods are proposed the local voltage regulation process to reduce the reactive power consumption value of voltage level, the Q(V) regulation show that in fig.3.

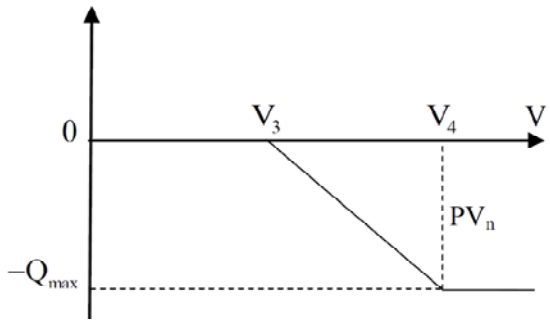


Figure 3: Droop characteristic of Q(V) method [3]

The algorithm of the Q(V) method can summarize by (7).

$$Q = \begin{cases} Q_{max} & V < V_1 \\ (V - V_1) \cdot \dfrac{Q_{max}}{V_1 - V_2} + Q_{max} & V_1 \le V \le V_2 \\ 0 & V_2 \le V \le V_3 \\ (V + V_3) \cdot \dfrac{Q_{max}}{V_3 - V_4} & V_3 \le V \le V_4 \\ -Q_{max} & V > V_4 \end{cases} \qquad (7)$$

The only concern is the voltage rise issue that the PV inverter is required only to inject or absorb reactive power, the (7) upper is considered implement.

Section IV is the methodology about the result of the radial 33 bus system and the analysis optimization of PV generators in the system to reduce power losses.

IV. METHODOLOGY

In this paper studies, the radial distribution system 33 buses with three solar PV generators show that in figure 4.

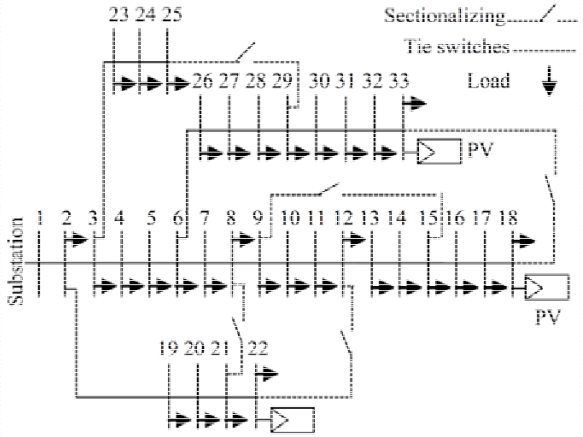


Figure 4: Diagram of 33 bus radial distribution system [9]

This paper utilizes the applicated MAT-POWER technique for optimization technique by the PSO algorithm. The PSO approach is solving optimal ofPV inverters to reduces power loss and to improves voltage profile [10]. The optimal reactive power of the Q(V) mode as follow:

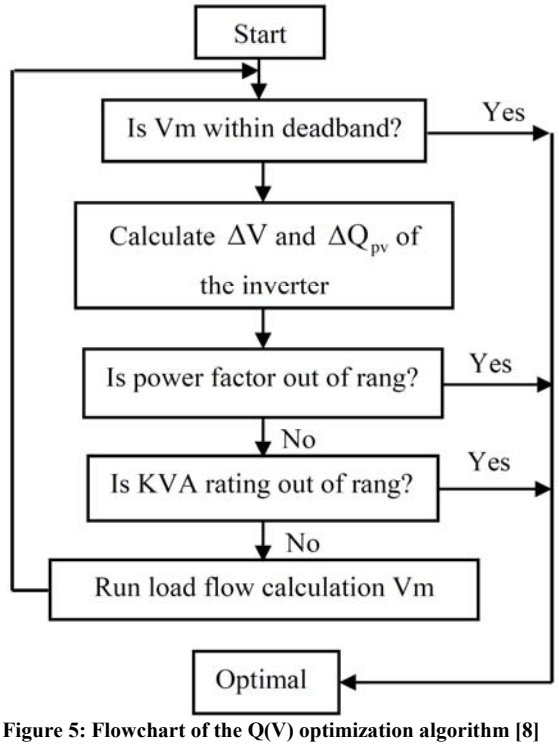


Figure 5: Flowchart of the Q(V) optimization algorithm [8]

The total loads for this test system are 3.72 MW and 2.3 MVAr [9]. The minimum and maximum voltages set at 0.9p.u. and 1.10 p.u., respectively. Therefore, maximum iteration for the PSO algorithm is 200. The result in each case as follows:

1) Case 1: Unity power factor (PF=1.0 p.u.)

In the case 1 with three small power producers can provide the real power supply in the system by PV inverters. There are located producers at buses 18, 22, and 33 with PV capacities are 0.25 MW, 0.25 MW, and 0.5 MW respectively. The results for case 1 as follow in Table 1.

Table 1 Reconfiguration results without and with PV generators

No	Case	PV buses installed	PV generator (MW)	Real power losses (MW)	Reactive power losses (MVAr)
1	without PV	-	-	0.163	0.11
2	with 1 PV	18	0.5	0.124	0.08
3	with 2 PV	18, 22	0.5, 0.25	0.123	0.08
4	with 3 PV	18, 22, 33	0.5, 0.25, 0.25	0.104	0.07

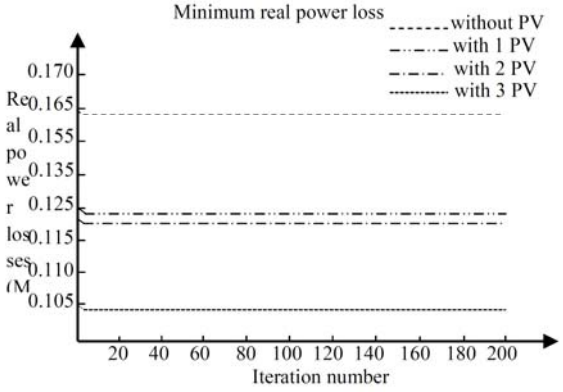


Figure 6: Real power losses reduction process without and with PV generators of mode 1

In figure 6 PV generators at buses 18, 22, and 33 are active power increased by PV generators. It is supplied real power into the system. In this case, PV generators can improve voltage profile problems and can reduce power losses in the system.

2) Case 2: Fixed power factor (PF=0.9 p.u.)

Under the fixed power factor method is approached in order a suitable for the static power factor supply by PV inverters on the system. This method is using the fixed power factor characteristic.

Table 2 Reconfiguration results without and with PV generators

No	Case	PV buses installed	PV generator (MW)	Real power losses (MW)	Reactive power losses (MVAr)
1	without PV	-	-	0.163	0.11
2	with 1 PV	18	0.5	0.112	0.07
3	with 2 PV	18, 22	0.5, 0.25	0.111	0.07
4	with 3 PV	18, 22, 33	0.5, 0.25, 0.25	0.085	0.06

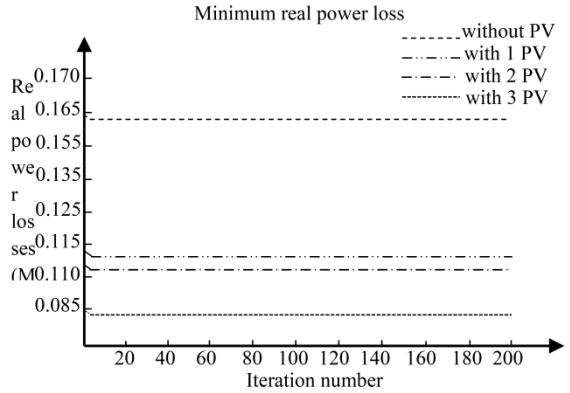


Figure 7: Real power losses reduction process without and with PV generators of mode 2

Fig. 7 shows that the power losses at buses without and with PV generators. This method is primarily suitable for the system where the active power output generation is constant. An unstable of PV generators in the system, the PV system recommend using the power factor characteristic fixed cosφ or fixed reactive power characteristic.

3) Case 3: Power factor as cosφ (P)

The low voltage level of the feeder, when the PV buses 18, 22, and 33 are reduces to 50% and 75% of the total load feeder to improve voltage. From fig. 5, the total loads for this test system are 3.72 MW and 2.3 MVAr but for the lateral feeders with two cases as follows:

$$\sum_{i=1}^{n_{pv}} P_{pv,max} = 50\% \times \sum_{i=1}^{N_{load}} P_{load,max} = 0.5 \times 1.505\text{MW} = 0.753\text{MW}$$

Case 1: For the feeder 2 (buses 26-33), the total loadsare 0.92 MW and 0.95 MVAr, feeder 3 (buses 1-18), the total loadsare 1.505 MW and 0.74 MVAr and feeder 4 (buses 19-22), the total loadsare 0.36 MW and 0.16 MVAr. The output power from PV penetration is to reduce 50% of peak load. Therefore, buses connected there are 0.46 MW, 0.753 MW, and 0.18 MW respectively.

Case 2: For the feeder 2 (buses 26-33), the total loadsare 0.92 MW and 0.95 MVAr, feeder 3 (buses 1-18), the total loadsare 1.505 MW and 0.74 MVAr and feeder 4 (buses 19-22), the total loadsare 0.36 MW and 0.16 MVAr. The output power PV penetration is to reduce 75% of peak load. Therefore, buses connected there are 0.69 MW, 1.129 MW, and 0.27 MW respectively.

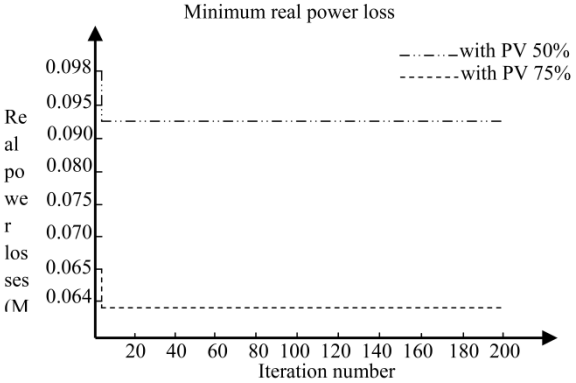


Figure 8: Real power losses reduction process with PV generators 50% and 75% rated power.

4) Case 4: Reactive power Q(V)

The Q(V) strategy of voltage regulation presented in fig.3, it is calculating to amount of reactive power present in each PV inverter will depend on the voltage magnitude. The power factor as cosφ(P)method is used local voltage information in the regulation process with the reactive power consumption of the voltage level. For mode 4, V1 = 0.95 p.u., V2 = 1.0 p.u., V3 = 1.02 p.u., V4 = 1.05 p.u., the Q(V) regulation method can be implemented in the optimal reactive power.

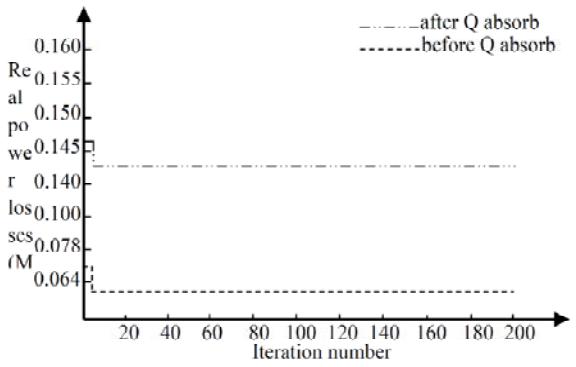


Figure 9: Real power losses reduction process with before and after Q absorb

Fig. 9 shows that the optimization process of the propped method when PV inverters absorbed reactive power. In case before Q absorb, there is the power loss to high more than after Q absorb. In this case, PV inverters with absorb reactive power from the system to minimize losses. By using the proposed methods when power from PV 18, PV 22, and PV 33 reduces to 50% and 75% of capacity, it can absorb reactive power from the system. The optimal real power loss values are 0.064 MW and 0.147 MW to minimize

losses. From this result in figure 8, power loss at each bus at feeder 2-4 are decrease of PV inverters to reduce 50% and 75% of capacity. At any given output the PV generators may be requested to inject active power help manage voltage profile in the system. On the other hand, the limitation of reactive power in Q(V) (absorb) help the optimal value of reactive power. From fixed power factor and power factor as cosφ(P) are reduced power losses in each droop characteristic of inverters on the system, unity power factor can reduce power loss and there is required for small producers due to no inject reactive power.

CONCLUSION

The method of applied MATPOWER and PSO algorithm are used PV inverters to reactive power control modes. In this paper is proposed to reduce the real power loss and to improve voltage profile in radial distribution 33 bus system. The present method is a mitigate overvoltage and under voltage from PV generation. This paper show four methods: unity power factor, fixed power factor, cosφ(P), and Q(V). Moreover, the power produced each different of characteristic from thePV inverter modes and gridconnected limit voltage values. Both cosφ(P) and Q(V) strategies perform successfully the amount inject/absorb with droop characteristic of cosφ(P) significantly. The Q(V) can mitigate undervoltage and overvoltage an independent power supply of PV generators. The results analysis of the PV inverter can reduce power losses and improve voltage profile problems. Therefore, inverter that is connect closer to the transformer working together reactive power absorption from high power injection of PV generators. In the case, Q(V) mode is achieved high PV generator providing the slightly overloaded transformer.

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