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Management Real Power Loss of Distribution System Connected with Distributed Generator; Comparisons between Planning and Optimal Dispatching Scenarios Using Least Square Quadratic Approximation

Komson Daroj
Department of Electrical and Electronics Engineering, Faculty of Engineering,
Ubonratchathani University, Phone 045-353367, Fax 045-353333, E–mail: daroj@hotmail.com

Abstract

This paper compared two scenarios for managing real power loss of a distribution system connected with Distributed Generator (DG). These two scenarios are formulated as optimization problems of minimizing real power loss under planning and real time operating stages. The proposed scenarios are solved with a proposed Least Square Quadratic Approximation (LSQA) technique. The LSQA proposed in this paper is formulated based on a quadratic nature of a real power loss versus its real power output injected from DG. This technique is reliable and has a high accuracy in term of the obtained results. A 93-bus radial distribution system under North-Eastern region 2 of Provincial Electricity of Thailand (PEA) connected with a synchronous based DG sizes 7.5 MW is adopted as a tested system. The obtained results shown that managing loss under both scenarios bring benefits to a system. Moreover, the proposed LSQA technique is easy to understand, thereby can be used alternatively with others present optimization techniques.

Keywords: distributed generator, least square, real power loss, distribution system, optimal capacity.

1. Introduction

High penetration of DG connected in a distribution system has significance impacts to reliability and quality of supply to the end customers [1], [2]. To compatible with this circumstance, it required for administered strategies and technologies. Besides mitigating disadvantages from a feeder connected with high penetration of DG, gaining the benefits use from DG is of interested [3]. This can be done through both the planning and real time operating stages. The achievement is limited by several factors e.g., the utility policies, lack of proper regulations and the structure of electric supply industry. For some countries like Thailand, almost of DGs under VSPP (Very Small Power Producer) program is normally invested by private sectors without intervention from the government agencies. Therefore, gaining benefits of DG by governing its size and location cannot be implemented. This situation cannot be maintained due to drastically increasing penetration level of DG and their impacts to the end customers in a system.

From a research view point, there are several suitable measures and technologies which can be adopted to cope with the unpleasant impacts from DG. For example, the used of advanced inverter technologies, Static Var Compensator (SVC), and Energy Storage (ES) system can solve the problem of voltage fluctuations occurred from an intermittent resource nature of Photovoltaic (PV) and Wind Turbine (WT) plants. However, these technologies are not mature [4]. Moreover, rely on these technologies has an expensive cost. As a result, from utility viewpoint, launching the policies and regulations for mitigating unsuitable impacts, meanwhile accommodating several benefits use of DG from cannot be avoided.

From a steady state viewpoint, the impacts of DG to distribution real power loss and voltage profile are basically interested [5]. From planning and real time operating perspectives, real power loss and voltage profile, depend on various factors e.g., type, size, and location of DG and also the amount and distributions of loads along a primary feeder. The intervened policy regarding verifying the proper size and location of DG can be found in literature however it still not be implemented in any utility. As a result, the size of DG has limit by technical factors e.g., capacity of a primary distribution line, short circuit level, and reliability and quality impacts. In contrast, the methodologies for reducing distribution real power loss for a system connected with DG under operating stage attracted much attention. This can be implemented under several programs e.g.: demand side management, demand response, and peak shaving programs [3].

In UK, the Distribution Network Operator (DNO) is reward or penalized for the loss lower or higher than the target. This regulation support DNO to perform mechanism to manage loss e.g.:

- call on customers who have backup generators during peak periods, and
- perform DG dispatch programs to supply peaking, reserve or load management capability [6].

In this paper, the methodology of using quadratic function to represent relationships between the real injected power from DG and its associated real power loss in distribution system is presented. To validation of the proposed method, it is applied with two scenarios of managing real power loss i.e., planning with the optimal capacity contract and the optimal dispatching real power of DG under real time operating stages. The LSQA algorithms proposed in this paper can illustrate the quadratic nature of the real power loss versus the real power injected from DG satisfactory. Besides, the advantages from easy for understanding and in term of accuracy made the proposed methodology can be competitive with others optimization techniques.

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2. Impact of DG Power to Real Power Loss

In a transmission system, at a specified time, real power loss can be simplified into a quadratic equation of generated power from generator bus. This relationship can be represented as a matrix called B coefficient matrix, which is classically use for Economic Dispatch (ED) and Optimal Power Flow (OPF) problems [7]. This relationship has more strong in a primary distribution than a transmission systems due to limitation of control variables and the absent of parallel flow path. Consequently, for any voltage control mode of DG i.e.: constant power factor, constant voltage, and constant reactive power, distribution loss function can be approximated from (1).

$$P_{Loss} = a\left(P_G\right)^2 + bP_G + c\,, \qquad (1)$$

The term P_G is a real power injected from DG. The coefficients *a, b,* and *c* are constant values obtained from a LSQA method, which can be presented in the next section.

3. The LSQA [8]

The LSQA is proposed to represent the quadratic nature relationship between generated power from DG and the distribution loss, which can be formulated as follow;

- generate a series of points between the gen power from DG and its associated distributio $\left(P_G^i, P_{Loss}^i\right)$, using a power flow program,
- from (1), the function of the sum square of th deviation for *n* number of coordination pairs c illustrated as (2)

$$F(a,b,c) = \sum_{i=1}^{n}\left[a\left(P_G^i\right)^2 + b\left(P_G^i\right) + c - P_{Loss}^i\right],$$

- to obtain the coefficients *a, b,* and *c* fro satisfied the minimal condition, the gradient respect to these coefficient must be zero as bel

$$2\sum_{i=1}^{n}\left[\left(a\left(P_G^i\right)^2 + b\left(P_G^i\right) + c - P_{Loss}^i\right)\left(P_G^i\right)^2\right] = 0$$

$$2\sum_{i=1}^{n}\left[\left(a\left(P_G^i\right)^2 + b\left(P_G^i\right) + c - P_{Loss}^i\right)\left(P_G^i\right)\right] = 0$$

$$2\sum_{i=1}^{n}\left[a\left(P_G^i\right)^2 + b\left(P_G^i\right) + c - P_{Loss}^i\right] = 0$$

- the equation (3) can be rearranged and represe a matrix form as (4)

$$\begin{bmatrix} \sum_{i=1}^{n}\left(P_G^i\right)^4 & \sum_{i=1}^{n}\left(P_G^i\right)^3 & \sum_{i=1}^{n}\left(P_G^i\right)^2 \\ \sum_{i=1}^{n}\left(P_G^i\right)^3 & \sum_{i=1}^{n}\left(P_G^i\right)^2 & \sum_{i=1}^{n}\left(P_G^i\right) \\ \sum_{i=1}^{n}\left(P_G^i\right)^2 & \sum_{i=1}^{n}\left(P_G^i\right) & nc \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n}\left(P_{Loss}^i\right)\left(P_G^i\right)^2 \\ \sum_{i=1}^{n}\left(P_{Loss}^i\right)\left(P_G^i\right) \\ \sum_{i=1}^{n}\left(P_{Loss}^i\right) \end{bmatrix}, \text{ and}$$

- equation (4) can be solved easily to obtained the coefficients *a, b,* and *c*, and
- eventually the generated power from DG; P_G, that resulted in the minimal loss is $-b/2a$.

Scripts *G, P, Loss* and *n* are denoted for DG bus, real power, real power loss and a number of snap shot data between PG and its associated real power loss respectively.

4. Calculation Algorithm

The optimal P_G obtained from the procedures presented in section 3 is an approximated value obtained from the quadratic nature of distribution loss. The accurate optimal P_G must be calculated iteratively. It is not depends on a number of pairs of data but depends on proximity of the data to the optimal value. Consequently, a three-point set cutting algorithm is proposed to fined tune the accuracy of the solution, which can be described below.

- Generate three pairs of data between the generated power from DG and its associated distribution loss, $\left(P_G^1, P_{Loss}^1\right)$, $\left(P_G^2, P_{Loss}^2\right)$, and $\left(P_G^3, P_{Loss}^3\right)$ using a power flow calculation.
- Calculate the approximated optimal P_G as d in section 3 and its associated real power loss
- Replace the optimal P_G and its associated rea loss to the most deviated pairs of the previous
- Repeat until the convergence criterion is satis

It should be noted that the formulation of LSQA not limit to a real power loss function. It can be further to energy loss function of summing real po of all specified periods.

5. Optimization Framework

5.1 Objective Functions

The objective function of the both scenarios of m loss under planning and operating stages is the shown in (5).

$$Minimize \quad E_{Loss} = \sum_{t=1}^{T}\left(P_{Loss}^t \Delta T\right),$$

The variables *t* is denoted for a specified period

5.2 Common Constraints

The common constrains of the both scenarios are

$$\left(P^t_{sch_i} + jQ^t_{schi}\right) = \sum_{j=1}^{N}\left(P^t_{ij} + jQ^t_{ij}\right), \quad \forall i, j \in N, \forall t \in T, \quad (6)$$

$$Q^{min}_G \le Q^t_G \le Q^{max}_G, \quad \forall t \in T, \quad (7)$$

$$V^{min}_k \le V^t_k \le V^{max}_k, \quad \forall k \in N, \forall t \in T, \quad (8)$$

Scripts N and T are denoted for a number of buses in a system and a number of periods respectively. Constrains (6) is a power flow equation. Inequality constraints (7) and (8) are to ensure that reactive power of DG and system voltage profiles are regulated within an acceptable range.

5.3 Individual Constraints

The control variables of the two scenarios to satisfy objective function of (5) are difference as described below.

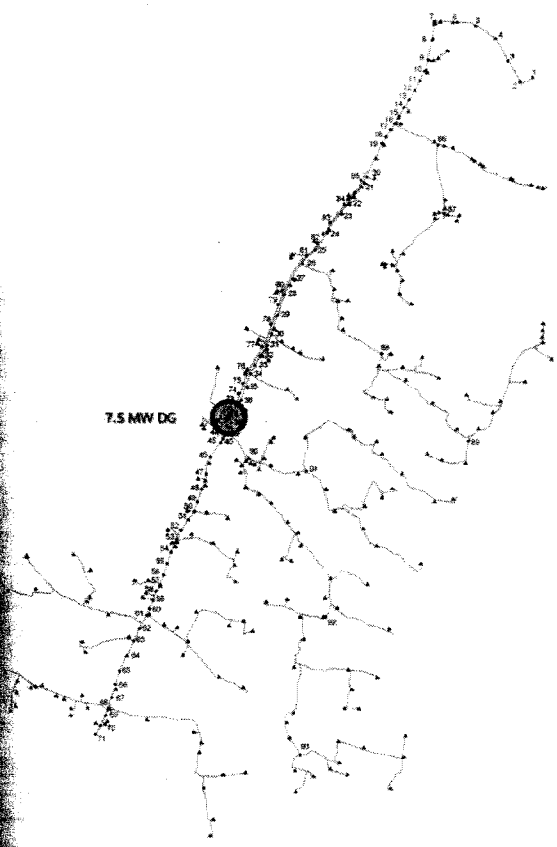
- **Under planning stage,** assumed that DG supplied power at an optimal purchasing contract, P^{Opt}_G, at all specified period as shown in (9).

$$P^t_G = P^{Opt}_G, \quad \forall t \in T, \quad (9)$$

- **Under operating stage,** scheduled power from DG is controlled of each period within an acceptable range as shown in (10).

$$P^{min}_G \le P^t_G \le P^{max}_G, \quad \forall t \in T, \quad (10)$$

TEST SYSTEM



1 Network topology of a 93-bus radial distribution system

A 93-bus radial distribution system with peak demand 6.42 MW connected with synchronous DG capacity of 7.5 MW at bus No. 42 as shown in Fig. 1 is used as a tested system. Daily load profile of this system is shown in Fig. 2.

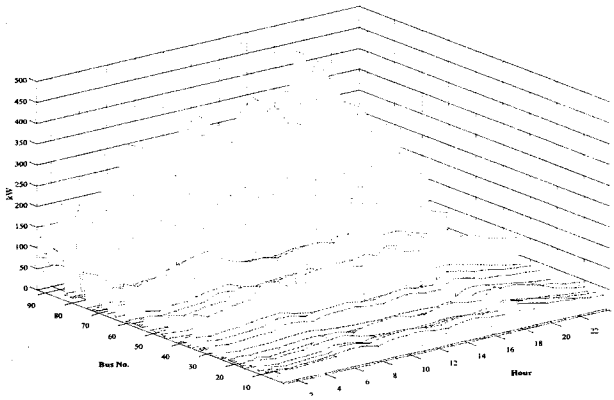


Figure 2 Daily load profile of a tested system

7. NUMERICAL RESULTS

7.1 Base-case Characteristics

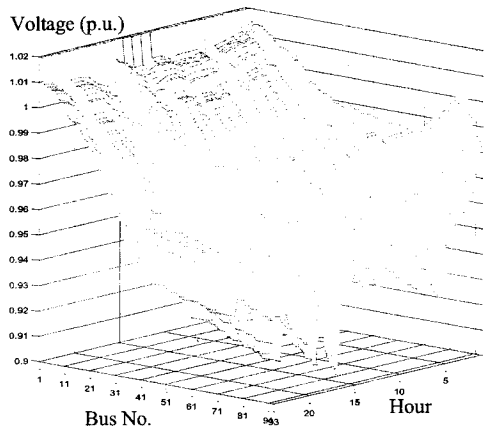


Figure 3 System voltages in case of without DG

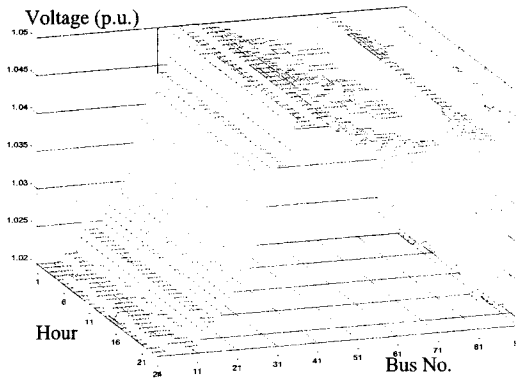


Figure 4 System voltages in case of DG sized 7.5 MW is connected

To evaluate a broad-view, simulation is performed in two cases i.e., cases with and without a 7.5 MW DG. Voltage of substation and DG buses are set to 1.02 and 1.05 p.u. respectively. The obtained results of voltage profiles and real power loss are shown from Fig. 3 – Fig. 5 respectively.

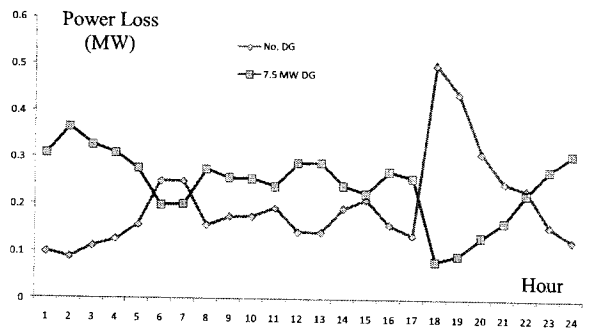


Figure 5 Daily energy loss of a system

Daily energy losses of Fig. 5 in the cases without DG and with DG are 4.764 and 5.841 MWh respectively.

7.2 The Optimal Purchasing Contract

The relationship of the purchasing contracts versus daily energy loss can be shown in Fig. 6.

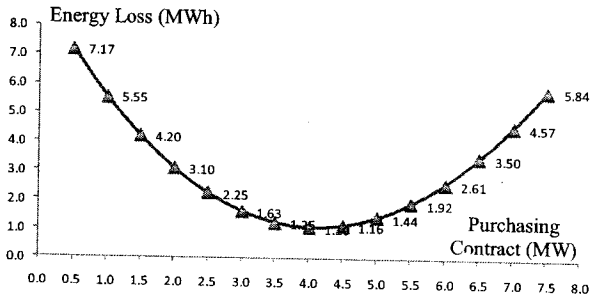


Figure 6 Quantity of the purchasing contract to distribution loss

The obtained results using LSQA described in section 3 can be summarized in Table 1.

Table 1 Loss approximated with different number of points

Points	Energy Loss Equation	P_G^{Opt} (MW)	Energy Loss (MWh)
3	$0.43811P^2-3.59655P+8.47525$	4.10462	1.09424554
5	$0.43833P^2-3.60314P+8.49805$	4.110077	1.09426805
7	$0.43867P^2-3.61305P+8.53225$	4.118187	1.09434938
9	$0.43911P^2-3.62631P+8.57782$	4.129159	1.09455057
11	$0.43967P^2-3.64295P+8.63475$	4.142823	1.09494755
13	$0.44035P^2-3.66302P+8.70302$	4.159214	1.09563781
15	$0.44114P^2-3.68656P+8.78258$	4.178447	1.09674528

Using methodology in section 4 to fined tune the accuracy, daily energy loss equation can be shown in (11).

$$E_{Loss} = 0.43367(P_G)^2 - 3.55833(P_G) + 8.39347 \quad (11)$$

The optimal purchasing contract is 4.10258 MW with its associated daily loss of 1.09424 MWh.

7.3 The Optimal Real Time Scheduling

The optimal P_G at each hour presented in section 5 can be shown in Fig. 7. The associated daily energy loss in this case is 0.83502 MWh. Comparison of energy loss between these two scenarios is shown in Fig. 8.

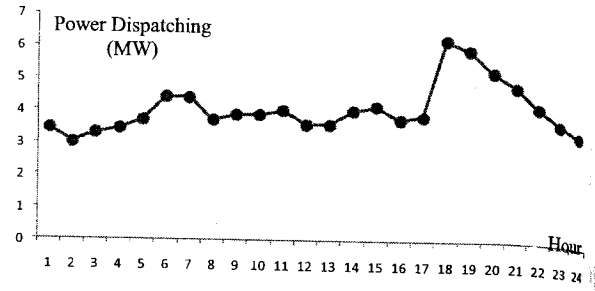


Figure 7 Optimal DG scheduling for each hour

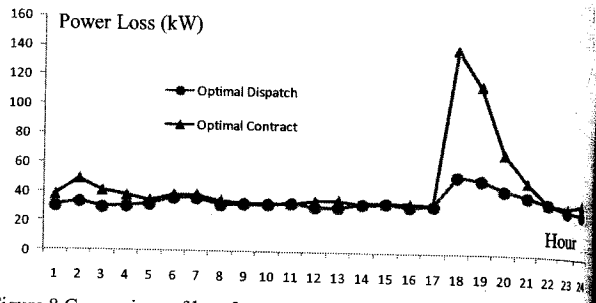


Figure 8 Comparison of loss for each hour

The percentage of additional loss reduction at the optimal scheduling of Fig. 5 can be shown in Fig. 6.

8. Conclusions

In this paper, two scenarios for managing real power loss under planning and real time operating stages are tested and compared. The Least Square Quadratic Approximation (LSQA) is proposed for solving the optimization frame works with satisfied results. The simulation is performed using a 93-bus radial distribution system under PEA network. The obtained result shown that the energy losses under managed scenarios are significance lower than the case without intervention.

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