The Effects of Multi-Distributed Generator on Distribution System Reliability

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***Abstract*—The paper investigates on the effects of multi-distributed generators (multi-DG) integrated to distribution system in terms of reliability indices. The distributed generators (DGs) under this study are solar photovoltaic (PV) connected to a 22 kV distribution system. In addition, it presents to determine the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI) and outage cost as reliability indices by comparing the SAIFI, SAIDI and outage cost (ECOST) of the cases that multi-DG is connected to a distribution system. The reliability indices will be calculated using data obtaining from simulation and analysis of power distribution system model created in DIgSILENT PowerFactory. The overall results can be summarized by focusing on the capacity of DGs and the location of DGs, which are important factors capable of affecting the reliability indices.**

***Index Terms*-- Distributed power generation, MATLAB, Power system reliability, Solar power generation**

I. Introduction

Nowadays, the world and Thailand have increasingly required electric energy. Electric energy consumption for industries and household has increased dramatically. In Thailand, the electric energy consumption during the first 10 months of the year 2015 was approximately 145,760 GWh, which is increased 3.2 percent. In addition, Power Development Plan (PDP2015-2036) decided to have electric energy production of new renewable energy resources increased about 19,635 MW. Consequently, the solar photovoltaic energy has rapidly increased in Thailand. However, there are also some drawbacks that need to be carefully considered about the integration of DG into the distribution system.

Several researchers [1]-[11] have studied a new method simulation for reliability evaluation of distributed generator (DG) integrated into the distribution system under location and capacity of DG. The criteria for the optimal placement of multi-DG is to maximize the reliability improvement. In [1], this paper has studied how DG penetration and DG location at a particular load point in radial distribution affects system reliability and how reliability indices can be used to select the best location of a DG in a radial distribution system. In [2], this paper has presented a methodology to evaluate the cost of energy losses and the cost of interruption in distribution networks with renewable distributed generation (DG) connections. Moreover, it presented a renewable DG allocation planning algorithm to determine the optimum locations and sizes of DG units in distribution network for reliability improvement and energy losses reduction. In [3], this paper has reported a novel application of multi objective particle swarm optimization with the aim of determining the optimal DGs places, sizes, and their generated power contract price. In the proposed multi objective optimization, not only for the operational aspects, such as improving voltage profile and stability, power-loss reduction, and reliability enhancement taken into account, but also an economic analysis is performed based on the distribution company's and DG owner's viewpoints. In [4], this paper studied the impact of penetration of Distributed Generation (DG) on the reliability of a radial distribution network. The authors evaluate the reliability of a radial network with and without DG connection at different load points. Reliability evaluation is performed using the analytical and Monte Carlo Simulation (MCS) techniques and enhancement of reliability is compared with both techniques for DG placement at different load points. In [5], this paper presented multi-objective function to determine the optimal locations to place DGs in distribution system to minimize power loss of the system and enhance reliability improvement and voltage profile. Moreover, to solve this multi-objective problem a novel approach based on dynamic programming is used. In [6], this paper proposed the planning distribution system in planning distribution networks in which the operation of distributed generators (DGs) and cross-connections (CCs) is optimally planned. Distribution systems are optimally upgraded in order to improve system reliability and to minimize line losses. An objective function is constituted, composed of the investment cost, loss cost, and reliability cost. In [7], this paper proposed a method to evaluate the worth of installing renewable distributed generation (DG) in distribution networks. The benefits considered that deferral of upgrade investments, reduction of the cost of energy losses, and reliability improvement, which is represented by the interruption cost reduction. In [8], this

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paper studied the impact of conventional and renewable distributed generation (DG) on the reliability of future distribution systems, even when the connection may not be simply radial. The stochastic nature of the renewable resources and their influence on the reliability of the system are modeled and studied by computing the adequacy transition rate. In [9], this paper proposed an analytical method to assess the distribution system reliability level considering these issues. The reliability model for DG and load are developed using scenarios reduction techniques based on historical data. In [10], this paper proposed a probabilistic based analytical method is developed to assess system reliability in terms of system average interruption duration index and system average interruption frequency index for distribution feeders containing dispatchable and nondispatchable renewable DG units. In [11], this paper presented optimized strategies for designing and enhancing the microgrids in distribution systems. By defining a new probabilistic index, called system wellbeing (SWB) index, both reliability and supply-adequacy concerns are taken into account in the objective function. However, few studies have reported on the effects of multi-DG on reliability analysis.

The purpose of this paper is to study the effects of multi-DG integrated into the distribution system in terms of reliability indices. The system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and outage cost (ECOST) will be used as the reliability indices in this paper. This research has proposed solar photovoltaics energy to be investigated including the location and capacity of solar photovoltaics energy. The simulations are performed using DIgSILENT PowerFactory program.

II. POWER SYSTEM SIMULATION USING DIGSILENT

The distribution system of Provincial Electricity Authority (PEA), which is a part of Thailand's distribution system, is used as the distribution system model. DIgSILENT PowerFactory is employed to simulate and analyze the improvement reliability and loss reduction, when DG is connected with a 22 kV distribution system as shown in Fig. 1. Considering the Fig. 1, the diagram shows that Thanyaburi distribution system with DG connected has 1 bus connected to the Thanyaburi substation. Data from geographic information systems (GIS) phase 2 are used as the parameters of PEA such

as distance of the distribution line between the buses and the placement of the loads. The location of loads, size of loads, sector of customers and quantity of customers are shown in Table 1. cable resistance and reactance of space aerial cable (SAC) 22 kV distribution system is shown in Table 2. The total connected load of the distribution system is 11.77 MW and 8.75 MVar. The placement of single-DG is installed at bus 5. To study the effects of DG, simulations are performed with various period of time so that the capacity of PV is varied between 0 MW and 5 MW (time-varying PV)

Considering the Fig.1., the diagram presents that Thanyaburi distribution system with multi-DG connected has 5 buses integrated to the Thanyaburi substation. Multi-DG, in this paper is 2 connected DG units integrated to the distribution system which PV2 is base and PV1, PV3, and PV4 are varied. Data from geographic information systems (GIS) are employed as the parameters of PEA such as the placement of the loads and distance of the distribution line between the buses. The location of loads, size of loads, sector of customers and quantity of customers are shown in Table I. The total connected load of the distribution system is 11.77 MW and 8.75 MVar.

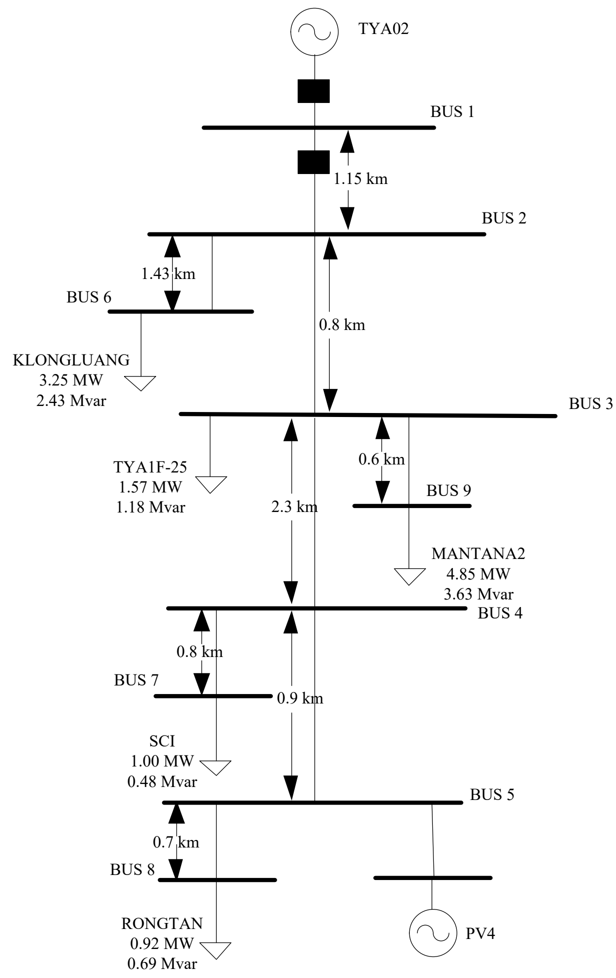


Figure 1. Diagram of distribution system with DG connected for case study in the simulation.

To study the effects of Multi-DG, simulations are performed with various conditions as follows:

- The placement of PV2 is based at bus 3.
- The placement of PV1, PV3 and PV4 is varied between bus 2, bus 4 and bus 5.
- The capacity of multi-DG installed at each bus is varied between 1 MW – 8 MW (step at 1 MW).

TABLE I. PLACEMENT, SIZE OF LOADS, AND SECTOR OF POWER USER

Placement	Load		Sector	Customers (Quantity)
	MW	*MVar*		
Substation TYA02	11.77	8.75	Substation	2,223
KLONGLUANG	3.25	2.43	Residence	435
TYA1F-25	1.57	1.18	Residence	326
MUNTANA2	4.85	3.63	Residence	1,136
SCI	1	0.48	Industrial	2
RONGTAN	0.92	0.69	Residence	324

The reliability indices are compared for the case of single-distributed generator (single-DG) and multi-distributed generators (multi-DG) connected in the distribution system. The case of multi-DG is divided into 8 capacities of DGs (1-8 MW) and 4 locations of DGs (PV2 is based and PV1, PV3, and PV4 are varied.) to study the effects of the reliability index when solar photovoltaic energy source is integrated into the distribution system. To evaluate the reliability of the system, the SAIFI, SAIDI and outage cost (ECOST) are investigated. Fig.2 shown SAIFI and SAIDI indices results in case with single DG. For multi-DG case SAIFI indices is shown in Fig.3 and SAIDI indices is shown in Fig. 4.

III. RESULT

For the first index, the SAIFI of multi-DG case is compared with the case of single-DG at each case. The capacity of single-DG at PV2 of 1-8 MW is 0.288781 times/customer/year. For example, the SAIFI of single-DG at PV2 of 5 MW is 0.288781 times/customer/year, which is more than multi-DG at PV2 capacity 1 MW is cooperated with PV1 or PV3 or PV4 at 4 MW; the indices are 0.226239, 0.158301 and 0.144343 times/customer/year, respectively. Thus, the SAIFI of multi-DG case tends to decrease and is less than that of the case of single-DG, especially the PV4 which was installed the farthest from substation, to cause the SAIFI improved and significantly decreased (minimum the SAIFI). For the location of multi-DG for PV1, PV3 and PV4 were considered which PV2 is base, the SAIFI tends to decrease for PV1, PV3 and PV4 respectively. In addition, the SAIFI of PV4 is less than that of PV3 and PV3 is less than that of PV1. Moreover, the PV4 which was installed the farthest from substation, caused the SAIFI improved and significantly decreased (minimum the SAIFI). For the capacity of multi-DG (1, 2, 3, 4, 5, 6, 7 and 8 MW) which was installed at each bus, the SAIFI tends to decrease and is less than that of the case of single-DG from equation (1) because the number of customers serves is decreased and thus, the failure rate of the equipment is decreased.

The second index, the SAIDI. Similarly to the previous analysis; thus the SAIDI of multi-DG case tends to decrease and is less than that of the case of single-DG, especially the PV4 which was installed the farthest from substation, to cause the SAIDI improved and significantly decreased (minimum the SAIDI). For the location of multi-DG, the SAIDI tends to decrease for PV1, PV3 and PV4 respectively. In addition, the SAIDI of PV4 is less than that of PV3 and PV3 is less than that ofPV1. Moreover, the PV4 which was installed the farthest from substation, caused the SAIDI improved and significantly decreased (minimum the SAIDI). For the capacity of multi-DG (1, 2, 3, 4, 5, 6, 7 and 8 MW) which was installed at each bus, the SAIDI tends to decrease and is less than that of the case of single-DG from equation (2) because the number of customers serves is decreased and thus, the repair time is decreased.

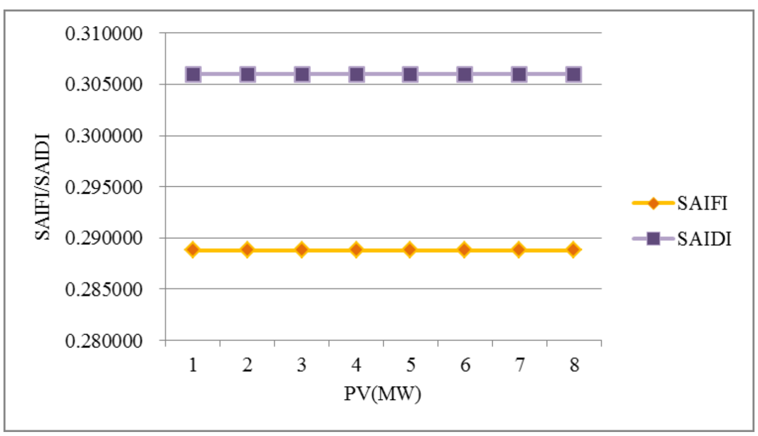
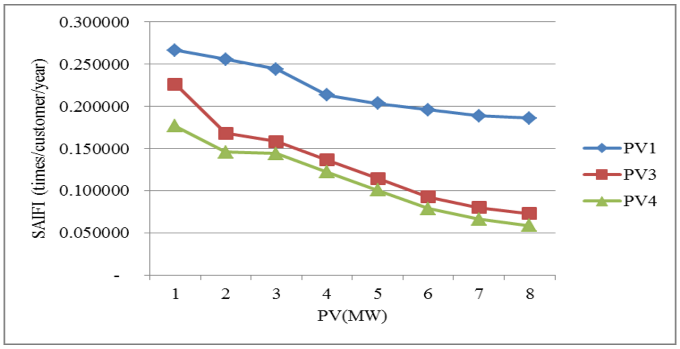
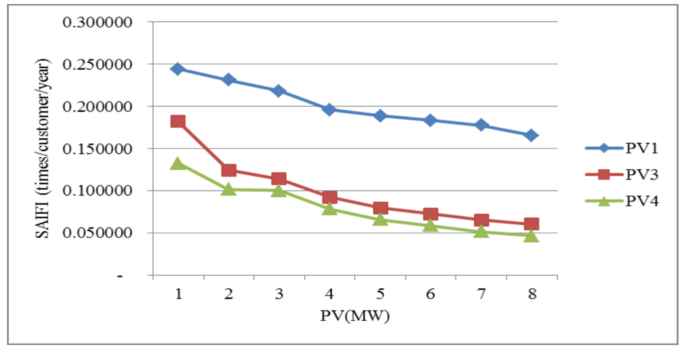


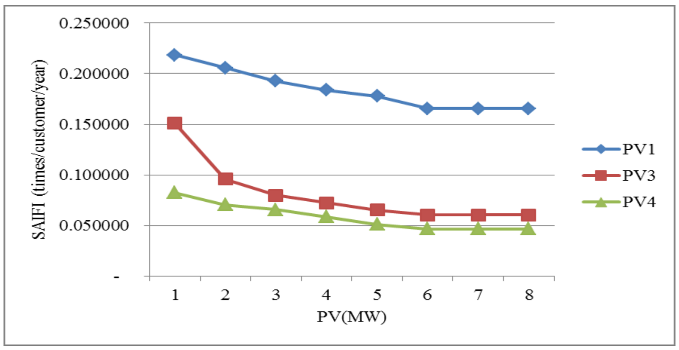
Figure 2. SAIFI and SAIDI of single-DG at PV2 of 1-8 MW



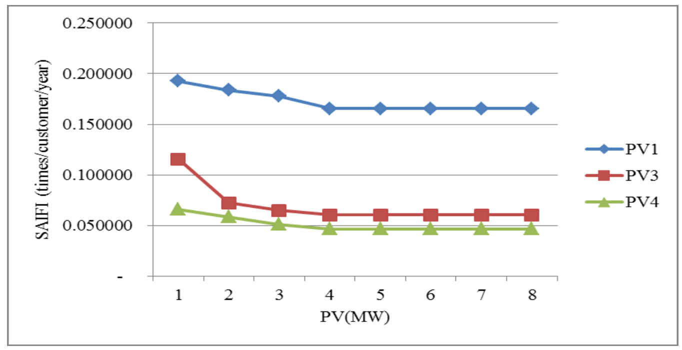
a) PV2 size 2 MW



b) PV2 size 4 MW

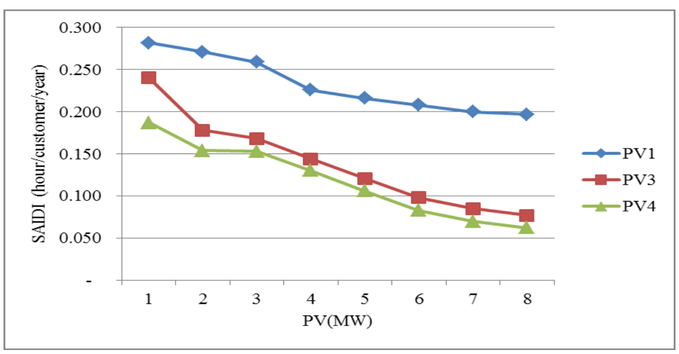


c) PV2 size 6 MW

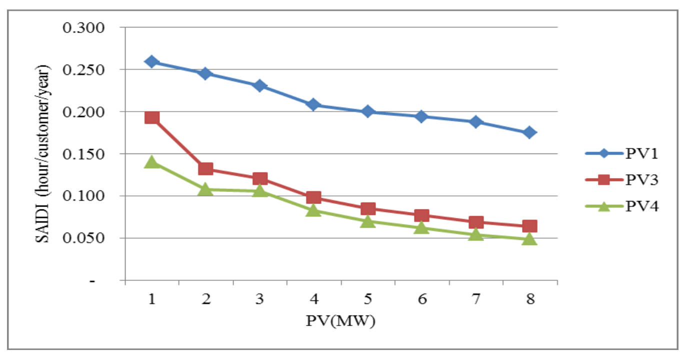


d) PV2 size 8 MW

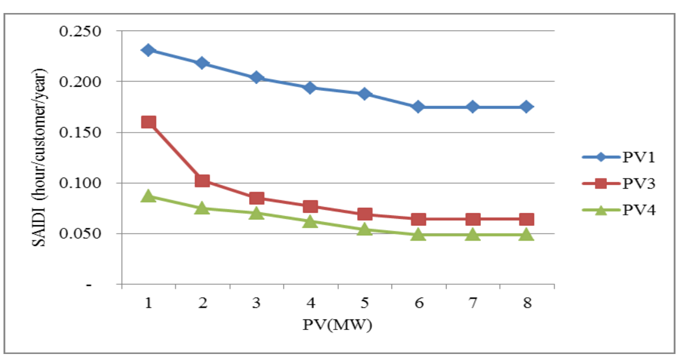
Figure 3. SAIFI in case of multi-DG



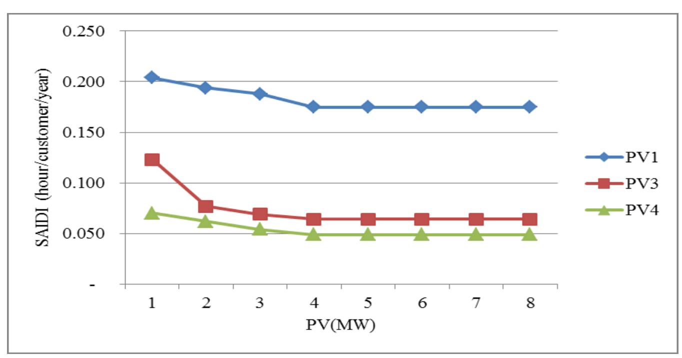
a) PV2 size 2 MW



b) PV2 size 4 MW



c) PV2 size 6 MW



d) PV2 size 8 MW

Figure 4. SAIDI in case of multi-DG

TABLE II. ECOST FOR MULTI-DG AND SINGLE-DG AT PV2 INSTALLED IN 22 KV DISTRIBUTION SYSTEM

PV2 DG No.1	PV 1,3,4 DG No.2	ECOST ($/year)							
		1 MW	*2 MW*	*3 MW*	*4 MW*	*5 MW*	*6 MW*	*7 MW*	*8 MW*
Single-DG @ PV2		5,216.00	5,216.00	5,216.00	5,216.00	5,216.00	5,216.00	5,216.00	5,216.00
PV2 1 MW	PV1	4,694.40	4,602.36	4,326.22	4,080.76	4,019.39	3,804.61	3,559.16	3,313.70
	PV3	4,050.07	3,190.97	3,068.24	2,546.64	2,178.45	1,932.99	1,840.94	1,626.17
	PV4	3,896.66	3,252.33	2,914.83	2,423.91	2,055.72	1,810.26	1,687.53	1,472.75
PV2 2 MW	PV1	4,602.36	4,387.58	4,234.17	4,019.39	3,804.61	3,559.16	3,405.74	3,221.65
	PV3	3,559.16	2,822.78	2,546.64	2,178.45	1,932.99	1,840.94	1,626.17	1,380.71
	PV4	3,375.06	2,730.73	2,423.91	2,055.72	1,810.26	1,687.53	1,472.75	1,227.30
PV2 3 MW	PV1	4,387.58	4,234.17	3,927.34	3,804.61	3,559.16	3,405.74	3,283.01	3,098.92
	PV3	3,160.28	2,577.32	2,178.45	1,932.99	1,840.94	1,595.48	1,380.71	1,227.30
	PV4	3,006.87	2,362.54	2,055.72	1,810.26	1,687.53	1,472.75	1,227.30	1,104.57
PV2 4 MW	PV1	4,234.17	3,927.34	3,681.89	3,559.16	3,405.74	3,283.01	3,098.92	3,037.56
	PV3	2,914.83	2,454.59	1,932.99	1,840.94	1,595.48	1,350.02	1,227.30	1,196.61
	PV4	2,761.41	2,086.40	1,810.26	1,687.53	1,472.75	1,227.30	1,104.57	1,073.88
PV2 5 MW	PV1	3,927.34	3,681.89	3,497.79	3,405.74	3,283.01	3,098.92	3,037.56	3,037.56
	PV3	2,792.10	2,178.45	1,840.94	1,595.48	1,350.02	1,227.30	1,196.61	1,196.61
	PV4	2,638.68	1,994.35	1,687.53	1,472.75	1,227.30	1,104.57	1,073.88	1,073.88
PV2 6 MW	PV1	3,681.89	3,497.79	3,405.74	3,283.01	3,098.92	3,037.56	3,037.56	3,037.56
	PV3	2,515.95	1,871.62	1,595.48	1,350.02	1,227.30	1,196.61	1,196.61	1,196.61
	PV4	2,362.54	1,718.21	1,472.75	1,227.30	1,104.57	1,073.88	1,073.88	1,073.88
PV2 7 MW	PV1	3,497.79	3,405.74	3,283.01	3,098.92	3,037.56	3,037.56	3,037.56	3,037.56
	PV3	2,209.13	1,595.48	1,350.02	1,227.30	1,196.61	1,196.61	1,196.61	1,196.61
	PV4	2,055.72	1,472.75	1,227.30	1,104.57	1,073.88	1,073.88	1,073.88	1,073.88
PV2 8 MW	PV1	3,405.74	3,283.01	3,098.92	3,037.56	3,037.56	3,037.56	3,037.56	3,037.56
	PV3	1,963.67	1,350.02	1,227.30	1,196.61	1,196.61	1,196.61	1,196.61	1,196.61
	PV4	1,779.58	1,227.30	1,104.57	1,073.88	1,073.88	1,073.88	1,073.88	1,073.88

IV. CONCLUSIONS

This paper investigated the effects of multi-distributed generators (multi-DGs), which were solar photovoltaics(PV) integrated into distribution system in terms of reliability. In addition, the location and capacity of DG were also varied. The results can be summarized as follows:

- For the reliability indices, the multi-DG case is compared with the case of single-DG. the reliability indices of single-DG at PV2 are more than multi-DG at PV2 is cooperated with PV1 or PV3 or PV4; thus the reliability indices of multi-DG case tend to decrease and is less than that of the case of single-DG, especially the PV4 which was installed the farthest from substation, to cause the reliability indices improved and significantly decreased (minimum the reliability indices).

- For the location of multi-DG for PV1, PV3 and PV4 which PV2 is base, the reliability indices tend to decrease for PV1, PV3 and PV4 respectively. In addition, the reliability indices of PV4 are less than those of PV3 and those of PV3 less than those of PV1. Moreover, the PV4 which was installed the farthest from substation, caused the reliability indices has improved and significantly decreased (minimum the reliability indices).

- For the capacity of multi-DG (1, 2, 3, 4, 5, 6, 7 and 8 MW) which was installed at each bus, the reliability indices tend to decrease and are less than those of the case of single-DG.

The power losses aspect is evaluated to the effect of solar photovoltaic (PV) by changing the capacity of DG as shown in Table 4. The total power losses consist of total active power loss (Total Ploss) and total reactive power loss (Total Qloss).

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