

# An Optimal Power Flow Based Dispatch Model for Distributed Generation Embedded Network

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**Abstract**—The installation of distributed generation (DG) introduces challenges to distribution systems operation. The distribution network operator needs to schedule DG outputs considering some constraints, such as DG characteristics, reactive power control mode of generators, automatic voltage regulation, compensator and power quality standard, etc. Based on an optimal power flow model, this paper proposes a dispatch model for DG embedded distribution systems. The model is proposed basing on energy prices, weather forecasting and load forecasting. The objective is to minimize the electricity supply cost of the distribution company. The proposed model is tested in the 33-buse system. The results show that DisCo's cost and losses of the distribution system can be reduced by enhancing system operation flexibility.

**Index Terms**—Distributed generation, dispatch model, optimal power flow

## NOMENCLATURE

### A. Parameters

$i$ : DG number.  
 $j, k$ : Bus number.  
 $\rho_S(P_S)$ : Price of electricity from power grid,  $\$/MWh$ .  
 $\rho_{DG_i}$ : Offer from  $DG_i$ ,  $\$/MWh$ .  
 $G_{jk}$ : Real part of admittance matrix element.  
 $B_{jk}$ : Imaginary part of admittance matrix element.  
 $\theta_{jk}$ : Phase angle difference between bus  $j$  and bus  $k$ .  
 $\underline{P}_{DG_i}$ : Lower boundary of  $DG_i$  output.  
 $\bar{P}_{DG_i}$ : Maximum output of  $DG_i$ .  
 $\eta_w$ : Overall efficiency of wind turbine.  
 $\rho_w$ : Air density,  $m/s$ .  
 $A$ : Wind turbine rotor area,  $m^2$ .  
 $C_w$ : Optimal power coefficient of wind turbine.  
 $V$ : Wind velocity,  $m/s$ .  
 $\bar{P}_{DG_i,W}$ : Rated active power of wind turbine,  $W$ .  
 $Q$ : Flow rate,  $m^3/s$ .  
 $H$ : Effective head of hydro power plant,  $m$ .  
 $\eta_h$ : Overall efficiency of hydro power plant.

$\rho_h$ : Water density,  $kg/m^3$ .  
 $g$ : Acceleration due to gravity,  $m/s$ .  
 $\bar{P}_{DG_i,H}$ : Rated active power of hydro power plant,  $W$ .  
 $a_1, a_2$  and  $a_3$ : Coefficients related to the design of CHP.  
 $p$ : Steam pressure of CHP,  $ata$ .  
 $G$ : Steam flux,  $Tun/Hour$ .  
 $G_1$ : High pressure extraction of CHP,  $Tun/Hour$ .  
 $G_2$ : Low pressure extraction of CHP,  $Tun/Hour$ .  
 $\Delta H$ : Steam enthalpy drop in turbine low pressure stage,  $J/Tun$ .  
 $\eta_g$ : Turbine low pressure stage efficiency.  
 $x_{s,DG_i}$ : Synchronous reactance,  $pu$ .  
 $\bar{E}_{q,DG_i}$ : Maximum internal voltage,  $pu$ .  
 $Q_{min,DG_i}$ : Region heating limit,  $MVar$ .  
 $S_{DG_i}$ : Rated capacity,  $MVA$ .  
 $r_r$ : Rotor resistance,  $pu$ .  
 $x_r$ : Rotor reactance,  $pu$ .  
 $r_s$ : Stator resistance,  $pu$ .  
 $x_s$ : Stator reactance,  $pu$ .  
 $x_m$ : Excitation reactance,  $pu$ .  
 $S$ : Induction generator slip.  
 $PF_{DG_i}$ : Power factor of  $DG_i$ .  
 $\underline{V}$ : Lower voltage boundary on bus,  $pu$ .  
 $\bar{V}$ : Upper voltage boundary on bus,  $pu$ .  
 $\underline{V}_S$ : Lower boundary of substation secondary side voltage,  $pu$ .  
 $\bar{V}_S$ : Upper boundary of substation secondary side voltage,  $pu$ .  
 $V_{set}$ : Set point of substation secondary side voltage,  $pu$ .  
 $Q_{C,j}$ : Reactive power of fixed capacitor on bus  $j$  when the voltage is 1.0 pu,  $Mvar$ .  
 $\bar{Q}_{SVC,j}$ : Maximum reactive power of SVC on bus  $j$  when the voltage is 1.0 pu,  $Mvar$ .  
 $\underline{Q}_{SVC,j}$ : Minimum reactive power of SVC on bus  $j$  when the voltage is 1.0 pu,  $Mvar$ .

### B. Variables

$P_S$ : Active power from power grid,  $MW$ .  
 $P_{DG_i}$ : Active power from  $DG_i$ ,  $MW$ .  
 $P_{G_j}$ : Total DG active power on bus  $j$ ,  $MW$ .  
 $P_{D_j}$ : Total active power demand on bus  $j$ ,  $MW$ .  
 $V_j$ : Voltages on bus  $j$ ,  $pu$ .  
 $V_k$ : Voltages on bus  $k$ ,  $pu$ .  
 $V_{DG_i}$ : Terminal voltage of  $DG_i$ ,  $pu$ .  
 $V_S$ : Substation secondary side voltage,  $pu$ .

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$Q_{Cj}$ : Reactive power of fixed capacitor on bus  $j$ ,  $Mvar$ .  
 $Q_{SVCj}$ : Reactive power of SVC on bus  $j$ ,  $Mvar$ .

## I. INTRODUCTION

**D**UE to the increasing concerns on the global warming, and the exhaustion of fossil fuels, clean energy based distributed generation is recognized as one of the feasible approaches for sustainable development. It is expected that the penetration rate of DGs in power system will keep rising and the conventional power system will evolve from a centralized generating system to a more decentralized one. Moreover, DGs have potential advantages to reduce power delivery losses, postpone or shift transmission system investment, and increase system reliabilities.

In a DG embedded distribution system, distribution network operators (DNOs) dispatch DGs to maximize social welfare, while satisfy system operation constrains. Hereby, price signals, DG techniques, system operation guidelines, and power quality standards could affect the operation results.

Various DG techniques used currently have different power characteristics. Some renewable energy based DG are subject to the meteorologic conditions, such as wind speed, solar radiation, and flow rate, etc [1], [2]. The electrical outputs of combined-heat-and-powers (CHPs) depend on heat load [3]. Other DGs, such as steam turbine, gas turbine and combined cycle turbine, are highly controllable [1], [2]. DGs' abilities on adjusting reactive power are different. Synchronous machine, double-fed machine or self-commutated converter based DGs can adjust their reactive power outputs for terminal voltage regulation or power factor control. The DGs using induction machines or line-commutated converters are not able to adjust reactive output [1]-[6].

Operation guidelines for distribution system are different from one region to another. DGs are operated in fixed power factor mode or voltage control mode in different systems [7], [8]. In recent years, active management has been applied as an alternative approach to improve system efficiency. In active management, the set points of AVRs can be adjusted real time, and, in some cases, fixed capacitors are replaced by SVCs, which have variable admittance [11]-[13].

Voltage variation is an important issue for system operation. Though detailed definitions of voltage variation are diverse in different standards, voltage variation is commonly known as a phenomenon that unacceptable steady voltage deviation occurs on buses [14]-[16]. In traditional distribution system with few generator embedded, voltage magnitude normally droop gradually along feeder. This situation is no longer true due to the installation of DG, which can change system voltage profile.

In this context, economical operation in a DG embedded distribution system is a challenge for DNOs. Some voltage control strategies and dispatch models have been proposed for this issue. For example, *Viawan* and *Karlsson* introduce the methods to minimize system losses by coordinating on-load tap changers, capacitors, and switches in the DG embedded system [9-10]. A widespread communication based strategy is discussed to minimize a linear combination of distribution

losses and voltage magnitude marginal [17]. A market model is proposed for distribution companies to coordinate wholesale market, load curtailment, distribution company (DisCo) owned DGs, and independent DGs [18]. The objective of the model is to minimize the total cost to procure the active power and reactive power.

In this paper, an optimal power flow (OPF) based dispatch model is proposed for the distribution system with DGs. The objective function is to minimize DisCo's cost. DG techniques, system operation guidelines, and voltage variation standards are described in the constraints.

The structure of this paper is as follows. Section II describes the models used in this paper. Section III and IV are the case studies and conclusions, respectively.

## II. MODEL DESCRIPTION

### A. Dispatch procedure

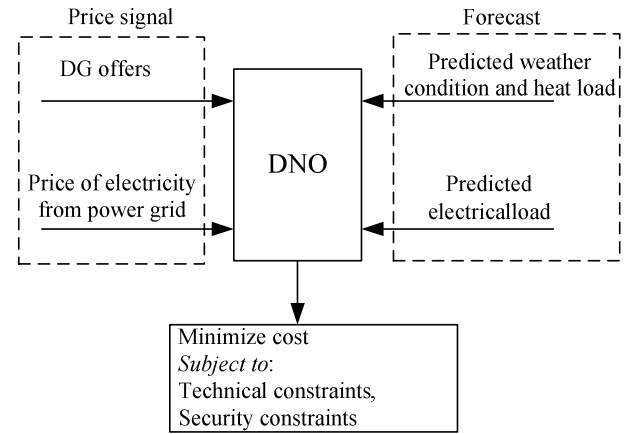


Fig. 1. Dispatch procedure for DG embedded distribution system

The proposed model is based on the assumption that DGs are independent and dispatchable. The dispatch procedure is shown in Fig.1. The DNO first receives offers from DGs. The weather conditions and heat loads are predicted to forecast the generation of renewable based DGs and CHPs for source-load matching. Based on this, the dispatch model is established. The objective of this model is to minimize the total cost of DisCo for energy supply, subjected to following constraints:

- Active power of renewable DGs: Maximum outputs of renewable DGs are subjected to generator capacities and weather conditions. On the other hand, in many countries, minimum outputs of renewable DGs are guaranteed in terms of laws, operation guidelines, or other terms from policy makers. In this paper, wind power generation and hydro power plant are considered as renewable DGs.
- Active power of CHP: The most commonly used CHP is steam turbine based CHP, which can be divided into two types, back-pressure CHP and condensing CHP. For the former one, all steam passes through the turbine and active power is determined only by heat demand [5]. While, condensing CHP can extract steam from the turbine for heat supply [5]. Its active power is adjustable [7].

- Active and reactive power characteristics (P-Q characteristics) of generators: P-Q characteristics affect system voltage profile significantly. Therefore, detailed steady state generator models are used in this paper. The output of synchronous generator is subjected to its field heating, armature heating and end region heating. Induction generator outputs are subjected to armature heating and slip.
- Reactive power control of synchronous generator: At fixed power factor mode, the proportion between active power and reactive power is a constant. While in voltage control mode, generator terminal voltage is kept constant by adjusting generator reactive power.
- AVR control strategy: The set point of the substation secondary side voltage is constant in the conventional AVR, while flexible in active management mode.
- Compensator performance: The equivalent admittances of fixed capacitors are constant. While those of SVCs are adjustable.

### B. Objective function

The objective function is to minimize DisCo's cost:

$$\text{MIN}[(P_S * \rho_S(P_S) + \sum P_{DG_i} * \rho_{DG_i})] \quad (1)$$

In this paper, the relationship between  $\rho_S(P_S)$  and  $P_S$  is described by a linear function.

$$\rho_S(P_S) = a * P_S + b \quad (2)$$

### C. Constraints

The constraints are introduced as following:

- Power balance constraints:

$$P_{G_j} - P_{D_j} = V_j \sum_{k=1}^N V_k (G_{jk} \cos \theta_{jk} + B_{jk} \sin \theta_{jk}) \quad (3)$$

$$Q_{G_j} - Q_{D_j} = V_j \sum_{k=1}^N V_k (G_{jk} \sin \theta_{jk} - B_{jk} \cos \theta_{jk}) \quad (4)$$

- Active power of renewable DG:

$$\underline{P}_{DG_i} \leq P_{DG_i} \leq \bar{P}_{DG_i} \quad (5)$$

For wind power generation [5]:

$$\bar{P}_{DG_i} = \min[0.5\eta_w \rho_w A C_w V^3, \bar{P}_{DG_i, W}]$$

For hydro power plant [5]:

$$\bar{P}_{DG_i} = \min[QH\eta_h \rho_h g, \bar{P}_{DG_i, H}]$$

In this paper, it is assumed that  $\underline{P}_{DG_i} = 0.5\bar{P}_{DG_i}$ .

- Active power of CHP:

For back-pressure CHP [7]:

$$P_{DG_i} = (a_1 - a_2 p)G + a_2 \quad (6)$$

For condensing CHP [7]:

$$\underline{P}_{DG_i} \leq P_{DG_i} \leq \bar{P}_{DG_i} \quad (7)$$

$$\underline{P}_{DG_i, CHP} = \sum_{n=1}^3 a_n G_1^n - \frac{G_2 \Delta H}{3600} \eta_g.$$

- P-Q characteristics of DG:

For synchronous generator [20]:

$$\begin{cases} P_{DG_i}^2 + (Q_{DG_i} + \frac{V_{DG_i}}{x_{s, DG_i}})^2 \leq [\frac{V_{DG_i} * \bar{E}_{q, DG_i}}{x_{s, DG_i}}]^2 \\ P_{DG_i}^2 + Q_{DG_i}^2 \leq S_{DG_i}^2 \\ Q_{DG_i} \geq Q_{\min, DG_i} \end{cases} \quad (8)$$

For induction generator [20]:

$$\begin{cases} P_{DG_i} = \frac{-r_e V_{DG_i}^2}{\sqrt{r_e^2 + x_e^2}} \\ Q_{DG_i} = \frac{x_e}{r_e} P_{DG_i} \\ P_{DG_i}^2 + Q_{DG_i}^2 \leq S_{DG_i}^2 \\ r_e = \frac{r_r x_m^2 S}{r_r^2 + S^2 (x_r + x_m)^2} + r_s \\ x_e = \frac{x_m r_r^2 + x_m x_r (x_m + x_r) S^2}{r_r^2 + S^2 (x_r + x_m)^2} + x_s \end{cases} \quad (9)$$

- Reactive power control of synchronous generators:  
Fixed power factor mode:

$$P_{DG_i} / \sqrt{P_{DG_i}^2 + Q_{DG_i}^2} = PF_{DG_i} \quad (10)$$

Voltage control mode:

$$\underline{V} \leq V_{DG_i} \leq \bar{V} \quad (11)$$

In this paper,  $\underline{V} = 0.93$  and  $\bar{V} = 1.07$ .

- AVR control strategy:

If conventional AVR is used:

$$V_S = V_{set} \quad (12)$$

In this paper,  $V_{set} = 1.05 pu$ .

If active management is used in AVR:

$$\underline{V}_S \leq V_S \leq \bar{V}_S \quad (13)$$

In this paper,  $\underline{V}_S = 1.0$  and  $\bar{V}_S = 1.07$ .

- Bus voltage variation boundaries

$$\underline{V} \leq V_j \leq \bar{V} \quad (14)$$

- Compensator performance:

For fixed capacitor:

$$Q_{C, j} = V_j^2 * Q'_{C, j} \quad (15)$$

For SVC:

$$V_j^2 * \underline{Q}_{SVC, j} \leq Q_{SVC, j} \leq V_j^2 * \bar{Q}_{SVC, j} \quad (16)$$

## III. CASE STUDY

The test system shown in Fig.2 is a 10kV system with a substation, three DGs, and two compensators. The system data is given in Appendix (Table VI). DG types and capacities are shown in Table I. DG parameters are given in Appendix (Table VII). DG offers and electricity price of power grid are in Table II. The offer of condensing CHP is higher than that of back-pressure CHP.

The scenarios are in Appendix (Table VIII). They created are to investigate the sensitivities of DisCo's cost to different technique options. In case A, all DGs are synchronous machines; back-pressure CHP and condensing CHP are applied in A1 and A2, respectively. In case B, DG1 and DG2 are induction machines and DG3 is a synchronous machine.

DG3 uses back-pressure CHP in B1, while condensing CHP in B2. In case C, all DGs operate in fixed power factor mode. In case D, active management is used in AVR; and SVC is used in D2.

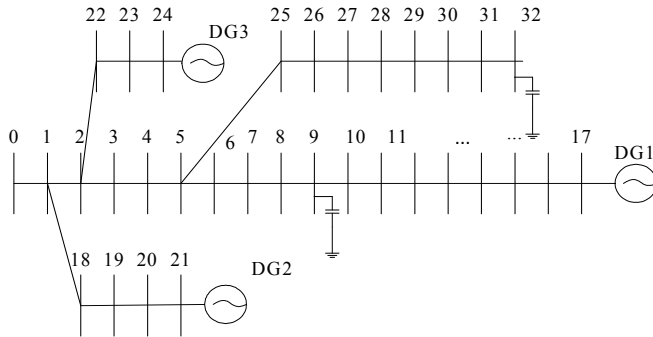


Fig. 2. Test system

TABLE I  
DG TYPES AND CAPACITIES

	Bus	Type	Capacity(MVA)
DG1	17	Hydro power plant	0.75
DG2	21	Wind power generation	0.6
DG3	24	CHP	0.8

TABLE II  
DG OFFERS AND ELECTRICITY PRICE FROM POWER GRID

DG1	23\$/MWh
DG2	75\$/MWh
DG3	26\$/MWh for Back-pressure CHP; 40\$/MWh for Condensing CHP
Power Grid	$\rho_s(P_s) = 3P_s + 23(\$/MWh)$

The expected DG biddable generation capacities according to predicted wind speed, predicted flow rate and predicted heat demand are shown in Table III.

TABLE III  
EXPECTED BIDDABLE GENERATION CAPACITIES OF DG3

DG1	[0.2, 0.4] MW
DG2	[0.15, 0.3] MW
DG3	0.365 MW for back-pressure CHP [0.269, 0.8] MW for condensing CHP

Table IV shows dispatch result for each scenario according to the demand given in Table VI. Table V are the dispatch results in cases that demand increases by 20 percent.

TABLE IV  
DISPATCH RESULT FOR THE DEMAND IN TABLE VI

	Total cost (\$)	Active power of DGs and power grid (MW)				Distribution loss (%)
		DG1	DG2	DG3	Power grid	
A1	123.4493	0.4000	0.1500	0.3654	2.9387	6.3206
A2	128.2513	0.4000	0.1500	0.6358	2.6591	6.0645
B1	124.1925	0.4000	0.1500	0.3654	2.9570	6.8245
B2	128.9655	0.4000	0.1500	0.6482	2.6647	6.5611
C1	129.0413	0.4000	0.1500	0.5681	2.7482	6.6572
C2	129.2035	0.4000	0.1500	0.5992	2.7207	6.7578

C3	129.4670	0.4000	0.1500	0.6325	2.6935	6.9253
C4	130.1263	0.4000	0.1500	0.6706	2.6714	7.3662
C5	131.1616	0.3952	0.1500	0.5711	2.8015	8.0764
D1	128.0273	0.4000	0.1500	0.6447	2.6441	5.8988
D2	123.5511	0.4000	0.1500	0.5496	2.6268	2.7975

TABLE V  
DISPATCH RESULT IF THE DEMAND IN TABLE VI INCREASES 20 PERCENT

	Total cost (\$)	Active power of DGs and power grid (MW)				Distribution loss (%)
		DG1	DG2	DG3	Power Grid	
A1	156.8114	0.4000	0.1500	0.3654	3.7153	6.4522
A2	159.4023	0.4000	0.1500	0.7902	3.2713	6.0115
B1	157.3402	0.4000	0.1500	0.3654	3.7269	6.7204
B2	159.9486	0.4000	0.1500	0.7929	3.2816	6.3099
C1	160.9470	0.4000	0.1500	0.6799	3.4097	6.6574
C2	160.7992	0.4000	0.1500	0.7201	3.3692	6.6501
C3	160.7170	0.4000	0.1500	0.7637	3.3268	6.6781
C4	160.9865	0.4000	0.1500	0.8000	3.2992	6.8786
C5	161.9093	0.4000	0.1500	0.7637	3.3545	7.3148
D1	159.3878	0.4000	0.1500	0.7917	3.2696	6.0059
D2	155.0934	0.4000	0.1500	0.7793	3.1799	3.6589

#### A. Discussions

Based on the results in Table III and Table V, the following can be found

- Using back-pressure CHP can reduce the total cost. In Table IV and Table V, the total costs in A1 and B1 are lower than those in A2 and B2, respectively. This is because back-pressure CHP has higher coal utilization rate; thus, can provide lower offer.
- Compared with back-pressure CHP, condensing CHP can improve distribution efficiency. This can be observed in Case A and Case B where the distribution losses in A1 and B1 are higher than those in A2 and B2, respectively. This is due to the adjustability of CHP active power. Back-pressure CHP can not adjust active power in a given heat load, while condensing CHP can adjust both active power and reactive power.
- Synchronous generator has potential advantage to improve distribution efficiency rather than induction generator. However, this potential advantage is achieved only if appropriate reactive power control scheme is used. The distribution losses in A1 and A2 are lower than B1 and B2, respectively. This fact illustrates that distribution efficiency can be improved if induction generator is replaced by synchronous generator with voltage control mode. While fixed power factor mode is not able to reduce distribution loss. For example, distribution losses of C1-C5 are higher than loss of B2.
- Distribution loss varies with power factor set point and load level. Take Case C for example, in Table IV, distribution loss increases scenario by scenario; while in Table V, C2 has a distribution loss lower than losses in C1, C3, C4 and C5.
- The enhancement of system flexibility can reduce total cost and distribution loss. This can be investigated from Case D. In D1, substation secondary side voltage is

variable and capacitors are fixed; it has lower cost and distribution loss than those in A2, B2 and Case C, whose substation secondary side voltages and capacitors are fixed. In D2, SVC is employed to replace fixed capacitors; the cost and distribution loss in D2 are even lower than those in D1.

#### IV. CONCLUSION

This paper proposed an OPF based dispatch model for distribution systems with independent DGs. This model aims to allocate DG outputs according to electricity price signals, load forecasting, and weather forecasting, while take into account operation and security constraints.

Cases are studied to verify the impact of technical factors, such as steam turbine types, generator types, reactive power control, AVR control, and compensator, on DisCo's cost and distribution losses. Back-pressure CHP can reduce DisCo's cost, however, it results in higher distribution losses due to lack of active power controllability. One feasible solution to reduce cost as well as enhance distribution efficiency is to improve system flexibility, such as using synchronous generator with voltage control mode, managing AVR actively, and installing SVC.

#### V. APPENDIX

TABLE VI  
PARAMETERS OF 33-BUS DISTRIBUTION SYSTEM

Branch				Load on sending end	
Sending end	Receiving end	r(pu)	x(pu)	P(MW)	Q(Mvar)
1	2	0.493	0.2511	0.1	0.06
1	18	0.164	0.1563	0.09	0.04
1	0	0.0992	0.047	0.12	0.08
2	3	0.366	0.1864	0.06	0.03
2	22	0.4512	0.3083	0.06	0.02
3	4	0.3881	0.1941	0.2	0.1
4	5	0.819	0.707	0.2	0.1
5	6	0.1872	0.6188	0.06	0.02
5	25	0.203	0.1034	0.06	0.02
6	7	0.7114	0.2351	0.045	0.03
7	8	1.03	0.74	0.06	0.035
8	9	1.044	0.74	0.06	0.035
9	10	0.1966	0.065	0.12	0.08
10	11	0.3744	0.1238	0.06	0.01
11	12	1.468	1.155	0.06	0.02
12	13	0.5416	0.7129	0.06	0.02
13	14	0.591	0.526	0.09	0.04
14	15	0.7463	0.545	0.09	0.04
15	16	1.289	1.721	0.09	0.04
16	17	0.732	0.574	0.09	0.04
18	19	1.5042	1.3554	0.09	0.04
19	20	0.4095	0.4784	0.09	0.05
20	21	0.7089	0.9373	0.42	0.2
22	23	0.898	0.7091	0.42	0.2
23	24	0.896	0.7011	0.06	0.025
25	26	0.2842	0.1447	0.06	0.025
26	27	1.059	0.9337	0.06	0.02
27	28	0.8042	0.7006	0.12	0.07
28	29	0.5075	0.2585	0.2	0.6
29	30	0.9744	0.963	0.06	0.04
30	31	0.3105	0.3619	0.21	0.1
31	32	0.341	0.5302	0.06	0.04
Fixed capacitor on bus9		2.25Mvar			
Fixed capacitor on bus32		0.4Mvar			

SVC on bus9	[-4.5Mvar, 4.5Mvar]
SVC on bus32	[-0.8Mvar, 0.8Mvar]
Base Voltage	10kV
Base Capacity	100MA

TABLE VII  
PARAMETERS OF DG3

	DG1	DG2	DG3
Base Voltage(kV)	10	10	10
Base Capacity(MVA)	0.75	0.6	0.8
Synchronous generator	$x_s(\text{pu})$	1.536	
	$E'_q(p.u.)$	2.231	
Induction generator	$r_s(\text{pu})$	0.0241	-
	$x_s(\text{pu})$	0.139	-
	$r_r(\text{pu})$	0.22	-
	$x_r(\text{pu})$	0.351	-
	$x_m(\text{pu})$	9.1	-

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TABLE VIII  
SCENARIOS FOR CASE STUDY

Case	Scenario	DG1		DG2		DG3		CHP Technique@ Constraints	AVR@ Constraints	Compensator @Constraints
		Gen Type@ Constraints	Reactive power control@ Constraints	Gen Type@ Constraints	Reactive power control@ Constraints	Gen Type@ Constraints	Reactive power control@ Constraints			
A	A1	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	BP@(6)	FX@(12)	FC@(15)
	A2	Syn.@(9)	VC@(11)	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	CO@(7)	FX@(12)	FC@(15)
B	B1	Ind.@(9)	-	Ind.@(9)	-	Syn.@(8)	VC@(11)	BP@(6)	FX@(12)	FC@(15)
	B2	Ind.@(9)	-	Ind.@(9)	-	Syn.@(8)	VC@(11)	CO@(7)	FX@(12)	FC@(15)
C	C1	Syn.@(8)	PF@(10)@0.85Lag	Syn.@(8)	PF@(10)@0.85Lag	Syn.@(8)	PF@(10)@0.85Lag	CO@(7)	FX@(12)	FC@(15)
	C2	Syn.@(8)	PF@(10)@0.90Lag	Syn.@(8)	PF@(10)@0.90Lag	Syn.@(8)	PF@(10)@0.90Lag	CO@(7)	FX@(12)	FC@(15)
	C3	Syn.@(8)	PF@(10)@0.95Lag	Syn.@(8)	PF@(10)@0.95Lag	Syn.@(8)	PF@(10)@0.95Lag	CO@(7)	FX@(12)	FC@(15)
	C4	Syn.@(8)	PF@(10)@1.0	Syn.@(8)	PF@(10)@1.0	Syn.@(8)	PF@(10)@1.0	CO@(7)	FX@(12)	FC@(15)
	C5	Syn.@(8)	PF@(10)@0.95Lead	Syn.@(8)	PF@(10)@0.95Lead	Syn.@(8)	PF@(10)@0.95Lead	CO@(7)	FX@(12)	FC@(15)
D	D1	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	CO@(7)	AM@(13)	FC@(15)
	D2	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	Syn.@(8)	VC@(11)	CO@(7)	AM@(13)	SVC@(16)

Syn.: synchronous generator; Ind.: induction generator; VC: voltage control mode; PF: power factor control mode; BP: back-pressure CHP; CO: condensing CHP; FX: fixed substation secondary side voltage; AM: active management; FC: fixed capacitors;

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