RESEARCH ARTICLE | MAY 31 2023

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AIP Conf. Proc. 2752, 080013 (2023)
https://doi.org/10.1063/5.0137787

Application of Algorithm Based Unit Commitment Optimization for N-1 Transmission Contingency with Nano-Photovoltaic Generation

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Abstract.A power system contingency causes disruption in power supply due to failure or loss of one or more components. The aim of the power system operators is to ensure the availability of electricity to consumers despite any unplanned disturbances or outages. The n-1 transmission contingencies include transmission line contingencies as well as generator outages.
Unit Commitment (UC) is performed before the actual dispatch of electrical power considering all generators to be functional. In the event of any n-1 generator contingency, the UC costs will also be altered, however, there will be little or no impact due to line contingencies. Distributed Generation (DG) in the form of solar power plants gathered momentum in the past few decades. However, the penetration of electronic waste forced further research in utilizing the organic as well as inorganic nano-materials for manufacturing Nano-Photovoltaics (NPv) to produce electrical energy from sunlight.
In this paper, the effects of (n-1) transmission contingencies and NPv plants are analysed on the UC costs when UC is determined by the modified Dynamic Programming (DP) technique. The analysis is performed on the modified 24-bus, 26-generator and 38-line IEEE Reliability Test System (RTS).

Keywords : Unit Commitment, n-1 generator contingency, contingency analysis, Nano-Photovoltaics, IEEE RTS, Distributed Generation.

INTRODUCTION

Contingency Analysis is the study of implementing the outage of transmission lines and generators, either individually or simultaneously. When the outage of a single entity is performed at one time, it is termed as n-1 contingency. If two entities are considered to be out at the same time, it is known as n-2 contingency. This is also termed simultaneous outage. Similarly for ‘k’ outages, the contingency is referred to as n-k contingency.
Unit Commitment is the process of finding the sequence in which the generators in a power system network can be turned on or off correspondingly. If a generator failure occurs, the supply disruption may take place to some loads. In order to ensure that it doesn’t happen, we analyze the n-1 generator contingencies, sort out the severe ones and take appropriate measures to avoid that from happening. But if a generator fails, it may incur some extra costs in

Emerging Technologies; Micro to Nano: Proceedings of ETMN-2021
AIP Conf. Proc. 2752, 080013-1–080013-9; https://doi.org/10.1063/5.0137787
Published by AIP Publishing. 978-0-7354-4508-6/$30.00

unit commitment as well as energy dispatch. Thus, the need arises for the analysis of n-1 generator contingency based unit commitment, which is proposed in this paper.

UC has been performed with the addition of many constraints in the past. The scheduling of generating units may be pre-determined for the upcoming day, week or month depending on the availability of forecasted demand data. The day ahead UC using Dynamic Programming (DP) technique is suggested in [1,2]. The reliability estimation with solar energy integration can also be done [1]. Stochastic UC with DG uncertainty and n-1 contingency is explored in [3]. The large scale maintenance can also be clubbed with UC through a decentralized method [4]. With the gradual developments in restructuring of power system, Demand Response Programs (DRPs) have gained momentum. The system flexibility becomes important in the presence of DRPs, which is analyzed in [5] for Security Constrained UC (SCUC). Though there are many techniques for solving UC but recently DP and Mixed Integer Linear Programming (MILP) are explored. A comparison of these two techniques is done in [6]. Contingency Analysis (CA) also holds its significance with UC, which is analyzed in [7,8,9].
IEEE RTS was proposed by the IEEE committee in 1979 [10] so that the researchers across the globe can have a standard system for simulating the various analyses. Many data is already specified for this system. Over the years, much more data is incorporated into the base system with the previous data[11,12,13].
With the depletion of fossil fuels and increase in global warming, the environment friendly energy sources are focused on. Solar energy harnessing gained widespread implementation on a large scale but the electronic waste accumulation has forced the research on organic or inorganic NPv. Research on NPv is under process in MIT [14]. Perovskite Nanoparticles form an ingredient of NPv and are being studied in detail for the same [15]. The nano and micro structuring of elements for improving the efficiency of NPv is also explored in [16]. The growth and progress of Perovskite for implementation of solar photovoltaics till the year 2020-2021 is highlighted in [17]. A summary of the nanomaterials being utilized for the manufacture of NPv is reviewed in [18].

The paper is organized as follows.
The objective function of UC with its necessary constraints are mentioned in Section II. The procedure for determining the contingency based UC in the presence of NPvs is described in Section III. The description of the IEEE RTS is briefed in Section IV. All the related relevant results of UC taking all the constraints and conditions, are compiled, compared and analyzed in Section V. Conclusion and the extent of the further work that can be done, are put forward in the next Section followed by references.

PROBLEM FORMULATION

UC is performed to find out the minimum cost schedule of turning ‘on’ or ‘off’ of generators in each time period, based on certain constraints.
The objective function of cost of UC is given by eq. (1)

$$C_{UC,G} = \sum_{i=1}^{n}\sum_{t=1}^{T} F_i^t(P_{i,t}) + M_i^t(P_{i,t}) + StC_i^t + SdC_i^t\,] \tag{1}$$

The various constraints accounted for are mentioned below from eq. (2) to (8)
i) Generator Fuel Cost,

$$F_i^t(P_{i,t}) = (\alpha_i P_{i,t}^2 + \beta_i P_{i,t} + \gamma_i) \tag{2}$$

ii)Maintenance cost is the sum of Base and Incremental cost,

$$M_i^t(P_{i,t}) = M_{B,i}^t + M_{I,i}^t(P_{it}) \tag{3}$$

iii) Turbine Start-up cost $StC_{T,i}^t$, Boiler Start-up cost $StC_{B,i}^t$ and Maintenance Start-up cost $StC_{M,i}^t$ form the start up cost StC_i^t

$$StC_i^t = StC_{T,i}^t + \{1 - e^{Hd,i/Bc,i}\} StC_{B,i}^t + StC_{M,i}^t \tag{4}$$

where, $H_{d,i}$ = Number of hours a unit is down,

$B_{c,i}$ = Boiler Cool Down Coefficient

iv) Shut Down Cost SdC_i^t is the cost of shutting down a unit

$$SdC_i^t = K.P_{i,t} \tag{5}$$

where, K = Incremental shut down cost

v) Minimum up time, $t_{\min,i}^{up}$

vi) Minimum down time $t_{\min,i}^{dn}$

vii) Active power limits on generators

$$P_i^{\min} \le P_i^t \le P_i^{\max} \tag{6}$$

viii) Ramp rate

$$\nabla P_i^t \le \nabla P_i^{\max} \tag{7}$$

ix) Generation demand balance

$$\sum_{i=1}^{n} u_i^t P_i^t = D_f^t + losses \tag{8}$$

x) Must run Units

xi) Must out Units

xii) Spinning Reserve

xiii) Limited staff

TECHNIQUE FOR DETERMINING N-1 CONTINGENCY BASED UC IN PRESENCE OF NPV

An introduction to Forward Dynamic Programming (FDP) technique for solving UC with its objective function can be found in [1,2]. In this paper, Modified FDP is used for determining the optimal solution of UC. The effect on n-1 transmission contingencies (transmission-line as well as generator contingencies) is analyzed. The economy of UC is judged for n-1 generator contingencies. The block diagram representation for the applied technique is shown in Fig.1.

Pre contingency analysis without and with Distributed Generation

The contingency based UC requires the pre contingency data for the following two conditions:

i) UC is first performed on the IEEE RTS at full load without taking DG into consideration. The pre-contingency UC costs without DG are determined.

ii) Then DG in the form of solar plants are considered and UC is again simulated on the system at full load. The pre-contingency UC costs with DG are calculated.

These two costs form the basis of comparison.

Performing n-1 contingency on the system without and with Distributed Generation

The n-1 transmission contingency based UC analysis involves the following steps, as explained below:

Step I: First perform the n-1 contingency analysis without connecting DG in the system

i) Create line outage, one by one. For each line contingency, run the load flow and identify weak buses and overloaded lines.

ii) Create generator outage, one by one. For each generator contingency, run the load flow and identify weak buses.

iii) Rank the weak buses based on the p.u. magnitude of voltage. These buses form the location at which DGs are then connected.

Step II: Connect DG in the system and perform the n-1 contingency analysis again

i) Connect DGs on the identified weak buses.
ii) Create line contingency and identify weak buses and overloaded lines
iii) Create generator contingency and again identify weak buses.

Compilation of n-1 generator contingency based UC report and it's analysis

UC is performed on modified IEEE RTS using modified Forward Dynamic Programing technique. The results of the analysis described in the Steps I and II of the previous section III (B) are compiled and analyzed.
The pre-contingency UC costs are compared with the costs after n-1 contingency analysis, for the following two cases:

i) Without DG
ii)With DG

The results are then compared and the contribution of the DG in improving the bus voltage as well as line overloading is observed. The following are determined from the analysis:

i) Weak bus identification for the n-1 line contingency and n-1 generator contingency, based on the magnitude of voltage of bus, b for contingency k, V_b^k

$$0.95 \leq V_b^k \leq 1.05 p.u. \tag{9}$$

ii) Overloaded line(s) for contingency k are found out by determining the flow of active power P_L^k and reactive power Q_L^k on line L. These should be within the minimum and maximum thermal limits of line

$$P_{L,th}^{\min} \leq P_L^k \leq P_{L,th}^{\max} \tag{10a}$$

$$Q_{L,th}^{\min} \leq Q_L^k \leq Q_{L,th}^{\max} \tag{10b}$$

Distributed Generation (DG)

The DG in the form of solar power plants, is considered. The environmental concerns have led to the emergence of NPv whose efficiency is estimated to be about 20% [14-18]. Further research is being performed to increase efficiency of organic as well as inorganic NPv [16]. In this paper NPv are considered for solar energy based DG. A penetration of about 25% DG is considered, taking into account the large scale construction and installation of solar power plants worldwide. That means the capacity of solar plants is twenty-five percent of the total installed capacity of IEEE RTS. The average efficiency of total solar generation is assumed to be 20%.

Technique for determining UC - Modified Forward Dynamic Programming (FDP)

The details of the FDP technique can be found in [1,2]. Modified FDP is considered in this paper, which can be summarized by means of following expression

$$C_{UC,G}(p) = [C_n(h) + C_{n-1}(p-\lambda_1.h) + C_{n-2}(p-\lambda_2.h) + ...+ C_1(p-\lambda_{n-1}.h)] \tag{11}$$

where,

$C_{UC,G}(p)$ = UC cost of distributing p MW load on *n* generating units

h = MW generated by unit '*n*'

$C_n(h)$ = UC cost of 'h' MW delivered by n^{th} generator

$C_{n-1}(p-\lambda_1 h)$ = UC cost of $(p-\lambda_1 h)$ MW delivered by the $(n\text{-}1)^{th}$ generator.

$\lambda_1, \lambda_2 .... \lambda_{n-1}$ = weights designed for the n-1 generators such that the following condition is obeyed

$$P_i^{\min} \le (p-\lambda_j h) \le P_i^{\max} \qquad (12)$$

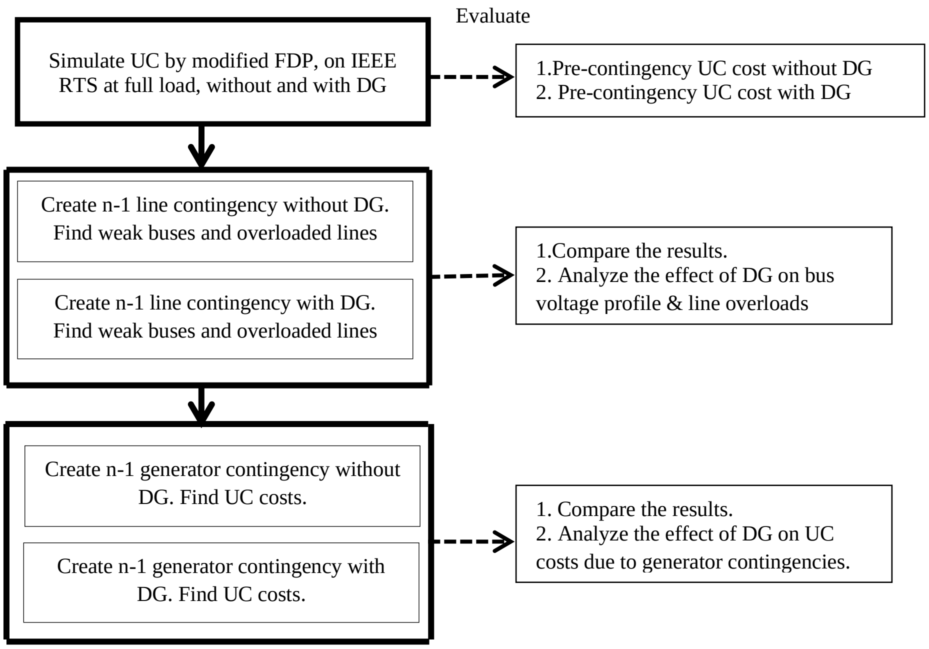

FIGURE 1. Block diagram of n-1 generator contingency based UC

CASE STUDY – SYSTEM DESCRIPTION

In this paper, modified 24-bus, 26-generator IEEE Reliability Test System (RTS) [10-13] is considered for performing n-1 generator contingency based UC. The RTS was prepared by the Reliability Test System Task Force of the Application of Probability Methods Subcommittee, in 1979 [10]. The objective was to provide the researchers with a system that could be used as a reference for performing reliability analysis of generation/transmission sectors. The system was extended by the IEEE Power System Engineering Committee of the IEEE Power Engineering Society, and the same was published in 1986 [10].

The task force committee suggested a multi-area RTS in 1996 [11]. Some data was kept the same but few details were added into the base system of IEEE RTS. In the generation sector the data added was- Unit start-up (hot and cold start) heat input, net plant incremental heat rates, unit cycling restrictions & ramping rates and unit emissions. It was done for the analysis of production cost and emissions. The transmission sector was enhanced by addition of a phase shifter, a two terminal DC transmission line, and five inter-area ties. Substation data was also added.

Another update for the system was proposed in 2019 [12], where several nuclear & oil generating units were removed and others with energy storage were added. Reserve requirements and multi-period generation scheduling data was also included. To incorporate these, the system was assigned a geographic location in the southwestern United States.

Despite the amendments in the base system, the researchers are encouraged to make the assumptions necessary for the undefined parameters, or to modify the parameters as per the analysis requirements. In this paper, the modified IEEE RTS is considered for analysis. The Single line diagram of the same is shown in Fig.2.

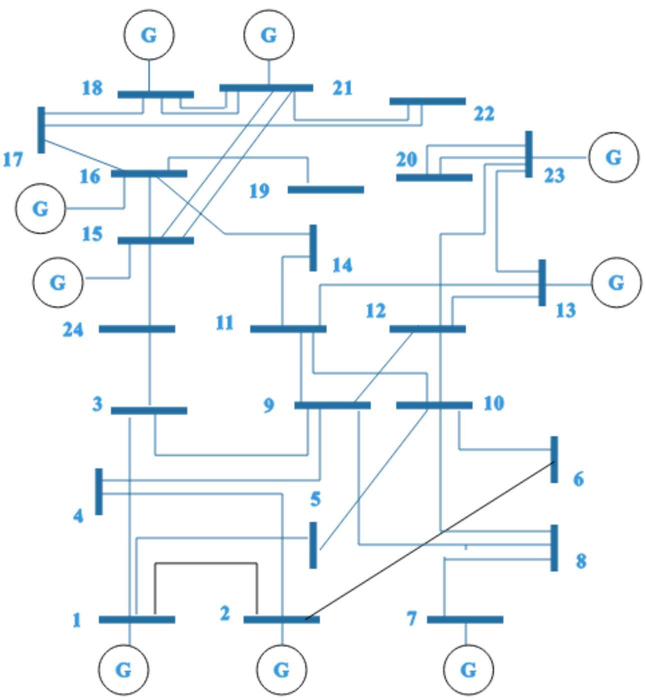

FIGURE 2. Single Line Diagram of modified IEEE RTS

RESULTS AND DISCUSSION

Compilation of Results

After compiling the severe n-1 generator contingencies, the unit commitment program is simulated with the outage of the generator corresponding to each severe contingency. To estimate the increase in costs (if any) for each n-1 generator contingency, the pre contingency UC costs are compared with these costs.

TABLE 1. Analysis of Overloaded Lines and Weak Buses for n-1 line contingences, without DG

Line contingency	Overloaded Lines	Weak Bus No.	Bus Voltage	Rank (bus)
6-10	10-8, 10-5, 10-11, 10-12, 6-2	3	0.93	2
		4	0.94	
		6	0.77	
9-11	9-12, 9-3, 9-4, 9-8, 11-13, 11-14	3	0.93	4
14-16	14-11, 16-15, 16-17, 16-19	24	0.93	3
		3	0.94	
15-24	24-3, 3-1, 3-9, 15-16, 15-21	24	0.88	1
		3	0.88	

Table 1 lists the severe line contingencies in column 1 for UC performed on IEEE RTS without DG in the system. The overloaded lines due to the contingency are compiled in column 2. The altered bus voltages of weak buses are listed in column 4. Based on the drop in voltage level, the rank of the weak bus is assigned. The bus with highest voltage drop is assigned rank 1 and the remaining buses are assigned higher ranks as the voltage drop decreases.

TABLE 2. Analysis of Overloaded Lines and Weak Buses for n-1 line contingences, with DG

Line contingency	Overloaded Lines	Weak Bus No.	Bus Voltage	Rank (bus)
6-10	10-8, 10-5, 10-11, 10-12, 6-2	6,3	0.86	1
		3	0.93	
15-24	24-3, 3-1, 3-9, 15-16, 15-21	24	0.92	2

Table 2 identifies the overloaded line and weak buses for N-1 line contingency with consideration of DG. DG with a capacity of 25% of the total generation capacity of IEEE RTS is considered. The total generation capacity of the 26-generator, 24-bus, 38-line system is 3105 MW. The solar generation of 776 MW capacity is to be added i.e. twenty-five percent of 3105 MW. Assuming an average yearly efficiency of 20% for the solar NPv plants, the maximum generation in MW would be around 155. The weak buses are identified from the data in Table 1 and the DG is applied on these identified buses in the system i.e. bus numbers 3,4,6 and 24. The NPv DG is considered on the four identified buses simultaneously and an equal capacity of 38 MW is implemented on each one of them.

TABLE 3. UC costs for n-1 generator contingencies, without DG

Bus No.	Capacity of Generator out (MW)	Post contingency cost, UC_k ($)	Pre contingency cost, UC_p ($)	Percentage increase in cost (%)	Contingency Rank (Economy)
1	20	773865	706404	9.5	8
2	76	779482	706404	10.3	5
7	100	775794	706404	9.8	6
13	197	799872	706404	13.2	3
15	12	774763	706404	9.7	7
18	400	Not Possible	706404	-	1
21	400	Not Possible	706404	-	1
23	155	797762	706404	12.9	4
23	350	Not Possible	706404	-	2

TABLE 4. UC costs for n-1 Generator Contingencies, with DG

Bus No.	Capacity of Generator out (MW)	Post contingency cost, $UC_{k,DG}$($)	Pre contingency cost $UC_{p,DG}$($)	Percentage increase in cost (%)	Contingency Rank (Economy)
1	20	709933	709933	0	5
2	76	712276	709933	0.3	4
7	100	707184	709933	-0.4	7
13	197	702858	709933	-0.9	8
15	12	709857	709933	-0.01	6
18	400	UC not possible	709933	-	1
21	400	UC not possible	709933	-	1
23	155	722711	709933	1.8	3
23	350	UC not possible	709933	-	2

Table 3 lists the pre and post contingency UC costs for each generator contingency, when DG is not considered into the system. Column 1 lists the bus number at which the generator outage is considered. The capacity of the generator is mentioned in column 2. The post and pre contingency cost of UC are listed in column 3 and 4. The percentage increase in cost from pre contingency to post contingency is compiled in column 5. The last column mentions the rank of contingency based on the increase in cost.

Table 4 compiles the pre and post contingency UC costs for each generator contingency, when DG is considered into the system.

Analysis of Results

The results obtained can be judged and analyzed by means of the data in Table 1 to 4. The analyses can be derived for the two following cases, without and with DG:

N-1 Transmission line contingency

The n-1 line contingency will not cause any modification on the UC schedule since UC is evaluated on the generator end. Thus effect of all individual n-1 line contingencies is analyzed on the bus voltage profile and line overloading. The contingencies distorting bus voltage or causing line overloads are mentioned in Table 1 and 1. It can be seen that with DG, the number of under-voltage buses reduce, as well as number of overloaded lines decrease.

N-1 generator contingency

The generator contingencies are analyzed on buses 1, 2, 7, 13, 15, 18, 21, and 23, since the outage of these generators create significant change in UC schedule and its associated costs. The outage of the corresponding generators, with their capacities are listed in column 1, 2 of Table 3 and 4.
It can be seen that the pre contingency cost of UC is quite low i.e. without any generator outage the system runs smoothly. It can be seen that the post contingency costs are quite high, for the high capacity generators. For the generators of 300 MW and 450 MW, their outage leads to the system fallout and the UC schedule can't be determined, for both the cases – without and with DG.
The rank of contingency is decided based on the economic results. A rank of 1 thus corresponds to the most expensive/uneconomic contingency and a rank of 8 shows the comparative least cost option. While including DG the economy improves, compared to the case when DG is not included.

CONCLUSION

The n-1 contingencies can be either line contingencies or generator contingencies. Both hold a significant contribution to the analysis of system security and UC costs. The n-1 line contingencies do not have any effect on UC schedules and UC costs, but they have impact on bus voltages and line overloads. The effect of contingencies is recorded and the weakest bus in the system can be identified by the rank of the bus (listed in the last column of Tables 1 and 2). When DG is not connected the weak buses and overloaded lines are more, but the implementation of DG reduces the number of weak buses and overloaded lines.
The n-1 generator contingencies increase the cost of UC and modify the schedule of generation. This will increase the cost of dispatch too.The increase in cost of UC due to generator contingencies in the system are identified from Tables 3 and 4. When DG is not connected, the increase in UC cost is more, but the application of DG reduces the UC costs during contingencies.
Thus the utilization of DG is helpful for improving system bus voltage profile, reducing the overloaded lines and reducing the UC costs during n-1 contingencies. Also the application of modified FDP technique gives the UC solution in less amount of time.

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