Journal of Interdisciplinary and Multidisciplinary Research (JIMR)
E-ISSN:1936-6264| Impact Factor: 8.886| UGC CARE II
Vol. 19 Issue 06, June- 2024
Available online at: https://www.jimrjournal.com/
(An open access scholarly, peer-reviewed, interdisciplinary, monthly, and fully refereed journal.)

ATC IMPROVEMENT: AN INVESTIGATION OF TRANSMISSION CONGESTION DISTRIBUTION FACTORS

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ABSTRACT

In this research work, a novel sensitivity-based factor (ATCDF) employing TCDF data is introduced. ATCDF values are utilized to determine the best position for the producing source in order to maximize the system's ATC value. TCDF values are used to create clusters/zones under line outage contingency scenarios. ATCDF values are produced by averaging the TCDF values acquired for different congested lines during single line outage situations. The incorporation of WPG acquired from the ATCDF value results in an increased value of ATC. ATC is determined using the DCPTDF and ACPTDF algorithms. The values are compared in order to produce more accurate ATC values using the ACPTDF approach. The findings are compared to demonstrate the efficacy of the suggested technique.
Keywords: ATCDF, ATC, congestion distribution factors, WPG etc.

INTRODUCTION

In deregulated power networks, available transfer capacity (ATC) is critical to power transactions and commercial activity. ATC for power systems refers to the transfer capacity available in the physical transmission network for further commercial activity beyond what has already been committed. Power system deregulation involves creating a competitive electricity market that encourages the use of alternative energy sources such as wind, small hydro, solar, and so on. Wind energy is the fastest-growing renewable energy source since it is both clean and abundant in nature. The wind power infusion might increase the ATC value of the deals.

[1] highlights the state-of-the-art ATC calculating work done by many scholars. The repeated alternating current power flow (RACPF) technique to calculating ATC has been presented. [2] takes into account inter-area line and generator outage situations for contingency analysis. Reference [3] examines the short- and medium-term dependability of increased wind power penetration. [4] describes an analytical technique for reliably simulating huge WFs. Rarely has study been conducted on the ATC model and its computation in the presence of power system-connected WTs. An effective technique of calculating ATC for power systems that use WPG should be developed [5]. A lot of study has been conducted on the ATC model and computation to alleviate congestion. A brief examination of an optimization technique, ATC calculation, and CM is described in [6].

In this paper, a novel average TCDF value (ATCDF) is suggested to determine the best position for WPG integration in a zone. Before that, the zones are created with TCDF values by causing a line outage, and the ATCDF values are determined. The suggested work enhances the ATC. To locate an appropriate position for WPG integration, no optimization strategy was utilized to minimize calculation time and system simulation complexity. To the best of our knowledge, no research has been conducted on the appropriate position of WPG for ATC improvement.

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CALCULATION OF ATC

In an open-access electricity market, transactions may be classified into two types: bilateral and multilateral. A bilateral transaction occurs when there is just one seller and one buyer, whereas a multilateral transaction involves several sellers and buyers. ATC may be estimated using a variety of methodologies, including the DC power flow approach, the sensitivity-based approach, the integration of FACT devices, the optimal power-based approach, and so on [7] [8]. The literature describes two fundamental power transfer distribution factor approaches for calculating ATC: the DCPTDF method and the ACPTDF method.

ATC CALCULATION USING DCPTDF

The power transfer distribution factor is calculated using DC load flow [9], and the real power flow between lines connected between bus-a and bus-b is given by Equation (1). However, the DCPTDF method does not produce better results than the ACPTDF method due to the calculation assumptions.

$$P_{ab} = \frac{1}{x_{ab}} (\theta_a - \theta_b) \quad (1)$$

Where P_ab represents the real power flow from a transmission line, and are the voltage angles at buses, respectively. Equation (2) calculates 〚DCPTDF〛_(ab,sd), which is the ratio of power transactions between buses to changes in power flow in the connected line.

$$DCPTDF_{ab,sd} = \frac{X_{ac} - X_{bc} + X_{bd}}{x_{ab}} = \left(\frac{\Delta P_{ab}^{New}}{P_{cd}^{New}}\right) \quad (2)$$

where X_ac represents the reactance of the line between, and X_bc represents an item in the reactance matrix X. Equation (3) calculates the change in real power resulting from new transactions.

$$\Delta P_{ab}^{New} = DCPTFab,sd * P_{cb}^{New} \quad (3)$$

where ΔP_{ab}^{New} represents the change in the real power flow between line connected between buses a and b, linked with new transaction P_{cb}^{New}.

ATC CALCULATION USING ACPTDF

The ACPTDF is employed when a transaction occurs between seller bus-c and buyer bus-d [10]. If MW represents the active power change in the transmission line connecting bus-a and bus-b. The ACPTDF is then calculated using Equation 4.

$$ACPTDF_{ab,cd} = \frac{\Delta_{qu\,1} MW}{\Delta tr_{cd} MW} (4)$$

where ∆_qu1 MW represents the change in transmission line quantity from bus a to bus b or bus b to bus a. Higher 〚ACPTDF〛_(ab,cd) values indicate lower ATC values for that system line. This indicates that the line is reaching its predetermined boundary. This increased ACPTDF number also implies that if power flow continues to grow, the line will become crowded.

ACPTDF is calculated for the base case using the Newton Raphson load flow for the seller-buyer transaction. Equations (5) and (6) describe the change in active power as a function of the state variable.

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$$\frac{\partial P_{ab}}{\partial U_k} = \begin{Bmatrix} 0 & ; k \neq a,\ b \\ 2U_a Y_{ab} \cos(\theta_{ab}) - U_b Y_{ab}\ \cos(\delta_a - \delta_b - \theta_{ab}) & ; k = a \\ -U_a Y_{ab}\ \cos(\delta_a - \delta_b - \theta_{ab}) & ; k = b \end{Bmatrix} \quad (5)$$

$$\frac{\partial P_{ab}}{\partial \delta_k} = \begin{Bmatrix} 0 & ; k \neq a,\ b \\ U_a U_b Y_{ab}\ \sin(\delta_a - \delta_b - \theta_{ab}) & ; k = a \\ -U_a U_b Y_{ab}\ \sin(\delta_a - \delta_b - \theta_{ab}) & ; k = b \end{Bmatrix} \quad (6)$$

$$\Delta P_b = +\Delta tr_{cd}\, MW \quad (7)$$

$$\Delta P_b = -\Delta tr_{cd}\, MW \quad (8)$$

Where are the Δ⟦tr⟧_cd seller bus transaction and -Δ⟦tr⟧_cd MW?illustrates the buyer-bus transaction described by Equations (7) and (8). The ACPTDF technique is used to compute ATC in the basic situation, between buses C and D. Equation (9) depicts the ATC calculation formula for the transmission line. The heat burden on the line is used as a limit criteria. The lowest value determines the limit point and provides the desired ATC value for the critical line defined by Equation (10).

$$T_{ab,cd} = \begin{Bmatrix} \dfrac{(P_{ab}^{max} - P_{ab}^{0})}{ACPTDF_{ab,cd}}; & ACPTDF_{ab,cd} > 0 \\ \propto (Infinite); & ACPTDF_{ab,cd} = 0 \\ \dfrac{(-P_{ab}^{max} - P_{ab}^{0})}{ACPTDF_{ab,cd}}; & ACPTDF_{ab,cd} < 0 \end{Bmatrix} \quad (9)$$

$$ATC_{cd} = mi\{T_{ab,cd}\};\ \text{ab} \in N_L \quad (10)$$

T_(ab,cd) is the transfer power value of each line throughout the transaction; P_ab^max is the loading limit of the line between buses a and b; and P_ab^0 is the base case power flow between buses a and b. ⟦ACPTDF⟧_(ab,cd) is the AC power transfer distribution factor; ⟦ATC⟧_cd is the available transfer capability in MW for lines that exceed the restrictions; and N_L is the total number of lines.

PROPOSED METHODOLOGY

In this part, numerical analysis of various strategies and techniques for ATC augmentation is carried out. It aids in understanding the change in ATC values before and after CM.

ZONES/CLUSTERS CONCEPT USING THE AVERAGE TCDF VALUES

TCDF represents the active power change (⟦ΔP⟧_mn) in line-k that connects bus-m and bus-n owing to a unit change in active power injection at bus-m (⟦ΔP⟧_mn). The TCDF values are calculated using the Jacobian matrix of Newton Raphson load flow. uses two methods: DC load flow and AC load flow. In this chapter, the AC load flow technique is utilized to determine the TCDF values for the congested line, resulting in the zones defined by Equation 11.

$$TCDF_m^k = \frac{\Delta P}{\Delta P_m} \quad (11)$$

TCDF values are used to identify a group of buses that provide a comparable effect under any crowded circumstance. These TCDF values are used to establish the zones, with the most sensitive zone (zone 1) having the highest and uneven TCDF values. The less sensitive zones (zone 2 and higher order) are generated with tiny and comparable TCDF values. Thus, any transaction or problem in zone 1 has the greatest impact on line power flow. Power changes in zones 2, 3, and above will have little effect on line flow. TCDF values are calculated for each congested line, and zones are formed based on these values. The TCDF values vary for different crowded lines, resulting in distinct zones for each. As a result, a superposition of these zones is utilized to depict the cumulative effect of crowded routes. The important observations are as follows:

- Buses on a crowded line have the same TCDF value, but opposite sign.
- Some buses have positive TCDF values while others have negative ones.
- Injecting power to a positive TCDF value bus reduces the ATC value, whereas injecting power to a negative TCDF value bus raises it.
- To enhance ATC, incorporate the power source into the bus with the largest negative TCDF value.

Because certain buses in a zone have positive TCDF values for one crowded condition but negative TCDF values for the second congested condition, it is difficult to determine the best position of WPG for ATC enhancement. It is possible that a single line loss scenario causes N number of lines to become congested, resulting in numerous congestions.In this situation, zones may be created for each congested line based on TCDF data. The ATCDF is introduced in this paper to discover the ideal bus placement for WPG integration, as indicated by Equation (12). The absolute average value of TCDF is utilized to compute the ATCDF value. The greatest ATCDF value will provide the ideal position of the WPG for ATC.

$$ATCDF = \frac{TCDF_1 + TCDF_2 + \cdots TCDF_N}{N} \quad (12)$$

It is apparent that integrating WPG will increase the ATC value if positioned properly. The ATCDF value identifies the ideal bus position for integrating WPG, resulting in higher ATC value compared to alternative places. alternative purposes recommend alternative bus sites for WPG hookup. The major goal of this chapter is to pick the appropriate bus for ATC augmentation in the limiting lines. The ACPTDF technique was studied for ATC computation. The ACPTDF approach is simple, rapid, non-iterative, and takes less time to compute, hence it is used in this study. The steps for calculating ATC are as follows.

- Calculate Newton Raphson load flow based on base case
- Outage line for TCDF calculation and zone construction
- Calculate ATCDF for different buses in zones
- Choose ideal placement based on highest ATCDF values for greatest ATC value in limiting line.
- Wind power integration on transmission bus based on ATCDF value
- ATC calculation using ACPTDF method with WPG integration
- Comparison of ATC value results obtained from integrating WPG at different buses

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- Optimal location provides maximum ATC enhancement compared to other locations for the same data input.

Several tactics and procedures are utilized to improve ATC. In this comparison analysis, only the literatures that demonstrate the improvement of ATC in IEEE 30-bus are evaluated, as shown in Table 1.

TABLE 1 COMPARISON OF ATC ENHANCEMENT METHODS AND TECHNOLOGY USED FOR IEEE 30-BUS POWER SYSTEM

REF.	METHODS	TECHNOLOGY	ATC (MW)	
			BEFORE	AFTER
[11]	Sensitive based	Emergency DR	34.47	41.12
[12]	Implementing 5- TCSC	Hybrid grey wolf optimization and flower pollination algorithm (HGWFPA)	21.3	621
[13]	Implementing one static VAR compensator (SVC) and one TCSC	Hybrid mutation particle swarm optimization (HMPSO)	89.164	113.7
[14]	Optimal location and capacity of TCSC	Real genetic algorithm (RGA) associated with analytical hierarchy process (AHP) and fuzzy sets	215.52	291.55
[15]	TCSC, SVC, UPFC	PSO	24.821 (single area)	30.938
			92.613 (multi area)	96.371
[16]	Sensitive factor approach	OPF and FACT controller (SSSC, STATCOM and UPFC)	19.35	19.4832
[17]	Incorporation of SVC	Using Newton Raphson and ACPTDF formula	162.11	184.99
[18]	Parameter optimization of UPFC	Cuckoo search algorithm (CSA)	60.855	69.145
[19]	Non-iterative	Holomorphic embedding power flow (HEPF)	0.907	0.907 (less time)
[20]	Optimal location of TCSC	Least bus voltage magnitude and real	162.11	184.96

		power loss values		
[21]	Parameter optimization of IPFC	PSO	758.2363	781.2232
[22]	Voltage-stability constrained optimal power flow (VSC-OPF)	Weighted sum approach and PSO	1.4956	1.69
[23]	Optimal location of FACTS by SPCR	MEEPSO	DCPTDF	34.8% More
			ACPTDF	33.06% More

RESULTS AND DISCUSSION

The load flow analysis, ACPTDF, ATCDF, and ATC calculations are carried out on the example six-bus system and a modified IEEE 30-bus power system. The data are presented in Appendices C and D, respectively.

CALCULATIONS OF ACPTDF, TCDF AND ATC FOR 6-BUS SYSTEM

Three bilateral transactions, T1 (between buses 2 and 4), T2 (between buses 3 and 5), and T3 (between buses 3 and 6), are performed in a six-bus system to calculate the ATC values. Table 2 displays the computed ACPTDF value for transactions T1 through T3. The line with the greatest ACPTDF value is the limiting line, and it sets the system's ATC.

TABLE 2 ACPTDF AND MAXIMUM POWER TRANSFER LIMIT FOR DIFFERENT BILATERAL TRANSACTIONS

LineNo.	From	To	T1 (2-4)		T2 (3-5)		T3 (3-6)	
			$ACPTDF_{ab,24}$	$T_{ab,24}$ (MW)	$ACPTDF_{ab,35}$	$T_{ab,35}$ (MW)	$ACPTDF_{ab,36}$	$T_{ab,36}$ (MW)
1	1	2	-0.151	1070.12	0.074	2167.89	0.014	2537.34
2	1	4	0.202	84.79	0.021	8832.06	0.010	1661.60
3	1	5	-0.036	4662.09	0.113	281.04	0.003	8758.51
4	2	3	0.0419	1077.51	0.246	303.50	0.151	492.09
5	2	4	**0.703**	**44.23**	0.118	263.73	0.008	10660.38
6	2	5	0.073	518.75	0.175	217.09	0.003	21319.81
7	2	6	0.047	361.19	0.112	911.66	0.177	95.83
8	3	5	0.045	1054.39	0.357	119.53	0.121	392.65
9	3	6	-0.003	30240.25	**0.399**	**21.64**	**0.729**	**10.66**
10	4	5	-0.126	537.87	0.095	541.28	0.001	37638.05
11	5	6	-0.041	1611.32	0.248	267.53	0.119	448.96

Congestion arises due to outages on lines 1-5. The interruption of line 1-5 causes congestion on lines 1-2 and 1-4. Equation (11) is used to determine TCDF, and congestion clusters are generated depending on the resulting value. Table 3 depicts the congestion clusters for a six-bus system in the bilateral transaction T1 instance.

TABLE 3 CONGESTION CLUSTERS FOR LINE OUTAGE 1-5 IN 6-BUS SYSTEM

Congestion of Line 1-2				Congestion of Line 1-4			
Zone 1		Zone 2		Zone 1		Zone 2	
Bus	TCDF	Bus	TCDF	Bus	TCDF	Bus	TCDF
1	0.3398	4	-0.1233	1	0.3496	2	-0.1574
2	- 0.3398	5	-0.2497	4	-0.3496	3	-0.1997
3	-0.3468			5	-0.2543		
6	-0.3652			6	-0.2131		

Table 4 displays the ATC value for several transactions using the DCPTDF and ACPTDF algorithms under normal and contingency situations, respectively.

TABLE 4 ATC (MW) VALUE IN LIMITING LINE FOR SIX BUS SYSTEM

		ATC (Base Case)		ATC (Contingency Case)
TRANSACTIONS	LIMITING LINE	DCPTDF METHOD	ACPTDF METHOD	LINE OUTAGE (1-2)
T1	2-4	44.1241	44.2347	64.3561
T2	3-6	20.5456	21.6421	25.6188
T3	3-6	12.2457	10.6612	12.4182

PROPOSED ATCDF APPROACH FOR CLUSTERS/ZONES

The simulations are done using a modified IEEE 30 bus power system.

ACPTDF AND ATC DETERMINATION

The ATC calculation takes into account the bilateral changeover between buses 6 and 28. The ACPTDF technique is used to calculate the ATC. Table 5 shows that the lowest value of the transfer limit is the ATC value in the limiting line between buses 6 and 28. For bilateral transactions 6-28, the system's ATC value is 21.97 MW in normal operation.

TABLE 5 LINE FLOW, ACPTDF, AND TRANSFER LIMIT VALUE FOR BILATERAL TRANSACTION

LINES	FROM BUS	TO BUS	P_{ab}^{max}(MW)	P_{ab}^{0}(MW)	$ACPTDF_{ab,6\_28}$	$T_{ab,6\_28}$(MW)
1	1	2	130	118.14	0.0028	4187.06
2	1	3	130	58.36	0.0034	21112.51
3	2	4	65	34.52	0.0032	9507.39

4	3	4	130	54.55	0.0032	23309.93
5	2	5	130	63.18	-0.0002	867302.73
6	2	6	65	45.13	0.0015	13432.88
7	4	6	90	46.51	-0.0070	19461.18
8	5	7	70	-11.30	0.0003	246246.08
9	6	7	130	34.49	-0.0026	64193.37
10	6	8	32	10.29	0.1831	118.51
11	6	9	65	17.83	0.0159	2970.62
12	6	10	32	12.57	0.0090	2154.45
13	9	11	65	-12.24	-9.79E-05	538802.61
14	9	10	65	30.07	0.016	2158.86
15	4	12	65	33.93	0.014	2107.03
16	12	13	65	-12.00	-2.37E-05	2239626.65
17	12	14	32	8.22	0.0026	9103.35
18	12	15	32	18.67	0.0103	1289.14
19	12	16	32	7.82	0.0020	11603.38
20	14	15	16	1.94	0.0025	5554.73
21	16	17	16	4.24	0.0020	5822.84
22	15	18	16	6.45	-0.0006	34668.10
23	18	19	16	3.19	-0.0006	30265.00
24	19	20	32	-6.31	-0.0006	40798.70
25	10	20	32	8.59	0.0012	19502.93
26	10	17	32	4.80	-0.0008	44380.81
27	10	21	32	15.81	0.0175	924.16
28	10	22	32	7.63	0.0112	2169.20
29	21	22	32	-1.81	0.0157	2140.58
30	15	23	16	5.67	0.0131	782.38
31	22	24	16	5.77	0.0261	391.62
32	23	24	16	2.41	0.0130	1040.06
33	24	25	16	-0.58	0.0387	427.65
34	25	26	16	3.55	8.93E-06	1394858.94

35	25	27	16	-4.13	0.0388	518.18
36	28	27	65	17.44	-.0039	2110.14
37	27	29	16	6.19	3.49E-05	281397.19
38	27	30	16	7.09	4.42E-05	201467.38
39	29	30	16	3.70	1.02E-05	1205159.23
40	8	28	32	2.40	0.1911	154.87
41	6	28	32	15.05	0.77163	21.97

TCDF AND ATCDF CALCULATION

A line outage between buses 4 and 6 generates congestion on lines 1-2 and 2-6, resulting in a multi-congestion event. The TCDF values for crowded lines 1-2 and 2-6 are reported in Table 6. Figures 1 and 2 illustrate the clusters/zones for crowded lines 1-2 and 2-6, based on TCDF values.

The combined zones are established by superimposing the zones formed by congested lines 1-2 and 2-6. The primary goal is to identify the best bus site for WPG installation in order to maximize ATC improvement. The positive value of TCDF cannot be utilized for integration since it reduces the ATC value. The bus with a negative TCDF value is considered for the best bus site to integrate with WPG in both zones. In both crowded line scenarios, the ATCDF value is only evaluated if the TCDF has a negative sign. The opposite sign of the TCDF value in two distinct congested lines is likewise not evaluated for ATC purposes.

TABLE 6 ATCDF VALUES FOR DIFFERENT BUSES

LINE 4-6 OUTAGE TO CREATE CONGESTION IN THE SYSTEM			**TO SELECT A LOCATION IN ZONE**
BU NO.	**TCDF FOR LINE 1-2**	**TCDF FOR LINE 2-6**	**ATCDF= (|TCDF|+|TCDF|)/2**
1.	0.451429986	0.296316434	0.37387321
2.	-0.451429986	0.315348992	0.383389489
3.	-1.66E-05	0.237259465	0.118638029
4.	-0.104744465	0.223559259	0.164151862
5.	-0.488282239	0.008369509	0.248325874
6.	-0.449189506	-0.315348992	0.382269249
7.	-0.47042956	-0.188857727	0.329643643
8.	-0.45122861	-0.315997429	0.38361302
9.	-0.396918618	-0.229483984	0.313201301
10.	-0.368950413	-0.183540818	0.276245616
11.	-0.396918618	-0.229483984	0.313201301

12.	-0.215456835	0.039020258	0.127238547
13.	-0.215456835	0.039020258	0.127238547
14.	-0.24033903	0.012221665	0.126280347
15.	-0.264547546	-0.022038746	0.143293146
16.	-0.282762509	-0.054986438	0.168874474
17.	-0.345455706	-0.146100945	0.245778326
18.	-0.309954679	-0.082777762	0.19636622
19.	-0.33518787	-0.118732864	0.226960367
20.	-0.344515188	-0.135703598	0.240109393
21.	-0.371721733	-0.182162824	0.276942278
22.	-0.370380009	-0.180406785	0.275393397
23.	-0.306752867	-0.081007668	0.193880268
24.	-0.36055573	-0.160596736	0.260576233
25.	-0.400999436	-0.224260012	0.312629724
26.	-0.409754376	-0.22960663	0.319680503
27.	-0.420821989	-0.259916364	0.340369176
28.	-0.449158392	-0.311009852	0.380084122
29.	-0.441601268	-0.273167256	0.357384262
30.	-0.456843497	-0.282887185	0.369865341

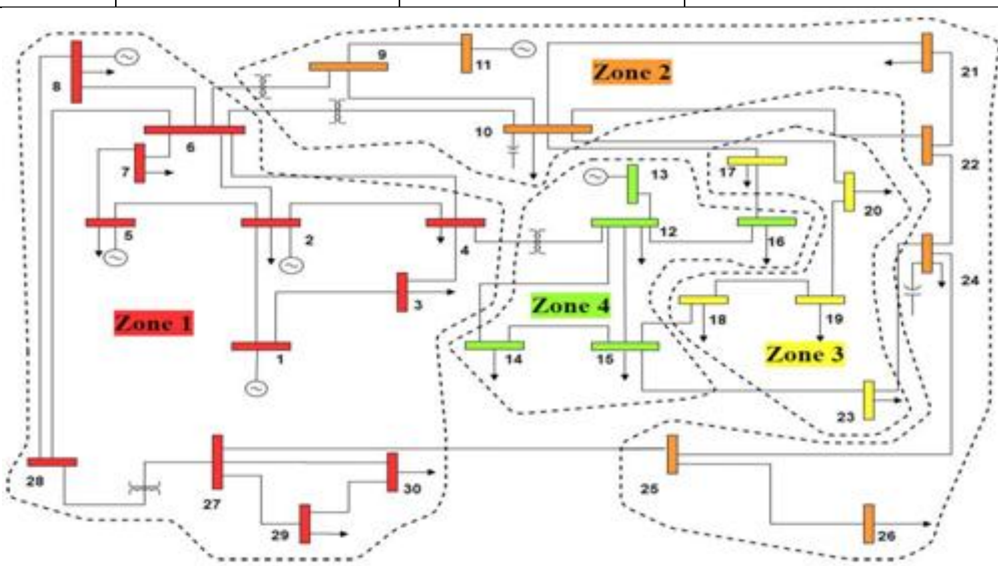

FIGURE 1 CLUSTERS/ZONES FOR CONGESTED LINE 1-2

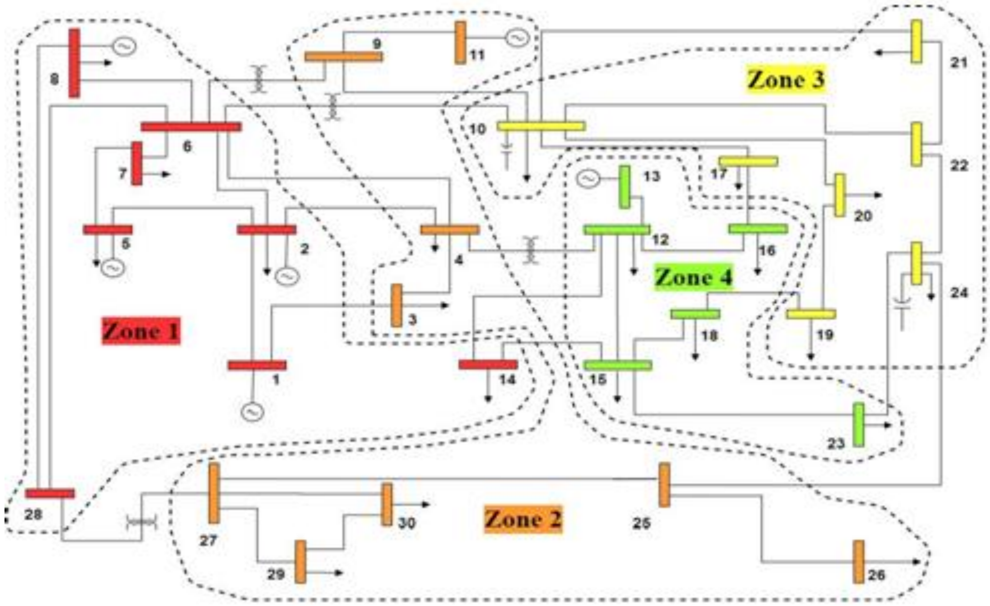

FIGURE 2 CLUSTERS/ZONES FOR CONGESTED LINE 2-6

CONCLUSIONS

Electrical power consumption is rising on a daily basis, and renewable energy output is expanding in response. The transmission line is limited in its ability to carry power. It necessitates system analysis throughout the transaction. The ATC determines the system's available power transfer capacity. It is also handy for contingency analysis. This paper demonstrates the best site for WPG utilizing recommended ATCDF values for ATC augmentation. ATC is computed using the ACPTDF technique. The maximum load on the line is used as a limiting condition for problem formulation. A novel technique has been proposed for the optimal positioning of the WPG. The comparison of ATC and WPG at various bus stops reveals that the ideally situated WPG based on ATCDF values improves ATC more than others. The results also indicate the second best position for WPG for maximal ATC augmentation. The ATCDF value may be used to determine the best position for numerous WPG integrations or for installing WPG in different sensitive zones. The conclusions of the redesigned IEEE 30-bus power system offer the following findings:

- TCDF is generated from the NR load flow Jacobian sensitivity, therefore it may be adjusted quickly for any contingency scenarios.
- Zones are constructed based on TCDF values, and the average values for crowded lines yield ATCDF values. The bus with the greatest ATCDF value is the best place for an active power shift.
- The WPG that is best situated based on the ATCDF value bus provides the most ATC benefit as compared to other sites. The hierarchical order of ATCDF data identifies the next appropriate place for RES integration.

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