Impact Valuation of all Connected Generators Separately by Power Sharing Approach in the Wind Incorporated System

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Received: 03.08.2016 Accepted: 22.09.2016

Abstract- This paper presents a maiden attempt to the impact of renewable (wind) energy on the power system from an individual generator to all demands. A modified method is proposed by which the proportion of power going from a specific generator to the loads, and to rest of the transmission networks has been traced in a grid system under thermal as well as wind-thermal environment. Also, it gives the individual load distribution and generator contribution to overall system losses. The method is simple, fast and accurate to the solution obtained. To clarify the analysis, the resolution to a sample case study is provided using the proposed method. The developed technique has been experimented on a modified IEEE 6-bus test system with thermal as well as wind-thermal generations. A wind generator of 10.2235 MW with wind speed 5.1376 m/sec has been incorporated into the system to see the impact of the wind generation to the system. To validate the method, the outcomes of both the cases under the projected algorithm of the test systems are compared.

Keywords Electrical energy resolution, Power tracing approach, Wind generator incorporation, Individual generator contribution, Transmission loss apportionment.

1. Introduction

The significance of electrical power tracing over systems has been gradually needed due to the variations in electrical energy over the system and the disparity between the power generated and the power demand due to uncertain system shutdowns. The effective operation of electrical power systems needs the balance between total power generated and the total power consumed with associated system losses. Even a minor alteration in demand from its nominal value, results deviations in the individual generation as well as overall transmission losses, which may yield unwanted effects. For dealing with this type of situations, we have to find out first that how much power is going from an individual generator to an individual load. This can be achieved with the help of Power Flow Tracing whose major objectives are to track the overall power flow as well as the transmission line losses over the system. The concepts of tracing the power has been given by Bailek J. [1], which employed upstream and downstream algorithm to find out the inflows to a bus and outflow from the bus. The authors in [2] present a technique to determine which load is fed by which generator, usage of transmission line by generators and generator's contribution to the system losses. By assuming proportionality, contributions of generators to the load and system losses has been calculated. The MW-MILE method has been taken into consideration in [3] to trace the output of each and every generator as well as the input to each and every load. The method assumes that the power inflows and outflows are shared proportionally. The method has been used to deal with the transmission supplementary charge to real and reactive power loads. The authors in [4] have applied graph theory for evaluating the influences of individual generators and demands to transmission flows and active power transfer between them. To avoid the problem arising from the nonlinear coupling between real and reactive power flows caused by losses, in [5] the authors translated all power injections into real and imaginary currents. The method then tracks these currents to calculate what amount of current each generator supplies to each demand. Reta *et al.* [6] determines the influence areas and computes the network losses, based on circuit theory analysis, which are shown by the connection between their lines independent of the slack bus position. Two lemmas were proved by the authors in [7]. Firstly, it shows the reasons behind the circulating power. Then, the presence of circulating power was proved by applying graph theory. After that optimal power flow (OPF) approach is recommended to abolish circulating power. Bialek *et al.* [8] organized a proportional sharing principle using game theory and information theory. The method displayed that the Shapley value, attains all properties for a loss apportionment scheme, with the supports of proportional sharing law. The authors in [9] attempt to capture the optimum among the post-facto method and postage stamp method of exploring variation of the answer space of the tracking problem, within given limits. Based on extended incidence matrices, Xie *et al.* [10] proposed a more logical model and process for real power tracing. Instead of using proportional sharing law, matrix theory was adopted for power flow tracing. An active power tracing strategy for estimating the ex-ante point of connection (POC) rates for the members of decentralized market has been provided by the authors in [11]. Barcia *et al.* [12] determined the amount of power, each generator is sending to each load in a manner that the flow arising from this assignment is such that each transmission line flow is broken in plots as much as possible which gives an appliance for transmission cost apportionment. Based on the physical flow in the network, the authors in [13] presented a simple power flow tracing and loss allocation method which can be applied easily and directly, and it works on the principle of proportional sharing. Peng *et al.* [14] resolves the power flow over transmission lines into generation driven components. The characteristics of additivity, symmetry and conservation are merged in electrical circuit analysis equations, for estimating the power flow over transmission line under the deductive reasoning of Shapley theorem. A modified method for power flow tracing based on Bialek's method has been proposed by the authors in [15]. There is no necessity to determine the matrices for upstream and downstream distribution, load and generation.

In view of the above discussion, this paper aims to apportioning the overall transmission loss for each and every connected generator individually. The resolution of power flow with and without wind source by tracing the line transferred has been made to be an attempt in this paper. The power contribution by individual generators to each and every load are also evaluated for both cases.

2. Assumptions

The system is supposed to be linked and defined by a number of *p* nodes, *q* branch (transmission lines) having *2q* movements (at sending and receiving end of each line) and a number of producers (generators) and consumers (loads) associated to the nodes (buses). Basically the only prerequisite for the input data is that Kirchhoff's Law should be fulfilled for all the buses in the system. For any node the sum of the power input is equal to the sum of the power output. Modified IEEE 6-bus test system has been taken into consideration as a test study for analysing the projected algorithm. Matlab and Matpower software has been used for power flow analysis.

3. Power Sharing Methodology

The power tracing approaches are mainly based on the circuit analysis and electrical concepts. The law used to trace the flow of power will be that of power sharing law which states that the system node is a perfect combination of incoming and outgoing power movement. The total sum of input power is equal to the total sum of output power for every node (or bus), which satisfies the laws of energy conservation. This principle is illustrated in Fig. 1 where a number of lines are connected to node (or bus) *0*, with *n* number of input power and *m* number of output power. The input and output power movements are P_i and P_o respectively. The total power flow through the node is $\sum P_i = \sum P_o$, i.e. the total sum of input power or output power.

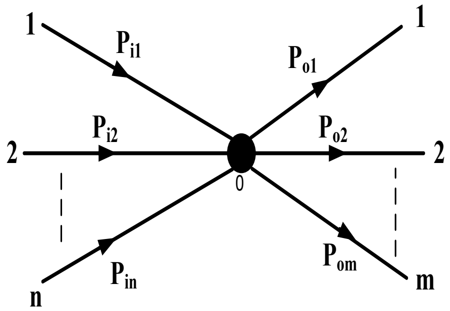

Fig. 1. Kirchhoff's power law.

Out of which, input power supplied to the bus is given by $\frac{P_{iu}}{\sum_{u=1}^{n} P_{iu}} * 100\%$, where, *u* = 1, 2, 3, …, *n*. And output power flows from the bus is given by $\frac{P_{ov}}{\sum_{v=1}^{m} P_{ov}} * 100\%$, where, *v* = 1, 2, 3, ..., *m.* Each of the power outgoing lines from a bus (or node) *0* is dependent only on the voltage rise and the impedance of the line, it may be supposed that each power, leaving from the bus contains the same proportion of the inputs as the total nodal flow**.** Hence the power outgoing from the bus *0* supplied by lines is given by $\frac{P_{iu}}{\sum_{u=1}^{n} P_{iu}} * P_{ov}$, which gives a generalized expression for the overall sharing of each input power movement to each and every output power movement of the bus. From the above mentioned expressions the complete distribution of power flow among the system network has been estimated.

4. Mathematical Formulation

The power transfer contribution from a specific generator to the transmission lines and corresponding loads is evaluated by using power sharing principle. The Fig. 2 illustrated that a simple two bus transmission line having bus *x* and *y* where active power is transferred from the bus *x* to bus *y*. By taking bus *x* as a consideration, it has been assumed that a generator P_g is connected to the bus, having *k* number of input powers P_i to the bus and a number of power outputs P_o from the bus. The sending end power P_s from bus *x* and the receiving end power P_r to the bus *y* has been clearly shown in the Fig. 2.

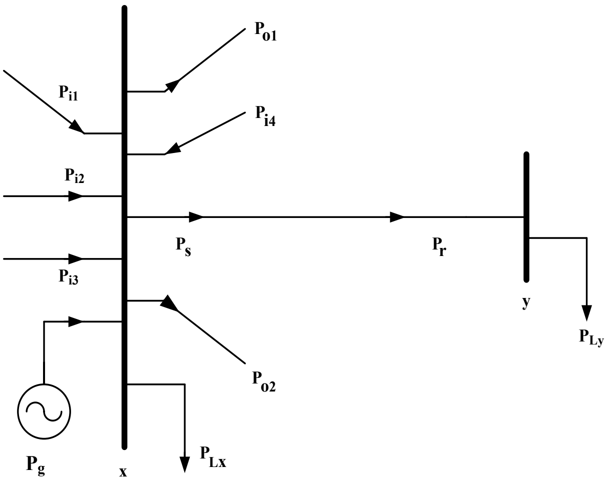

Fig. 2. Power flow in between two bus.

The power flow coefficient for sending as well as receiving end of *x*-*y* line has the form given by (1) and (2).

$$PFC^s = \frac{P_s}{P_g + \sum_{j=1}^{k} P_{ij}} \tag{1}$$

$$PFC^r = \frac{P_r}{P_g + \sum_{j=1}^{k} P_{ij}} \tag{2}$$

Where, PFC^s is sending end power contribution coefficient, PFC^r is receiving end power contribution coefficient, P_s is sending end power, P_r is receiving end power, P_g is the power generation and P_i is power input to the bus, P_L is an load connected to the respective bus. Where, *j* = 1,2,3,…,*k*.

5. Steps Proposed for Power Flow Tracing

The modified steps for the power flow tracing among the power system is proposed which can be used for any system for tracing the overall power over the system.

Step-1: - Run base case power flow.
Step-2: - With the power flow, find power flows in lines.
Step-3: - Develop the power contribution coefficient for all the lines.
Step-4: - Identify the number of generators connected (should be more than one).
Step-5: - For each generator individually, find power flow among the system.
Step-6:- Evaluate the transmission line losses for each generator separately.
Step-7:- Determine the particular generator contribution to all loads.
Step-8:- Apportioning the total transmission line losses.
Step-9:- Compare the power solutions for both cases (with and without wind source).

6. Test Study and Analysis

A modified IEEE 6 bus test system is taken under study. The power flow is shown in Fig. 3 which consists of three generators and three loads. Fig. 4 shows the power flows in the bus system after incorporating wind generator (WG) to bus no. 4 of the test system. In this study, an attempt has been made to track the optimal power flows in the system. The power contribution coefficients of the branches are estimated by using equations (1) and (2). The estimated values of the power contribution coefficient for both cases have been shown in Table 1.

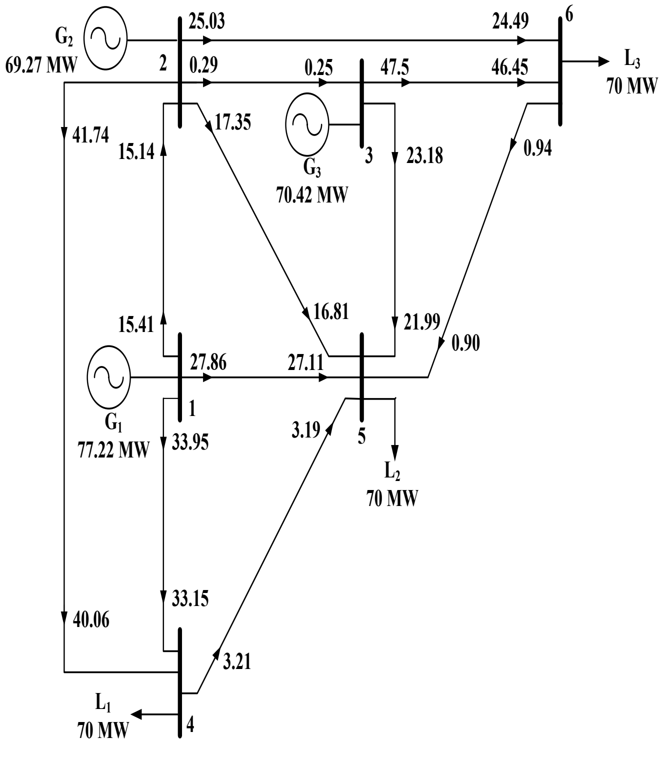

Fig. 3. Modified IEEE 6-bus test system showing power flows.

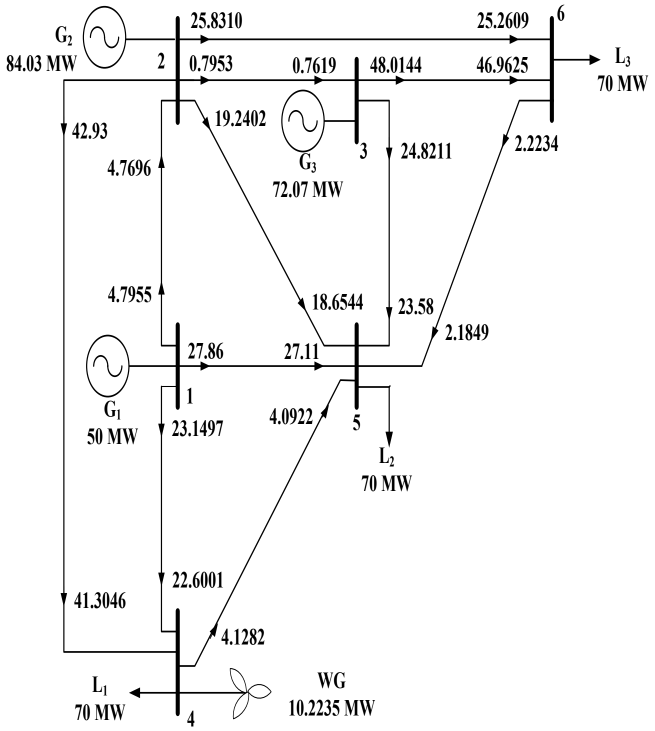

Fig. 4. Modified IEEE 6-bus test system with Wind Generator showing power flows.

Table 1. Power contribution coefficients of all the branches for both cases

Sl. No.	Lines	Without Wind Generator		With Wind Generator	
		From bus	To bus	From bus	To bus
1	1-2	0.1995	0.196	0.09591	0.095392
2	1-4	0.4396	0.429	0.462994	0.452002
3	1-5	0.3608	0.35107	0.441104	0.429698
4	2-3	0.0034	0.00296	0.008956121	0.00858
5	2-4	0.494	0.474	0.483481908	0.465144
6	2-5	0.2055	0.199	0.216669895	0.210073
7	2-6	0.2965	0.290	0.29089095	0.284471
8	3-5	0.328	0.311	0.340799842	0.323811
9	3-6	0.672	0.65728	0.659249587	0.644807
10	4-5	0.0438	0.04357	0.064599317	0.064036
11	5-6	0.01325	0.012687	0.030785036	0.030252

In this study, the effects of individual generators are considered independently for both the cases.

Table 2. Power flow (in MW) through the lines with the impact of Generator 1 for both the cases

Sl. No.	Lines	Without Wind Generator		With Wind Generator	
		From bus	To bus	From bus	To bus
1	1-2	15.41	15.14	4.7955	4.7696
2	1-4	33.95	33.15	23.1497	22.6001
3	1-5	27.86	27.11	22.0552	21.4849
4	2-3	0.05	0.0448	0.0427171	0.04092314
5	2-4	7.479	7.176	2.3060153	2.21855076
6	2-5	3.11	3.01286	1.0334287	1.00196427
7	2-6	4.489	4.3906	1.3874335	1.35681229
8	3-5	0.016	0.0152	0.0139466	0.01325138
9	3-6	0.03279	0.03207	0.0269786	0.02638752
10	4-5	1.766	1.757	1.6032679	1.58928659
11	5-6	0.0586	0.0561	0.0425819	0.04184452

Table 3. Power flow (in MW) through the lines with the impact of Generator 2 for both the cases

Sl. No.	Lines	Without Wind Generator		With Wind Generator	
		From bus	To bus	From bus	To bus
1	1-2	0	0	0	0
2	1-4	0	0	0	0
3	1-5	0	0	0	0
4	2-3	0.235	0.205	0.75258288	0.72097686
5	2-4	34.219	32.83	40.6269847	39.0860492
6	2-5	14.235	13.78	18.2067713	17.6524357
7	2-6	20.538	20.088	24.4435665	23.9040877
8	3-5	0.067	0.06375	0.24570881	0.23346054
9	3-6	0.13776	0.13474	0.47530372	0.46489076
10	4-5	1.4379	1.4304	2.52493209	2.5029134
11	5-6	0.26795	0.25656	0.7501999	0.73720957

Table 4. Power flow (in MW) through the lines with the impact of Generator 3 for both the cases

Sl. No.	Lines	Without Wind Generator		With Wind Generator	
		From bus	To bus	From bus	To bus
1	1-2	0	0	0	0
2	1-4	0	0	0	0
3	1-5	0	0	0	0
4	2-3	0	0	0	0
5	2-4	0	0	0	0
6	2-5	0	0	0	0
7	2-6	0	0	0	0
8	3-5	23.09776	21.9006	24.561445	23.3370881
9	3-6	47.32	46.2856	47.512117	46.4712217
10	4-5	0	0	0	0
11	5-6	0.61328	0.5872	1.43061826	1.40584593

In the segment discussed above, three test studies are carried out in both the cases (with and without wind generator) to evaluate the consequence of each generator and to find out the direction and value of the flow of active power. The sending end as well as receiving end values of the real power flows for both the cases is tabulated in Table 2 by considering Generator 1. The values of the active power flow and the transmission line losses in the system with the effect of Generator 2 are obtained by applying the proposed method and noted in Table 3. The effect of Generator 3 for both cases is studied and shown in Table 4. The impact of wind generator to the individual generator as well as system has been clearly shown. Table 5 shows the overall active power losses across the system for both the cases. A comparison is also shown in the Table 5 between the cases where the impact of wind generation to the system has been traced. It is also revealed from Table 5 that the losses obtained after the injection of wind generation in the system have been minimized to some extent. The proposed method is easy, reliable and gives maximum accurate results. The amount of power supplied by each generator to the loads is tabulated in the Table 6. In Table 6, the amount of active power flow from each generator to all loads is shown by considering both cases. Table 6 shows the total amount of generation by the individual generators and the amount of power shared by the connected loads. It also shows that by introducing wind generator to the system, the contribution of individual generator to all connected loads has been effected.

Table 5. Comparison of line Power losses (in MW) for both cases

Lines	Without Wind Generator				With Wind Generator			
	G_1	G_2	G_3	Line Power Losses	G_1	G_2	G_3	Line Power Losses
1-2	0.27	0	0	0.27	0.0259	0	0	0.0259
1-4	0.8	0	0	0.8	0.5496	0	0	0.5496
1-5	0.75	0	0	0.75	0.5703	0	0	0.5703
2-3	0.0052	0.03	0	0.0352	0.001794	0.031606	0	0.0334
2-4	0.303	1.389	0	1.692	0.0874645	1.540935	0	1.6284
2-5	0.09714	0.455	0	0.55214	0.0314645	0.554336	0	0.5858
2-6	0.0984	0.45	0	0.5484	0.0306212	0.539479	0	0.5701
3-5	0.0008	0.00325	1.19714	1.2	0.0006952	0.012248	1.224357	1.2373
3-6	0.00072	0.00302	1.0344	1.03814	0.000591	0.010413	1.040896	1.0519
4-5	0.009	0.0075	0	0.0165	0.0139813	0.022019	0	0.036
5-6	0.0025	0.01139	0.02608	0.03997	0.0007373	0.01299	0.024772	0.0385
TOTAL				**6.94235**	**TOTAL**			**6.327**

Table 6. Power contribution (in MW) from the individual generators to the loads for both cases

Bus No.	Linked Load	Without Wind Generator			With Wind Generator			
		GEN 1	GEN 2	GEN 3	GEN 1	GEN 2	GEN 3	WG
4	LOAD 1	38.56	31.68621	0	23.209687	36.56112	0	10.2235
5	LOAD 2	31.95116	16.053071	21.81342	24.131247	21.12602	24.742936	0
6	LOAD 3	4.36407	19.95479	45.67232	1.475212	22.7201	45.5832	0

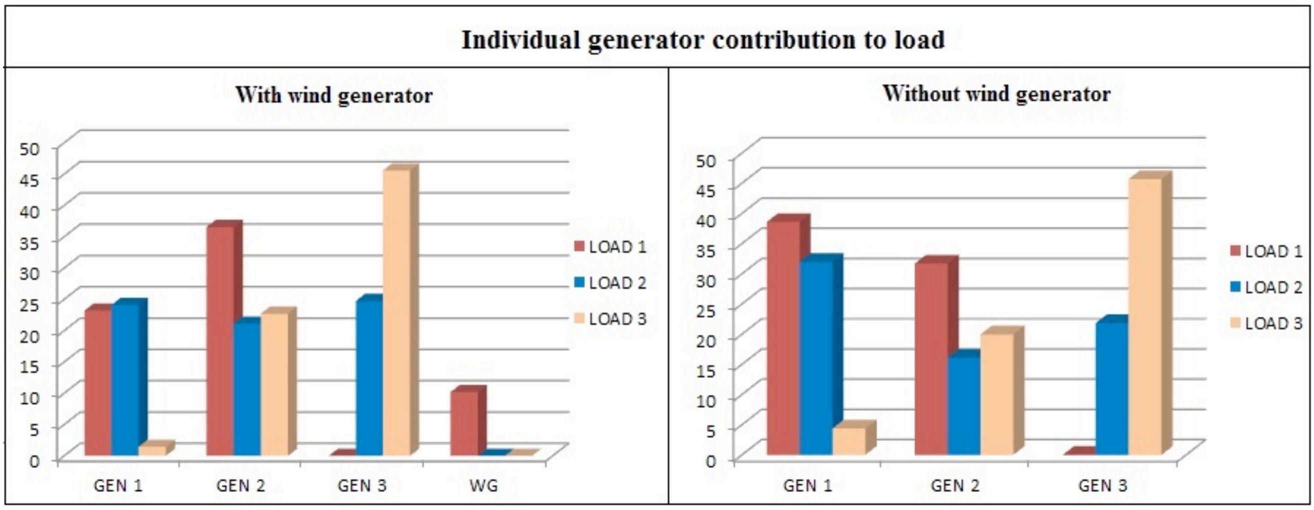

Fig. 5. Graph showing sharing of power by the loads from the individual generator for the test study.

Based on the Table 6, a graph is shown in Fig. 5 which illustrates the active power shared by the loads, generated by the individual generators. It shows the percentage of power shared by the individual generator out of the total power generated and to be distributed among the loads with considering thermal as well as wind-thermal generations. By which the total scenario of the system network has been elaborately displayed that how much power has been transferred from the individual generator to the individual demand for both the cases.

7. Conclusion

The power contribution coefficients is proposed with the help of Kirchhoff's law for the active power flow tracing under renewable as well as non-renewable conditions, by which the share of power going from an individual generator to the loads, and to rest of the transmission system are estimated. An alternative approach for the tracing of active power based on the power sharing methodology and power contribution coefficient is proposed in this paper. The method is simple, robust and accurate. The developed algorithm is applied to the modified IEEE 6 bus test system considering thermal and wind-thermal generations separately. The outcomes of the both cases i.e. with and without wind generator has been compared to show the impact of wind generation to the active power flow of the system. It is observed from the outcomes that, with the inclusion of wind generator in the system the overall line losses have been reduced.

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