Comparative techno-economic analysis of power system with and without renewable energy sources

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ABSTRACT

The primary aim of this work is to feature the advantages of integrating natural source of energy from the solar and wind to the prevailing electric power systems. Two types of analysis are carried out in two test systems (standard and modified test systems) and the outcome of the test systems are compared. The two analyses are technical analysis and economic analysis. The stability of the voltage is analyzed under technical analysis and the price of energy consumed from the electric grid is calculated and analyzed under the economic analysis. Dynamic hourly load data, hourly solar radiation, hourly wind velocity, and dynamic electricity prices are considered for the standard IEEE system and modified test system (with the integration of RES). Voltage stability index (L-Index) and price of the electricity consumed from electric grid are found for standard test system and the outcome is compared with the outcome of modified test systems. MATLAB coding is done for techno-economic analysis for both test systems. It is inferred from the outcome that the integration of renewable energy sources fairly contributes to the economic benefit of the system by lowering the power purchased from the grid and enhance the stability of the system.

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1. INTRODUCTION

Nowadays, most of the countries developed several solutions to produce clean and green energy. Among them is the integration of renewable energy sources (RES) [1] to the electric grid which benefits both the environment and humans [2]. In this work, the benefits of integrating RES are analyzed in two different aspects. One essential technical aspect that cannot be overlooked is its voltage stability. The economic aspect of analyzing a system is to compute the operation costs incurred. Both technical and economic aspects are presented in this paper with a basis of power flow analysis.

In the examination of power systems, load flow studies are critical. The total real and reactive power flow, as well as the magnitude and phase angle of the voltages at each bus, may be determined using a load flow analysis for a system [3]. When adjustments to the power system architecture are required, a load flow analysis is used to determine the condition of each operational stage. This status will assist us in maintaining overall control, ensuring stability, and determining whether or not economic restrictions are met. Load flow studies are utilized not only for system planning and design, but also for evaluating changes in the current system [4]. Load flow studies provide steady state solutions of bus voltages and power flow information for a given load condition [5]. With the load and operating conditions, the power flow and voltages at the buses will fluctuate dynamically.

In a successful power system, voltage stability should be kept within safe ranges**.** The term "voltage stability" is described as "the ability of a power system to maintain acceptable voltage in the system both under normal conditions and also after being subjected to a disturbance [6]-[9]." There are a variety of methods for determining voltage stability [10]. They are L-Index [11], P-V curve, V/V_0index, modal analysis, line stability index L_{mn}, line stability index, FVSI, line stability index LQP, and line stability indices VCPI [12], [13]. Among all the most simple and effective way to find the voltage stability is L-Index.

If the energy generation by the renewable energy sources (RES) is higher than the demand, electrical energy is fed in the utility grid respectively if the energy generation by RES is lower than the required demand, additional energy is needed from the utility grid [14], [15]. To minimize the operating costs of the system, a battery storage unit can be added to the grid. Furthermore, dynamic pricing represents a good opportunity to minimize the total operating costs for a specific time period (here: 24 hours). Dynamic pricing means that the electricity price varies depending on supply and demand instead of being fixed. The economic analysis shows the cost benefit of the integration of renewable energy sources.

In the MATLAB coding environment, the techno-economic analysis of the system incorporated with the renewable energy sources (solar, PV) [16] are carried out [17]-[20]. To ensure practical applications of the proposed analysis, time-varying data of load, solar radiation, wind velocities and grid electricity costs are considered. Both the voltage stability and cost analysis with and without RES are carried out in standard IEEE test beds (IEEE 14 bus system and IEEE 30 bus system) [21]-[30].

The paper comprises three sections, in which the section 2 describes the techno-economic analysis, section 3 explains the proposed algorithm of techno-economic analysis. Section 4 gives the IEEE standard bus system data, renewable energy sources design and corresponding data. The techno-economic analysis is carried out in the MATLAB platform on IEEE 14 and 30 system and a comparative study of the system with and without RES is carried out in section 5.

2. TECHNICAL AND ECONOMICAL ANALYSIS

The provided technical-economical assessment of the studied system takes into account both economic and technical aspects of study in terms of voltage regulation and power acquired from the grid. The analysis is split into three stages namely–power flow analysis, technical (stability) analysis and economic (cost) analysis. Each of these analyses along with necessary flowcharts and equations is detailed in this section.

2.1. Power flow analysis

Power flow, or load flow, is widely used in power system operation and planning. Any electrical system study necessitates the estimation of line and node parameters such as voltage, current, and power. In this paper, newton-raphson (NR) method of power flow analysis is used to compute the system parameters.

2.2. Technical: stability analysis

Voltage stability within the permissible level must always be sustained for a reliable electrical network [31]-[35]. The L-Index [36], which is a simple but effective statistical technique for evaluating voltage stability [37], [38] is considered in this paper. L-index sensitivities will be used to determine the control actions. L-Index is calculated for load bus. L-index in [1] has been adopted in this paper for on-line voltage stability enhancemnt. It computed as (1),

$$L_j = \left|1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j}\right| \quad (1)$$

where,
- V denotes the Voltage at the bus
- i denotes the generator bus
- j denotes the load bus
- 1,….,g are the generators
- n is the no of buses

The admittance matrix computation according to (2) can be used to compute the term Fji

$$\left[V_l\ I_g\right] = \left[Z_{ll}\ F_{lg}\ K_{gl}\ Y_{gg}\right]\left[I_l\ V_g\right] \quad (2)$$

where
- F_{lg} is calculated as $\left[F_{lg}\right]$ = - $[Y_{ll}]^{-1}$ $\left[Y_{lg}\right]$
- Y_{ll} denotes self-admittance at the node *l*
- Y_{lg} denotes mutual admittance between node *l* and *g*.

The level of voltage stability is shown by the local indicator-index. Its range can be anywhere from 0 to 1. When there is no load on this load bus, the Local Indicator index score is 0. Voltage stability has collapsed when the local indicator index value is 1. As a result, the lower the local indicator index, the more consistent the voltage stability.

2.3. Economic: cost analysis

In this research, the system's daily cost is evaluated for examination. When compared to the price of electricity consumed from the electric grid, the daily operation and maintenance expenditures of renewables [39] are negligible. In this analysis, the prices of power acquired from the grid are based on a dynamic scheme. To calculate daily operation costs, compute the daily power used from the grid and multiply it by the dynamic rates of electricity.

3. PROPOSED TECHNO- ECONOMIC ANALYSIS METHODOLOGY

The main objective of the paper is to analyse the voltage stability of the test system and the price of power purchased from the grid [40]-[49]. In this section, the step-by-step procedure for evaluating the Techno-Economic analysis is presented. The presented techno-economic assessment of the standard test system (IEEE 14 and IEEE 30 bus) and Modified test system (with solar PV, Wind and STATCOM) are considered. The Algorithm contains 6 steps which involves Newton Raphson and L-Index calulation using MATLAB Coding Environment.

Step1: Consider a standard test system in which the Techno-Economic Analysis has to be carried out. In our paper, IEEE 14 and IEEE 30 bus system are used for Analysis.

Step2: Perform Newton Raphson Load Flow Analysis on the Standard Test system [50] (IEEE-14 and 30 bus system) [51]

Step 3: Find the L-Index value for each load bus

Step 4: Find the cost of the power purchased from the grid to meet the load demand of the system. When considering the price of energy acquired from the grid, the daily O &M costs of renewable sources are negligible.

Step 5: Identify the suitable bus to which the Renewable [52]-[56] and STATCOM can be added considering the following factors

i) Heavy Load demand
ii) Identify Weakest bus using L-Index calculation

Step 6: Modify the standard test system (IEEE 14 and 30 bus) by incorporating RES (PV and WIND)

4. RESULTS AND INFERENCES

In this part, the Techno-Economic analysis is done for two different IEEE standard system (IEEE 14 bus and IEEE 30 bus) and three cases for each IEEE standard system [57]. The case1 is the comparative technical analysis of standard test system (IEEE 14 and IEEE 30) and Modified test system. Case 2 is the comparative technical analysis of standard (IEEE 14 and IEEE 30) bus system with the modified system with hourly 1 day load. Cost of the electricity purchased - IEEE 14 bus system - 1 day load is considered for case 3. The results are depicted with the help of Table and Graph.

4.1. Test system 1: IEEE 14 bus

- Case 1: Comparative technical analysis of standard IEEE 14 bus system with the Modified-IEE 14 bus system.

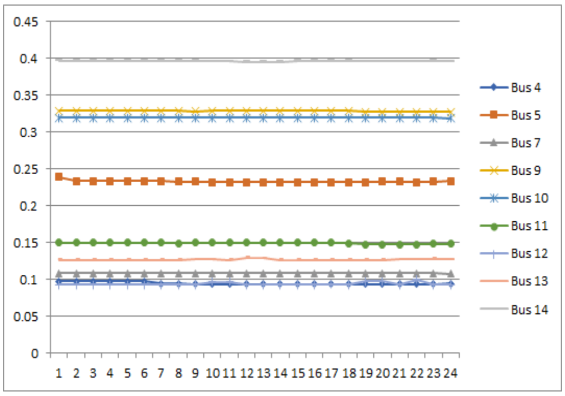
The Table 1 shows the comparative technical analysis of IEEE 14 bus system [58] with the modified IEEE-14 bus system after adding photovoltaic (PV) and Wind to the bus 9 and bus 11 respectively. The renewable energy sources (PV and Wind) is incorporated to the standard IEEE 14 bus system [59]-[61]. The L-index of the load buses 4,5,7,9,10,11,12,13 and 14 are found using (1).

Table 1. Comparative L-Index values of IEEE 14 bus with standard load

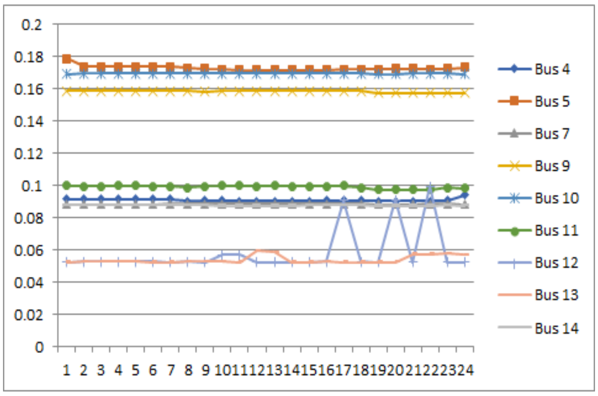
Bus No	L-Index of Standard IEEE-14 bus	L-Index of Modified IEEE-14 bus
4	0.0976	0.0912
5	0.2389	0.1762
7	0.1083	0.0891
9	0.3287	0.1572
10	0.3198	0.1653
11	0.1498	0.0971
12	0.0926	0.0521
13	0.1265	0.0763
14	0.3969	0.1072

- Case 2: Comparative technical analysis of standard IEEE 14 bus system with the Modified-IEE 14 bus system with hourly 1 day load

The graph as shown in Figure 1(a) depicts the L-Index of all the 14 buses for 24 hours. X-axis indicates the hours (24 hours) and the Y axis implies the L-Index value and the graph as shown in Figure 1(b) depicts the L-Index of all the 14 buses for 24 hours. X-axis indicate the hours (24 hours) and the Y axis express the L-Index value.



(a)



(b)

Figure 1. (a) L-Index of IEEE-14 bus for 1-day hourly load and (b) L-Index of modified IEEE-14 bus for 1-day hourly load

- Case 3: Cost of the electricity purchased-IEEE 14 bus system-1 day load

The Table 2 shows the price of the Electricity acquired from grid by IEEE 14 bus system and Modified IEEE-14 bus system [62]. The Total cost of the Electricity purchased from the grid by IEEE 14 bus system for a single day are 113616.44 Euro. The total cost of electricity purchased by Modified IEEE 14 bus system from the grid for a single day are 150567.80 Euro.

Table 2. Cost of electricity purchased from grid during each hour (in Euro)

Hour	Cost of IEEE-14 bus	Cost of Modified IEEE-14 bus	Hour	Cost of IEEE-14 bus	Cost of Modified IEEE-14 bus
1	3042.22	533.68	13	6381.23	5943.14
2	2677.97	1266.22	14	6189.99	2903.95
3	2490.39	1625.13	15	5733.17	0
4	2384.4	1594.09	16	5424.62	2422.93
5	2385.21	1776.26	17	5317.67	4604.81
6	2642.03	2151.76	18	5565.9	4892.92
7	3313.43	3098.84	19	5637.79	4986.63
8	4744.78	4575.76	20	5780.69	5580.71
9	5727.73	5259.14	21	5808.45	5130.28
10	6157.52	4160.01	22	5263.72	5083.58
11	6385.5	4342.55	23	4525.44	3966.71
12	6467.24	4504.58	24	3569.36	3036.86

4.2. Test system 2: IEEE 30 bus

- Case 1: Comparative technical analysis of standard IEEE 30 bus system with the Modified-IEE 30 bus system.

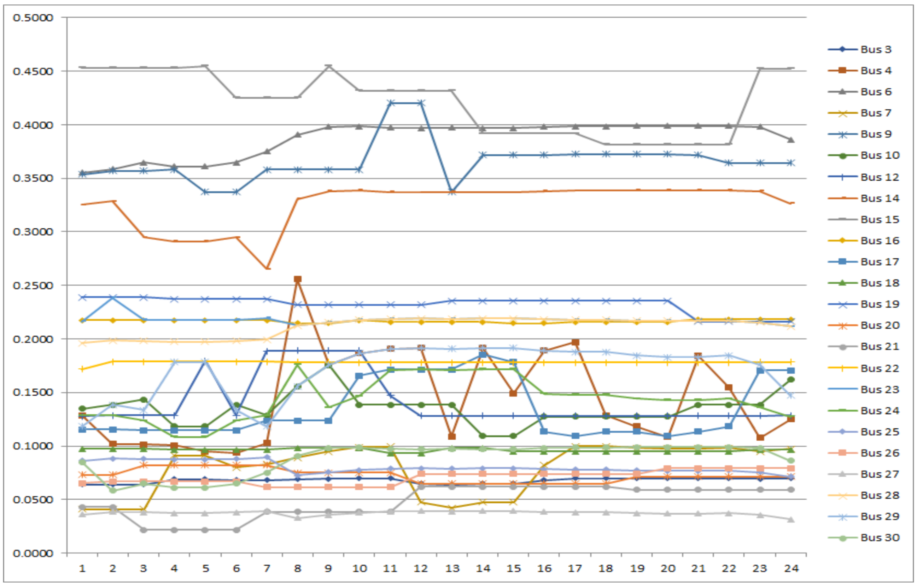
The Table 3 shows the comparative technical analysis of IEEE 30 bus system [63]-[65] with the modified IEEE-30 bus system after adding PV and Wind to the bus 25 and bus 7 respectively. The renewable energy sources (PV and Wind) is incorporated to the standard IEEE 30 bus system. The L-index of the load buses 3,4,6,7,9,10,12,14,15,16,17,18,19-30 are found using (1).

- Case 2: Comparative Technical Analysis of Standard IEEE 30 bus system with the Modified-IEE 14 bus system with hourly 1 day load

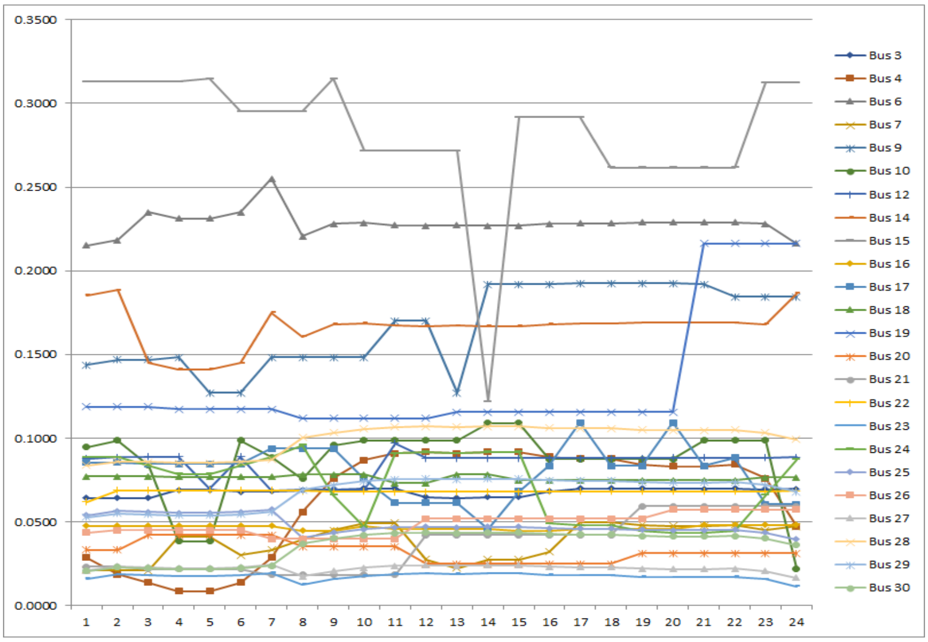
The graph as shown in Figure 2(a) depicts the L-Index of all load buses for 24 hours. X-axis implies the hours (24 hours) and the Y axis refers to the L-Index value and the graph as shown in Figure 2(b) depicts the L-Index of all the load buses for 24 hours. X-axis express the hours (24 hours) and the Y axis indicates the L-Index value.

Table 3. Comparative L-Index values of IEEE 30 bus with standard load

Bus No	L-Index of Standard IEEE-30 bus	L-Index of Modified IEEE-30 bus	Bus No	L-Index of Standard IEEE-30 bus	L-Index of Modified IEEE-30 bus
3	0.0643	0.0337	19	0.2387	0.1162
4	0.1831	0.1741	20	0.0731	0.0668
6	0.3552	0.2314	21	0.0432	0.0231
7	0.0412	0.0196	22	0.1721	0.0632
9	0.3538	0.1436	23	0.2368	0.0165
10	0.1347	0.0916	24	0.1299	0.0881
12	0.1277	0.0842	25	0.0876	0.0747
14	0.3276	0.1890	26	0.0652	0.0476
15	0.4531	0.3171	27	0.0332	0.0113
16	0.2176	0.0468	28	0.1961	0.0954
17	0.1153	0.0883	29	0.1138	0.0873
18	0.0972	0.0756	30	0.0921	0.0835



(a)



(b)

Figure 2. (a) L-Index of IEEE-30 bus for 1-day hourly load and (b) L-Index of Modified IEEE-30 bus for 1-day hourly load

- Case 3: Cost of the electricity purchased-IEEE 30 bus system-1 day load

The Table 4 shows the price of the electricity acquired from grid by IEEE 30 bus system and modified IEEE-30 bus system. The Total price of the electricity purchased from the grid by IEEE 30 bus system for a single day are 99770.96 Euro. The total price of electricity purchased by Modified IEEE 30 bus system from the grid for a single day are 70293.72 Euro.

Table 4. Cost of electricity purchased from grid during each hour (in Euro)

Hour	Cost of IEEE-30 bus	Cost of Modified IEEE-30 bus	Hour	Cost of IEEE-30 bus	Cost of Modified IEEE-30 bus
1	2671.49	162.95	13	5603.6	5165.51
2	2351.63	939.87	14	5435.67	2149.63
3	2186.91	1321.65	15	5034.52	0
4	2093.83	1303.52	16	4763.57	1761.88
5	2094.54	1485.6	17	4669.65	3956.79
6	2320.07	1829.8	18	4887.63	4214.65
7	2909.65	2695.06	19	4950.76	4299.6
8	4166.58	3997.55	20	5076.25	4876.27
9	5029.74	4561.15	21	5100.62	4422.45
10	5407.16	3409.65	22	4622.27	4442.14
11	5607.35	3564.41	23	3973.96	3415.23
12	5679.13	3716.47	24	3134.39	2601.89

5. CONCLUSION

With and without the integration of renewable energy sources, the voltage stability – in terms of L-indices of load buses–and the price of Electric power consumed from grid were computed (PV and Wind). The analysis is carried out for two standard IEEE system (IEEE 14 bus and IEEE 30 bus) and the following observations were made. In IEEE 14 bus system, on comparing the voltage stability index of the IEEE 14 bus with and without the incorporation of RES, there is an average of 38 % improvement in the stability of the system when PV and Wind is added to the standard system. The price of electricity acquired from the grid is lowered by 33% when the RES is added to the system. In IEEE 30 bus system, on comparing the voltage stability index of the IEEE 30 bus with and without the incorporation of RES, there is an average of 34 % enhancement in the stability of the system when PV and Wind is added to the standard system. The price of electricity acquired from the grid is lowered by 30% when the RES is incorporated to the system. Overall, the voltage profile, voltage stability and the cost analysis show a considerable increment in both voltage stability and economic aspects of the system when RES is incorporated.

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