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DETERMINATION OF BESS IMPACT IN LOCAL DISTRIBUTION SYSTEM WITH QUASI-DYNAMIC SIMULATIONS STUDY CASE: THE IEEE 34 NODES TEST FEEDER

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ABSTRACT

In Colombia, Battery Energy Storage Systems (BESS) is expected to be included in transmission and distribution power systems in the following years. In this paper, Quasi-Dynamic Simulations are performed to evaluate the BESS include impact in a Local Distribution System (LDS) lightly loaded. Simulation is performed in the IEEE 34 Node Test Feeder System modified with the Commercial and Industrial Colombian sectors demand curves. BESS operates during two peaks of load profiles. Voltages, Active and Reactive Power Levels are analyzed during a 24 hours period. Loading in transformers and distributions lines are analyzed too, in order to verify the electrical behavior during the operation of BESS. BESS do not increase considerably the voltage levels in the nodes but modify the active power pro-file during the peaks of the curves and change the reactive power levels in the LDS. The loading in lines and transformers have important changes. The Quasi-Dynamic simulation shows that is necessary include voltage regulators in a distribution system to keep the levels in the adequate range. In a distribution system lightly loaded the BESS cause small voltage changes in the nodes.

Keywords: battery energy storage systems, quasi-dynamic simulation, local distribution system.

1. INTRODUCTION

In Colombia, the Commission for the Regulation of Energy and Gas (CREG) is the entity in charge of regulating electricity and gas services, issuing resolutions for the establishment of criteria for design, standardization and efficient use of electrical energy. The National Operating Council (CNO in Spanish, NOC in English) is a private organization whose main function is to agree on technical aspects to guarantee that the operation of the National Interconnected System (SIN in Spanish, NIS in English) is safe, reliable and economical, being the executor of the operating regulations. Due to the changes in the electrical energy generation, the government have tried to motive the investment in Non- Conventional Energy Sources (FNCE in Spanish, NCES in English) and Non-Conventional Renewable Energy Sources (FNCER in Spanish, NCRES in English).

In resolution CREG 030-2018 [1] the small-scale self- generation and distributed generation in the SIN are regulated including the production of electric energy close to the consumption centers connected to a Local Distribution System (LDS). In resolution CREG 098-2019 [2] the mechanisms to incorporate storage systems are defined in order to mitigate inconveniences presented by the lack or insufficiency of energy transport networks in the SIN and the agreement 1300, issued on April 2, 2020 [3]; the chapters of the Battery Energy Storage Systems (BESS) that are connected to the SIN are approved. It includes the definitions and technical conditions for connection and tests that must be met before entering into commercial operation.

Due the expedition of these resolutions and agreements, is necessary to verify the integration impact in the grid by including these new systems. The power generated by renewables sources at any given time cannot be controlled or be reliably predicted, so it poses unique challenges to grid utilities [4], for that reason, the inclusion of BESS in power systems have been a particular research topic. In many cases, the BESSs are used to compensate fluctuations in Renewable Energy System (RES) and stabilize the power system [5].

For instance, in [6] BESS keep constant the output power in the Point of Common Coupling (PCC) by regulating the Double Fed Induction Generator active power regardless of wind intensity in Eolical Parks connected to medium-voltage distribution networks. BESS can reduce the frequency deviation in a microgrid with wind generation [4].

Besides, [7] BESS is proposed for reducing the PV power infeed to the grid with minimum ESS degradation. Nevertheless, [8] noted a significant improvement in energy losses by the introduction of BESS units in a distribution network with high PV penetration, regardless whether if the BESS units are installed near the PV units, or one BESS unit is installed near the substation.

In [9] the BESS application contributes to reduce the peak of demand at the feeder once it is discharged during the peak time. In [10], the deployment of distributed BESS is a better economical option for peak load demand support than the centralized BESS. The deployment of distributed BESS also reduces the power loss in distribution networks as compared to centralized BESS. However, to have distributed BESS placement in a distribution network it needs appropriate infrastructure and control mechanism.

In [11] the functionality of a BESS provides extra control range to compensate reactive power and to balance currents and voltages in a grid without affecting its storage service life. On that topic, in [12], concluded that through coordinated control of active and reactive power of BESS,

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power loss in distribution networks can be decreased more remarkably compared with that when active power of BESS is dispatched only.

When BESS is only used for frequency control in the system in proportion to the capacity, the system frequency control is not properly performed because the output cannot be continuously operating according to the State-Of-Charge (SOC), and stable BESS operation respectively [5]. The same reference indicates the operating SOC range can be set to 10%-90% depending on characteristics provided by the BESS manufacturer.

The energy capacities of these Energy Storage System (ESS) are finite, and unlimited charge/discharge range can cause overcharge or over discharge of BESS. This problem can eventually result in the operation failure of the BESS [13]. In a grid with BESS, concepts as time of use (TOU) price has to be introduced into the electricity market, where, the owners of the BESS can exploit the price difference between peak load and valley load to increase the total revenue in the process of charging and discharging the battery [14]. Finally, the cost of BESS is expected to decrease in the following years, this can also be an economic solution, especially in urban centers, where the installation of new feeders might be quite costly [15].

In this work a lightly charged distribution system is simulated in order to analyze the behavior of electrical variables when some costumer decides sell energy form their BESS to the network operator company. The ubication of the BESS in not a result of a previous analysis and are assigned in the nodes furthest from the connection point of the distribution network, reflecting a scenario where customers decide to have BESS in their own electrical network. Simulation is performed in the IEEE 34 Node Test Feeder System modified with the Commercial and Industrial Colombian sectors demand curves. BESS operates during two peaks of load profiles. Voltages, Active and Reactive Power Levels are analyzed during a 24 hours period. Loading in transformers and distributions lines are analyzed too, in order to verify the electrical behavior during the operation of BESS.

2. IEEE 34NODE TEST FEEDER SYSTEM MODELING WITH BESS ANDCOLOMBIAN LOAD PROFILES

The IEEE 34 node test system is an actual feeder located in Arizona, with a nominal voltage of 24.9 kV. It is characterized by long and lightly loaded, two in-line regulators, an in-line transformer for short 4.16 kV section, unbalanced loading, and shunt capacitors [16]. This feeder is not the largest test feeder available, but displays a variety of components and topological features like specified real and reactive power values of each load on each phase, distributed load models that represent load on feeders with closely spaced load taps and very long distributions lines [17] [18].

A model of the test feeder was implemented in DIGSILENT Power Factory 19. The results of the load flow calculation were close similar with the results presented in [16]. This test system is for use by software developers and field engineers for validating their studies and it is good system to include and analyze a distribution system including distribution generation technologies [17].

2.1 Modification of the Loads

The industrial and commercial customers in the Colombian electric market are the most interested in implement projects that help decrease the energy consumption and save money too. That kind of consumers represents the potential users that would have the economic advantages to acquire and generate or storage electricity looking for be more independent of the distribution network operator and profiting from eventual discounts and assistance offered from the Colombian electrical legislation.

For that reason, each load of the distribution system was modeled with a daily demand curve with the profile of the industrial and commercial demand in Colombia with the aim to have an approximation to a distribution system in the country.

2.2 BESS Modeling

On the nodes 840, 848 and 890 were modelling BESS and their respective transformer that adequate the voltage to 690 V to 22, 9 kV and 4, 16 kV which are the voltage levels in those nodes. The model assumes that the network operator is interested in include small size BESS in the system to decrease the electric demand on the "peak" of the demand curves. The capacity of the storage systems are commercial values present in the BESS regular markets. The power factor of the BESS is 1. The power values of the new generators included are listed on Table-2.

To determinate variations in the LDS with the inclusion of the BESS in some nodes, two simulation scenarios are proposed.

2.2.1 Conventional scenario: This scenario describes the normal operation of the LDS, where the node 800 is the connection with the external grids and is the power source of the distribution network operating at 69 kV.

2.2.2 BESS scenario: In this scenario, the electrical network has BESS operating on their nominal capacity on the nodes 840, 848 and 890. The hours where the BESS are operating on the peaks identified in the conventional scenario: 10h-12h and 15h-18h on this context, we do not include the way that the BESS are charged. Those systems can be charged by a DG system like photovoltaic system or directly by the network on the hours of low consumption.

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Table-1. Loads modified with the demand curves in Colombia.

Load		Demand Type	Load		Demand Type
802	806	Industrial	862	838	Commercial
818	820	Industrial	854	856	Commercial
820	822	Industrial	842	844	Commercial
824	826	Industrial	816	824	Commercial
830		Industrial	828	830	Commercial
836	840	Industrial	846	848	Commercial
844	846	Industrial	858	864	Commercial
858	834	Industrial	808	810	Commercial
860	836	Industrial	840		Commercial
890		Industrial	834	860	Commercial
832	858	Commercial	848		Commercial
824	828	Commercial	860		Commercial

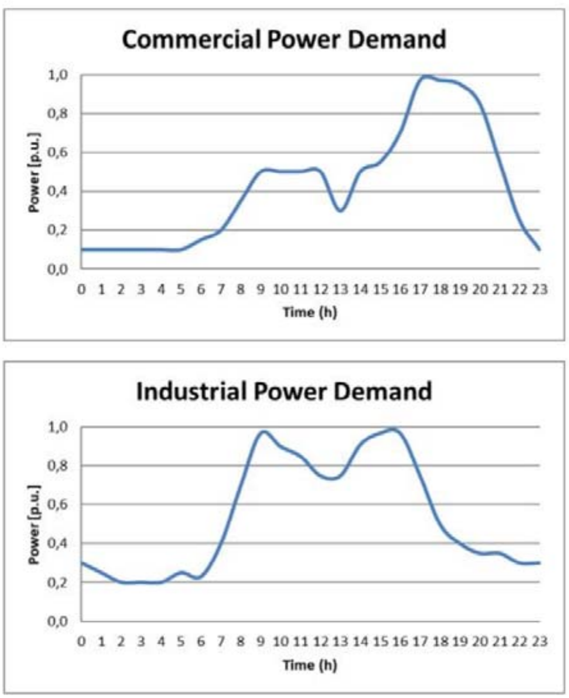

Figure-1.

Table-2. Loads modified with the demand curves in Colombia.

Generator	Active Power
840	200 kW
848	200 kW
890	400 kW

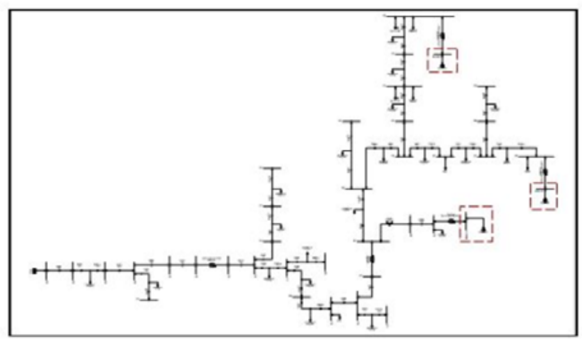

Figure-2. Simulation in power factory of the IEEE 34-node feeder with BESS.

3. "QUASI-DYNAMIC" SIMULATION

The "Quasi-Dynamic" models have been used in different researches in Electrical Engineering, for example in [20] [21] [22] the quasi-dynamic simulations are performed to estimate the impact of distributed energy resources (DER) on the electrical network, in [23] the quasi-dynamic simulations are performed to determinate the impact of distributed generation in a LDS. In [24] using optimal power flow, the quasi-dynamic simulations are used to get system losses, power losses and state of charge of the BESS, in [25] the quasi-dynamic interactions between heating systems and electricity systems is studied and in [26], continuing with the previous study, they add quasi-dynamic interactions using security control to relieve congestion in electricity systems. In [27] the authors present three phase detailed models and using a quasi-dynamic state estimation, they get the best estimate of the distribution system states, in [28] the quasi dynamic simulation is used to get the optimal size of a PV plant and in [29] it was used for validation of power system restoration and finally in [30] the quasi dynamic simulation allowed to include large DGs through variable load modeling.

DigSILENT® PowerFactory includes the quasi-dynamic simulation toolbox. It allows to perform load flow simulations in a time range selected by the user, for a certain period and simulation step size. This toolbox is useful for medium or long-term simulation studies in which the characteristics of the study case are variable with time; this can be simulated adding variations or expansion stages modifying the network elements.

3.1 Voltage Level Variations

This and the other sections show the most significant changes in the different nodes of the network. Figure-3 illustrates the differences between the voltage levels in each scenario. In the conventional scenario, Nodes 852 and 890 present a serious decrease in the voltage level, near to the 19 hours. Including BESS in the LDS help to soft the decrease caused by the injection of active power in the network. That decrease will produce quality problems in the node. Other "small" changes between the voltage levels in the two scenarios are associated to the BESS operation input and output. Figure 3 and Figure-4 shows the relation between the increase of the active power levels and the voltage levels in each moment of the Quasi-Dynamic simulation.

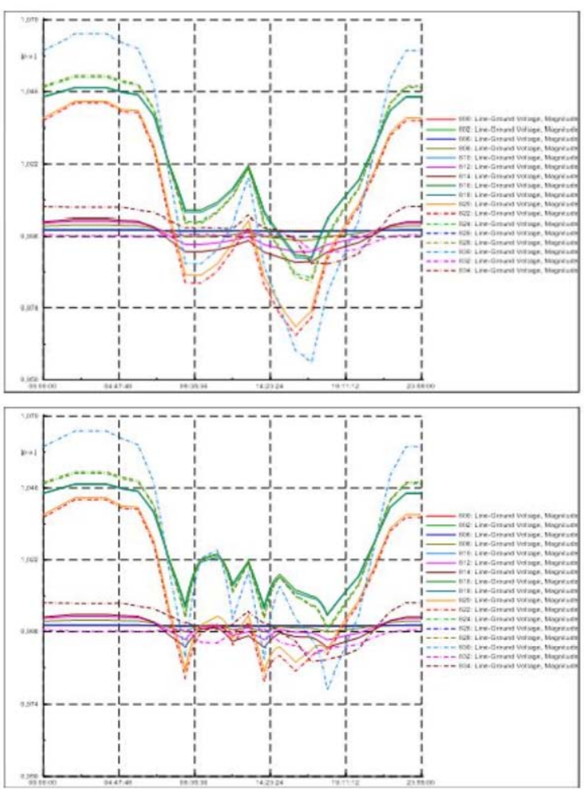

Figure-1. Voltage levels in some LDS nodes. Conventional scenario (top) BESS scenario (bottom).

3.2 Active Power Variations

Including BESS into the systems cause significant changes during the peaks of the demand curves. A significant change is observed on the peak of the morning, from 10-12 hours, BESS are bringing power supply into the system modifying the duration of the highest demand. On the other hand, during the second and higher peak, the levels decrease as a consequence of the low power demand, which now are BESS nodes of the LDS. As a result, the peak of the LDS demand changes from 1, 7 MW to 1, 5 MW. All the nodes continue feeding the load, but the general power demand of the LDS is lower.

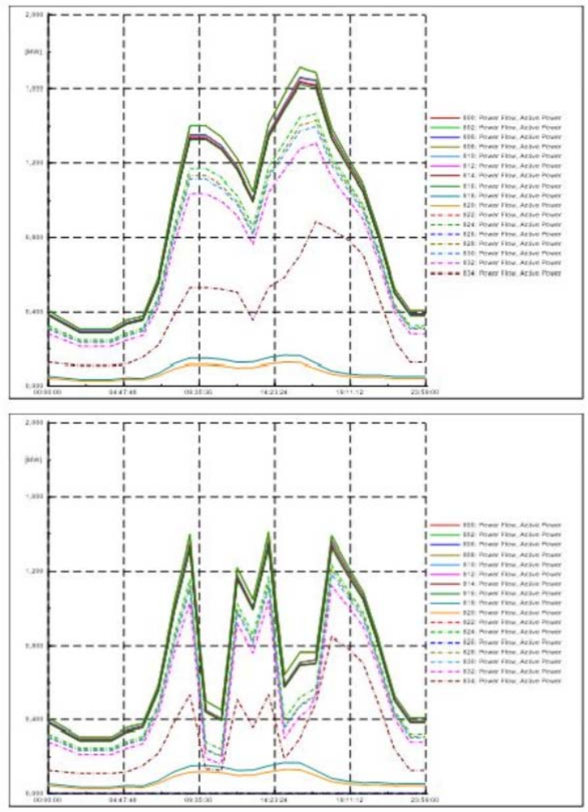

Figure-2. Active power levels in some LDS nodes. Conventional scenario (top) BESS scenario (bottom).

3.3 Reactive Power Variations

Including BESS into the systems cause significant changes during the peaks of the demand curves. In first place, we can see a significant change on the peak of the morning, where for 10-12 hours, BESS are bringing power supply into the system modifying the duration of the highest demand. On the other hand, during the second and higher peak, the levels decrease as a consequence of the low power demand, which now are BESS nodes of the LDS. As a result, the peak of the LDS demand changes from 1, 7 MW to 1, 5 MW. All the nodes continue feeding the load but the general power demand of the LDS is lower.

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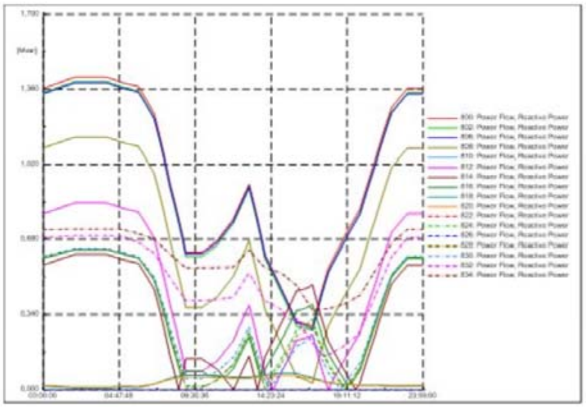

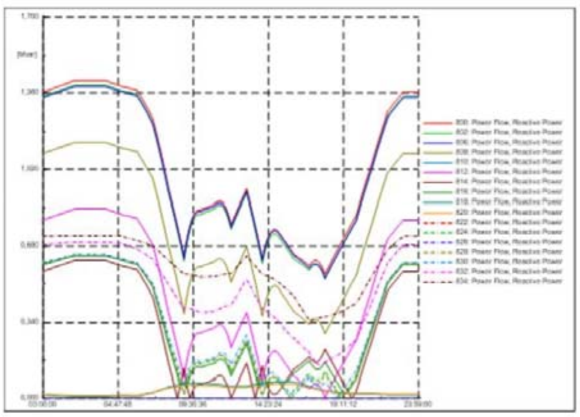

Figure-3. Reactive power levels in some LDS nodes. Conventional scenario (top) BESS scenario (bottom).

4. RESULTS AND DISCUSSIONS

4.1 Transformers Loading Variation

The operation of the BESS reduces the loading in the distribution transformer. As we can see in the previous sections, the IEEE 34 node test feeder is a lightly loaded feeder, the change in the power demand of the LDS decrease the loading of the transformers in 49% and 64%. The distribution transformer 22, 9/4, 16 kV is not taking into account because all the load that support is supply by the BESS in the node 490.

Table-3. Loads modified with the demand curves in Colombia.

Line	Loading	Losses
Trf 814/850	-49,74%	-80,92%
Trf 832/852	-64,08%	-85,99%

4.2 Lines Loading

The changes in the losses and loading in the lines represent a serious consequence of including BESS in a lightly loaded distribution system. On the first place, the bidirectional power flow increases the loading in the 836/840 in 400%. That line is in the furthest part of the LDS and have a BESS in the node 840. On the other hand, most of the lines of the LDS have a serious decrease in the loading as a consequence of the presence of new power sources in the network which cause the demand current value of connection point (Node 800) to decrease.

Table-4. Variation in the line's indicators in the scenarios.

Line	Max. Loading	I Max	Losses	Line	Max. Loading	I Max	Losses
800/802	-39,5%	-39,5%	-68,2%	834/842	-25,0%	-25,0%	-43,5%
802/806	-40,1%	-40,1%	-68,6%	834/860	-39,9%	-39,9%	-65,4%
806/808	-40,9%	-40,9%	-72,8%	836/840	402,1%	402,1%	2503,0%
808/810	-0,3%	-0,3%	-0,5%	836/862	-0,1%	-0,1%	-0,3%
808/812	-50,7%	-50,7%	-79,3%	842/844	-25,0%	-25,0%	-43,5%
812/814	-52,6%	-52,6%	-81,3%	844/846	1,9%	1,9%	-9,8%
816/818	1,1%	1,1%	2,2%	846/848	1,9%	1,9%	3,7%
816/824	-59,8%	-59,8%	-85,3%	850/816	-49,7%	-49,7%	-80,5%
818/820	1,1%	1,1%	2,2%	854/852	-64,1%	-64,1%	-87,9%
820/822	1,9%	1,9%	3,9%	854/856	4,2%	4,2%	8,6%
824/826	-2,3%	-2,3%	-4,5%	858/834	-40,2%	-40,2%	-67,7%
824/828	-61,8%	-61,8%	-86,4%	858/864	-0,3%	-0,3%	-0,4%
828/830	-62,3%	-62,3%	-86,5%	860/836	-44,7%	-44,7%	-57,0%
830/854	-64,1%	-64,1%	-87,8%	862/838	-0,1%	-0,1%	-0,3%
832/858	-38,9%	-38,9%	-66,0%	888/890	-53,3%	-53,3%	-78,2%

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4.3 Power Flow Variations

The operation of the BESS in the distribution network do not present important changes into the voltage levels of the load flow in comparation with the conventional scenario results. Table-4 shows the differences between the voltage levels of the two scenarios. Nodes 852 and 890 reflect the biggest changes with 7, 2 % and 9, 1% that change is a benefit of the system, because those nodes have low voltage levels during the demand peak hour.

Table-5. Voltage magnitude variation in the scenarios.

Node	Phase A	Phase B	Phase C	Node	Phase A	Phase B	Phase C
800	0,0%	0,0%	0,0%	836	-0,1%	-0,1%	-0,3%
802	0,0%	0,0%	0,0%	838	-	-0,1%	-
806	0,0%	0,0%	0,0%	840	-0,1%	-0,1%	-0,3%
808	0,2%	0,2%	0,2%	842	-0,1%	-0,2%	-0,3%
810	-	0,2%	-	844	-0,1%	-0,2%	-0,3%
812	-	0,5%	0,5%	846	-0,1%	-0,1%	-0,3%
814	0,7%	0,7%	0,7%	848	-0,1%	-0,1%	-0,3%
816	1,9%	1,8%	1,9%	850	1,9%	1,8%	1,9%
818	-	-	-	852	7,2%	7,1%	7,1%
820	1,9%	-	-	854	4,2%	4,1%	4,2%
822	1,9%	-	-	856	-	4,1%	-
824	2,3%	2,3%	2,3%	858	-0,3%	-0,3%	-0,4%
826	-	-	-	860	-0,1%	-0,2%	-0,3%
828	2,4%	2,4%	2,4%	862	-0,1%	-0,1%	-0,3%
830	4,1%	4,1%	4,1%	864	-0,3%	-	-
832	-0,4%	-0,4%	-0,5%	888	1,3%	1,3%	1,1%
834	-0,1%	-0,2%	-0,3%	890	9,1%	8,9%	8,4%

5. CONCLUSIONS

A Quasi-Dynamic simulation was performed in a LDS, modelling as the IEEE 34 nodes test feeder, with BESS in three different nodes located in the most remote areas of the network. The test feeder was modified including the demand load curves of the Colombian electric sector.

The nodes with low voltage problems during the demand peaks increase the voltage levels with the inclusion of the BESS in the system but is important to note that those nodes need another strategy to solve those conditions. The Quasi-Dynamic simulation shows that is necessary include voltage regulators in a distribution system to keep the levels in the adequate range. In a distribution system lightly loaded the BESS cause small voltage changes in the nodes.

On the other hand, the active power levels have important changes during the operation of the BESS. The load peaks decrease and keep the power demand in fewer levels. In addition, the levels of reactive power suffer some changes as a result of the modifications in the voltage and active power. The changes represent important increases during the peak demand hours where the BESS is operating. This increase becomes a topic of interest for the operators of the distribution network.

The inclusion of the BESS in the systems decreases the loading of the transformers up to 60% but increase the loading in one of the lines where a BESS was including. Most of the lines of the LDS decrease the loading associated.

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