VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# ENHANCEMENT OF ENVIRONMENT-FRIENDLY POWER GRIDS′ FLEXIBILITY TO SUCCESSFULLY HOST RESS AND EVS

S. Gasim Mohamed, J. Jasni, M. A. M. Radzi and H. Hizam
Department of Electrical and Electronic Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
E-Mail: salahgasim1@gmail.com

## ABSTRACT

Besides the economic aspect behind the renewable energy sources (RESs) and the electric vehicles (EVs), burning less fossil fuel is a significant response to the calls for the environment preservation. The RESs and EVs can optimize the grid operation. However, the RESs are intermittent in nature, and the EVs have different operation modes. Their changing pattern of operation is challenging and may initiate serious problems in the power grid. They necessitate enhancing the flexibility of the grid to enable handling the dynamics. This paper investigates the problem of lines' flow congestion as a result of the arising dynamics. Then, the congestion is relieved through the action of the Phase Shifting Transformer (PST) as used to control the active power flow. It is found that two PSTs are sufficient to enhance the flexibility of the grid to enable securely facing operating conditions like EVs fleet connection-disconnection, power system components outage, wind farm's output drop or complete shutdown considering 11.08% penetration level, and various combinations of such changing circumstances. MATLAB/SIMULINK is used to model a modified IEEE-14 bus system, the RESs, the EVs, and the PSTs. The results revealed the successful interaction of the grid with the dynamics of the RESs and EVs, and components outage.

**Keywords**: electric vehicles, grid flexibility, power flow control, phase shifting transformer, renewable energy sources.

## INTRODUCTION

The energy crisis and the global heating call to pay more attention to looking for alternatives to fossil fuels. Along with, deregulation of the electricity sector has encouraged the investment in power generation to aid the competitiveness in the energy market. On the other hand, the transportation sector is moving towards electrification of the vehicles. As a direct response to these calls, there is a global acceptance to integrate renewable energy sources (RESs) such as the wind and solar, and electric vehicles (EVs) to the power grids. By 2020, 2030, and 2050, China has set a goal that foresees wind farm capacities of 200 GW, 400 GW, and 1000 GW respectively [1], [2]. This escalating trend will facilitate supplying 17% of the electricity requirements. It is also proposed that the installed capacity of solar PV power generation units in China reach 35 GW and more by 2015, and 50 GW by 2020 [3]. Concurrently, the Department of Energy (DOE) of the US has examined feasibility of using wind power to cover 10% of the electric demand in 2020, 20% in 2030, and 35% in 2050 [4], [5]. Besides that the RESs reduce consumption of the fossil fuel and emission of gasses, their energy is also used in the transportation industry to empower the EVs for further saving of fossil fuel and reduction of gas emissions. The feasibility and economics of the joint interface between the grid and the EVs are investigated [6]. The EVs with their vehicle to grid (V2G) facility [7], [8], [9] and the RESs can optimize operation of power systems [10]. Integration of RESs and EVs in the deregulated power market with advanced communication and control systems [11] is shifting the previous century's power grid to a smart one. To this end, owing to being environment friendly, and owing to the low operating costs of the RESs and EVs, in a smart grid, it is economically advantageous to utilize their outputs fully and to commit them to the highest possible degree [12].

However, as the installed wind capacity grows more than 10% of the demand in an area, its intermittency becomes a major issue [13]. It increases the grid dynamics and in consequence, severe challenges are expected to arise if no flexibility is added to the present grid. While the RESs and EVs provide attractive opportunities, some challenges are imposed by the power grids. These challenges compel the changes in the planning, operation and control of the grids [14]. Hosting and relying on a large amount of the RESs and EVs may not take place fruitfully if the grid is not made flexible enough owing to the occurrence of some technical problems.

A serious problem that may occur is congestion of the transmission lines due to the RESs and EVs dynamics. These dynamics may also make the power system components outage more severe. Also, the congestion management difficulties are augmented owing to the nature of the RESs and EVs. When integrating these RESs and EVs to a grid, some important questions that arise are: Is the transmission network ready to host the high penetration of RESs? Is it able to withstand the dynamics of the EVs? What are the safety measures that should be taken? And what is the system state without and with these measures taken?

This paper is a direct reply to the recommendations addressed in [15], and it answers the above questions by examining effects of RESs' and EVs' dynamics on the transmission lines' flow security. It defines the network's lines weaknesses and grid's rigidness. Then, to add a degree of flexibility to the grid to mitigate the line's overloads, some Phase Shifting Transformers (PSTs) are located at the proper locations. The paper considers a variety of single and cascaded

VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

operating conditions such as wind farms shutdown, components outage, connection and disconnection of EVs, and their combinations.

## CHARACTERISTICS OF RESS AND EVs

The output of a wind power unit depends on the wind speed [13], and that of a PV unit depends on solar irradiance. Since wind speed and solar irradiance fluctuate, the output power varies. Figure-1 shows a variation of the output power of a wind turbine. The power curve of a 2.1 MW wind turbine is reproduced here from the actual data of [16]. There are times when no wind blows, and the energy drops to zero. On the other hand, when wind speed goes beyond the rated value, wind turbines are shut down, and their output power drops to zero. Such shutdown may initiate major problems in the power grid.

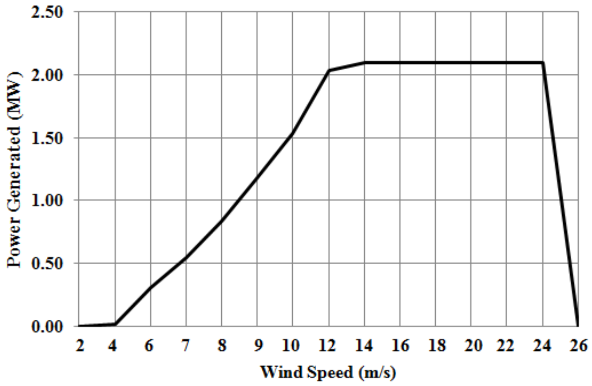



**Figure-1**. Power curve for a 2.1 MW wind turbine [16].

Figure-2 shows solar radiation's curve in summer [17]. The sun shines for about half of the daytime and completely disappears for the rest of the time, and thus, the PV output drops to zero. Also, within the daytime, the solar irradiation may fluctuate owing to the clouds.

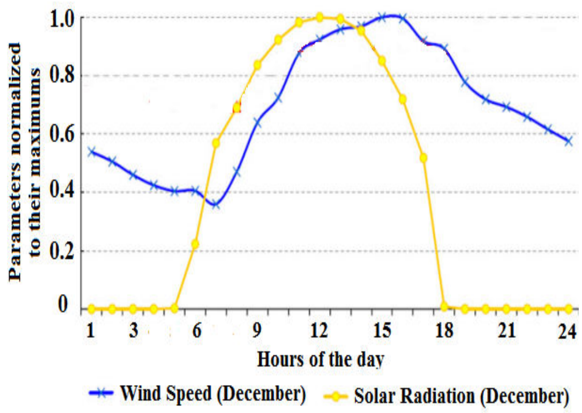



**Figure-2.** Daily load curve, wind speed, and solar radiation normalized to their maximum value in summer [17].

Electrification of the transportation scheme is expected to have significant impacts on the power grid owing to the increase in power consumption on one hand and the changing demand of the EVs on the other. It has been estimated that the total charging load of the EVs in the US can reach 18% of the US summer peak demand at the EVs penetration level of 30% [18]. The generation pattern is expected to change. The increasing demand and its pattern are expected to alter the overall load shape of power systems, and thus the transmission lines' flows. Charging of a bulky population of EVs has a noteworthy impact on the power network. Wu [19] has studied the effects of the EVs integration on distribution networks, considering voltage levels up to 60 kV. It is also stated that the congestion that is caused by the EVs can be observed at the medium-voltage level [20], [21].

## MITIGATION OF RESS' AND EVS' DYNAMICS

The combination of some wind farms results in a more stabilized output [12] as can be seen in Figure-3. The figure compares the normalized output of five equally sized farms located in the N. Ireland region with the averaged output of all farms. The variation is still high besides that, the fitting degree of the combination may not always be viable.

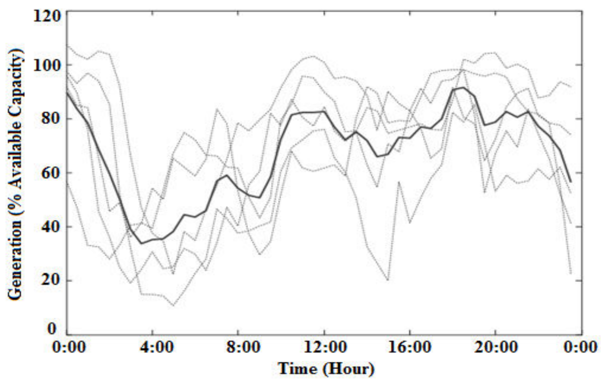



**Figure-3.** Five wind farms' variability (24 Hours) [12].

The EVs' fleets can be aggregated and controlled under the virtual power plant (VPP) concept model [22]. In such VPPs, a large number of EVs is grouped and managed as a single distributed energy source [23]. The aggregation takes place in different ways depending on the control schemes and the objectives to realize the V2G concept [24].

Wind forecast, and energy storage systems (ESS) [13], as well as wind farms' aggregation, are useful tools to mitigate the intermittency. However, the major difficulty is that presently the available ESS options cannot successfully be used at utility-scale capacities [25]. Currently, the ESS options are expensive and have limited potential applications [25]. Owing to these limitations, a suitable mix of implementation of the ESSs and enhancement of the network's flexibility is useful. The intermittency of the RESs and the mobility and charging-discharging nature of the EVs along with the frequent components outage should be met by a counter action in

VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



the grid through its controls. Self-healing, flexible and smart grids are needed to smooth introduction of RESs and EVs and to meet the repeatedly occurring changes securely and reliably [13], [15].

## CASE STUDY AND METHODOLOGY

A modified IEEE-14 bus system, which is shown in Figure-4 is considered in this study. The modified data are in Table-1 and Table-2. The modification included penetration of 75 MW rated wind farm, which represents 11.08 % of the demand, 30 MW EVs charging load, 20 MW rated PV unit, and 20 MW rated V2G power supply. MATLAB/SIMULINK is used for modelling and simulation. Load flow analysis is used to investigate effects of the RESs' and EVs' dynamics and transmission line outage on the lines' flow security. The flow security is judged by using transmission line loading index PIp [12]. The network weaknesses are determined, and some PSTs are located to enhance the lines' flow security. Then, the simulation is run again with the PSTs action to check the status of the security.

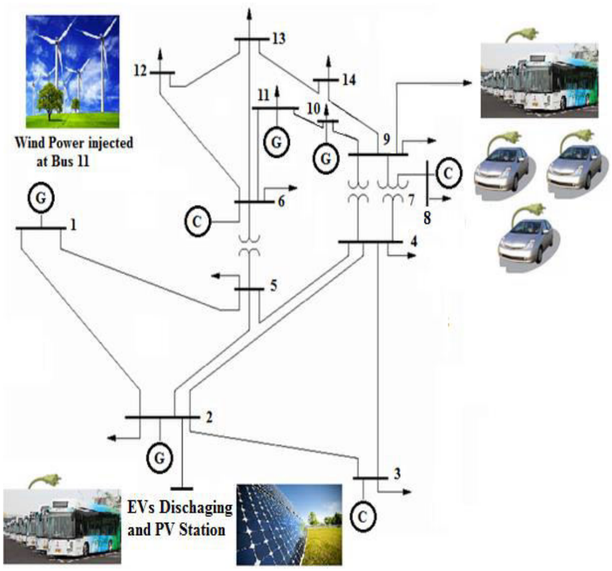



**Figure-4.** A modified IEEE-14 bus system.

## TRANSMISSION LINE LOADING INDEX

Transmission line active power loading security can be estimated through usage of the index ($PI_P$) [12]. The index is given by:

$$PI_P = \sum_{i=1}^{l} \left( \frac{P_i}{P_{i-\max}} \right)^{2n} \tag{1}$$

where $i$ is the transmission line number, $l$ total number of transmission lines, $P_i$ actual active power flow in line ($i$), $P_{i\text{-}max}$ maximum allowed active power loading of line ($i$), and $n$ a real positive integer.

Value of the integer ($n$) should be increased up to disappearance of the masking error. Value of the index PIp in Equation. (1) with a large value of ($n$) is a large number for the cases where at least an overloaded line exists.

## SIMULATED SCENARIOS AND RESULTS

Besides the base case, i. e. the base operating condition, simulation of five scenarios is considered. These scenarios include three single cases and two cascaded ones. The individual cases are **1**. connection of EVs fleet to charge, **2**. shutdown of the wind farm, and **3**. Trip of PV unit (or unplug of V2G-EVs). The cascaded cases include **4**. drop of wind farm's output power to 50% during EVs charging, and **5**. outage of the line (9-10) during EVs charging. In the base case, all transmission lines, transformers and generation units are connected including wind farm and PV (or V2G-EVs). Two PSTs are located at the congested paths which are Trans. (5-6) and Trans. (4-9). The results in Figure-5 to Figure-9 show active power flow in the congested transformers among three main paths in base case and in the considered operating condition pre and post the PST action. Besides, Figure-10 shows values of the $PI_P$ in all of the considered operating conditions pre and post the PSTs' action.

### Connection of 30 MW rated EVs fleet to charge

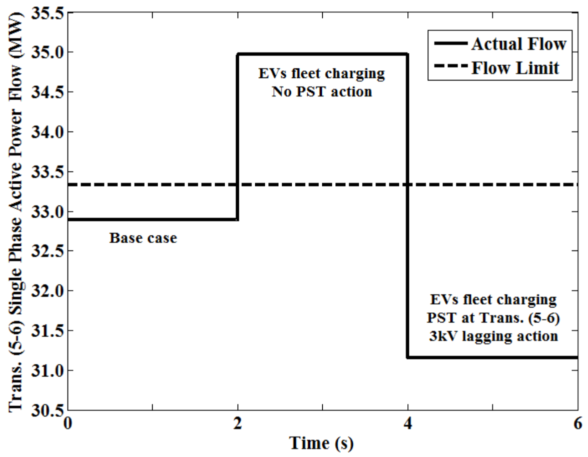
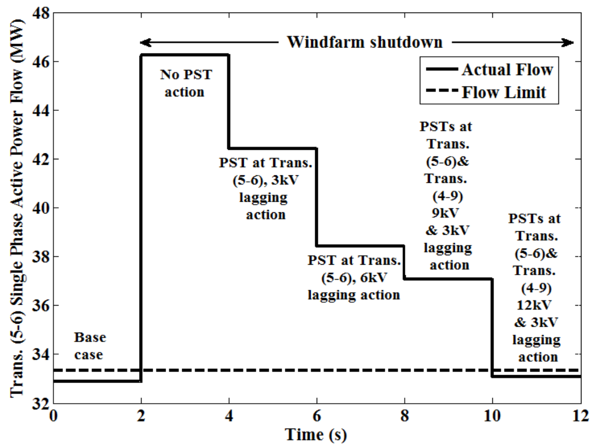



**Figure -5.** Connection of 30 MW rated EVs fleet to charge at bus 9: active power flow of Trans. (5-6).

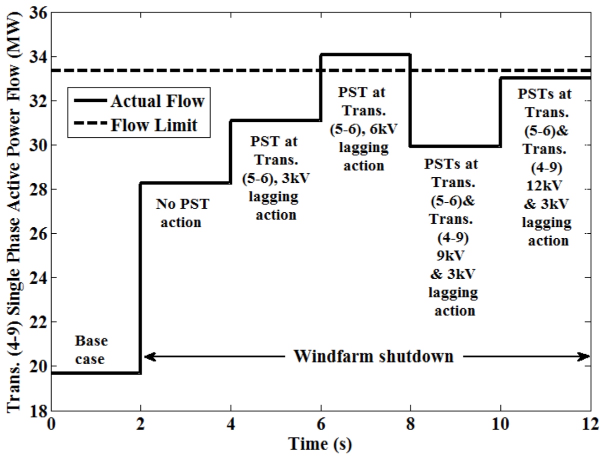
### Shutdown of the 75 MW rated wind farm




(a)

VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com



(b)

**Figure-6**. Shutdown of the 75 MW rated wind farm: active power flow of (a) Trans. (5-6), (b) Trans. (4-9).

**Trip of 20 MW PV unit (or unplug of the V2G-EVs)**

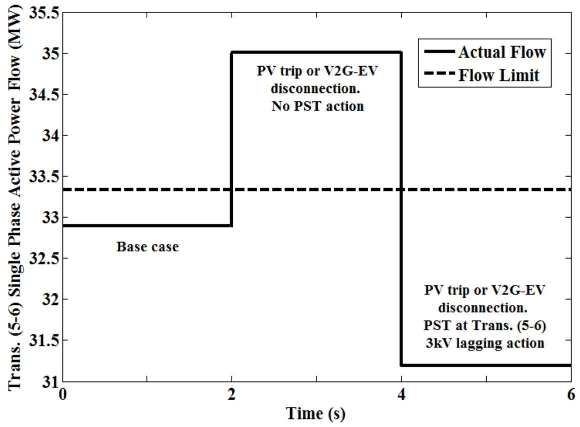
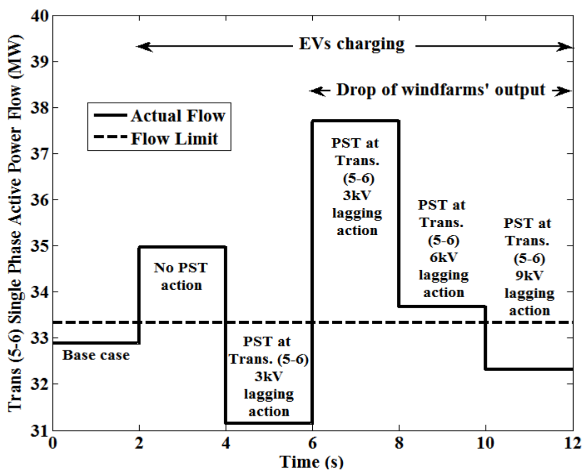
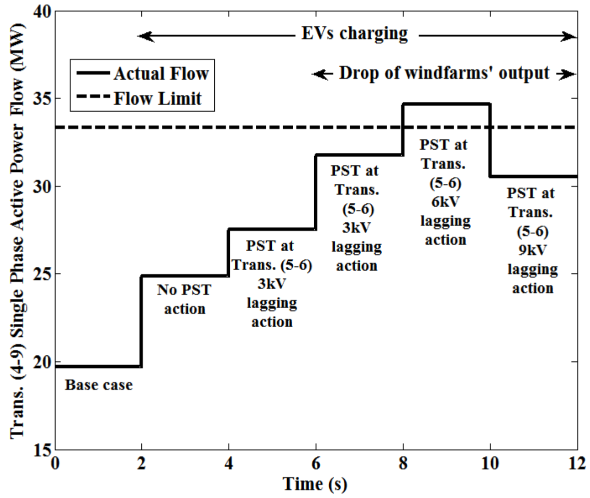



**Figure-7.** Trip of the PV (or unplug of the V2G-EV): active power flow of Trans. (5-6).

**Drop of wind farm's output during EVs charging**



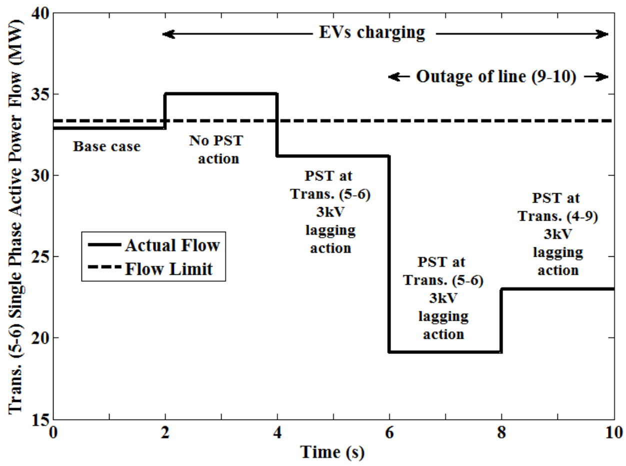
(a)



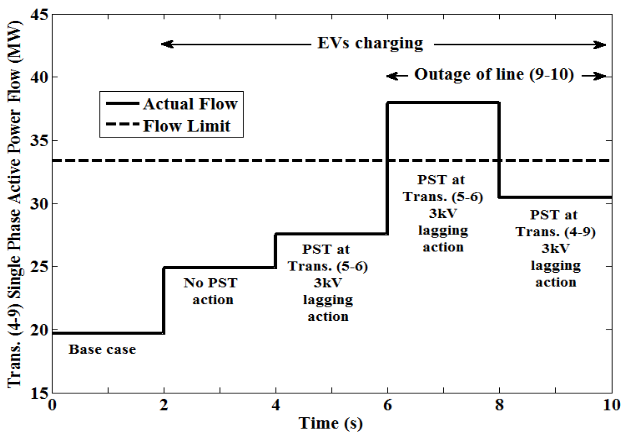
(b)

**Figure-8.** Shutdown of the wind farm during charging the EVs: active power flow of (a) Trans.(5-6), (b) Trans.(4-9).

**Outage of line (9-10) while charging the EVs**



(a)



(b)

**Figure-9.** Outage of the line (9-10) during EVs charging: active power flow of (a) Trans. (5-6), (b) Trans. (4-9).

VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

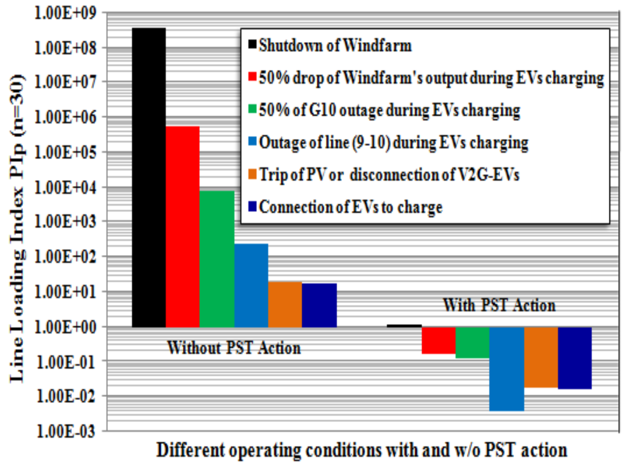



**Figure-10.** Values of the PIp index for the considered operating conditions pre and post the PSTs action.

## ANALYSIS AND DISCUSSION OF RESULTS

In this study, a wind farm is assumed whether working fully, its output drop to 50%, or completely shut down. Vehicles of the EVs fleet are assumed to be connected and disconnected altogether as one source or one load. The study has focused on steady state active power flow without considering the transition periods. Also, among all of the lines and transformers of the system under study, the results only showed power flow of the always congested paths. In the base case operating condition, lines loading index PIp = 0.448 revealing that the lines' active power flow is secured. In each of the five operating scenarios, Trans. (5-6) is get congested as can be seen in Figure-5 to Figure-9. Activation of the lagging action of a PST connected to this transformer has reduced its active power flow. PST's action on Trans. (5-6) shifts the excessive active power to Trans. (4-9) and Trans. (4-7). Only one step of the PST is needed to relieve the congestion of Trans. (5-6) in the operating scenarios 1 and 3. The worst operating scenario is shutdown of the wind farm. With penetration level of 11.08%, shutdown of the wind farm caused 38.7 % overloading on Trans. (5-6). This represents a significant congestion that needs to be relieved. Rather than in summer, in winter, the permissible four hours' emergency rating of circuit breakers should not exceed 34% of its rated capacity [27]. In this case, four steps of PST are activated to relieve the congestion of Trans. (5-6) as can be seen in Figure-6 (a). While Trans. (5-6) is still congested, when applying its PST's second step (6kV lagging), Trans. (4-9) started to get congested. Setting the PST's action of Trans. (4-9) to 3kV lagging relieves its congestion. Final setting of the PSTs at Trans. (5-6) and Trans. (4-9) is 12kV and 3kV respectively. This resulted in decreasing value of Pip from $3.33 \times 10^8$ to 1.194 as a sign of elimination of all overloads. In the cascaded cases, the action is performed in sequence. Thus, the same action of the PSTs is needed first to relieve the congestion as that of case 1. During charging the EVs, a drop of 50% of wind farm's output in operating scenario 4 and outage of the line (9-10) in operating scenario 5 caused congestion of Trans. (5-6) again, and congestion of Trans. (4-9) respectively. Outage of the line (9-10) during the EVs charging caused drop of the active power flow of Trans. (5-6) that resulted in resetting its PST's lagging action to zero. Figure-10 depicts raise of the value of the PIp index in all considered operating scenarios, and success of the PST's setting to drop the value of the PIp in all considered operating scenarios. The results revealed the added flexibility to the grid through usage of two PSTs. The results also showed success of the PSTs in handling the dynamics of all different single and cascaded operating scenarios.

## CONCLUSIONS

This work has addressed importance of enhancement of the flexibility of the grid to ensure its continuous successful operation when the RES units output intermits, the EVs are connected and disconnected, and when the power system components trip. The paper first investigated lines' loading security problem as an impact of RESs and EVs dynamics and components outage. It identified the bottlenecks and then improved the lines' loading security through enhancing the grid's flexibility by using a set of PSTs introduced to the weakest links. The PST with its relatively slow response as compared to power electronics based FACTS devices is reasonable to be used to enhance the lines' flow security against RESs' and EVs' dynamics. PSTs' relatively small cost aids their wide usage for such purpose. Since the transmission lines and transformers can withstand emergency overloading conditions for some minutes in case of severe violations, and some hours in case of slight ones, the results revealed that PSTs' stepping action of 2 seconds interval is sufficient for the purpose of real-time transmission lines congestion relief. The study focused on steady state load flow analysis. For during the dynamic changes periods, i. e. instants of RESs and EVs transients within interval of activation of a PST's step, a support by a small RES unit would enhance stability of the grid.

## APPENDIX: DATA OF THE MODIFIED SYSTEM

Transmission lines and transformers impedance data are not altered. They are typical as that in [26]. The transformers' three phase active power capacity is taken as 100 MW each. The modified data are as shown below. Table-1 shows modified capacities of the fossil, RES units, and EVs fleet. Table-2 shows modified ratings of loads and synchronous condensers.

**Table-1.** Modified generation capacity.

| Gen. No. | Type | Rated Capacity (MW) |
|---|---|---|
| 1 | Fossil | 600 |
| 2 | Fossil + PV/EVs | 40 + 20 + 20 |
| 10 | Fossil | 100 |
| 11 | Wind | 75 |
| 13 | Fossil | 50 |

ARPN Journal of Engineering and Applied Sciences



**Table-2.** Modified load and compensation.

| Bus No. | P (MW) | Q (MVAr) | Synchronous Condensers (Mvar) | |
|---|---|---|---|---|
| | | | Min | Max |
| 3 | 80 | 20 | -20 | 40 |
| 4 | 70 | 30 | -30 | 120 |
| 5 | 90 | 40 | -30 | 130 |
| 6 | 55 | 20 | -20 | 20 |
| 8 | 25 | 20 | -20 | 20 |
| 9 | 62+30(EV) | 34+1(EV) | -- | -- |
| 11 | 105 | 30 | -- | -- |
| 12 | 40 | 30 | -- | -- |
| 14 | 120 | 50 | -50 | 90 |
| Total | 677 | 275 | -170 | 420 |

## REFERENCES

[1] J. Kejun, H. Xiulian, Z. Xing and L. Qiang. 2009. China′s Low-carbon Scenarios and Roadmap for 2050[J]. Sino-Global Energy. Vol. 6, No.6, pp. 21-26.

[2] Wang Z., Shi J. and Zhao Y. 2011. Technology roadmaps: China wind energy development roadmap 2050.. Paris, France: International Energy Agency: http://www.iea.org/publications/freepublications/publication/china_wind.pdf.

[3] M. Zhang, D. Zhou and P. Zhou. 2014. A real option model for renewable energy policy evaluation with application to solar PV power generation in China. Renewable and Sustainable Energy Reviews. Vol. 40, pp. 944-955.

[4] 20% Wind Energy by 2030, Increasing Wind Energy’s Contribution to US Electricity Supply, Tech. Rep. DOE/GO-102008-2567. July 2008: http://energy.gov/sites/prod/files/2013/12/f5/41869.pdf July 2015.

[5] Lindenberg S. 2009. 20% Wind Energy By 2030: Increasing Wind Energy’s Contribution to US Electricity Supply. DIANE Publishing. pp. 1-20.

[6] Y. Dashora, J. W. Barnes, R. S. Pillai, T. Combs and M. Hilliard. 2012. Optimized energy management for large organizations utilizing an on-site PHEV fleet, storage devices, and renewable electricity generation. Energy Systems. Vol. 3, pp. 133–151.

[7] Guille C. and Gross G. 2008. Design of a conceptual framework for the V2G implementation. In: Energy 2030 Conference. ENERGY 2008. IEEE. pp. 1-3.

[8] W. Kempton and S. Letendre. 1997. Electric vehicles as a new power source for electric utilities. Transportation Research Part D. Vol. 2, No. 3, pp. 157–175.

[9] F. Mwasilu, J. J. Justo, E. K. Kim, T. D. Do and J. W. Jung. 2014. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. Renewable and Sustainable Energy Reviews. Vol. 34, pp. 501-516.

[10] W. Su, H. Rahimi-Eichi, W. Zeng and M-Y. Chow. 2012. A survey on the electrification of transportation in a smart grid environment. IEEE Trans. Industrial Informatics. Vol. 8, No. 1, pp. 1–10.

[11] V. C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati and G. P. Hancke. 2013. A survey on smart grid potential applications and communication requirements. IEEE Trans. Industrial Informatics. Vol. 9, No. 1, pp. 28-42.

[12] Fox B., Flynn D. and Bryans L. 2014. Wind Power Integration: Connection and system operational aspects. 2nd Edition. IET. London. UK.

[13] Daneshi H. and Srivastava. A. K. 2012. Impact of battery energy storage on power system with high wind penetration. In: 2012 Transmission and Distribution Conference and Exposition. pp. 1-8.

[14] M. D. Galus, M. G. Vayá, T. Krause and G. Andersson. 2013. The role of electric vehicles in smart grids. Wiley Interdisciplinary Reviews: Energy and Environment. Vol. 2, No. 4, pp. 384-400.

[15] Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage. White Paper International Electrotechnical Commission. 2012. p. 60

[16] Wind power problems, alleged problems, and objections.http://ramblingsdc.net/Australia/WindProblems.html. July 2015.

[17] P. De Jong, A. S. Sánchez, K. Esquerre, R. A. Kalid and E. A. Torres. 2013. Solar and wind energy production in relation to the electricity load curve and hydroelectricity in the northeast region of Brazil. Renewable and Sustainable Energy Reviews. Vol. 23, pp. 526-535.

[18] Ma Z., Callaway D. and Hiskens I. 2010. Decentralized charging control for large populations of plug-in electric vehicles. In: Decision and Control (CDC), 2010 49th IEEE Conference. pp. 206-212.

[19] Wu Q. 2013. Grid Integration of Electric Vehicles in Open Electricity Markets. John Wiley & Sons. UK.

[20] Lopes J. A. P., Soares F. J. and Almedia. P. M. R. 2009. Identifying management procedures to deal with

connection of electric vehicles in the grid. In: 2009 IEEE Bucharest PowerTech. pp. 1–8.

[21] Clement K., Haesen E. and Driesen J. 2009. Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids. In: 2009 IEEE/PES Power Systems Conference and Exposition. pp. 1–7.

[22] M. Vasirani, R. Kota, R. L. G. Cavalcante, S. Ossowski and N. R. Jennings. 2013. An agent-based approach to virtual power plants of wind power generators and electric vehicles. IEEE Trans. Smart Grid. Vol. 4, No. 3, pp. 1314–1322.

[23] J. R. Pillai and B. Bak-Jensen. 2011. Integration of vehicle to grid in the western Danish power system. IEEE Trans. Sustainable Energy. Vol. 2, No. 1, pp. 12–9.

[24] E. Sortomme and M. A. El-Sharkawi. 2012. Optimal scheduling of vehicle-to-grid energy and ancillary services. IEEE Trans. Smart Grid. Vol. 3, No. 1, pp. 351–359.

[25] Begovic M. M. 2013. Electrical Transmission Systems, and Smart Grids: Selected Entries from the Encyclopedia of Sustainability Science and Technology. Springer Science & Business Media. New York. USA.

[26]Power Systems Test Case Archive - UWEE, University of Washington www.ee.washington.edu/ research/pstca/.

[27] Capacity Rating Procedures by the System Design Task Force, August 1970, Corrected October 2004 www.isone.com/rules_proceds/isone.../capacity_rating _procedures.pdf.