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Smart Voltage Stability Enhancement Using Optimized Fuzzy Inference System

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Abstract. Today's electrical grids are evolving at their unprecedented pace, therefore; stability issues became more prominent than ever before. Although many solutions are used to achieve voltage conservation, many grids are still suffer from black outs due to voltage collapse phenomenon. In such critical operating points, arbitrary load shedding would be more economical rather than forced wide spread shut downs. Meanwhile, whether or not the amount of load and the assumed bus are the most appropriate choices, can be a serious concern. In this paper, a methodological concept of fuzzy-PSO inference is used to determine more reliable response for load shedding programs. The results indicate that load shedding procedure could be operated more beneficial by means of smart loads operation based on Fuzzy logic.

Keywords: Voltage Stability, Intelligent Load Shedding, Optimized Fuzzy Inference, Smart Grid

1. Introduction

Economical and environmental issues limited the possibility to build new bulk power plants and transmission lines. Accordingly, today's electrical networks are operating close to their permissible stability limits. Conservation of voltage stability in restructured networks is a part of ISO services and defined and classified in FERC 888 order [5]. Improving the voltage stability margin of a power system, some methods have been used for long.

- Installation of reactive power compensator devices such as shunt capacitors, SVC & STATCOM
- Using On-Load Tap Changer transformers
- Generator's automatic voltage and reactive power regulation
- Cooperation between control and protection algorithms of the system
- Emergency Load Shedding

Among all the proposed solutions, shunt capacitors and SVCs are not reliable as the injected reactive power is proportional with V^2 then in case of voltage decrease, less reactive power would be injected.

OLTCs probably have adverse effects since the tap changing process, increases the secondary voltage which leads to increased primary current and loads will be restored to the grid afterwards [4].

During voltage instability occurrence, controlling systems may decide to detach a part of increasing load before the operation of protective devices shuts down a whole feeder. This is called as Load Shedding (LS) which varies in implementation methods. As far as almost every implemented method of LS leads to excessive load curtailment due to non-real-time calculated measurements besides slow operation [6], the methodology in this paper tries to define an intelligent approach to determine more precise response from loads to such critical situations. By advent of Smart Grid concept, and improvement of demand response programs, the proposed method is more feasible in Direct Load Control (DLC) or Emergency Demand

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response (EDR) frameworks [7]. Proposed approach in this paper is based on fuzzy inference systems for better implication and faster response. In order to enhance the reliability of the result, membership functions are optimized by PSO algorithm.

2. Proposed Methodology

A specific evaluation of voltage stability of a power system reveals that we are more dealing with uncertain definitions and observations rather than certain numerical parameters. An index which shows the risk of voltage instability (RVI) is introduced in some papers [1-3] for voltage stability study and inasmuch as the risk measurement is not defined by certain degrees, this in turn shows the feasibility to use this index as an input variable of a fuzzy inference system.

LS process requires two separate steps. First the suitable bus for implementing LS should be determined. This level is done in [1] by considering RVI and V_m as two input variables of a Mamdani fuzzy system and acquiring Suitability of Buses for Load Shedding (SBLS) as an output. RVI index is defined as bellow.

$$RVI_j = \left|1 - \frac{\sum_{i\in\alpha G} F_{ji}V_i}{V_j}\right|, j \in \alpha L \tag{1}$$

Where, αL, is the load bus set; αG, is the generator bus set; V_i, is the complex voltage at generator bus i; V_j, is the complex voltage at load bus j; F_{ji}, is computed as bellow:

$$[F] = -[Y_{LL}]^{-1}[Y_{LG}] \tag{2}$$

Where $[Y_{LL}]$ and $[Y_{LG}]$ are sub matrices of the Y-bus matrix.

RVI=1 indicates instability phenomenon and smaller RVI means more stable situation the system is working in.

Related membership functions and Fuzzy decision matrix is proposed in [1] and Figure 1 depicts that the value of output is higher when the NRVI index is closer to 1 and voltage magnitude recedes from 1 p.u..

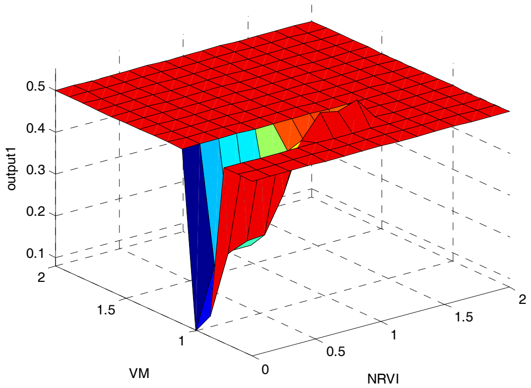
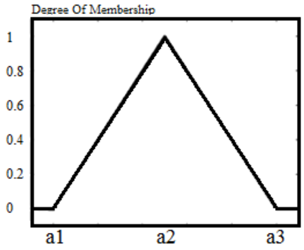


Fig. 1: The behavior of output of the proposed system in different input values



$$A = [a_1 \ < \ a_2 \ < \ a_3]$$

Fig. 2: Spot respective sequence constrain

In the next step by which the amount of load is going to be obtained for shedding, Takagi Sugeno Kang (TSK) method is proposed to be used because of more suitability for computational study. It is also considered to optimize membership functions of the fuzzy inference for even more appropriate results. Subsequently, PSO algorithm is applied on membership functions which are considered with Gaussian shapes instead of triangular to prevent additional constrain of spot respective sequence. By means of Gaussian function, variance and central point can be independently optimized. Related Gaussian function used for TSK membership functions is defined..

$$y = \frac{\sum_{i=1}^{r}\mu_i(\vec{x})f_i}{\sum_{i=1}^{r}\mu_i(\vec{x})} \tag{3}$$

$$\mu_i(\vec{x}) = \prod_{j=1}^{n} M_{ij}(x_j) = \exp(-\sum_{j=1}^{n}(\frac{x_j-m_{ij}}{\sigma_{ij}})^2) \tag{4}$$

$$\mathrm{f_i}(\vec{x}) = \sum_{j=1}^{n} W_j x_j + W_0 \tag{5}$$

Where, y, is the output variable of TSK fuzzy system; $\mu_i(\vec{x})$, is the membership function of input variables x; $\mathrm{f_i}(\vec{x})$, is the function of input variables; σ_{ij}, is the variance of Gaussian function; m_{ij}, is the central point of Gaussian function; r, is the number of rules; and n, is the dimension of given data.

By defining a cost function includes square of summation of difference of bus voltage magnitudes with their nominal voltage which should be minimized, and a penalty for positive results of subtracting nominal voltages from voltage bus to prevent over voltages, PSO will give us the optimized value of a vector of σ, m and f variables.

Same rule matrix is considered for the fuzzy inference system at this stage and another input variable is defined for calculating the appropriate shedding load. This variable is indicated by ΔRVI and is considered as described below [1].

$$\Delta RVI_j = \sqrt{(\Delta RVI_j^I)^2 + (\Delta RVI_j^R)^2} = RVI_j - TV \tag{6}$$

Where, TV is a Threshold Value shows the required sensitivity of the system against instability occurrence. Lower TV makes the shedding operate in less critical situations and leads to unnecessary load curtailments; while, higher TV results in operation of power system near instability limits.

Finally, specified TSK fuzzy inference algorithm with two input variables of ΔRVI and V_m and an output variable of Sheddable Load (SL) create the response of the power system encountering with voltage instability.

3. Numerical Case Study

To understand how effective can the proposed method be on the enhancement of voltage stability of a power system, an IEEE 14-bus test system is used to pursue numerical study. Before implementing the proposed method through the network, continuation load flow is used to acquire bus voltages and λ-V curve under normal operating of the system. The results are depicted in Figure 3 and Figure 4 and minimum eigenvalues (Figure 5) of the system is compared before and after LS to represent the advantages of the proposed method. The ameliorated voltage profiles of buses can be easily illustrated in Figure 7 while Figure 8 shows the improvement in loading factor after ILS method is launched.

Fig. 3: The diagram shows the load margin at 2.5 load factor

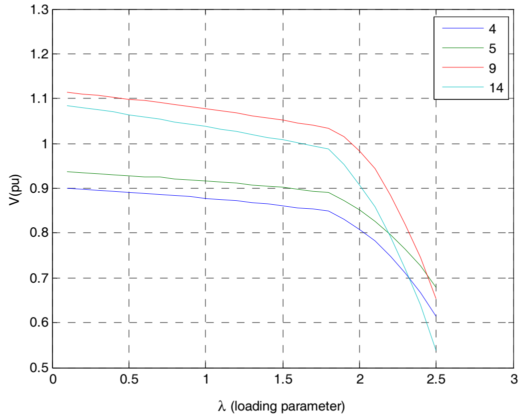
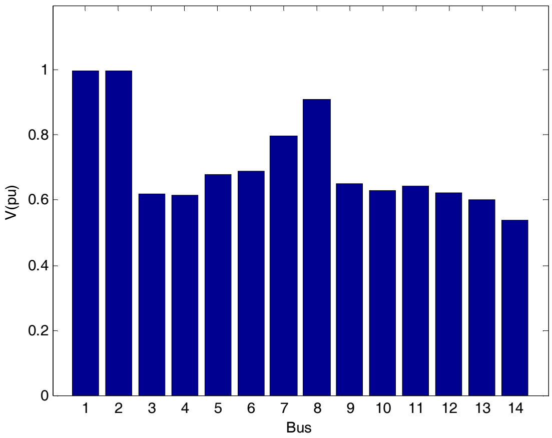


Fig. 4: Bus-Voltage magnitudes before ILS program



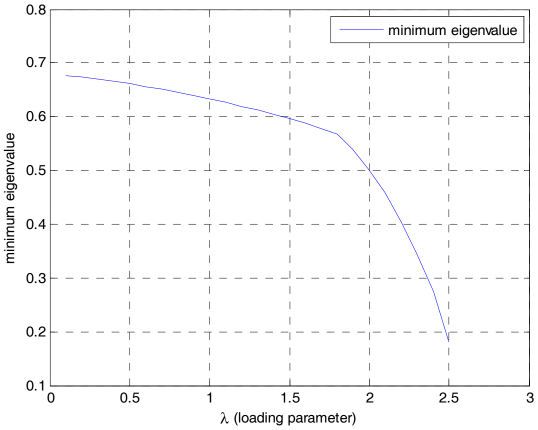


Fig. 5: Minimum eigenvalues of the system before ILS

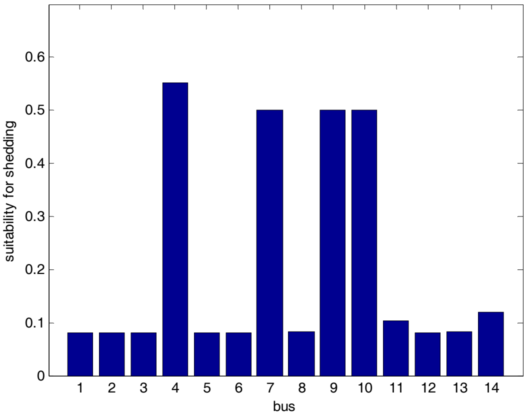


Fig. 6: SBLS output of mamdani fuzzy inference system

This evaluation is carried out with condition of steady load increment and should also be investigated during uncertain load increment. Following diagrams indicate the result of proposed ILS method during uncertain load increment which is closer to the realty of power systems. Without implementing ILS method, maximum loadability of the system is roughly the same as previous load increment. The results of enhancing load margin of the system after ILS, can be inferred from Figure 10.

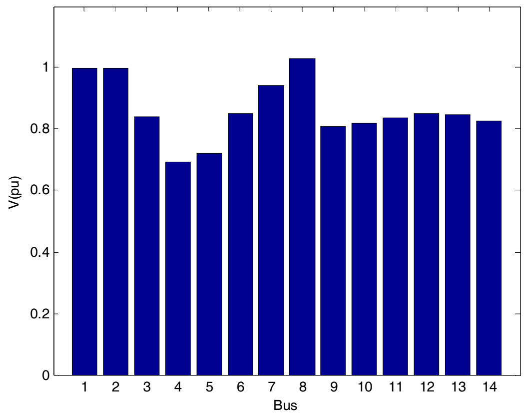


Fig. 7: Ameliorated voltage profiles

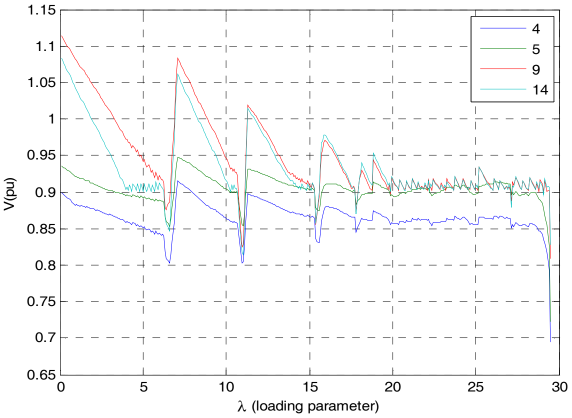


Fig. 8: Improvement of load margin after ILS

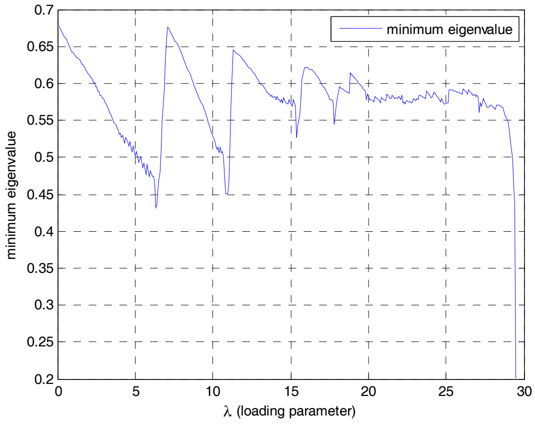


Fig. 9: Improvement of minimum eigenvalues

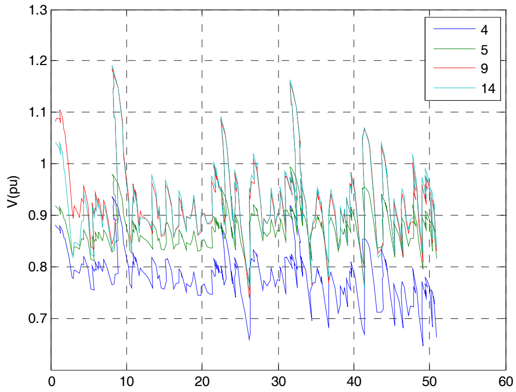


Fig. 10: Enhancement of load margin after ILS program during uncertain load increment conditions

The results point out in case of running the proposed Intelligent Load Shedding program the maximum load factor of the system improves from 2.5 to near 30 and by drawing minimum eigenvalue curve, gradation of stability margin of the given system can be evolved.

4. Conclusion

To sum up the main point, it is accepted that emergency solution of load shedding in undeniable for power systems to prevent voltage collapse phenomenon during instability situation. Some methods presently used by operators are not accurate and thoroughly reliable. The proposed method of intelligent load shedding in this paper, results in more compatible determination of amount of load and bus number to launch the ILS program there. This method is based on fuzzy inference logic for fast response and also since the risk of instability of the network considered as an uncertain parameter. TSK is chose for better possibility of optimization of membership functions using PSO algorithm for more accurate decision. Results shown that after implementing the proposed method both the load ability and bus voltage profiles are enhanced.

5. References

[1] J. Sasikala∗, M. Ramaswamy, "Fuzzy based load shedding strategies for avoiding voltage collapse" Applied Soft Computing 11 (2011) 3179–3185

[2] D. Thukaram, *Senior Member, IEEE,* Lawrence Jenkins, *Senior Member IEEE,* H. f. Khincha, *Senior Member, G.* Yesuratnam, B. Ravi Kumar, "Monitoring the effects of On-Load Tap Changing Transformers on Voltage stability"

[3] Claudia Reis Polytechnic Institute of Braganca Portugal Email: claudia-reis@ipb.pt, F.P. Maciel Barbosa Faculty of Engineering of Porto University Portugal Email: fmb@fe.up.pt, "A Comparison of Voltage Stability Indices"

[4] Stefan Johansson & Fredrik Sjögren, "Voltage collapse in power systems - The influence of generator current limiter, on-load tap-changers and load dynamics" Licentiate thesis Chalmers University of Technology 1995

[5] Promoting Wholesale Competition through Open Access Nondiscriminatory Transmission Services by Public Utilities. Federal Energy Regulatory Commission of the United States of America, April 1996.

[6] Shervin Shokooh Tanuj Khandelwal, Dr. Farrokh Shokooh, "Intelligent Load Shedding Need for a Fast and Optimal Solution" IEEE PCIC Europe 2005

[7] H.A. Aalami, M. Parsa Moghaddam *, G.R. Yousefi, "Demand response modeling considering Interruptible/Curtailable loads and capacity market programs" Applied Energy 87 (2010) 243–25