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Overloaded Transmission Lines Protection Based on Intelligent Control Protection Scheme

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Abstract: Some significant issue transmission lines protection in areas that have high renewable energy resources penetration especially wind power generation have defied the System Protection Scheme (SPS) designing these days. It is potentially, unavoidable to experience overloading problem during critical contingencies when a specific geographic area gathers around large wind generations. The primary focus of this study rests on creating an intelligent special protection and control scheme which integrates an intelligent strategy. Broadly speaking, the wind farms system stays far from the main center load based on the N-2 contingency indicating the loss of any (line, transformer and generator) seeking to ascertain the operating restrictions in different contexts. To address the issue of transmission lines overloading in high wind generation area for regulating the generation, the load is shed and system configuration changed in a reliable and efficient manner. The rationale for the proposed strategy will be experimented on a standard IEEE test system.

Key words: Protection, transmission line, contingency, stretegy, primary

INTRODUCTION

In recent times, renewable energy resources have demonstrated a striking development in the wind energy sector all across the world. The total generation has already occupied a significant whirlwind energy in a lot of the European countries. Due to the fact that the increasing number of wind generating facilities in the utility system is rapid, there is an emergence of many issues concerning their integration into the power system. It is different from one utility to another, the issuesare determined by the system size, location, wind power penetration and the network strength. In order to get some insights into the multitude of problems occurring or may be occurring to the utilities due to the large-scale integrated wind power the next thing to do is to select and study a test reference system such as IEEE test systems and share a large wind power generation. At this point, the MidAmerican Energy Company (MEC) system is thought to be very ideal for the study as the share of wind power in their system has achieved 30% by the installed capacity.

The system protection has been regarded by many world scholars as the primary menace to transmission networks. With the reduced investment of power system expansion of late and with the load growth especially in areas with weak transmission and generation and deregulation of the market demonstrating unusual load patterns, the protection system assessment has become an extraordinary tool and a series of theories to explain and analyze it are currently being constructed (Fagan *et al*., 2005). The main connection between the transmission issues is with the overloading of the transmission lines when all the wind power generated fails to be fully delivered due to the previous outage conditions. High wind resources can generally be found at a remote location and are quite distant from major load centers. Various control techniques have been adopted to enhance the wind power generation in wind areas with restricted transmission capability (Bousseau *et al*., 2006; Soder *et al*., 2007; Currie *et al*., 2006; Palsson *et al*., 2003). Such a scheme works only for the case where wind farms reside at the tip of interconnection and there is a certainty that all the power from the wind farm is going to flow only via the interconnected transmission line identified. The inevitable thing that will occur is that the areas will have limited transmission capabilities as they were designed mainly to cater for small loads in the area. A high level of penetration of wind power has transformed those areas into large generation areas. Administering such large

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generations in a fragile network with some shifting generation patterns can turn out to be a real operational issue. The cost of the wind energy spill is compared with that of the grid reinforcement that has economically beenintegrated in the system. This brings us to the development of wind turbines with fault ride through capability either through the control modification in DFIG and full converter design or through the external dynamic reactive support for the squirrel cage machines (Mullane *et al*., 2005; Causebrook *et al*., 2007; Molinas *et al*., 2008; Ummels *et al*., 2007). We cannot deny the fact that the traditional security assessment tools and methods used to handle the characteristics specific to wind power do have some limitations.

MATERIALS AND METHODS

Theoretical background

System Protection Schemes (SPSs): If we look into the design of the System Protection Schemes (SPSs), it serves to detect abnormal system conditions which are typically contingency-related and set off pre-planned, corrective actions to lower the risks or consequences of the abnormal system conditions and simultaneously provide up-to-standard system performance. The changes in load (load shedding), generation or system configuration to sustain the system stability, maintain acceptable voltages or power flows (Vinnakota *et al*., 2008) are some of the SPS actions. SPS is a system wide protection that works based on a coordinated control with various signals as inputs and the performance may be done in various locations. SPS triggering is normally performed by system disturbances, to name a few transient angular instability or frequency instability (Vinnakota *et al*., 2008). The characteristics of the SPS are as follows.

Protection which operates on selected rare contingency, usually out of design ranges of equipment permitting control actions, e.g., in secure operating case the generation and load shedding are the two aspects not executed. System wide protection functioning in various locations with a good coordination of control of multiple signals.

Systems permit greater operational risk-taking with probably the outside capabilities possibly protected by classical techniques. As, the network operation has been growing in complexity in the past years in regard of its growth in load, changes in market conditions and increased imports/exports, the stress in the network and the proliferation in the SPS is becoming more overwhelming than ever before.

Generation and load shedding techniques: As one of the most successful and commonly used corrective actions, generation shedding functions to allay the insecurity of power systems and transmission lines overloading under large disturbances. Balaraman and Kamaraj (2012) have introduced an intelligent generation rescheduling method based on the back propogation neural network to forecast the amount of overloading to reduce the line overloading due to a single contingency or system's abrupt change demand. The proposed model consists of three ANNs in a cascade. Sharma and Srivastava (2008) next, confirmed on her identification of the amount and overload transmission line based on the cascade Neural Network (CNN). The IEEE 14-bus system serves to validate the proposed techniques based on a variety of loading/generation conditions.

In the researchers have suggested on a new method that can work to enhance power system security including remedial actions using the Adaptive Artificial Neural Networks (AANN) technique. The method regards generation shedding as a control action in the presence of a fault, to make the power system more stable. A comparison of results of the proposed algorithm with other common methods can well make out that ANN can provide the right amount of generation redispatch and load shedding instantly. Bikas *et al*. (2009) had looked into the problem of dynamic security classification and the security control of the power system. Hybrid Neuro-Fuzzy Decision Trees (N-FDTs) came up with the, i.e., fuzzy decision tree with neural in order to sort out the power system's security status. The method runs an investigation on two case studies, the first concentrates on the stressed operation of the system and proposes corrective load shedding to prevent voltage collapse from taking place. The second presents the scenario of large scale wind power integration to the system and proposes wind power shedding to serve as a preventive action. Another technique called the Particle Swarm Optimization (PSO) has been proposed in Deb and Goswami (2012) for transmission congestion mitigation by rescheduling generator output. Rescheduling is performed in an Optimal Power Flow (OPF) framework to actively curb the entire congestion. The basis of the selection of the generators rests on their Generator Sensitivity Factor (GSF) and the PSO is used to reschedule the selected generators. Hagh and Galvani (2010) talked about a modified version of Non-Dominated Sorting Genetic Algorithm (NSGA) in effective optimization tools aiming to solve minimum load shedding problem under varying contingency conditions. Their approach works to

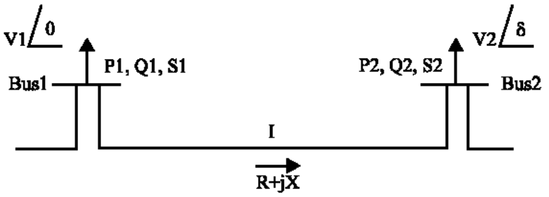

Fig. 1: Two-bus power system model

ascertain both the location and amount of load shedding in the power system and generator rescheduling in post contingency conditions such as transmission lines overloading and voltage violations. The same technique has been presented and modified in (Musirin and Rahman, 2002; Alganahi *et al*., 2009; Ishak *et al*., 2014) as a new version labelled the Bare Bones particle swarm optimization (BBExp) to verify the algorithm for load shedding. The load shedding has been presented by the algorithm to alleviate the lines overloading with the adoption of the Teaching Learning Based Optimization (TLBO). Therefore, optimal load shedding at the selected buses have been achieved for 30, 39-bus test systems.

Line voltage stability: The voltage stability condition in a power system can be attributed by the use of voltage stability index. This index can either be referred to a bus or a line. The FVSI being referred to a line is formulated as the measuring instrument in forecasting the voltage stability condition prevalent in the system (Murisin and Rahman, 2002). Figure 1 illustrates the proposed FVSI derived from a 2-bus power system model:

$$\mathrm{FVSI}_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \tag{1}$$

Where:

Z = Line impedance
X = Line reactance
Q_j = Reactive power at the receiving end
V_j = Sending end voltage

Mohamed *et al.* (1989) introduced a stability index based on the transmission line of a power system as the transmission line model in Fig. 1:

$$\mathrm{LQP} = 4\left(\frac{X}{V_i^2}\right)\left(\frac{X}{V_i^2}P_i^2 + Q_j\right) \le 1 \tag{2}$$

Therefore, conclusively, since the stability index LQP stays >1, the system's stability is maintained. If any value is more than that, the LQP indicates the collapse of tension.

Where, V_i, V_j = Sending and receiving bus voltage; P_i, P_j = Sending and receiving bus active power; Q_i, Q_j = Sending and receiving bus reactive power; S_i, S_j = Sending and receiving bus Apparent power; δ = Difference angle between receiving and sending bus, the $Z = R+jX$ is noted as line impedance.

Also, the symbols 'i' and 'j' depict the sending and receiving bus respectively. Finally, the particular line is closed to its instability point as voltage stability index closes to 1 further leading to line collapse.

The proposed intelligent spcs system: The Parallel Algorithm (PA) approach will be recommended here to calculate on the wind farm level as an alternative to the approaches commonly used. The introduction of this PA serves to assess system protection under both normal overload and contingency working conditions. In this study, the feasibility of the Special Protection and Control Scheme (SPCS) will be analysed on the IEEE 30-bus system using the voltage line stability indices and PA. Therefore, the optimization approach was run to minimize the wind farm generationinto a two-step approach as follows:

Step 1: The proposed PAto minimize the wind generation shedding in Eq. 3:

$$\min(\sum_{i\in K}\Delta P_{wi}^{t}) \ \forall t = 1,2,\ldots,T \tag{3}$$

Where:

T = Overload time to clear
t = The time step
K = Set of wind farms buses
ΔP_{wi}^{t} = Wind farm real power of ith

Step 2: If the transmission line overloads problem instep one, then it will be followed by loadshedding in Eq. 4:

$$\min(\sum_{i\in D}\alpha_{di}\Delta P_{di}^{t}) \ \forall t = 1,2,\ldots,T \tag{4}$$

Where:

α_{di} = Load priority during emergency
D = Total number of load buses
$\Delta p_{di}{}^{t}$ = Amount of shed load at each bus

Figure 2 shows the entire proposed algorithm which includes all strategies which reduce the transmission lines overloading during contingencies.

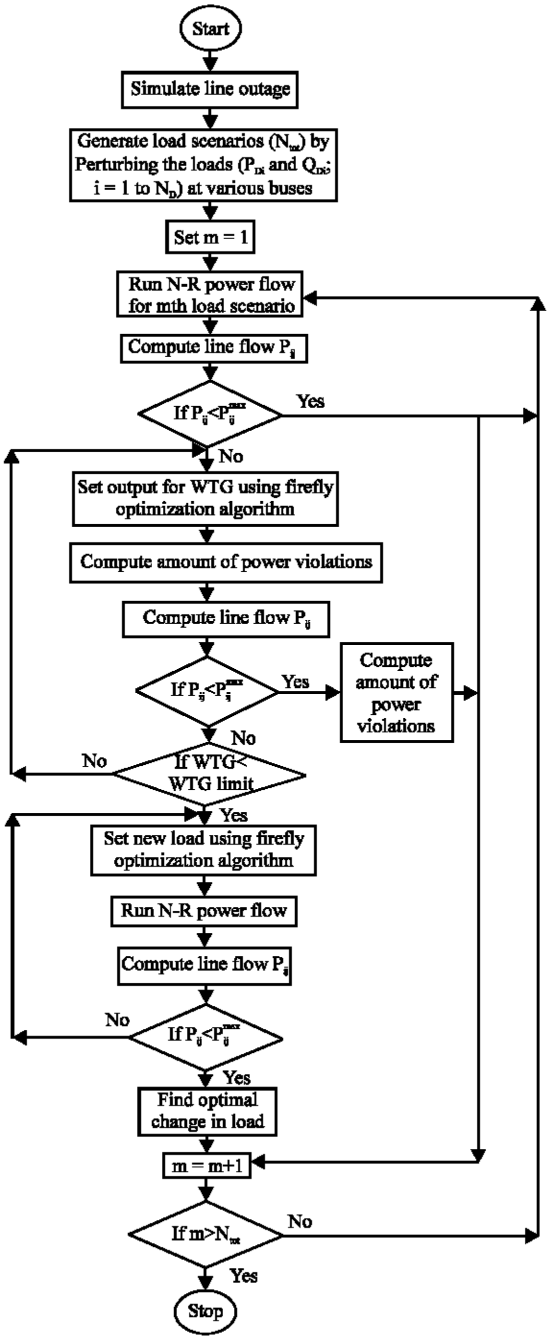

Fig. 2: The proposed PSS system

RESULTS AND DISCUSSION

The voltage stability indicators performances are revealed for various incident types used for IEEE 30-bus testing systems as indicated in Fig. 3 in which they include 24 loads buses, 41 transmission lines and 6 generator buses. In general, there are 25 stages or levels of load enhancement in all tests performed and every enhancement stage describes 0.1 multiplied by the base incident loading for the selection loading bus. The enhancement begins from the basic indicator loading of a prescribed load bus and afterwards, enhancing gradually and stably before the maximum load capacity of the load bus is completed.

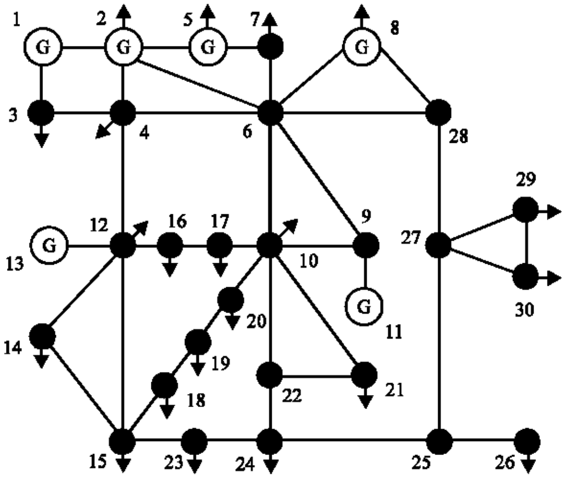

Fig. 3: IEEE 30-bus system

Performance of line stability indices: Under various situations, the change in transmission line/load incidents were performed in system test of IEEE 30-bus.Since the three distinct loading conditions are expected, the loadability of system was researched.

With respect to the first condition, after the calculation of FVSI, the two other distinct techniques are used for compariation in the load increase which continues before the load flow is deviated under the first condition at bus 24 the active and reactive power of single bus alters for each load level and the CPFLOW (continuation power flow) remains performing to obtain the voltage of relevant buses. At bus 24, the increase of the load is slow, varying from its fiducial value (P_{24} and Q_{24}) to voltage breakdown at (P_{24} and Q_{24})*2.5. Test was conducted through step by step loading the enhancement (reactive and active power) at selection buses and the indicator line values related with the bus were enhanced which possess the higher values than other lines indicating that it is most critical. A table was made for all line stability indicator's performances as to the most critical lines as underlined in Table 1. The line indicators linked to bus 24 are influenced step by step by the enhancement of loading. Obviously, the indicator values of line 31 through line 33 at the maximum loading have arrived at the maximum. For all indicators, at the very moment, the maximum value is indicated at line 31 which

Table 1: FVSI and LPQ for lines 31-33

	FVSI			LQP		
Steps	Line 31	Line 32	Line 33	Line 31	Line 32	Line 33
5	0.3940	0.3390	0.3086	0.3397	0.2756	0.1812
10	0.5157	0.4523	0.4677	0.4524	0.3677	0.2578
15	0.6408	0.6183	0.6059	0.6213	0.5059	0.3834
20	0.7833	0.7729	0.7245	0.7664	0.6245	0.5467
25	0.9802	0.9184	0.8700	0.9443	0.7713	0.6308

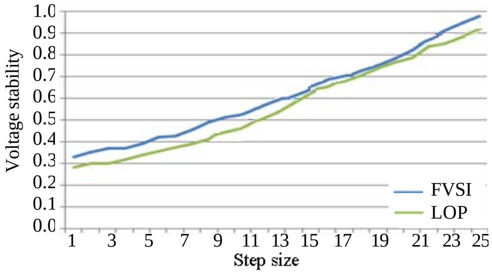

Fig. 4: Line 31s evaluate FVSI and LQP influanced by enhancing (P_{24} and Q_{24}) at bus 24

comes near the limit of stability and any other enhancement will result in 24 bus breakdown. The implication is presented that the index of FVSI has the greater sensibility than other proposed indicators and line 31 has reached the condition of unstability.

As shown in Table 1, a table was made for indicator values on line 31 to incorporate all indicators simultaneously. Obviously, the FVSI has higher value than other indicators. In Fig. 4, it is indicated that the indicator values were enhanced correspondingly to the increment of loading. It is also indicated that for all indicators, the highest value exists in line 31 and therefore simply recorgnized as the line with the greatest sensitivity. Meanwhile, it can be seen that the LQP value was highest followed by FVSI, separately.

As to the second situation, at bus 24 the active power of single bus alters for every load level and a performing CPFLOW exists to obtain the buses corresponding voltages. At bus 24, the loading has enhanced gradually and it changes from its fiducial value (P_{24}) to the level of voltage breakdown at (P_{24})*2.5. Through slowly enhancing the active power loading at selection bus, tests were performed, followed by increasing the indicator value for lines related with the bus, which include the highest values in comparison with other lines, inicating at the same time that it is the most decisive line. A table was made for all line stability indicator's performances as to most key lines which is indicated in Table 2.

As seen in Fig. 5, it can been seen that the exponential values are enhanced correspondingly with respect to load increment. Among all indicators, the highest value lies in line 31 and therefore, it is considered as the lie with the most sensitivity.As shown in Table 2, a table is made for the indicator values at line 31 to plot all indicators simultaneously for comparison. From the table, obviously, the FVSI owns the higher value than other indicators.

Table 2: LPQ and FVSI in line 31-33 accompanying active power loading at Bus 24

	FVSI			LQP		
Steps	Line 31	Line 32	Line 33	Line 31	Line 32	Line 33
5	0.5385	0.4057	0.3665	0.3975	0.3486	0.3531
10	0.6258	0.5401	0.4660	0.5040	0.4421	0.4031
15	0.7350	0.6385	0.5911	0.6351	0.5573	0.4650
20	0.8368	0.7768	0.7282	0.8062	0.7078	0.5523
25	0.9793	0.9327	0.9147	0.9684	0.8504	0.6285

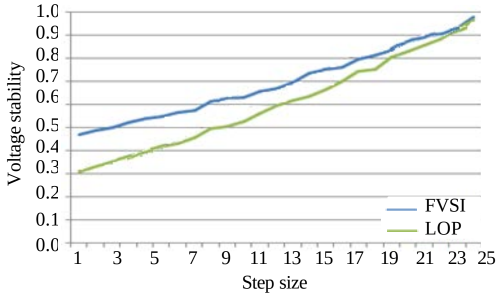

Fig. 5: Line 31s evaluated FVSI and LQP affected by enhancing (P_{24}) at Bus

As to the third situation, the incident of line was performed at two lines linked to bus 24 in the system of IEEE 30-bus. Such two lines are line 32 which links between bus 23 and 24 and line 31 which connects between bus 22 and 24. The system loadability was researched while considering the loading situations. In the first situation, the line incident was performed at line 31 indicating the line 31s disconnection and then the reactive and active power of single bus for every loading level at Bus 24 and the CPFLOW is performed to obtain the voltages of homologous buses. At bus 24, the load enhanced and slowly changed from its fiducial value (P_{24} and Q_{24}) to the voltage breakdown level at (P_{24} and Q_{24})*2.5. Through gradually increasing the reactive and active powers loading at the selection bus, the tests were performed and the rest lines indicator values with the connection of the bus increasing and carrying the highest values while comparing to the rest lines. It is indicated that the key conditions are proved by the rest lines. For the stability indicators of all lines, the performances were the most key lines underlined in Table 3.

In Fig. 6, the value of such indicator is the load incrementation increased correspondingly. In our observation, it is also suggested that the highest value of

Table 3: Line 32 and 33's FVSI and LPQ with respect to the incident of line 31

	FVSI		LPQ	
Steps	Line 32	Line 33	Line 32	Line 33
5	0.950451	0.942263	0.022558	0.020749
10	0.955704	0.946489	0.130680	0.117016
15	0.967859	0.960069	0.226999	0.207247
20	0.974125	0.965566	0.319223	0.285336
25	0.984037	0.975382	0.948806	0.900468

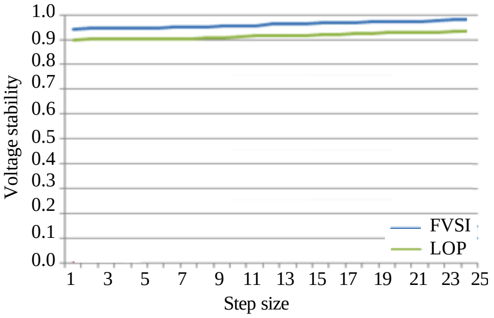

Fig. 6: FVSI and LQP evaluation for line 32 affected by line contingency of line 31

all indicators is carried in line 32 including the line with most sensitivity reasonably. As shown in Table 3, a table for the value of indicator in line 32 was made to compare all indicators simultaneously. As in the Table 3, it is obvious that the FVSI has the value higher than other indicators. Besides, according to the observation, the highest LPQ and FVSI have been incorporated into the sequence, separately.

Determination list of key N-2 incident: The efforts prepared to solve the key N-2 incident overloading the transmission equipment has been recognized in the course of the study of the system impact for new wind power plant integration. In Table 4, a list is supplied in large-scale wind power plant MEC controlled area. These wind power plant's output will decrease to relieve the overloading during the appearance of key incidents within the system. Bus 15 and 22 as well as bus 25 wind power plant which has a total volume of 35 MW are recommended for the use along with IEEE 30 bus. Nevertheless, numerous overloads for adjacent N-2 or outage incident that occurs before has been proved.

From our analysis, the wind power plant's temperature drop speed is considered as 10% of MW capacity for each minute, the traditional genetation's ramp-up rate is indicated as 1% of MW capacity for each minute and the effective period of clearing the condition of overloading is assumed simply as 10 min. In Table 5, the selection of dual emergency events in the influenced project area that resulted in the overload of a few transmission equipment. The system was in transient state.

Table 4: List of propositional generator of wind farms and existed IEEE 30 bus

Bus No.	Generators	Capacity (MW)
1	Thermal	90
2	Thermal	40
5	Thermal	20
8	Thermal	20
11	Thermal	40
13	Thermal	50
15	Wind farms	10
22	Wind farms	15
25	Wind farms	10

Table 5: Selection event sample

Events	N-2 contingency
1	Bus 22-24
	Bus 19-18
2	Bus 22-24
	Bus 14-15
3	Bus 24-25
	Bus 19-20
4	Bus 22-24
	Bus 24-25
5	Bus 23-24
	Bus 25- 27

CONCLUSION

In this study, the problem of transmission overload is illustrated in a high wind area. A few other problems are related to the LSI (Large-Scale Integration) aspect of grid wind power. An obvious problem exists in the wind variation that performs a direct action on distinct system operation reserve types. Extra operation reserve must be collected by this system in order to satisfy the requirements of reliability. In two methods of line voltage stability, the LPQ and FVSI are adopted for quantification of the reserve need within a system consisting of obvious wind penetration. For investigating reserve requirement and relieving the indeterminacy related with the wind power, the forecast of wind power makes a critical difference.

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