Implications of Smart Grid Technology on Transmission System Reliability

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***Abstract*--This research work explores the feasibility of increasing system reliability by applying condition monitoring systems to selected circuit breakers and transformers. Smart grid technology decreases maintenance costs by deploying condition monitoring systems that informs the operator of impending failures or ameliorates those conditions. Since condition monitoring systems can themselves increase operating costs, only selected critical transformers and circuit breakers are chosen to be equipped with these systems. This paper describes a method to identify the most critical transformers and circuit breakers with the aid of contingency ranking methods. Different summer load cases are studied and the results are compared to find the most severe contingencies that affect the study area. Once the critical components of the system are identified, corrective actions are found for each severe contingency to be applied.**

***Index Terms*-- Circuit breakers, maintenance, power system monitoring, power system reliability, power transformers, power transmission, smart grid.**

I. Introduction

THE SMART GRID is a general term for a series of infrastructural changes applied to the electric transmission, and distribution systems. According to the definition by the U. S. Department of Energy [1], the smart grid applies emerging technologies in order to bring more knowledge to the power system. With the growing increase in consumer demand and with more complex equipment being installed in power systems the need for a grid with enhanced intelligence is more evident than before. Although electric grids are facing more environmental, technological and infrastructural challenges, the technological advancements provide a mean to deal with these challenges. The emerging technologies in communication, control, sensing and computing all contribute to make the power grid smarter. Condition monitoring systems are one of these technologies that have found more applications in today's grids due to the increased system complexity. A very simplified concept of the smart grid is shown in Fig. 1.

With the rapid growth in the rate of load increase in recent years, there has been a considerable increase in transformer deployment [2-3]. As a result of this increased usage more transformers are in need for maintenance due to excessive electrical and thermal stress. Moreover, most of the transformers and circuit breakers are not designed for the new operating conditions during the peak loads which results in fast ageing of these transmission system components. Although a need for maintenance is more evident than before, it is expensive and in some cases a hard task to implement, due to the fact that some of these components are located in remote areas. Therefore, maintaining all these transmission system components is not a practical solution for the existing power systems. Condition monitoring of the circuit breakers and transformers optimizes the maintenance costs by providing the information about the status of those elements and whether there is an impending failure in any of those system components. Therefore, operators can decide on needed maintenance only if a transformer or circuit breaker is identified as nearing an impending failure.

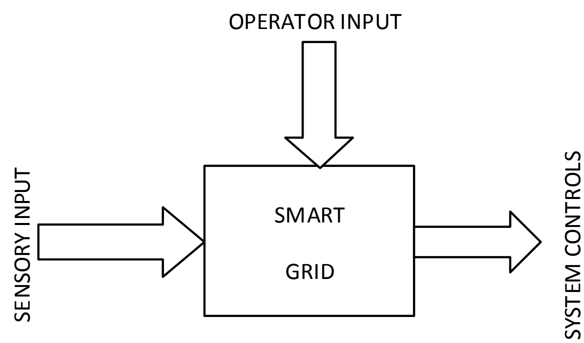

Fig. 1. A conceptual picture of the smart grid

This paper is structured as follows: Section II discusses the approach used in this work for condition monitoring of the transformers and circuit breakers while section III briefly introduces contingency ranking methods used in literature and the ranking methods used in this work. Section IV presents contingency ranking study results along with the description of the system under study. Corrective actions that could be taken in case of each severe contingency are discussed in section V. Section VI summarizes the main conclusions of this work.

II. Identification of Critical Assets for Smart Monitoring

Recent blackouts have shown the need for a more reliable and resilient power system. Condition monitoring systems optimize maintenance costs while providing the operators the status of the system components. Although condition monitoring systems contribute to increasing system reliability; monitoring all the transformers and circuit breakers is not cost effective but also requires a significant amount of data processing which in many cases might be unnecessary and

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redundant. It is vital to identify those transmission system components whose failure affects the entire system the most. Contingency ranking is an approach introduced by many references [4-6] and is deployed in this work in order to pinpoint the critical elements of the power system such as circuit breakers and transformers whose failure can cause severe contingencies such as line overloading. Power flow data such as bus voltages and branch flows are used to calculate a series of performance indices that rank components based on the severity of the contingency caused by their outage or failure. Fig. 2 shows the basic structure of the method proposed in this paper.

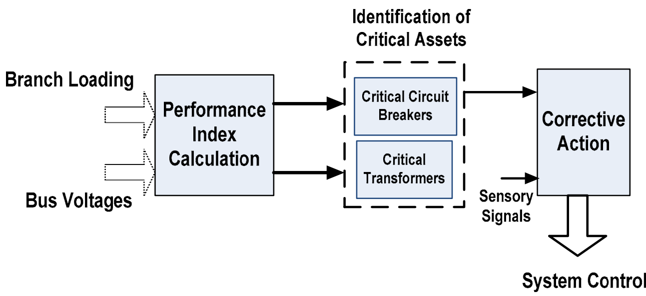

Fig. 2. Condition monitoring and assessment of critical transmission system components.

These transmission system components are assessed to be the best candidates for condition monitoring. Once these critical transformers and circuit breakers are identified, this information is then deployed to take a corrective action that reduces the impact of the failure of those elements in case a contingency occurs in the system. Corrective actions are identified for the most critical contingencies based on offline system studies and are discussed further in the proceeding sections. Corrective actions could entail rescheduling power flow to alleviate critical component loading.

III. Contingency Ranking Methods

Steady state contingency analysis traditionally involves analyzing all the contingencies in a system in order to investigate system reliability and performance under different operating conditions. Although beneficial, this traditional approach is not always practical due to the exhaustive and hence costly testing and computations required. Moreover, limiting these analyses to only a group of contingencies, selected based on experience, can be insufficient for planning purposes. In other words, some important contingencies might be left out since sufficient data of their occurrence is not available to the planners. Therefore, contingency ranking methods are essential in effectively ranking all the contingencies within a system and selecting those that are more critical for planning purposes.

Some contingency ranking methods are based on voltage violation in all the buses of the considered system while some other methods are solely based on line power flows and overloads caused on different branches. In all these methods a performance index is defined and calculated for each bus in case of several contingencies. However, these methods vary based on the definition of the performance index and their effectiveness in identification of the critical elements. In all these methods computer simulations of the power system is essential in contingency ranking. In contemporary software for power system simulation and analysis, contingency ranking has found more applications in power system operation and planning.

As suggested in [7] most of the contingency ranking methods are not accurate since they neglect nonlinearities of the reactive power equations as well as the effects of the voltage regulators. Moreover, the loads are affected by the variations in the voltage, and hence this effect should be included in the ranking methods. The above mentioned inaccuracies which are mainly due to the modeling of the power system can lead to misranking of the contingencies. In order to deal with these issues, the authors in [7] have suggested a new contingency ranking method which represents the effect of the voltage regulators and the sensitivity of the loads to bus voltages. Also, nonlinearities due to the regulator tap positions and reactive power generation are included in the model for contingency ranking studies.

In another work [2], Ejebe and Wollenberg have proposed an online security analysis method which analyses the contingencies based on the most recent operating conditions. This method updates the list of the most severe contingencies in an adaptive manner by ranking the contingencies followed by an AC power flow to achieve a set of critical contingencies in the system. Contingency ranking is again based on defining a set of performance indices for line and generator outages. These indices are defined in a way to treat the constraints of the load bus voltage and line flows as *soft* limits. In other words the violation of the limits imposed on the bus voltages and line flows are penalized in the performance index. The ranking methods deployed in this work are mainly inspired by the above mentioned work. Two performance indices are defined in [2] that are referred to as PI_V and PI_{MVA}. The first method classifies each contingency based on the severity of the overloads enforced on different branches. The second, however, utilizes the amount of voltage violations of each bus as the basis for defining the performance indices. These indices are defined in (1)-(2),

$$PI_V = \sum_{i=1}^{l} \frac{W_i}{2n}\left(\frac{|V_i| - |V_i|^r}{\Delta V_i^{lim}}\right)^{2n} \quad (1)$$

$$PI_{MVA} = \sum_{i=1}^{nl} \frac{W_{li}}{2n}\left(\frac{S_l}{S_l^{lim}}\right)^{2n} \quad (2)$$

where $|V_i|$ is the voltage magnitude at bus i and l is the number of buses in the system. The parameter n is the exponent of the penalty function which is usually set to one. The larger this value, the more would be the penalty for violating the voltage limits. The weighting factors W_i are set arbitrarily for each bus. However, the more appropriate the definition of weighting factors, the better the ranking of the contingencies. The term ΔV_i^{lim} represents the limit on the voltage deviation on each bus. In normal operating conditions this value is set to be ±5% of the rated voltage. In (2) S_l is the power flow of the line while S_l^{lim} is the maximum allowable power flow of the line. The parameter nl is the number of the lines while W_{li} is the weighting factor of each line. These performance indices are easy to calculate and can give a good understanding of the effect of each contingency on the entire system.

In previous work, the indices indicated are calculated utilizing arbitrary weighting factors. In [9] the authors have proposed a method called an *adaptive hierarchy process (AHP)* to determine the weights which are used in calculation of the performance indices. In AHP, depending on the importance of the transmission line or the bus in comparison to the rest of the system, a value is assigned to the weighting factors subject to,

$$\sum_i W_i = 1 \tag{3}$$

In other words, an expert system will determine the importance of the voltage security at each bus and assign weights accordingly. The more important the bus, the higher the weighting factor, and therefore the higher the penalty for violating the voltage or line flow limits. For the case of this paper, in order to capture the effect of an overloading in the performance index, the weights are chosen to penalize any overloading while the branches with no power violation have the same lower weights. Therefore for overloading, the weights are chosen to change proportional to the amount of the overloading of a branch. For voltage ranking method, weights are also set to highlight the effect of any violation in the index and reduce the effect of buses with voltages within the tolerance, in the performance index.

These indices associate the severity of each contingency and its effect on the entire system with a number so that it would be easier to compare and rank all the contingencies. Usually, the higher the performance index, the worse is the contingency, and hence the more severe is the effect of that contingency on the rest of the system. It should be noted that what is meant by contingency in this work is, in effect, failure of a transformer branch for the case of critical transformer monitoring; and outage of a branch equipped with circuit breakers for circuit breaker monitoring. In the proceeding sections, the aforementioned performance indices are calculated for the transformers and circuit breakers of the study area.

IV. Establishment of the Concept via Numerical Simulation

In order to identify the best candidates for condition monitoring in the study area, transformers and circuit breakers of the system are ranked based on the method described in the previous sections. In the following sections the studied system is described followed by ranking results of the transformers and circuit breakers.

A. System Description

The system under study is part of the U.S. Western Electricity Coordinating Council (WECC) with about 600 buses and 53 generators in the system. The total generation in this system is 8477 MW during the peak hours and the loads can vary from 7122 MW during summer peak hours to 5798 MW for the summer Simultaneous Import Limit (SIL) case. Table I presents a summary of these two load cases for comparison purposes.

TABLE I
Load Case Summary for Summer Peak Case and Summer SIL Case of the Study Area

	Summer Peak Case	Summer SIL Case
Total Load (MW)	7122.06	5797.94
Total Generation (MW)	8476.92	5759.05
Total Export (MW)	1130.15	-246.24
Total Losses (MW)	223.25	205.94

B. Identification of Critical Transformers

The two different load cases described above are studied in this work in order to compare the results and achieve a better list of critical transmission components under different operating conditions. The first case considered is the normal summer peak load case in which most of the generation capability of the generators is utilized. All the transformers in the study area which are above 115 kV are considered for identification purposes, which yield a total of 71 transformers. Hence, each contingency in the system is in fact the outage of any of these transformer branches. Therefore, each contingency number in this paper corresponds to the associated transformer in the studied transmission system. As stated before, for each contingency, steady state information such as bus voltages and branch flows are gathered and voltage based and power based performance indices are calculated for each case. These set of information is gained by conducting an n-1 contingency analysis on the system under study. Voltage Security Assessment Tool (VSAT) which is part of DSA^{Tools} power simulation package is used for simulation purposes. Fig. 3 shows the flow chart of the ranking procedure used in this work.

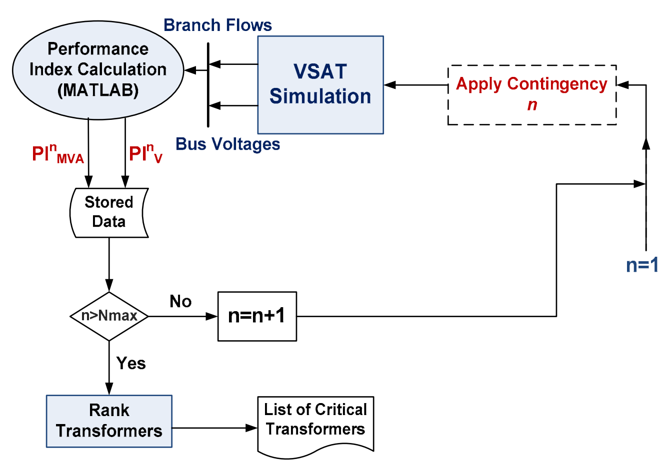

Fig. 3. Flow chart of the ranking procedure.

Contingency ranking results shown in Fig. 4 presents the calculated PI_{MVA} index versus PI_V for all the transformers considered for ranking. These results illustrate a few facts for the contingency cases. The first observation is that the cases with high MVA index are not necessarily the cases with high voltage index. In fact, in some severe cases in terms of branch loading, such as contingency number 71, the voltage index is low and hence no severe voltage violation is observed in these cases. Analyzing the cases in terms of voltage violations, it is observed that the worst contingency case and the least severe case are not significantly different than the base case. In the summer peak case, the PI_{MVA} index plays a more important role in ranking than the voltage based index. Consequently, PI_{MVA} is used for ranking purposes for the normal peak case rather than the PI_V index.

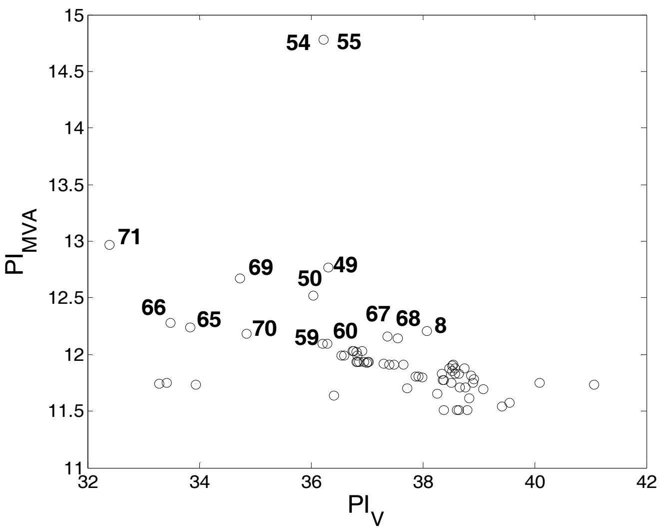

Fig. 4. Summer peak PI_{MVA} index versus PI_V index for all the 71 contingencies in the system.

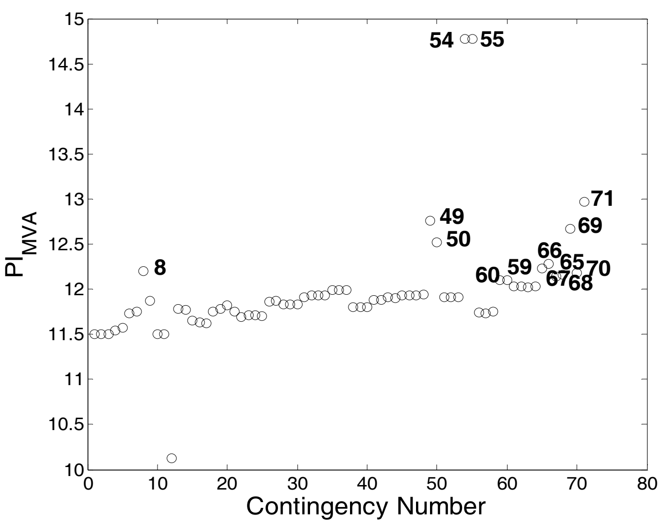

Fig. 5. Summer peak PI_{MVA} index calculated for all the 71 contingencies in the system.

Fig. 5 illustrates the ranking results of the transformers by only considering the MVA index. From this figure, it is clearly observed that few contingency cases stand out as the severe cases while others have the PI_{MVA} index close to each other. As mentioned before, these transformers are the best candidates for condition monitoring. Table II summarizes the list of these critical transformers.

TABLE II
LIST OF CRITICAL TRANSFORMERS OF THE STUDIED SYSTEM FOR SUMMER PEAK CASE

Case Number	From Bus	To Bus	ID
71	79	332	1
54,55	133	353	1 or 2
69	599	419	2
49,50	52	369	2 or 4
65,66	170	154	1 or 2
67,68	266	91	1 or 3
59,60	285	199	1 or 3
8	505	507	4
70	500	67	4

The same procedure is followed for the SIL case while it is expected to have less overloading since the total load and generation in this case is considerably less than the peak load case. Similar to the peak load case it is observed that PI_{MVA} index is a better indication of the severe cases rather than the voltage based index. Fig. 6 presents the ranking results for the SIL case considering only the MVA based index. As seen from these results, three cases, i.e. contingencies 70, 69, and 68, along with contingency number 8 are the severe contingencies in terms of the power based index. It should be noted that these transformers have already been identified as critical cases in the peak case and are listed in Table II.

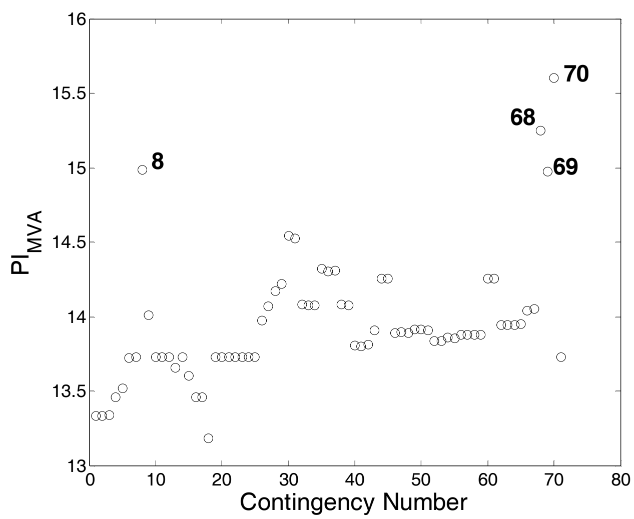

Fig. 6. PI_{MVA} index calculated for summer SIL case for all the 71 contingencies in the system.

C. Identification of Critical Branches

As explained before, although circuit breaker monitoring (CBM) can improve system reliability, monitoring all the circuit breakers of the system is not practical. High costs of circuit breaker monitoring and the need for signal processing equipments are among the reasons limiting condition monitoring to only a selected number of breakers. Therefore, identifying those breakers that monitoring them could benefit the system the most is essential for improving system reliability.

In order to find the critical circuit breakers, the same procedure as transformer identification is followed. However, only the PI_{MVA} index is calculated for each branch. The reason for only considering one index for calculations is the fact that circuit breaker operation depends on current interrupting capability. Hence, failure to interrupt currents above the circuit ratings may lead to damage to system components and consequently outage of the line equipped with the failed CB. As a result of this outage, excessive overloading might occur at other branches that could prevent opening of the CB contacts at those branches. Calculating the PI_{MVA} index for each contingency determines the severe cases and thus the critical circuit breakers in the system at hand.

Candidate circuit breakers are selected from the branches above 115kV. This results in 122 contingencies in the studied case. The contingency in each case is outage of any of the described branches due to a circuit breaker failure. Simulation results of different load cases confirm that peak case is the better representation of the critical branches in terms of the severity of the effects caused by their outages. Fig. 7 illustrates the plot of calculated PI_{MVA} index versus contingency number for the peak case.

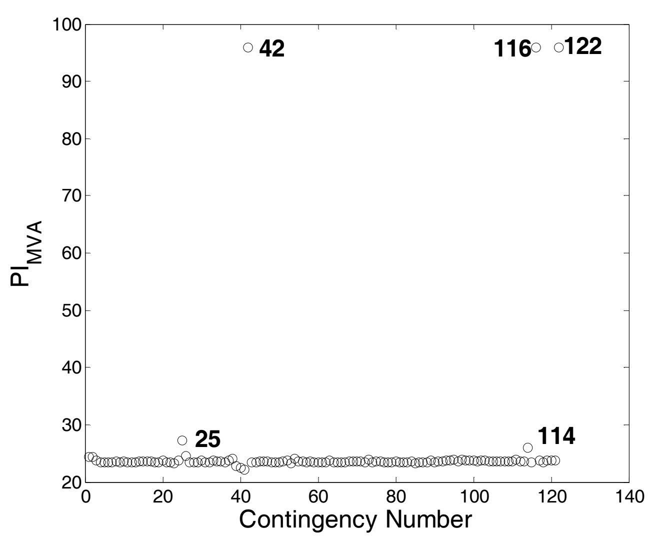

Fig. 7. PI_{MVA} index calculated for summer peak case for candidate circuit breakers in the system.

As seen from these ranking results, there are three branches that seem to be more critical than the other branches in the study area, as they significantly differ in performance index in comparison with the rest of the branches. Further analysis of these critical branches shows that in fact severe overloading is caused as a result of their failure on the system. Therefore, monitoring circuit breakers available on these branches could notably increase system reliability while other circuit breakers are not as much important for monitoring purposes than these branches. These branches are referred to as branch number 42, 116, and 122 for the rest of this paper.

V. Alleviating the Impact of Contingencies

Identifying critical transformers and circuit breakers has the advantage of locating the ideal location in the system for applying condition monitoring. Monitoring system components increases the reliability of the system by informing the operators of the impending failures. Upon receiving the data from the monitoring equipment, the operator decides on an action in order to reduce the effect of the failed circuit breaker or transformer on the rest of the system. Alleviating the consequences of the failure could be temporary or last until the failed transmission system component has been maintained.

A. Corrective Actions

There are two sets of actions that could be taken in case of any contingency: corrective and preventive actions. Preventive actions, as suggested by their names, are taken in order to prevent occurrence of a failure in the future. Circuit breaker and transformer maintenance are among those actions, which are usually expensive and in most of the cases time consuming. Corrective actions, on the other hand, assume that a contingency has already occurred in the system and therefore the taken action compensates for the failed component in different ways that are shown in Fig. 8. The objective of a corrective action is therefore to alleviate the effect of a system component failure by reducing or eliminating the effect of that power transmission component.

As observed from Fig. 8 there are three sets of corrective actions that are taken in case of any critical contingency in the system. These actions are identified for each severe contingency based on offline studies of the system at hand and once identified are taken in case the contingency occurs in the future. However, these actions are prioritized based on their applicability to the system. In other words, actions such as load shedding are only applied to the system as a last resort, once other actions have failed to alleviate the consequences of a particular contingency.

A constrained optimal power flow (OPF) problem is solved by the operators once they are informed of the impending failures by the smart sensors installed on the critical transformers and circuit breakers of the system. *N*-1 contingency analysis adds an additional constraint to the previously solved optimal power flow problem to alleviate the overloading or voltage violations caused by a transformer outage or circuit breaker failure. The objective of an OPF problem can vary depending on the application. Minimizing total generation cost, minimizing transmission loss, minimizing total reserve generation or minimizing slack bus generation or maximizing security margin index (SMI) are among the most important objectives mentioned in literature [10-11]. As in most of the OPF problems, cost minimization is selected as the objective in this paper. Therefore, cost functions are defined for each generation type that properly represent the total generation cost of the system.

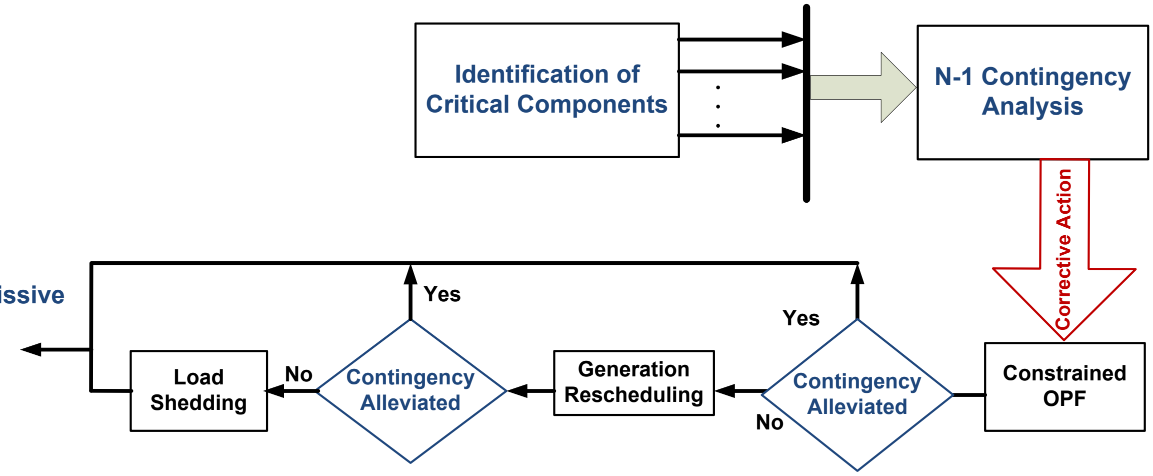

Fig. 8. Corrective actions taken in a smart grid in order to alleviate the contingencies.

In most of the contingencies the OPF is capable of alleviating the overloading by re-routing the power from other branches. However, this translates to an increase in total generation cost of the system.

Although OPF can be effective in alleviating over loadings caused by outages, in some severe contingencies there would not be any solution to the system with the new set of constraints. Therefore, other actions such as generation rescheduling are required to deal with the added contingency. Generation rescheduling is particularly effective if there is sufficient generation available in the neighborhood of the overloaded line. Consequently by using other generation resources, detrimental effects of the contingency could be alleviated. In the following section, some of the most stressed transformer branches are further analyzed to determine the corrective action that is effective in case these contingencies occur.

B. Study Results

The most severe transformer branch outages were introduced in Section IV. In this section the effect of those will be first investigated on the studied system followed by determining the proper actions that should be taken in case these contingencies happen in the future. Hence, the top severe transformer branch outages are analyzed in detail.

1) Transformer Branch 79-332 Outage

The outage of this transformer is expected to have severe overloading effect on the other branches of the system. Summer normal peak is chosen as loading of the system. It is observed from simulation results that the outage of the aforementioned transformer will cause over loadings of up to 103% in the neighboring branches in comparison to the 14% loading of the base case. This overloading needs to be decreased in order to ensure secure operation of the system.

As explained before, the system is analyzed to determine whether the above described overloading could be decreased by proper rescheduling. PowerWorld Simulator is used as a tool for solving a constrained OPF problem, while each generator in the study area is associated with a cost function defined based on the models available in this software. The objective function is hence to decrease the total generation cost while keeping the loading of all the branches in the studied system bellow 100%. Simulation results show that no possible rescheduling is able to eliminate the overloading of the aforementioned branch. In other words, this constraint is an *unenforceable* constraint in PowerWorld and consequently OPF cannot be solved. Therefore, even with a price of increasing the generation cost, with the existing system topology, outage of the *79-332* transformer branch results in a subsequent branch overloading. This in turn could result in equipment damage, if it persists for a long period of time, and therefore cannot be permitted in the long term.

According to the above statements, the only action that could be taken in this case is to shed loads in order to be able to decrease the loading in the overloaded branch. In other words, load shedding will be the chosen action by the smart grid if the same contingency occurs in the future. As stated before, since load shedding will discontinue service to certain customers, it is chosen only as a last resort. It is also important to categorize the loads and shed the less important loads first before cutting service to more sensitive loads. However, not all the loads are going to affect the overloading. Hence, a sensitivity analysis is carried out on the system to identify the loads that can affect the overloading, if they are shed. Therefore with the aid of a program that automatically calculates the MVA index discussed in Section IV for each of the loads above 30MW and the steady state information of the branch flows, the most effective loads are found. Fig. 9 illustrates these study results. As seen from this figure, only three loads, marked as load numbers 28, 15, and 21, are capable of decreasing the loading of the aforementioned branch to below 100%.

By including these loads in the previously applied OPF problem and assigning a high cost for load shedding, minimum required load shedding for any of the three aforementioned loads is found. Table III presents these loads along with minimum shedding required from these loads. It should be noted that these values are only the minimum required to drop the overloading to just below 100%.

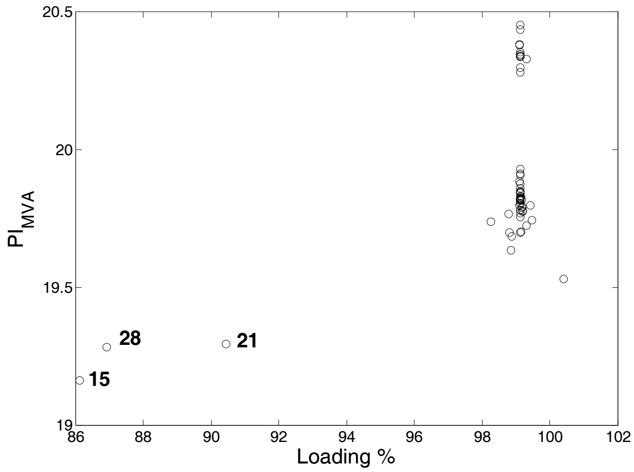

Fig. 9. Overloaded branch loading versus PI_{MVA} for system loads above 30MW while reduced to half.

2) *Transformer Branch 133-353 Outage*

Outage of this line has also shown to be a severe contingency since it overloads the parallel branch to 110 % from the 55% in the base case. Therefore a corrective action should decrease this loading to below 100%. As seen from the system map, there are quite a few generators around this transformer branch. This provides the system with more rescheduling capability than the other cases discussed before. Constrained OPF is the first action that is applied to the system in order to decrease the overloading at the parallel transformer branch. With the objective of minimizing total generation cost, OPF decreases the overloading to 100%. However, it is desired to decrease this loading even further to below 100% which translates to increasing generation cost. By reducing the generation at the closest generation source to the aforementioned transformer, it is expected to reduce the loading of this branch. Simulation results show that 40 MW decrease in generation of this source reduces loading of the aforementioned branch to 93%. With the generation cost functions defined, this generation reduction will translate to an additional 407 $/h in total generation cost as the generation reduction is compensated by another, more expensive, generation source.

TABLE III
LIST OF EFFECTIVE LOADS IN REDUCING OVERLOADING IN CASE OF TRANSFORMER BRANCH 79-332 OUTAGE

Load Number	Original Load (MW)	Minimum Shed (MW)
15	48	5.03
28	42.4	4.66
21	45.2	7.08

3) *Outage of Branch Number 42*

As it was observed in contingency ranking results of section IV, outage of this branch creates a severe contingency on the rest of the system. Following the same procedure as the critical transformer branches, a solution to the contingency is sought through a constrained OPF problem. As it was expected from the ranking results, OPF is not able to find a solution to the problem while alleviating the contingencies in the system. OPF results in PowerWorld simulator indicate that there will be three branches with overloading of up to 116% as a result of outage of the aforementioned branch. Similar to the case with critical transformers, load shedding is the last resort in order to alleviate the contingency. However, sensitivity analysis results, reveal that even load shedding is not effective in decreasing the overloading caused by outage of this critical branch. Therefore, it can be concluded that condition monitoring of the circuit breakers of this branch is extremely beneficial in ensuring the secure operation of the system.

VI. CONCLUSION

This paper discusses a method to increase power system reliability by providing more awareness to the operator of the impending failures in the system. The concept is considered to be an implementation of the smart grid philosophy. Condition monitoring of the circuit breakers and transformers were introduced to monitor the status of these components and based on the collected data estimate the chance of component failure.

Simulation results indicate that sensory signals can be used to increase power system reliability. If the signals received from condition monitoring of circuit breakers and transformers indicate an increased chance of component failure, the operator is suggested with a corrective action to be taken in order to prevent the effect of possible outages in the future.

Contingency ranking methods presented are shown to be effective in identifying the most stressed transformers and circuit breakers. Simulation results of the system under these stressed circumstances suggest that contingency ranking methods are valuable for this application.

One of the advantages of the suggested approach is to bring more awareness of the system stressed points and the potential to avert outages. Consequently, more secure operation and a more reliable system may be possible. By applying different corrective actions as presented in Section V, it is observed that although generation rescheduling may be an effective way of reducing line loadings in case of a line or transformer outage, rescheduling might not assist in some contingencies.

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VIII. Biographies

Sara Eftekharnejad (StM ’07) received her B.Sc. degree in electrical engineering from University of Tehran, Iran in 2006. She received her M.Sc. degree from West Virginia University, Morgantown, WV in 2008. She is currently a Ph.D. student at Arizona State University, Tempe, AZ.

Gerald Thomas Heydt (StM ’62, M ‘64, SM ’80, F ’91, LF ‘08) is from Las Vegas, NV. He holds the Ph.D. in Electrical Engineering from Purdue University (1970). His industrial experience is with the Commonwealth Edison Company, Chicago, and E. G. & G., Mercury, NV. He is a member of the National Academy of Engineering. Dr. Heydt is presently the site director of a power engineering center program at Arizona State University in Tempe, AZ where he is a Regents’ Professor. He is also a site director of a new NSF engineering research center on Future Renewable Electric Energy Delivery and Management (FREEDM) Systems. Dr. Heydt is the recipient of the 2010 Richard H. Kaufmann award.

Vijay Vittal (SM'78, F'97) received the B.E. degree in electrical engineering from the B.M.S. College of Engineering, Bangalore, India, in 1977, the M. Tech. degree from the Indian Institute of Technology, Kanpur, India, in 1979, and the Ph.D. degree from Iowa State University, Ames, in 1982. Dr. Vittal is a member of the National Academy of Engineering. Dr. Vittal is currently the director of the Power Systems Engineering Research Center (PSerc) and is the Ira A. Fulton Chair Professor in the Department of Electrical Engineering at Arizona State University, Tempe.