VOL. 16, NO. 1, 2017, 6-10
www.fke.utm.my/elektrika
ISSN 0128-4428

ELEKTRIKA
Journal of Electrical Engineering

Optimization of Power Quality Monitors in Transmission System Network

Abubakar K.A[1*], Dalila M.S[1], N.Ahmad[2], Abdirahman M.A[2], Abba L.B[3]

[1] Centre of Electrical Energy System, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[2]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[3]Department of Electrical Engineering, Faculty of Engineering, University of Maiduguri, Nigeria, P.M.B 1069

[*]Corresponding author: muhammadkabir87@gmail.com, Tel: +2348066930078

Abstract: Due to an increase in population growth, more sensitive equipment and the significant usage of electricity. Power quality issues are of paramount importance, in order to get reliable and of high efficient power supply. Among all power disturbances, voltage sags are considered as the most frequent and severe type of disturbances that lead to loss of operation of equipment's. The power quality monitoring system is the first to consider in power quality assessment and mitigation so as to get a reliable and efficient power supply. Installing power quality monitors in every component of the power system network is not feasible due to economic reasons and its need to be minimized. And then how to get the optimal number and locations of power quality monitors while maintaining system observability becomes an important problem. The aim of this paper is to find the optimal number and location of power quality monitors in the transmission system network. The IEEE 14 bus test system was modelled and simulated using POWERWORLD software, to obtain fault voltage and monitor reach area considering both balanced and unbalanced faults in the system. The optimization formulation problem is also formed and solved using an Integer Programming (IP) algorithm MATLAB toolbox to find the minimum number of Power Quality Monitors (PQMs) in the transmission system that lead to voltage sags, the Sag Occurrence Value (SOV) is used to find the best position of the PQMs. Finally, to prove the proposed Integer Programming (IP) algorithm, this paper end with optimizing the PQMs using Genetic Algorithm (GA) techniques.

Keywords: Power quality, power quality monitors, monitor reach area, fault voltage magnitude.

1. INTRODUCTION

Recently power quality has become of paramount important concern for utility companies, facility managers and engineers. PQ is gaining more importance due to the following factors: Population i.e. many people nowadays are wholly depends on electricity in their daily life that is reliable and efficient. Consumers are now aware of their right and demand low price of electricity of high reliability, efficiency and good quality.[1] Due to the advancements of technology, consumers' equipment's is more sensitive to power disturbances that has an effect on both the supply system and within the consumers' facilities. Equipment's such as microprocessors, computers, variable speed, welder machine, etc. A deregulated market in the power sector has led to an important structural change in the utility industries. Customers have the choice to purchase electricity from the utility that provide reliable, efficient and least cost of energy.[2]

According to IEEE 1159-1995 standard, there are seven main classes of power quality disturbances which are; transient (impulsive and oscillatory), short duration variation (voltage sags, voltage swells and interruption), long duration variation (over voltage, under voltage and sustained interruption), waveform distortion (noise, notch, harmonics, inter-harmonics, DC offset), voltage imbalance, frequency variation and voltage fluctuation.[3] In all the disturbances of PQ, voltage sags are the most frequent disturbances that have a great impact on sensitive loads [4]. According to IEEE standard 1159-1995 defined voltage sags as the reduction of voltage in its RMS value to between 0.1 and 0.9p.u for a duration between half a cycle and less than 1 minute [5]. Voltage sags are caused due to short circuit faults and earth fault occurring in both transmission systems and radial systems. Starting a large induction load and energizing a transformer also caused a reduction in voltage which is voltage sags. Short circuit faults are generally contributed to many random and unpredictable facts like a failure in electrical appliances, insulation breakdown, lighting strikes, tree encroachment, animals and birds factors etc.[6]

Utilities and regulatory bodies worldwide used to monitor the amount of power that is being delivered to their consumers by placing a monitor at each bus of the power system. These monitors used to measure various parameters such as voltage, current, frequency, etc. Monitoring system helps engineers and operators to detect and analyze the power quality disturbances and identify their cause, so that proper mitigation can be taken. Due to a short circuit fault, sensitive electronics equipment's that cause a huge amount of financial losses especially in an industry. Therefore, monitoring is of great important for economic purposes. Power system parameters must be maintained at acceptable level to avoid damages of electronics equipment on the consumer side [7].

Power quality monitoring PQM is the first to consider in PQ assessments and mitigation. Ideally the power system network should be monitored by PQM at each bus. Advancement in PQM placement methods and techniques has brought many changes in terms of flexibility, reliability and speed. So each utility wants to monitor their system to know the quality of their electric power system.[8] It is not cost effective to install PQM in every component of the power system network. Power quality monitor cost about RM 40000 each, which is of high cost to be installed at every power system components. Therefore, researchers have worked a lot and are still working to find the most effective placement method and the optimization technique [9].

This paper presents an integer programming IP algorithm to obtain the minimum number of PQMs and the best placement position to install the PQMs on the transmission system network using sag occurrence value (SOV).

2. SHORT CIRCUIT ANLYSIS FOR VOLTAGE SAGS

There are several causes of voltage sags, but short circuit is the most probable. In G.olguin 2003 the calculation of voltage sags magnitude during both balanced and unbalanced faults was based on three principles; superposition theorem, node impedance matrix and symmetrical components. Voltage sags magnitude of three phase fault was generated based on the derived expression as in equation 1

$$V_{dip} = ones\ - Z.inv(diag\ Z) \quad (1)$$

For the prefault load to be neglected and the voltage before the fault, i.e. residual voltage to be set as 1p.u. Where ones are matrix with all elements equal to one and has the same dimension as impedance Z [10].

However, unbalanced operation can occur due to unsymmetrical fault and can be analyze using symmetrical components where unbalanced value of voltages and currents are transformed into three sets of balanced voltages and currents called symmetrical components. Unsymmetrical fault are more occurrence that the symmetrical faults.[11] There are three types of unsymmetrical faults which are; single line to ground, line to line and double line to ground.

Single line to ground fault: is a short circuit between one line and the ground caused by physical contact due to lighting strike, storm damage etc. usually phase voltage A equal to zero. Line to line fault: is a circuit between lines, usually caused by ionization of air, physical contact of lines such as insulation pollution etc. usually phase voltage B equal to phase voltage C. Double line to ground fault: is a short circuit between two lines in contact with the ground commonly due to storm etc. usually phase voltage B and phase voltage C equal to zero. [12]

Fault voltage (FV) matrix was termed as the values of the fault voltages at each bus during various types of faults. In this matrix, the column represents the bus number and the row represents the specific location and the voltage magnitude values of the fault.[13]

3. MONITOR REACH AREA (MRA) CONCEPT

The conventional power quality monitoring coverage concept is called the Monitor Reach Area (MRA). It is used based on transmission system network and not suitable for distribution system network. The term Monitor Reach Area MRA is defined as the area of the network that can be observed from a given meter position.

MRA is an area where different types of fault that lead to voltage sags can be detected by the monitor position at the corresponding bus [6]. However, PQM or voltage sags monitor detects and captures voltage variation by comparing the measured RMS value to a threshold value [13]. This MRA is a binary matrix where a 1 is filled in entry (j, k) of the matrix. When the values of residual voltage in FV matrix equal to or below the voltage threshold value.1 represents that k is covered by the PQM at bus j. The MRA matrix is filled with 0 in entry (j, k) of the matrix when the value of residual voltage in FV matrix is greater than the voltage threshold value. 0 represents that point k is outside the PQM coverage of bus j [4]. The MRA matrix is constructed by the expression in equation.

$$MRA\ (j,k) = \begin{cases} 1,\ if\ FV\ (j,k) \le Threshold\ value\ p.u.at\ any\ phase \\ 0,\ if\ FV\ (j,k) < Threshold\ value\ p.u.at\ all\ phase \end{cases} \forall\ j,k$$

(2)

4. OPTIMIZATION PROBLEM FORMULATION

There are three constituents for the binary optimization techniques, which are:

1. Decision vector
2. Objective function
3. Optimization constraints

The optimization search for the optimal solution as defined by the objectives function through bits manipulation of decision vector subject to the optimization constraints. The process is iterated for a certain number until convergences is achieved. Each of the above constituents is going to be explained and its formulation so as to obtain the optimal solution of PQM placement [14].

4.1 Decision Vector

For the satisfaction of PQM optimization process, the monitor placement (MP) vector is introduced to represent the binary vector (X_{ij}) in bits in the optimization process. The bits of the vector indicate the positions of the monitors that are either needed or not in the power system network. The vector dimension corresponds to the number of buses in the power system network. A value 0 (zero) in the MP(n) represents that no monitor is needed to be installed at bus n and a value 1 (one) represents that a monitor is needed to be installed at bus n. The expression of MP vector is described below.[15]

$$MP(n) = \begin{cases} 1,\ if\ PQM\ is\ needed\ at\ bus\ n \\ 0,\ if\ PQM\ is\ not\ needed\ at\ bus\ n \end{cases} \forall\ n$$

(3)

4.2 Objective Function

Optimization tools for the PQM are used to obtain the minimum number of monitors with the best placement position in a power system network that is capable of observing any fault that may lead to voltage sag in the system. The objective function of PQM is categorized into two:

To form the expression for the optimal number of monitors needed. The expression for the minimal number of required monitors (NRM) to be installed on the power system network can easily be obtained as;

$$NRM = min \sum MP(n) \tag{4}$$

4.3 Optimization Constraints

The algorithm must be run to fulfil all the constraints that are used to find the optimal number of PQM in the transmission system network. In this problem the constraints are: multiplication of MRA matrix with the transpose of MP vector must be greater than one (1). This means that any events lead to voltage sag must be detected/monitored by at least one PQM. The expression is given below.

$$\sum_{i=1}^{N} MRA(n,i) * MP^T(i) \geq 1 \; \forall n \tag{5}$$

5. SAG OCCURRENCE VALUE (SOV)

SOV is defined as a bus that is having the lowest sum of residual voltages for a particular fault type. Lowest sum indicates that severe voltage sag occur on that bus for a particular fault type. If the PQM is placed on that bus, then it will ensure complete observability of the system network.

Figure 1 illustrate the overall optimization process, which start from the fault simulation of the system network followed by the construction of fault voltage and monitor reach area matrices, then formulation of the three constituent of optimization which are; decision vector, objective function and the optimization constraints. The IP and GA techniques are used to obtain the minimum number of PQM in the system network based on the problem formulation, followed by computing the SOV of all the buses in the network and the last step is selecting the best position based on SOV.

6. RESULTS AND DISCUSSION

The 14 IEEE test system network data are obtained from test archive UWEE (University of Washington). 14 IEEE test system network comprises of 5 generating units 14 transmission lines. 11 static load, 4 transformers and 20 interconnected branches of the transmission network. The one line diagram of the system network, using the POWERWORLD simulator is shown in Figure 4. In this paper POWERWORLD simulator software is used for fault analysis. Three phase fault, single line to ground fault, double line to ground fault and line to line fault were simulated at each bus in the 14 IEEE bus test system with a bolted impedance in order to obtain the fault magnitude matrix.

IP algorithm and GA MATLAB toolboxes are used for the optimization. Both IP and GA optimization were run for several times, the same optimal number is obtained. SOV is used to find the best placement position to install the PQMs in the system network.

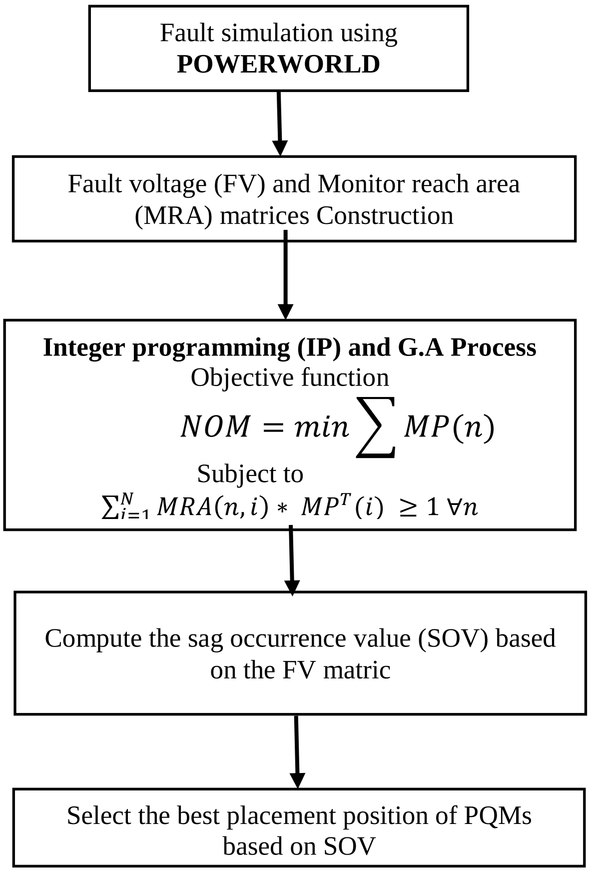

Figure 1. Overall Optimization Process

In this paper various threshold values are set, so as to show the sensitivity of voltage sags occurrences. Six faults were simulated which are 3PF, SLGF phase A, DLGF phase B, DLGF phase C, LLF phase B and LLF phase C. For a threshold value of <=0.9p.u, one monitor is sufficient to detect the voltage sags of the entire network for each simulated fault type. However, for both <=0.55p.u and <=0.2p.u different number of monitors are obtained based on the sensitivity of voltage sags occurrences. But for LLF phase B and LLF phase C no feasible solution found because all the fault voltage magnitudes are more than the threshold value. The optimal results based on (IP, GA) and the best placement position based on SOV are depicted in Table 1.

Sag occurrence value was used to find the best placement position based on the bus having the lowest sum of fault voltage magnitudes (p.u). The lowest sum of the fault voltage magnitudes indicates that, severe voltage sags occur on that bus for a particular fault type. So, if the monitor is placed there, complete observability will be guaranteed. Figure 2 and Figure 3 shows the bar charts of SOV of the bus system due to SLGF A and DLGF B respectively, and the best placement position based on SOV for all the simulated fault types is shown in Table I.

Table 1. Optimal number of PQMs by fault type and best placement of IEEE 14 bus system using the algorithms (IP and GA) and SOV respectively

Fault type	Number of PQMs / {Best placement position (SOV)}		
	≤ 0.9p.u	≤ 0.55p.u	≤ 0.2p.u
3PF	1/{4}	1/{4}	2/{4,5}
SLGF (A)	1/{1}	2/{1,9}	4/{1,9,6,2}
DLGF (B)	1/{9}	1/{9}	3/{9,7,6}
DLGF (C)	1/{1}	1/{1}	5/{1,2,5,4,6}
LLF (B)	1/{4}	4/{4,5,2,7}	No feasible solution found
LLF (C)	1/{1}	2/{1,2}	No feasible solution found

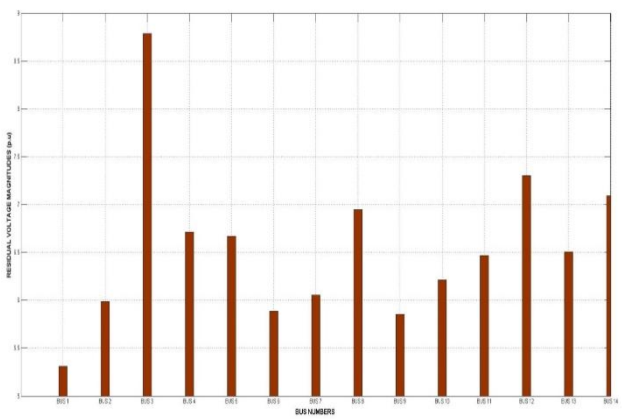

Figure 2. Sag occurrence value of SLGF phase A

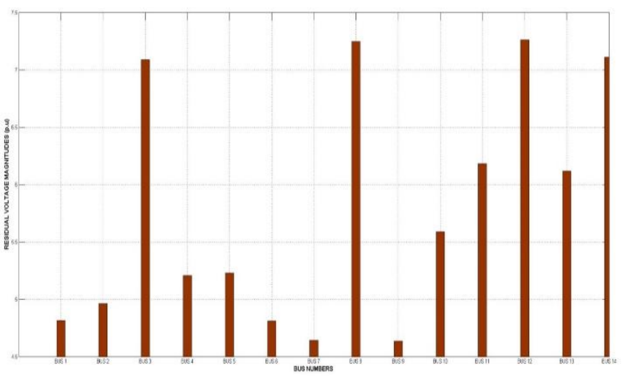

Figure 3. Sag occurrence value of DLGF phase B

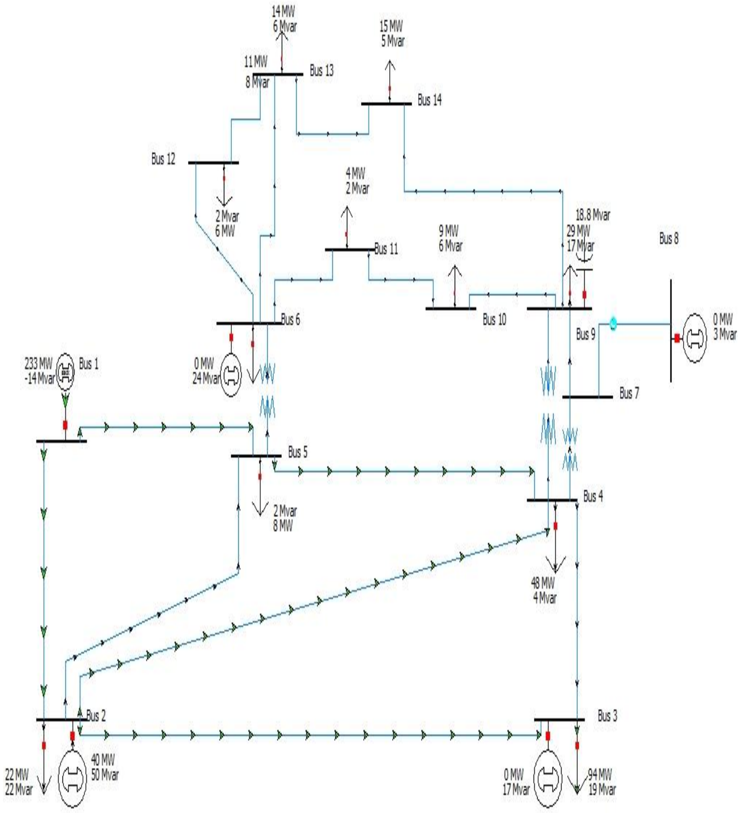

Figure 4. One line diagram of the IEEE 14 bus test system

7. CONCLUSION

This paper has presented a method to find the optimal number and best placement position of the PQMs in a 14 IEEE bus test system using MRA and SOV respectively. The proposed method is based on MRA that is obtained by calculating the fault voltage magnitude originated from all simulated fault types in the system using POWERWORLD simulator. The optimization is run using IP and GA techniques based on the concept of MRA and the three constituents of optimization problem formulation. It was proved that both the IP algorithm and GA gives the same optimal number. However, the optimal number was obtained for each of the simulated fault types. The best placement position to install the PQMs was also identified using sag occurrence value, so as to ensure complete observability of the system. The results showed that, it is not necessary to install PQMs at all the buses in the system in order to ensure complete observability of voltage sags in the whole system. This method may help the power companies and the planning engineers to minimize the installation cost of PQMs especially for voltage sags detection.

ACKNOWLEDGMENT

The authors would like to acknowledge the Ministry of Education Malaysia and Universiti Teknologi Malaysia under the research grant VOT Number = Q.J130000.2523.10H64 for their funding and supporting the paper.

REFERENCES

[1] M. H. J. Bollen, “What is power quality?,” Electr. Power Syst. Res., vol. 66, no. 1, pp. 5–14, 2003.

[2] M. A. Eldery, F. El-Saadany, and M. M. a. Salama, “Optimum number and location of power quality monitors,” 2004 11th Int. Conf. Harmon. Qual. Power (IEEE Cat. No.04EX951), 2004.

[3] Institute of Electrical and Electronics Engineers, IEEE Std 1159 - IEEE Recommended Practice for Monitoring Electric Power Quality, vol. 2009, no. June. 2009.

[4] A. A. Ibrahim, A. Mohamed, and H. Shareef, “Optimal Placement of Power Quality Monitors in Distribution Systems Using the Topological Monitor Reach Area,” pp. 394–399, 2011.

[5] A. A. Ibrahim, A. Mohamed, H. Shareef, and S. P. Ghoshal, “A New Approach for Optimal Power Quality Monitor Placement in Power System Considering System Topology,” Prz. Elektrotechniczny, vol. 88, no. 9a, pp. 272–276, 2012.

[6] C. W. C. Wei and H. H. H. Huimin, “A study on optimal placement of voltage sag monitors,” Electr. Distrib. (CICED), 2010 China Int. Conf., pp. 1–6, 2010.

[7] B. A. Ahmad, A. Ain, A. Ain, and A. Ain, “Review of Power Quality Monitoring Systems,” 2015.

[8] M. A. Eldery, S. Member, E. F. El-saadany, S. Member, M. M. a Salama, and A. Vannelli, “A novel power quality Monitoring Allocation Algorithm,” vol. 21, no. 2, pp. 768–777, 2006.

[9] M. H. J. Bollen and P. a Crossley, “Characterization of Voltage Sags In Industrial Distribution Systems - Industry Applications, IEEE Transactions on,” vol. 34, no. 4, pp. 682–688, 1998.

[10] G. Olguin and M. H. J. Bollen, “Optimal dips monitoring program for characterization of transmission system,” 2003 IEEE Power Eng. Soc. Gen. Meet. (IEEE Cat. No.03CH37491), vol. 4, pp. 2484–2490, 2003.

[11] D.Das, ELECTRICAL POWER SYSTEMS, no. 1. New Age International (P) Limited, 2006.

[12] “Mathematical Calculation and MATLAB Programming of Symmetrical and Asymmetrical Faults in Power System,” no. 2, pp. 184–187, 2014.

[13] A. A. Ibrahim, a. Mohamed, H. Shareef, and S. P. Ghoshal, “Optimal placement of voltage sag monitors based on monitor reach area and sag severity index,” Proceeding, 2010 IEEE Student Conf. Res. Dev. - Eng. Innov. Beyond, SCOReD 2010, no. SCOReD, pp. 467–470, 2010.

[14] A. A. Ibrahim, A. Mohamed, H. Shareef, and S. P. Ghoshal, “An Effective Power Quality Monitor Placement Method Utilizing Quantum-Inspired Particle Swarm Optimization,” no. July, 2011.

[15] A. A. Ibrahim, A. Mohamed, and H. Shareef, “Application of Quantum-Inspired Binary Gravitational Search Algorithm for Optimal Power Quality Monitor Placement 3 PQM Placement Formulation 2 the Monitor Coverage Concept,” pp. 27–32.