WIDE AREA MONITORING, PROTECTION AND CONTROL (WAMPAC) APPLICATION IN TRANSMISSION GRID – A LITERATURE REVIEW

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Abstract: This paper presents a review on WAMPAC application in Transmission Grid worldwide and application of Phasor Measurement Units (PMUs), FACTS devices and Phase Shifting Transformers in electric power transmission networks. Also this paper presents the current status of the research and developments in the field of the applications of PMUs, FACTS Devices and PSTs in electric power transmission networks. This paper uses the literature review already available for this subject. This research is very much needed for the inputs to the current project work of WAMPAC application in Transmission Grid.

Keywords: Phasor Measurement Units (PMU) Flexible AC Transmission Systems (FACTS), Synchro phasor enabled Protection Relays, Phase Shifting Transformers (PSTs), Electric power transmission networks.

1. INTRODUCTION

This Literature review has been done for the input to the proposed project of 'WAMPAC applications in Transmission Grid'. The PMUs, FACTS devices and PSTs are going to be modeled in the Transmission grid for which the optimal placement of PMUs, FACTS devices and PSTs will be simulated and studied. The Literature review will focus on this subject.

2. Phasor Measurement Unit (PMU)

A Phasor Measurement Unit is a device which measures both sinusoidal and non sinusoidal waveforms on the electrical network grid using a common time source for synchronization. The above Time synchronization allows synchronized real-time measurements of multiple remote measurement points on the network grid and the measurement is called as Sycnchrophasor.

Figure 1 shows a hardware block diagram of a PMU. The anti-aliasing filter is meant to filter out from the input waveform frequencies above the Nyquist rate. The phase locked oscillator converts the GPS1 pulse per second into a sequence of high-speed timing pulses used in the waveform sampling. The microprocessor executes the DFT Phasor calculations. Finally, the Phasor is time stamped and uploaded to a collection device known as a data concentrator.

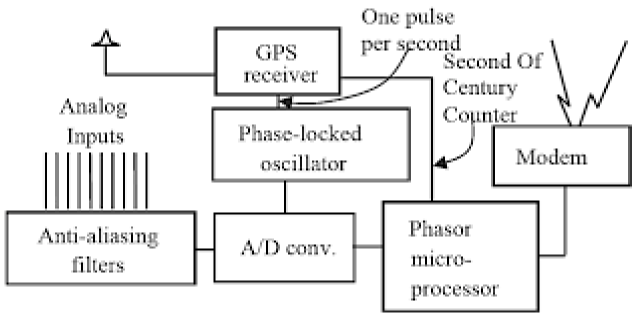

Fig. 1 – PMU Black diagram

Figure 2 shows the Sycnchrophasor measurement and how the sampling is being taken from the waveform.

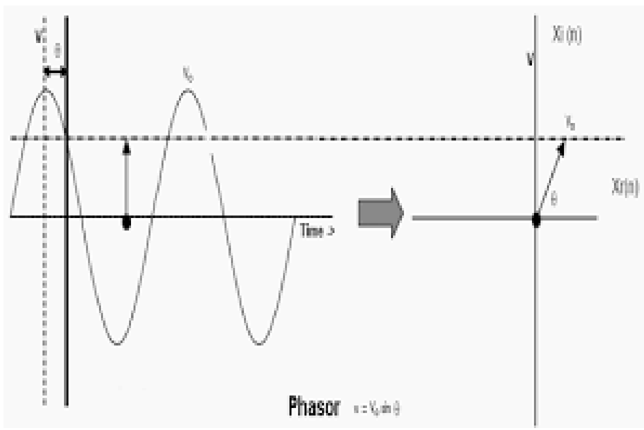

Fig. 2 Sycnchrophasor measurement

3. LITREATURE REVIEW

3.1 Wide Area Monitoring, Protection And Control in the future Great Britain – A PhD thesis by Deyu Cai, School of Electrical Engineering, University of Manchester

The main objectives of the research presented in this thesis are to design a GB WAMPAC system and develop solutions to overcome the challenges that will be involved in the initial stage of the GB WAMPAC project.

As Synchronized Measurement Technology (SMT) is the important enabler of WAMPAC, this presents a study of SMT and its applications. Furthermore this study gives the overview of the state of the art of those SMT applications, and worldwide experience with the operation of WAMPAC with emphases on system architecture, communication technologies and data management.

The above thesis put forward a new methodology for designing a roadmap that will ensure the future GB WAMPAC system will be developed in a logical and economic manner. This methodology proposed takes into account the international experience with WAMPAC project management and the practical challenges faced in the future GB power system. With the above, the GB strategies for the development of WAMPAC are devised.

Following two major SMT applications are then developed in the research study that can form main parts of the proposed future GB WAMPAC system. The reason behind those applications are developed to enhance the small signal stability of the future GB power system.

i. Wide Area Inter-area Oscillation Monitoring using Newton Type Algorithm.
ii. Wide Area Inter-area Oscillation Control
using Power Electronic Devices.

Finally, the operation of a proposed GB WAMPAC system is demonstrated using the Dig SILENT software package. The proposed real time applications in the research paper are tested and evaluated using dynamic simulations of a full GB power system model. In addition to the above, some key factors that will influence the operation of the future GB WAMPAC system will be analyzed and discussed.

The above research work without ambiguity discusses the road map for the future Great Britain network which can be used for our proposed project also.

3.2 Optimal Placement of PMUs in Power System Networks

Nabil H. Abbasy & Hanafy Mahmoud Ismail (2009) presented following: A unified approach is proposed to determine the optimal number and locations of PMUs to make the system measurement model observable and the same can be used for power system state estimation. The model PMU placement problem is explained as a binary integer linear programming (BILP), wherein the binary decision variables (0, 1) determine whether to install a PMU at each bus, while preserving the system observability and lowest system metering economy. The proposed approach integrates the impacts of both existing conventional power injection and the possibility of single or multiple PMU loss into the decision strategy of the optimal PMU allocation. Unlike other available techniques, the network topology remains unaltered for the inclusion of conventional measurements, and therefore the network connectivity matrix is built only once based on the original network topology. The mathematical formulation of the problem maintains the original bus ordering of the system under study, and therefore the solution directly points at the optimal PMU locations. Mat lab is used for the Simulation on a simple testing seven-bus system as well as on different IEEE systems to prove the validity of the proposed method.. [31]

Farrokh Aminifar et al (2010) presented a model for the optimal placement of contingency-constrained Phasor measurement units (PMUs) in electric power networks is presented. The conventional complete observability of power networks available is first formulated and then, different contingency conditions in those power networks including measurement losses and line outages are added to the main model. The communication constraints which plays a limiting factor for maximum number of measurements associated with each installed PMU is considered as measurement limitations. The relevant formulations as suggested are also proposed to make the model more comprehensive. The IEEE standard test systems are used for the applicability of proposed model. The results thus obtained are compared with those already available with the effectiveness of proposed model with regards to minimizing the total number of PMUs and the execution time. A large-scale system with 2383 buses is also analyzed to show the viability of proposed model to practical power system cases. [13]

Allagui et al (2013) presented the model of Monitoring and supervision of power systems are provided by the control center, whose role is the design, coordination and network management wherein they presented a control technique based on the implantation of measurement units at the network buses. This technique must meet two requirements: to ensure the complete system observability and to find the optimal locations of PMUs with the minimum cost. The problem was formed as a mono-objective optimization problem and its resolution was made by using a genetic algorithm (GA). The above proposed method is tested on three tests networks and the results are compared with other resolution techniques. The simulation results thus obtained ensure the complete system observability and validate the presented technique. [1]

Madhavi & Karthik (2014) presented an integer linear programming based methodology for optimal placement of PMU in a given power network for full observability of that network is presented in this paper. First conventional complete observability of the network under study is formulated and then, zero injection bus constraints are added in previous formulation. Both of the above results from conventional and modified formulation are than compared. Furthermore minimum PMU placement problem might have multiple solutions, so to decide best one, two indices are proposed, BOI and SORI, where BOI is Bus Observability Index and SORI is System Observability Redundancy Index respectively. The above results on 9 bus, IEEE 14 bus systems are presented. [24]

Pradeep & Singh (2014) presented the Phasor Measurement Unit (PMU) is an important tool for monitoring and control of the power system. The model gives real time, synchronized measurements of voltages at the buses and also current phase values which are corresponds to those buses where these PMUs are located. A topological approach to determine the optimal PMU placement in order to make the system completely observable using binary integer linear programming also has been presented. The above proposed formulation is tested on various IEEE test systems (Buses) and results so obtained for complete observability of system at normal condition and with loss of single PMU are also formulated in this paper. The proposed PMU placement has been implemented on IEEE - 14, 30, 57 and 118 bus systems, practical 75-bus system of Utter-Pradesh State Electricity Board (UPSEB) and New England 39-bus system and the results are tabulated. [34]

Kimiyaghalam et al (2013) implemented optimal PMU placement to make the network observable, and guarantees the observability of network under probabilistic events. In respect of the high cost of PMU units, another objective of the paper is to reduce PMUs' installation cost. To demonstrate the applicability of the proposed method, it is applied to IEEE 14-bus test system using a binary artificial bee colony algorithm (BABC) and compared with genetic algorithm (GA) and the results are furnished. [19]

Manousakis presented the following: The increasing availability of phasor measurement units (PMUs) at substations makes the synchronized measurements to various applications, such as the monitoring of system state under normal operations or the protection and control of power systems during Power system strains. The objective of the optimal PMU placement (OPP) problem is to determine a minimal set of PMUs such that the whole system is possible to observe. To solve the OPP problem, mathematical programming, heuristic, and meta-heuristic optimization techniques, have been adopted. This paper provides a detailed literature review on the OPP problem and the solution methodologies as such. [26]

Rahul H. Shewale et al (2012) presented a method for optimal placement of PMUs for full observation of power system and use of minimum number of PMUs. Heuristic Search method is used to find out the optimal location of the Phasor measurement unit in power system. The Problem is presented and solved by using systems network connectivity matrix and simple heuristics. The proposed algorithm has been implemented and tested on IEEE 14-bus, 30-bus, 57-bus, 118-bus, New England 39-bus systems. [35]

Mohd Rihan et al (2013) presented the following: Power grids, in the entire world, are operated as large interconnected networks to ensure reliability of supply. The interconnected nature of power network makes it vulnerable and sometimes even a small disturbance in the grid may propagate and result in a brown out or blackout. Investigations into major blackouts of the decade in the world have identified inadequate monitoring of the dynamic phenomena occurring in the power grid as the primary reason behind brownouts & blackouts. To overcome this drawback, it was recommended in various investigation reports that PMUs should be deployed in the entire grid. The investigation reports also recommended that even if a disturbance occurs, the system should be split into a number of independent islands to prevent propagation of fault and avoid brownouts & blackout in the grid. Previous work on PMU assisted islanding assumed infinite channel capacity of PMUs available which is unrealistic. The primary objective of the present work is to show that the channel capacity of PMU should be an integral consideration while devising an workable intentional islanding methodology. The islanding algorithm is adopted to IEEE 14 bus network which is installed with a minimum number of limited channel PMUs to make the system observable. The algorithm is able to split the IEEE 14 bus network in two independent, self sufficient islands and the results are formulated. [28]

Xin Tai et al (2013) presented PMUs provide globally synchronized measurements of voltage and current phasors in real-time and at a high sampling rate. Hence, they are permitted to improve the state estimation performance in power systems. A novel method is presented in this paper for optimal PMU placement in a power system suffering from random component outages (RCOs). The proposed method in this paper, for a given RCO model, the optimal PMU locations are chosen to minimize the state estimation error covariance. The researcher considered both static and dynamic state estimation. In order to reduce the complexity, the search for the optimal PMU location s is constrained to the set of locations guaranteeing topological observability. The numerical results thus obtained are presented the application and scalability of our method using the IEEE 9-bus, 14-bus, 39-bus and 118-bus systems. [45]

Saha Roy et al (2012) Power system state estimation with exclusive utilization of synchronous Phasor measurements demands that the system should be completely observable through PMUs only. To have optimum number of PMUs, the PMU placement issue in any network is an optimization problem. A three stage optimal PMU placement method is discussed in this paper using network connectivity information. The method proposed as above initially considers PMU in all buses of the network. Stage I

and Stage II of the algorithm iteratively determine the following:
(i)not so important bus locations from where PMUs are eliminated and (ii) strategically important bus locations where PMUs are retained as such. Stage III of the algorithm furthermore minimizes the number of PMU using pruning operation. The set of PMUs obtained after the completion of Stage III is an optimal set of PMU locations for network observability. Simulation results for IEEE 14-bus, 24-bus, 30-bus, 57-bus, 118-bus and New England 39- bus test systems are presented and compared with the existing techniques available. Results thus obtained show that the proposed method is simple to implement and accurate compared to other existing methods already presented in the various papers. [38]

Didier Geores (2012) presented the following: This research work is dedicated to a new methodology for designing an optimal monitoring architecture by using a limited number of PMUs and PDCs. The optimal design problem includes the defining the optimal location of both PMUs and PDCs by maximizing the expected value of the trace of the observability gramian of the power system network over a large number of set point scenarios, while minimizing some communication infrastructure costs. Furthermore, a nonlinear dynamical state-observer, based on the Extended Kalman Filter, is proposed in this paper. This state-observer allows to take transient phenomena into account for wide-area power system netwroks described by algebraic differential equations, without needing nonlinear inversion techniques. The overall approach is tested with the IEEE 10 generator 39 bus New England power system. [10]

Sodhi et al (2008) gave a two level approach for solving optimal PMU placement (OPP) problem in order to achieve complete observability of the power system. The proposed method utilizes a heuristic algorithm to partition the power system into two or more sub-networks. The algorithm discussed partitions the spanning tree of the network using integer linear programming (ILP). The ILP as above has been formulated based on eigenvectors of the adjacency matrix of the spanning tree. After decomposition, PMUs have been placed optimally in the sub-networks of the power system in order to minimize installation cost of the PMUs. [41]

Chakrabarti et al (2008) proposed a method for optimal placement of PMUs for complete observability of a power system for normal operating conditions, as well as for single branch outages. A binary search algorithm is used to determine the optimum number of PMUs needed to make the system observable. If the solution is more than one, a strategy is proposed to select the solution resulting in the most preferred pattern of measurement redundancy. [6]

Chakrabarti et al., (2009), demonstrated the uncertainties associated with the power system state variables obtained with the help of PMUs. An integer-quadratic programming- based method is used to determine the minimum number and the optimal locations of the PMUs to ensure complete topological observability of the power system network. In recent years, there has been a significant research activity on the problem of finding the optimum number of PMUs and their optimal locations for power system state estimation. [7]

Chakrabarti and Kyriakides, (2007) presented - An integer – quadratic – programming based method for finding the optimal PMU locations for complete power system observability. The method proposed achieves multiple objectives: it minimizes the required number of PMUs and maximizes the measurement redundancy at all the buses under study. During power system restoration after occurrence of fault, it is necessary to check the phase angle between two buses before extending the close command to circuit breakers to connect a line between them. A novel approach for reducing large standing phase angle (SPA) based on Genetic Algorithm (GA) is discussed in this literature. The proposed approach presents a state estimation on WAMS data measurements and considering power system operation and angular stability constraints, seeks an optimal control action scenario for reducing SPA. Since these constraints are evaluated based on WAMS data which is available, the presented approach is accurate. As an optimization problem, objective function of the proposed approach is to minimize the variation issue from the current state of the power system. [5]

Nourizadeh et al., (2010). Emami and Abur (2010) is concerned about optimal placement of synchronized Phasor measurements that can monitor
voltage and current phasors along network branches. Earlier investigations on optimal placement of PMUs have assumed that PMUs could be placed at a bus and would provide bus voltage Phasor as well as current phasors along all branches incident to the bus. [32]

Lin et al. (2004), presented a new fault detection/location technique with consideration of arcing fault discrimination based on PMUs for extremely high voltage/ultra-high voltage transmission lines. Synchronized Phasor measurements from a limited number of dispersed locations in the power netwrok can be used for enhanced monitoring of the power system, as well as for presentation of the critical dynamics in the power systemnetwork. [23]

3.3 Application of PMUs for Fault identification/ Location detection of Power Systems

Yu et al. (2002) suggested a new fault location algorithm based on PMUs for series compensated lines. From the beginning, the voltage drop of series device is computed by the device model in the fault locator of series compensated lines, but using this approach, errors are induced by the inaccuracy of the series device model or the uncertainty operation mode of the series FACTS device. The proposed algorithm in this paper does not utilize the series device model and knowledge of the operation mode of the series device to compute the voltage drop during the fault period. Rather, the proposed algorithm uses two-step algorithm, pre-location step and correction step, to calculate the voltage drop and fault location. [46]

Lee et al. (2006) presented a new numerical algorithm for fault location estimation and for faults recognition based on the synchronized phasors. The proposed algorithm is based on the synchronized Phasor measured from the synchronized PMUs installed at two-terminals of the transmission lines in a power system network. [21]

Pereira et al., (2004) presented a PMUs optimized allocation allows control, monitoring and accurate operation of electric power distribution systems, improving reliability and service quality. In this paper good quality and considerable results are obtained for transmission systems using fault location techniques based on voltage measurements are discussed. [33]

In Chuang et al. (2007) a modern fault detection/location technique for an EHV/UHV transmission network usually works based on the data measured by PMUs has been proposed in this literature. The synchronized voltage and current phasors together with phasor angle measured by PMU are transmitted to a monitoring center for analysis. [9]

Gopalakrishnan et al. (2000) presented adaptation of a time domain model of a transmission line for development of their algorithm. The above method is tested on very limited number of test-cases and the effect of fault resistance is not reported. [12]

Lien et al. (2006) presented a concept of fault-location observability and a new fault-location scheme for transmission networks based on synchronized PMUs. Using the above proposed scheme, minimal PMUs are installed in existing power transmission networks so that the fault, if it occurs, can be located correctly and reported in the network. [22]

Kamwa et al. (2009) presented a proposal of a systematic scheme for building compact and transparent fuzzy rule-based classifiers for rapid stability assessment; the classifiers as above are initialized by large accurate decision trees (DTs). The approach starts by selecting strategic monitoring buses where PMUs are placed to capture wide-area response signals in real-time operation in a power system network. [18]

3.4 Application of PMUs for power system Oscillations detection function

Samir & Amir (2010) presented Low frequency power oscillations may be triggered by many events in the system. Even though most oscillations are damped by the system, but undamped oscillations can lead to system collapse. Oscillations develop as a result of rotor acceleration/deceleration following a change in active power transfer from a generator to the network. Like the operations limits, the monitoring of power system oscillating modes is a most important aspect of power system operation and control. Un prevented low-frequency power swings can be cause of cascading outages that can rapidly extend effect on wide region if not eliminated. On this regard, a Wide Area Monitoring, Protection and Control Systems (WAMPCS) help in detecting such phenomena and gives a detailed insight into power system dynamics security. The monitoring of power system electromechanical oscillations is an important in the frame of modern power system management and control. The first part compares the different technique for identification of power system oscillations. The second part deals possible identification of some power system dynamics behaviors using Wide Area Monitoring Systems (WAMS) based on PMUs. [39]

Korba and Uhlen, (2010), addressed different approaches to detection of critical oscillatory modes. It uses fast sampled signals captured with Phasor PMUs and a WAM platform. The methods used here are model-based. [20]

Brian et al. (2008) introduced the use of regression analysis in the study of small signal stability in large interconnected power systems. [4]

Messina et al. (2009) discussed the application of non stationary time-frequency analysis techniques to identify nonlinear trends and filtering frequency components of the dynamics of large, interconnected power systems. In this paper two different analytical approaches to examine non stationary features are investigated. The first method uses selective empirical mode decomposition (EMD) of the measured data. The second method presented is based on wavelet shrinkage analysis. [27]

Guoping et al. (2008) presented a new extends the method of Frequency Domain Decomposition (FDD) towards real-time analysis of ambient PMUs measurements in power systems for the purpose of oscillation monitoring. The main idea behind the FDD is to apply Singular Value Decomposition (SVD) to the power density spectrum matrix. [11]

In (Jin et al. 2010) a smart power grid is an integration of the advanced measurement, communication, computer, and control techniques. Among all the state-of-the-art technologies in building a smart power grid, the PMUs is a foremost and the vital tool. [15]

Tripathy et al. (2010) investigated the possibility of using a nonlinear estimator for estimating the internal variables of a synchronous generator, such as the rotor angle, from the data acquired from PMUs. A divide-by-difference filter (DDF) has been used for accurate estimation of the rotor angle of the generators that are connected in the power system network. The proposed rotor angle estimator in this literature utilizes the measurements of the terminal voltage, active power output, and field voltage of the generator. [42]

Venkata et al., (2004) has suggested a direct method to compute the generators' internal dynamical states from the terminal measurements of the voltage, power, and field current of a generator. This method presented is fast, but the estimated rotor angle may not be quite accurate as it neglects the system dynamics presents in the network. [44]

Mai et al. (2010) presented the following: synchro phasors and frequency estimations play an important role in power system dynamics. Discrete Fourier transform (DFT) sometimes may introduce errors into Phasor and frequency estimations under dynamic conditions, such as power oscillation. A dynamic Phasor and frequency estimator for PMUs is proposed in this literature to improve accuracy by considering dynamic characteristics of power systems expressed as Taylor derivatives. [25]

3.5 Application of FACTS Devices in PMU environment

Bindeshwar Singh et al (2011) presented a critical survey on different application of Phasor Measurement Units (PMUs) in electric power system networks incorporated with FACTS controllers for advanced power system operations, monitoring, control, and protection. Also this paper discusses the current status of the research and developments in the field of the applications of PMUs in electric power system networks incorporated with FACTS controllers. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of the applications of PMUs in electric power system networks incorporated with FACTS controllers which will be useful in our project also. [2]

Bindeshwar Singh et al (2012) presents a review on applications of Flexible AC Transmission Systems (FACTS) controllers such as Thyristor Controlled Reactor (TCR), Thyristor Controlled Switched Reactor (TCSR), Static VAR Compensator (SVC) or Fixed Capacitor- Thyristor Controlled Reactor (FC-TCR), Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Switched Series Reactor (TSSR), Thyristor Controlled Brakening Reactor (TCBR), Thyristor Controlled Voltage Reactor (TCVR), Thyristor Controlled Voltage Limiter (TCVL Thyristor Controlled Switched Series (TSSC), Thyristor Controlled Phase Angle Regulator (TC-PAR) or Thyristor Controlled Phase Shift Transformer (TC-PST), Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Distributed Static Synchronous Compensator (D-STATCOM), Generalized Unified Power Flow Controller (GUPFC), Unified Power Flow Controller (UPFC), Inter-link Power Flow Controller (IPFC), Generalized Inter-link Power Flow Controller (GIPFC),and Hybrid Power Flow Controller (HPFC), Semiconductor Magnetic Energy Storage (SMES), Battery Energy Storage (BESS), in power system environments for enhancement of performance parameters of power systems such as reactive power support, minimize the real power losses, improvement in voltage profile, improvement in damping ratio of power systems, provide the flexible operation, measurement and control etc. Authors strongly believe that this survey article will be very much useful for the researchers, practitioners, and scientific engineers to find out the relevant references in the field of enhancement of performance parameters of power systems by different FACTS controllers such as series, shunt, series-shunt, and series-series connected FACTS controllers are incorporated in power system networks. This article is very much useful for our project. [3]

Ravi Kumar & Sarfaraz (2012) presented Power flow control, in an existing long transmission line, plays a vital role in Power System area. In this the shunt connected compensation (STATCOM) based FACTS device for the control of voltage and the power flow in long distance transmission line are modeled. The proposed device is placed in different locations such as sending end of the transmission line, middle and receiving end of the transmission line. The PWM control strategy of the thyristors is used to generate the firing pulses of the controller circuit. Simulations were carried out using MATLAB Simulink software and are depicted. The suitable location and the performance of the proposed model were examined in length. Based on a voltage-sourced converter, the STATCOM regulates system voltage by absorbing or generating reactive power as when required. The simulation results thus obtained reveals that the reactive power generated is better at the middle of the transmission line when compared with the other ends of the transmission line and also the voltage is controlled at the middle of the line. As such the location of STATCOM is optimum when connected at the middle of the line. This is an interesting finding. [36]

Moncef-J et al (2010) presented the following: The opening up of the power market has generated more power flows in the European electrical grid and as a consequence congestions have appeared. Differences in energy prices in different regions can generate congestions which may give rise to differences in energy pricing as well. As the extension of the grid with new high voltage overhead lines faces most often the opposition of the population due to environmental issues & right of way (ROW) issues, there are some solutions to be considered to reduce congestions: install Flexible AC Transmission Systems (FACTS) devices and install Wide

Area Control Systems (WACS). But a coordinated, synchronized, and reliable control of FACTS devices is necessary at the system level covering a wide area network. This contribution deals with the development of such a control for the Swiss HV network, aiming at preventing congestion in the north-south corridor across the Alps mountain. The control algorithms are developed and implemented on a reduced scale physical model in order to perform experimental validation. [30]

3.6 Compatibility of existing protection relays for PMU functions.

Saran, A et al (2013) presented the following: Power system protection is still one of the primary focuses of the utility companies worldwide. PMU is used to measure the data such as voltage, current, frequency & phase angle of the transmission line, buses and the equipment's associated with it. The data measured by the PMU's at different locations can be used to make the decisions for faulty and healthy zone in the power system network. During fault condition at specific location in the power system where ever the PMUs are installed, the data measured by PMU will show abrupt increase or decrease in the physical quantities like voltage, current, and phase angles. Based on the PMU values the relays associated with the faulty transmission lines will be triggered which in turn helps to isolate only the faulty portion of the system from the rest of the healthy portion of the power system network. This paper will compare two protection schemes: One protection scheme is based solely on the protective relays while the other protection scheme utilizes both the protective relays and the PMUs as well. Both the protection schemes were tested in real time (using RTDS) on the 3-bus power system for all kinds of line-to-ground faults and the results are formulated. [40]

Karthick & K.Lakshmi (2015) presented wide area backup protection scheme in power transmission lines. This paper deals with PMU based wide area backup protection scheme for transmission lines developed to identify the faulted line by with PMUs. After a fault occurs in the transmission network, zero and positive sequence currents entering the faulted backup protection zone increases rapidly and faulted backup protection zone can be determined as such. To overcome the above mentioned problems the optimization model is developed to identify the faulted line by using the wide area data of WAMS. Linear least squares method (LLSM) is used to determine the faulted line as well as the fault location by voltage and current phasors of the Backup Protection Zone (BPZ) with limited measurement points. The proposed method is executed for IEEE-9 bus system using MATLAB/Simulink software and the results are discussed. [17]

3.7. Application of PST in the Transmission network

Mohammed et al (2010) examined and tested an alternative method to control and redirect electric power flow through certain paths (transmission lines). The control and redirecting of power flow can be achieved through the use of phase shift transformers PSTs. An algorithm is presented which searches for a proper phase shift angle introduced by a PST at any given location where the PST is installed. The proposed method is based on modeling the PST and employing Newton-Raphson load flow approach. Finally, the installation of series of PSTs on the interconnected power systems aims at mitigating uncontrolled parallel flows and unbalanced sharing of power among transmission lines are discussed. The obtained results showed the effectiveness of the proposed method in sharing and controlling the electrical power flow among different interties of the 5-bus network on which the study is performed. [29]

S.Sachdeva (M/s. BHEL) et all presented the development of 315 MVA, 400 kV class, 3 – phase PST by BHEL for Andhra Pradesh Generation Corporation Ltd, Hyderabad. The theory, manufacturing concepts as well as advantages of the PST are discussed in this paper. [37]

Jody Verboomen et al short overview of existing technologies regarding phase shifting transformers (PST's). A classification is presented based on the symmetrical or asymmetrical and on the direct or indirect character of the PST. As a case-study, the PST's in Meeden, The Netherlands are studied more profoundly and presented. Furthermore, a model is developed on a real-time digital simulator (RTDS) in order to demonstrate the capabilities of the PST and the test results are discussed. [16]

Hossein Nasir Aghdam presented a scheme to solve the congestion problem and improvement of voltage profile using control with Phase-Shifting Transformer (PST). An efficient design of PST can improve Total Transfer Capability (TTC) in interconnected power networks. This paper uses optimization technique such as Linear Programming (LP) for TTC calculation. The PST is used to increase power flow of tie line subject to security constraints such as voltage magnitude and real power flow. In order to show the effectiveness of the implementation of PST, it has been tested on simple power system, and its results are presented and discussed in detail. The MATLAB/SIMULINK program is applied to investigate the effect of PST on power flow in power system. [14]

Tripathy (et al 2012) presented the following: India is poised to double the power generation by 2012. With the result the requirement of transmission & distribution is increasing abnormally. The optimal use of existing infrastructure needs to be done in order to contain investment. It is therefore necessary to load the existing lines to optimal capacity rather than providing the additional corridor in order to avoid the capacity addition. Sometimes it is necessary to provide additional corridor in order to maintain system's reliability and availability (Security concerns). Over loading of subsystem in a power system sometimes may pose stability issues, which may lead to unwanted tripping, equipment failures which will result long repair/ replacement cycle and heavy revenue losses to the utilities. Under these conditions, to ensure economical and reliable operation of the grid, power through the lines should be effectively and actively controlled within their capabilities. In case of HVDC systems, the power is automatically controlled as desired by the operator through the Thyristors controls. However, control of power in AC network requires special technology to be implemented. It is known that the operating efficiency of electric transmission system can be improved by using appropriate FACTS devices. Phase shifting transformer is one of the member of the FACTS family, which can be used for power control in a network. For demonstrating the ability of the phase shifting transformer in regulating the power flow in an alternate transmission network, simulation of Maharashtra zone and Utter Pradesh zone of an Indian grid is considered and depicted. From power flow solution, various overloaded lines and the alternate under loaded lines are identified and different cases are simulated to regulate the power using phase shifting transformer. By introducing phase shifting transformer in to the actual network of the Indian Grid, power flows in the area of interest is re validated and application of PST is justified so as to adopt in the Indian power networks. [43]

4. Proposed project – WAMPAC applications in a Transmission network

The main objective of this project is to simulate the transmission grid of 400 kV level. Study the present SCADA system available in the grid and shortcomings of the present SCADA system will be listed.

The study of optimal placement of PMUs in the existing 400 kV grid will be done. The study of application of protection devices presently available for the synchro Phasor application will be carried out. Usage of power electronics devices & Phase Shifting Transformers will be studied for the effective control of power system parameters. Simulation of the transmission grid in the PSS (E) or DIGI Sync software will be done to ascertain the effectiveness of the WAMPAC.

5. Conclusion

This paper discussed the current status of the research and developments in the field of the applications of PMUs in Transmission networks for enhancement of power system monitoring, stability and usage of Sycnchrophasor enabled Protection relays to act as PMUs. Also this paper presents the research articles available for the integration of FACTS devices & PSTs in the PMU environment and its implications. Authors will use this Literature survey for the proposed project of WAMPAC applications in a Transmission network.

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