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OPTIMAL PLACEMENT OF PHASOR MEASUREMENT UNITS FOR MADHYA PRADESH POWER GRID

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ABSTRACT

The tremendous demand for electricity makes entire power grid system very complex to monitor. There is an essential requirement to continuously monitor the power grid for making it smarter and reliable. Traditional measurement that was SCADA (Supervisory Control and Data Acquisition system) systems are getting replaced by PMUs, which enables the online monitoring of the power system more effectively. Improvements in power system control and protection is achieved by utilizing real time synchronized phasor measurements. PMU with the help of GPS can measure the phasor values of voltages at the bus, where it is placed and the current through the branches connected to that bus. The Current measurement enables us to estimate the voltages at the neighbouring buses. Because of this, placing PMUs at all buses for the complete monitoring of the power system is redundant. Finding the optimal locations of PMUs to make the power system completely observable is great area of research interest. This paper proposes the optimal locations of PMU in Madhya Pradesh state of Indian power grid using ILP (Integer Linear Programming). PMU placement problem has been formulated and optimization has been carried out.

Keywords- Phasor Measurement unit (PMU), Integer linear programming (ILP), State Estimation, Complete Observability.

I. INTRODUCTION

The load demand in power system is always varying during whole day. The minimum capacity of generator should be such that it should meet the maximum demand. Stable operation of power system requires accurate and online monitoring of various operating conditions. Conventional method of power system monitoring is accomplished by SCADA (Supervisory Control and Data Acquisition system) system .SCADA system usually consists of Remote Terminal Units (RTU). RTUs are the microprocessor controlled electronic devices which can measure real and reactive power flows, magnitude of bus voltages and currents. RTUs are placed at various substations and they send the measured values to the state estimator which is placed inside the central control center. From the received measurement values and the knowledge about the network topology, state estimator can estimate various electrical quantities related to the power system stability. These estimated values are used for the online power flow control and management. But one of the drawbacks of the RTUs is that it cannot directly measure the phase angles of the voltages and currents at any bus. If we can measure phasor values of bus voltages and currents, better state estimation and thereby better power system control can be achieved. With the aid of Global Positioning System (GPS), a new era of measurement technique was developed in mid-1980s called Phasor Measurement Units (PMU). PMUs utilize the synchronization signals from the GPS to provide the phasor values of voltages and currents at the bus or substation wherever it is connected [1]. These types of phasor measurements can improve the monitoring of power system.

PMUs can measure the phase angle and amplitude of voltages at the installed bus and current through all branches connected to that bus. So it is redundant and not economical to place PMUs at all buses for making the power system completely observable. Finding the optimal locations for PMU is of great interest so that with minimum number of PMUs the power system under consideration will be fully observable [2], [3], [5]. This paper proposes the optimal places for PMUs in the West Central Region Indian power grid, taking Madhya Pradesh state power grid, so that it will be completely observable.

II. PHASOR MEASUREMENT UNITS

Fig. 1 shows the functional block diagram of a PMU [1]. PMU measures electrical waves on an electricity grid, using a common time source for synchronization. Analog inputs from potential transformers and current transformers are fed to an anti-aliasing. This will restrict the bandwidth of the signal to approximately satisfy the sampling theorem. The signals from the output of anti-aliasing filter are converted to digital using A/D converters. Phase locked loop ensures the synchronization of sampling with reference signal from GPS. Sampled signals are then fed to the phasor microprocessor, where phasors of phase voltages and currents are computed using recursive Discrete Fourier Transform (DFT) algorithms. The computed of phasor values are assembled in a message stream and are then sent via the communication network to the wide area monitoring system .

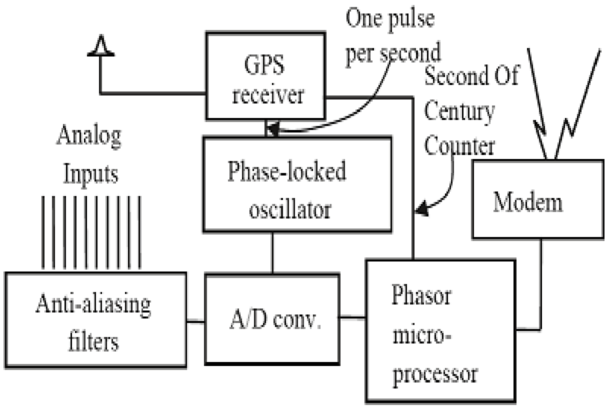


Fig. 1. Functional block diagram of PMU

III. THE CONCEPT OF OBSERVABILITY

A bus is said to be observable if a PMU is located on that bus and the voltage and phase angle are measured directly. A bus is said to be indirectly observable, if the voltage phasor at that bus is estimated using other PMUs. A bus is said to be unobservable, if its voltage phasor cannot be measured. This condition occurs when there is no PMU at that bus and neighbouring buses. From Fig. 2, at bus 2, 6 & 9 a PMU is placed so that voltage magnitude and phase angle at that bus and current through all the branches connected to it can be measured. So the bus 2, 6 & 9 are said to be directly observable since PMU is placed on these buses . Voltage magnitude at buses 1, 3, 4, 5, 7, 10, 11, 12,13 &14 can be estimated using ohms law. So these buses are said to be indirectly observable. But the voltage phasor at buses 8 cannot be estimated using PMU at bus any buses, so we can this bus 8 is unobservable. If all neighbouring buses of an unobservable bus are observable, then it is called depth of one un-observability [6]. A power system is said to be completely observable, if all the buses in that system are either directly or indirectly observable. A power system is said to be incompletely observable, if some buses are directly or indirectly not observable.

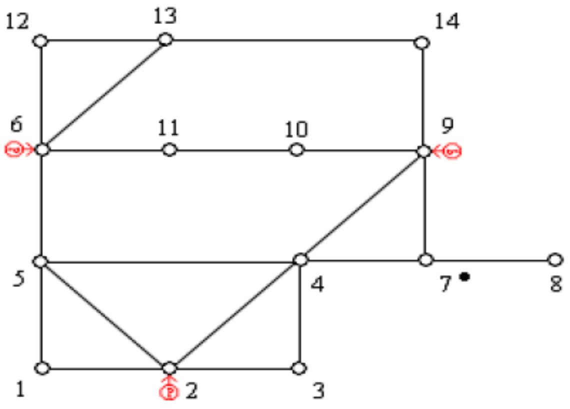


Fig. 2. A 14 bus system example

IV. MADHYA PRADESH POWER GRID

Indian power grid is broadly divided into five regions, northern region, southern region, eastern region, western region and north eastern region. In October 1991 North Eastern and Eastern grids region power grid were connected. In March 2003 WR and ER-NER were interconnected. August 2006 North and East grids were interconnected.

Madhya Pradesh comes under Western region of Indian power grid. Madhya Pradesh Power grid requires 7973 MW of load demand [6]. Madya Pradesh has total 51 district and for sake of convenience some big district are divided into two or three region. The single line diagram of Madhya Prasesh state power grid is shown in Fig. 4. The name of the buses corresponding to each bus number is given in Table. I.

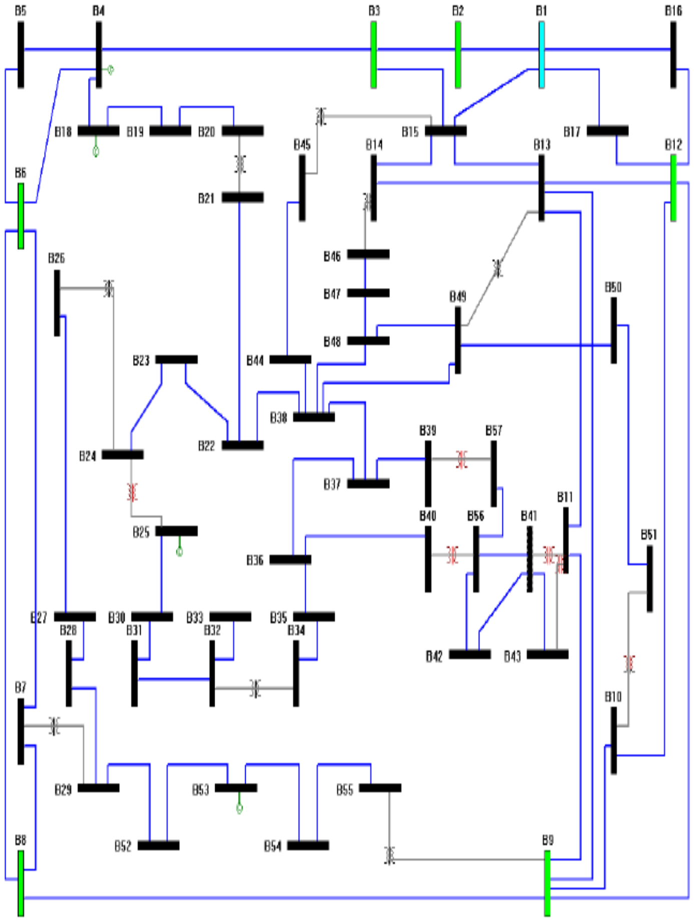


Fig. 3. Madhya Pradesh State Power Grid

TABLE I
MADHYA PRADESH POWER GRID BUS DETAILS

BUS	NAME OF THE BUS	BUS	NAME OF THE BUS
1	BHOPAL A	30	KATNI
2	BHOPAL B	31	MANDLA
3	BHOPAL C	32	NARSINGPUR
4	RAISEN	33	SEONI
5	RAJGARH	34	BETUL
6	SEHORE	35	HARDA
7	VIDISHA	36	HOSHANGABAD
8	MORENA	37	REWA
9	ASHOKNAGAR	38	SATNA
10	SHIVPURI	39	SIDHI
11	DATIA	40	SINGRAULI
12	GUNA	41	CHATTARPUR
13	GWALIOR A	42	DAMOH
14	GWALIOR B	43	PANNA
15	ALIRARAJPUR	44	SAGAR
16	BARWANI	45	TIKAMGARH
17	BURHANPUR	46	ANUPPUR
18	DHAR	47	DINDORI
19	AGAR-MALWA	48	UMARIA
20	INDORE A	49	AGAR
21	INDORE B	50	DEWAS
22	INDORE C	51	MANDSAUR
23	JHABUA	52	NEEMUCH
24	KHRGONE	53	RATLAM A
25	KHANDWA	54	RATLAM B
26	BALAGHAT	55	UJJAIN A
27	CHHINDWADA	56	UJJAIN B
28	JABALPUR A	57	SHAJAPUR
29	JABALPUR B		

V. INTEGER LINEAR PROGRAMMING

A numerical method based on Integer Programming is used to solve the optimal PMU placement problem. The formulation of problem is shown as below. For an n-bus system, the PMU placement problem can be formulated as follows:

$$\min \sum_{i}^{n} w_i . x_i$$

$$\text{s.t} \quad f(X) \geq \hat{1}$$

where

X is a binary decision variable vector, whose entries are defined a

$$x_i = \begin{cases} 1 & \text{if a PMU is installed at bus } i \\ 0 & \text{otherwise} \end{cases}$$

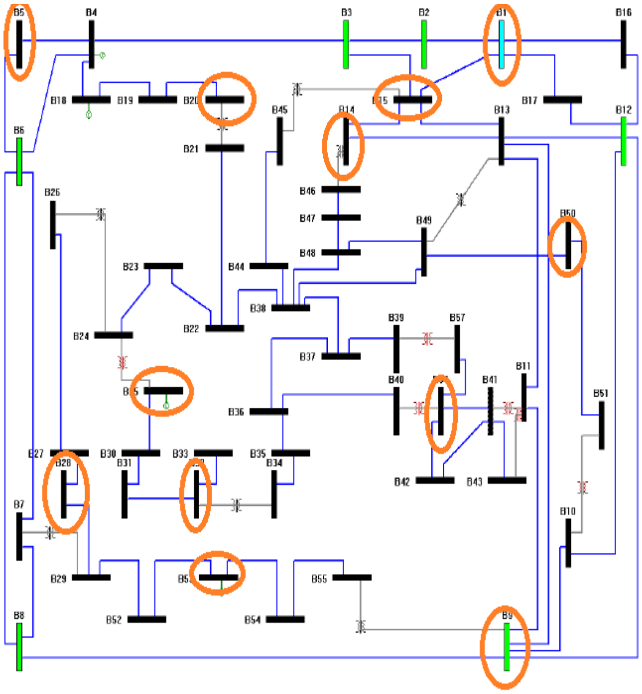
w is the cost of the PMU installed at bus i.

f (*X*) is a vector function, whose entries are non-zero if the corresponding bus voltage is solvable using the given measurement set and zero otherwise. Inner product of the binary decision variable vector and the cost vector represents the total installation costs of the selected PMUs. Constraint functions ensure full network observability while minimizing the total installation cost of the PMUs.

VI. SIMULATION RESULTS

In this paper two simulation results are required. First simulation is done for IEEE 14 bus system. It requires 3 PMUs placed at bus no. 2, 6 & 9 for making 14 bus system completely observable. Second simulation is done foe IEEE 57 bus system which is taken from the reference no. [4]. The bus at which PMUs are installed are shown by orange oval.

NUMBER OF PMU	LOCATION(BUS)
TWELVE(12)	1,5,9,14,15,20,25,28,32,50,53,56



VII. CONCLUSION

By optimal placement of PMUs, online monitoring will become a very easy task. This method of monitoring is more reliable than the traditional one. So it can be concluded from above work that it is a unanimous step towards making a grid smarter.

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