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A SMART GRID APPLICATION FOR DYNAMIC REACTIVE POWER MANAGEMENT

by

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SUMMARY

Indian Power Grid is a geographically wide spread and well grown power system network with bulk power transfer between two different regions interconnected by EHV network power corridor. Surplus power generation in one region and deficit in other region does happen. When some of the critical lines are under out of service the interregional power corridor gets weaken. Under such circumstances the power flow need to be diverted through some other inter/intraregional power corridor. When even a small disturbance can affect system stability. The huge power is transmitted can cause lines over loading which may even lead to load encroachment. This will cause deviation among two regions leading to system stability problem. In such a situation optimal utilization of system resources becomes very crucial. Sensing global power system conditions from local measurements using technology like PMU, WAMS and performing dynamic reactive power management will be very helpful in bringing the system to normal operating conditions from the edge of collapse. The recent northern region grid disturbance report [1] recommends for exploring new technologies with application of WAMS, PMU, etc. for online real time monitoring and control of the system especially under dynamic conditions. The report also recommends for exploring technology on predicting voltage collapse, sensing global power system conditions derived for local measurements.

This paper is proposing such Phasor Relativity Based Mathematical Control System (PRM Control System) as a Smart Grid Application for Dynamic Reactive Power Management. This paper also presents a photo type architecture for PRM Control System with Wide Area Measurement Systems(WAMS). The objective of the control system is online real time monitoring and control for dynamic reactive power management. Results are presented to demonstrate the performance of PRM control system in EHV networks. A special case study is also presented to demonstrate how the dynamic reactive power compensation can help the operator in improving system stability and security under conditions of system disturbances.

KEYWORDS

PMU, WAMS, Dynamic Reactive Power Management.

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1. SYSTEM ARCHITECTURE FOR WAMS IN INDIA

General system architecture for Wide Area Monitoring System (WAMS) in India is discussed in [2]. Similar system architecture is shown in fig 1, the same is considered for the present development. Since Indian Power System is divided into 5 Geographical regions for the purpose of Power System Operation the system architecture for WAMS is also following similar architecture of region wise classification. In the model architecture two regions and National Load Dispatch Center (NLDC) are shown but in practical case 5 regions, NLDC and back up NLDC will be there. In each region a generating power plant and a main substation are shown. But in practical case No. of generating plants, No. of main substations (mainly 765kV, 400kV, HVDC link substations and some other critical substations will be present). Data measured by PMUs will be collected by Phasor Data Concentrator (PDC) at the substations or generation plants called as Substation PDC (SPDC). SPDC at power plants and substations will send the data to Master PDC (MPDC) and transmits to Regional Load Dispatch Center (RLDC). RLDC will transmit the data to NLDC. This is the architecture of WAMS in India as proposed in [2].

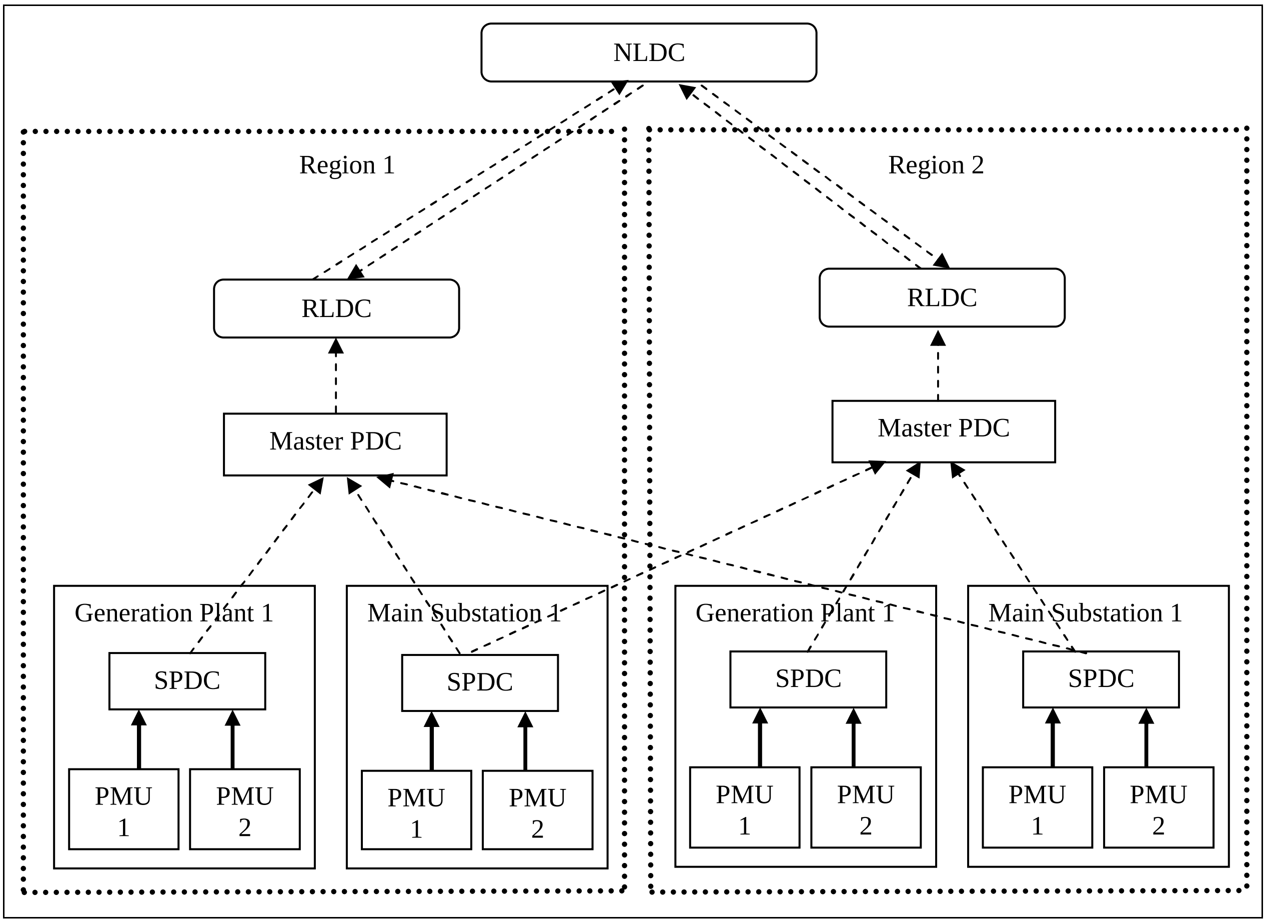

Fig 1: System Architecture for WAMS at National Level. The dotted arrow mark represent data flow with direction.

2. PROPOSED WAMS ARCHITECTURE WITH PRM CONTROL SYSTEM

The proposed architecture is to coordinate the Grid operation at national level. This control system will monitor and control the higher level of system operation being at NLDC/RLDC for maintaining voltage stability. Fig 2 shows the architecture of the proposed control system in national level WAMS system. The RLDC will collect the local measurement data from PMUs

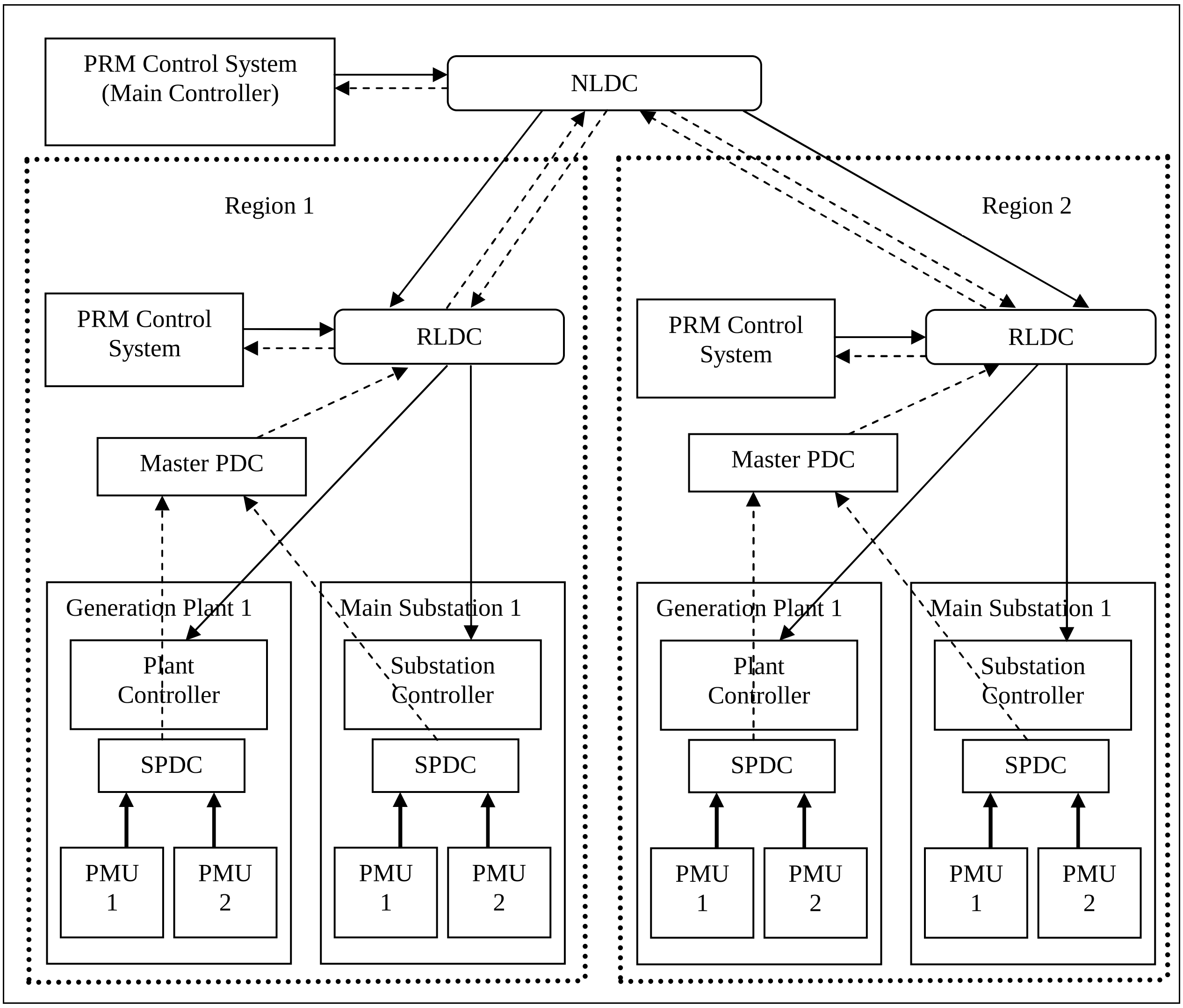

Fig 2: Control System Architecture with WAMS at National Level. The dotted line with arrow mark represents data flow with direction. And the solid line with arrow mark shows the control signal flow with direction.

Table(1):- The types of controls that can be considered for the PRM control system are as listed below:

Control Stations	Types of Controllers
Generating Plant	AVR, Governor, Transformer tap control, bus/line switchable reactors (if any available)
EHV/UHV substations	Transformer tap control, Switchable bus/line reactors, switchable capacitors, FACTS
HVDC substation	Converter control, Inverter control, switchable capacitors, switchable reactors
Non-Conventional Energy Sources	Switchable capacitors, switchable reactors, transformer tap control, FACTS

through PDC in WAMS system at regional level. The NLDC will collect the data from RLDCs at national level. There will be a Phasor Relativity based Mathematical Controller (PRM controller) present at NLDC and RLDCs. This controller will makes use of the raw data (local measurements) collected by the NLDC/RLDC and sense the global power system condition. This controller will give the control signals to all the existing controllers in the Grid through the

NLDC/RLDC. The communication and IT infrastructure available with NLDC/RLDC and the Grid (Generating plants, substations, etc.) will be utilized to send the control signals. Any time the controller at NLDC will be the supreme, but under the conditions of Grid islanded operation or in case the NLDC is not available the RLDC controller will be supreme for the regional control system. Even controller for sub regional levels can also be given for the sake of control under extreme conditions like islanded mode of operation. Table(1) shows the list of various controls that can be considered for various control stations (either generating plant or main substation). The overall control system time constant can be fixed to around 10-20s considering the network and other external controllers response time constant.

3. CASE STUDY OF PRM CONTROL SYSTEM

The development of the proposed control system is based on the PRM Control System. The general algorithm, case studies, analysis and results are presented in [3]. The results of the same test case are shown here for the sake of demonstration. An equivalent South Indian Grid EHV system with 24 buses, 4 generators, 7 loads as shown in fig 3, is chosen for analysis. The studies are performed for three cases.

Case(1):- This case is with fixed shunt reactors and no control in the system.

Case(2):- This case is with fixed shunt reactors and coordinated control is implemented with controls limited to generators, tap change transformer and switched shunt capacitors.

Case(3):- In this case along with all the controls in the case(2) Switchable Reactors and Controlled Shunt Reactor(CSR) are also installed at specified locations in the coordinated control.

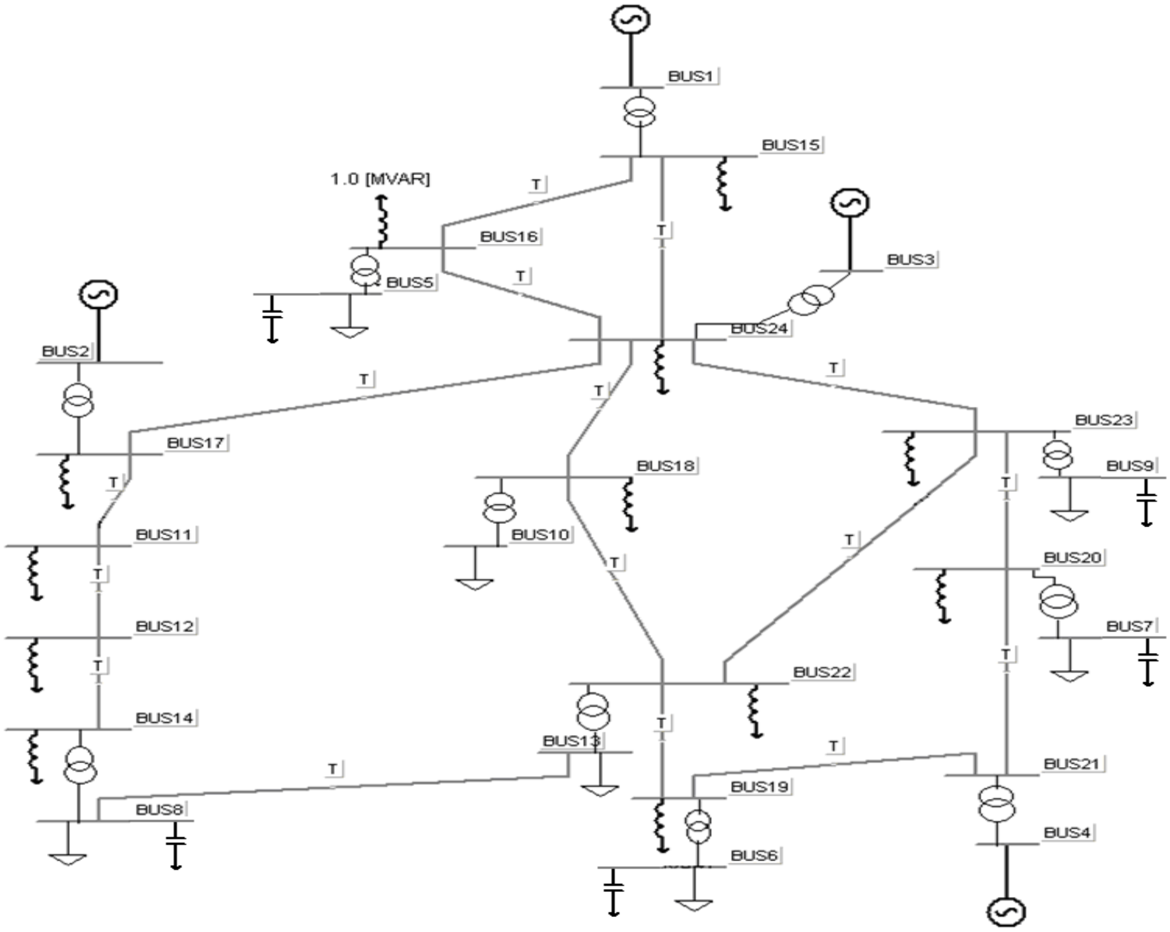

Fig 3: Equivalent South Indian EHV Grid system with 24 buses.

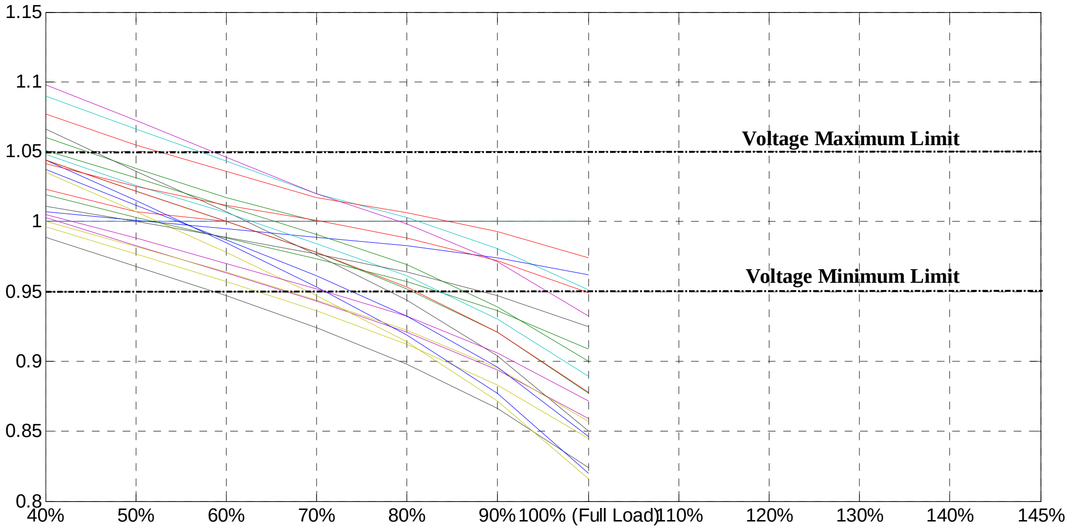

Fig 4: Voltage profile maintained for changing load in case(1). X axis shows the percentage of base load and Y axis Voltage magnitude in p.u..

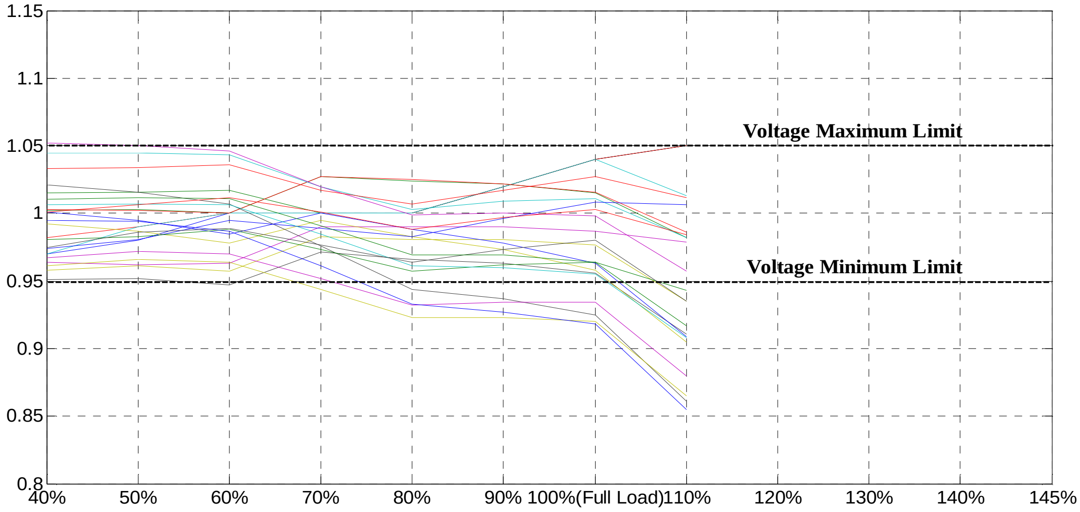

Fig 5: Voltage profile maintained for changing load in case(2). X axis shows the percentage of base load and Y axis Voltage magnitude in p.u..

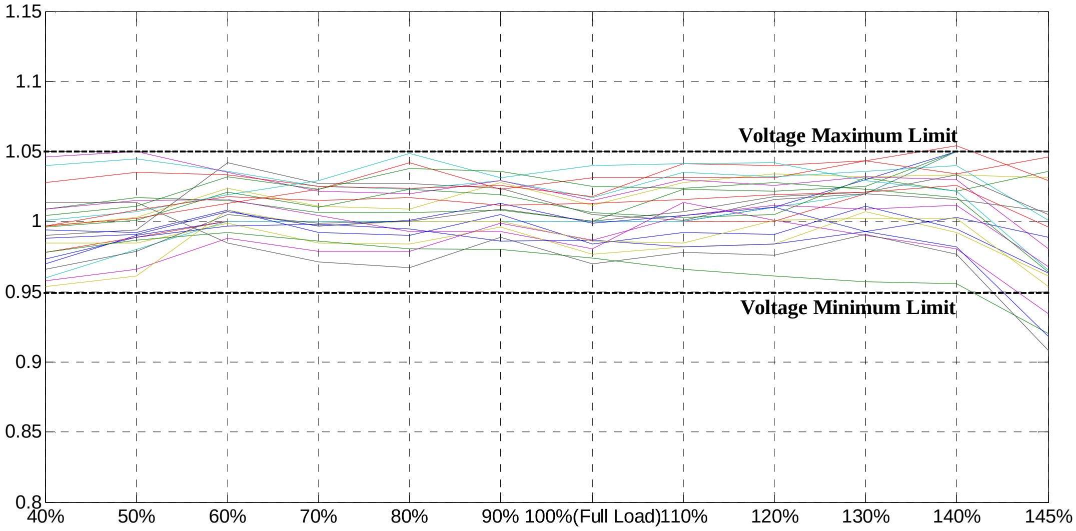

Fig 6: Voltage profile maintained for changing load in case(3). X axis shows the percentage of base load and Y axis Voltage magnitude in p.u..

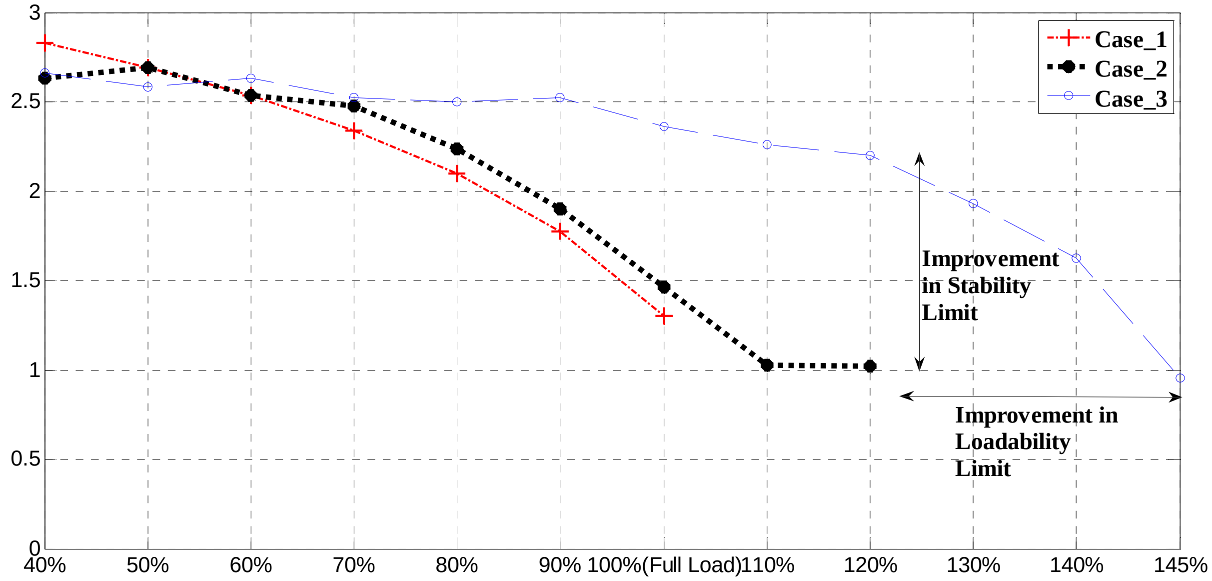

Fig 7: Voltage Stability Margins plot with changing load for the three cases. The distance of most dominant eigen value from real axis is on Y axis and varying load in percentage of base load in Xaxis.

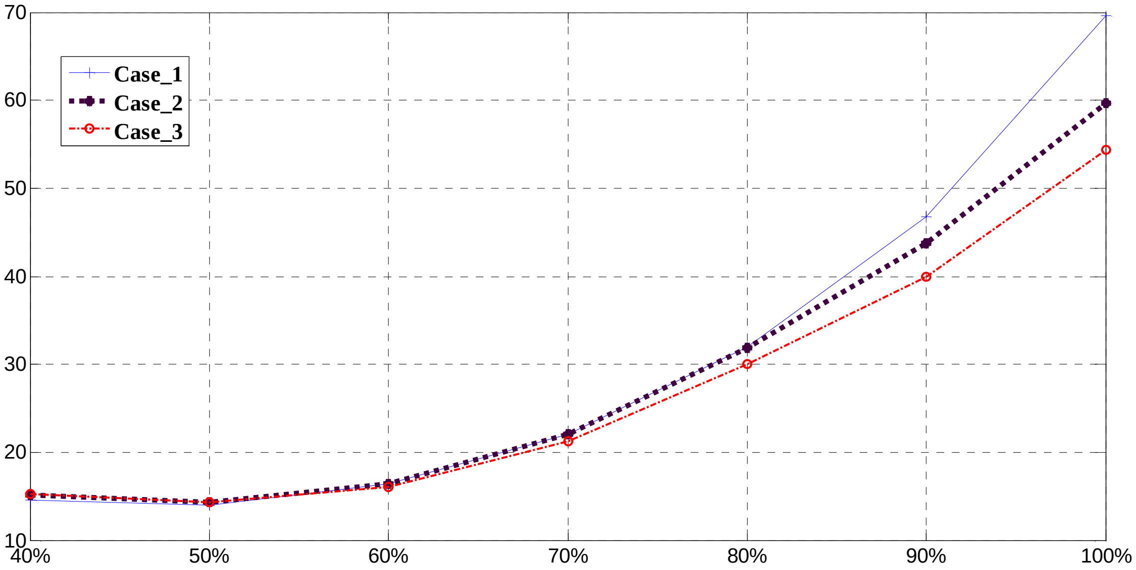

Fig 8: Losses drawn with changing load for the three cases. Power loss in MW is plotted in Y axis and percentage of base load in X axis.

Table(2):- The observations that are made are:

	No Control Case	Control without CSR	Control with CSR
Power Transmission Capacity	100%	115%	145%
Voltage Limits in p.u.	0.82-1.10	0.84-1.10	0.91-1.05 (0.95-1.05 upto 140%)
Types of Controls	No Controls	AVR, Onload Tap changer, Shunt Capacitors	AVR, Onload Tap changer, Shunt Capacitors, CSR.
Real power loss at rated full load	70MW	60MW	55MW

In each case the load is varied from 40% of the base load to the maximum permissible limit. Nodal analysis is performed with a snapshot taken for every 10% of load change. The observations of the three cases are shown in the table(2). The voltage profiles plots of the three cases can be seen in fig 4-fig 6. The voltage stability margins are computed based on eigen value analysis. The eigen value closer to real axis is plotted with the distance of the eigen value from real axis in snapshot. The voltage stability margin plots for the three cases are shown in fig 6. This demonstrates that the proposed control system can maintain stability for changing network conditions. With the optimum utilization of system resources the system security level is enhanced, this can be observed in enhanced power transfer capability of the network. In the fig 7 the losses drawn are plotted. The network losses are also reduced with the optimum utilization of asserts.

The PRM control algorithm will calculate the reactive power dispatch needed at various control buses based on the voltage magnitude profile of the network, voltage phase angles and power phase angles at the buses. State estimation gives the system operating condition, so the input data can be acquired from the state estimation. This technique is basically a relativistic approach. The calculation will be based on relativity between voltage phasor and power phasor in the network. In case PMUs are available in the network the input data required for PRM Control System can be acquired from the data provided by PMUs. So when the PMUs are deployed the overall time taken by the system to respond globally to any voltage disturbance will be as less as 20s. Anyway the controllers like AVR, FACTS will respond with their own time constants. So the concept of PRM Control System will be more applicable in WAMS systems.

4. CASE STUDY OF DYNAMIC STABILITY UNDER DISTURBANCE CONDITION

In case when a critical line is collapsed and totally removed from the network some other lines get overloaded, some generators may cross excitation limits. This causes power oscillations, angle stability and voltage stability problem. This may lead to oscillating voltages profile which will ultimately lead to either blackout or island operation of the system. In such a situation if some of the specific reactors are switched the intensity of the damage can be reduced and the system collapse can be avoided for some time. A simple study is performed on the EHV system to demonstrate how the stability will be affected with the coordinated control and controlled shunt reactor (CSR), which is a FACTS device [4], [5]. If the switchable reactors are switched with timing, the reactive power stress on the generators/grid will be reduced. This can enhance the power transfer capability of the network and support the system to sustain in the critical stability condition. Time domain simulation is performed in PSAT [6], [7]. The study was performed in two cases.

> Case(A):- The reactors are fixed reactors.
>
> Case(B):- The reactors are switched reactors which are switched with time grading operation as if in relays grading.

The branch between buses 23-24 is tripped from the network at the instant of 10s in both the cases. As this is the most critical line oscillations are generated in the network and voltages collapsed. This caused blackout in 3s of time in Case(A), as shown in fig-5. In Case(B) some selected reactors are removed after 1s of the branch removal, i.e. a time delay of 1s at 11s of simulation. Anyway the CSR takes a time of 10ms to get switched on or off. The system got settled in around 10s as shown in fig-6. In the eigen value analysis too the same is observed with the eigen values shifting to left side of the imaginary axis. This restoration of the stable state took without any load shedding, islanding of the network, and in very short span of time. That time gap of 1s can be still further reduced in the real time operation with proper planning and design of the system.

At any time a switched reactor should not respond normally for the power swings or for the fault cases. But for this kind of stability problem the reactor switching has to be with definite timing as if the relays respond in a sequence. This total process can be performed in 1s time with proper coordination in the operation. This timing can be specified at the time of operational planning or can be chosen adaptively with coordinated system operation. The operational scenario is demonstrated in the case study.

Initially the system is stable. With the removal of the most critical line the transmission system could not meet the required power transmission capability due to reactive power stress on the network. When some reactors are switched, as a control action, the transmission system power transfer capability was improved due to reduction in reactive power stress on the network. In the present case study the system reached a new stable operating state. But it may also reach an asymptotically stable state, where it can survive for around 10-20s. In such a situation the

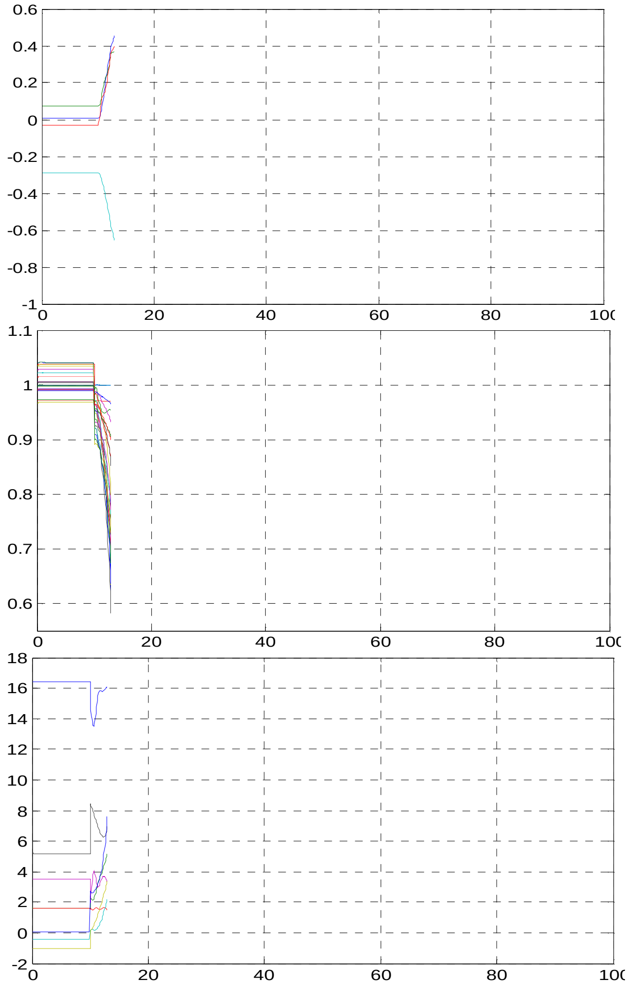

Fig-5 Case(A) plots are shown. X-axis shows varying time from 0 to 100s. Y-axis shows Rotor angle in degrees in first graph, voltage profile in p.u. in second graph and real power in MW, reactive power in MVAR in third graph.

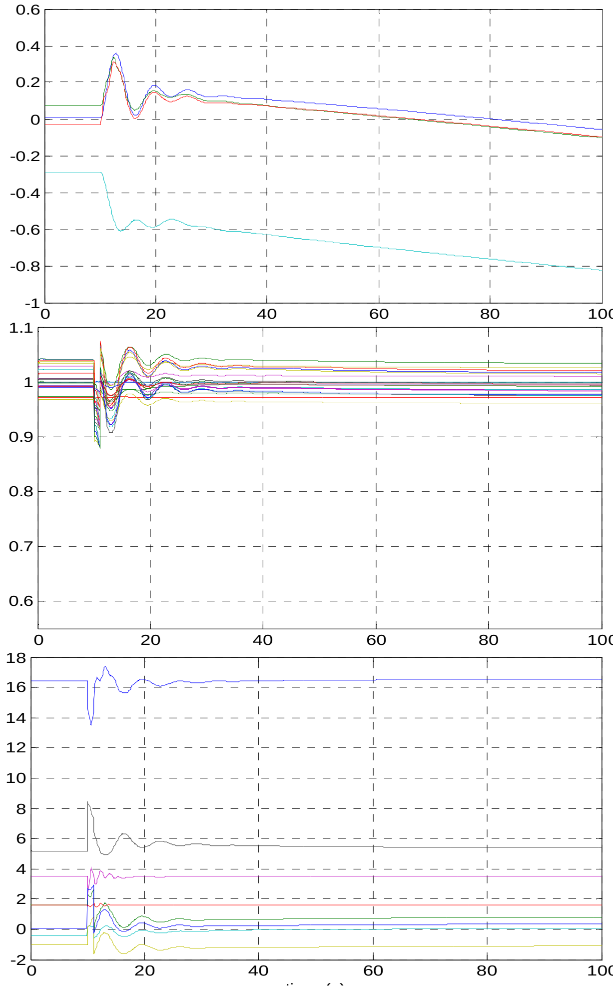

Fig-6 Case(B) plots are shown. X-axis shows varying time from 0 to 100s. Y-axis shows Rotor angle in degrees in first graph, voltage profile in p.u. in second graph and real power in MW, reactive power in MVAR in third graph.

operator will have to respond in that 10-20s. This time gap will be an advantage to the control system or the operator to respond and settle the system in a stable mode.

The Case (A) scenario is very much similar to 2012 Indian Grid collapse [1]. There on the two days of grid collapse one of the critical line tripped due to load encroachment. That automatically let the entire system collapse. There was no sign of any other fault or disturbance. In such a scenario this kind of automated coordinated control and dynamic reactive power management can play very crucial role.

According to stability philosophy [8], any particular kind of disturbance may not appear, angle stability or voltage stability, the issue need to be tackled as system behaves to the disturbances/controls. As in the case the disturbance is primarily due to sudden weakening of the power corridor/reduction in power transfer capability. The switching of reactors has strengthened the power corridor with improved power transfer capability. In case if the system has reached as asymptotically stable state, where system can be stable for few minutes of time, further control action need to be taken. In such a situation as optimal load dispatch for a span of few 10s of minutes to hours may help in system survival under critical conditions.

Some of the intelligent control actions that can save the system from collapse are listed below.

- Intelligent switching of line, bus reactors, shunt capacitors and FACTS devices
- Using optimum tap controls
- Intelligent and controlled switching of line circuit breakers (taking one of the parallel lines out of service when the group of parallel lines are under loaded and bringing back to service when line getting loaded using automated controlled breaker operation)
- Optimally setting the generator terminal voltage
- Intelligent switching FACTS devices or reactive power reserves at the time of network collapse
- Optimal load dispatch at critical loading points

With all the above actions 30-50% of network power flow can be controlled. And the power transfer capability of the network can be improved easily by a margin of around 30%. This power control will be good enough to support the system operation for practical conditions avoiding blackouts, improving reliability and operational simplicity. The above mentioned controls can help only when the system can be visualised and controllable with coordination as a whole.

5. SIGNIFICANCE OF THE PROPOSED CONTROL SYSTEM

The advantages of PRM control system are as listed below:

- The voltage profile can be maintained in a narrow band. In the case study it was 0.95-1.05p.u..
- Power transmission capacity can be enhanced. This will avoid the installation cost to greater extent for the expansion and up gradation of the transmission network for

increasing system capacity. In the case study it was 45%, this can be extended to 80% with installed shunt capacitors.

- As we are first removing the reactors and then injecting the reactive power required the system security will be improved with increased reactive power reserve.
- The losses can be reduced to some extent. In case study it was 15MW.
- Reduction in dynamic over voltage limit as its no more required to limit the reactive compensation to 60%, if switchable reactors are deployed.
- The faster response of the CSR (10ms) will act as primary control whereas the coordinated control will respond in 10-20s will improve the system dynamic performance.
- The coordinated operation of the system can avoid the system collapse when the system operates at marginal reactive power limits, which in turn avoids blackouts.

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