

Analysis of the Hybrid Power System's Maiden Voltage Control Using a Dynamic Voltage Restorer

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Abstract -This work is a first attempt to improve the voltage stability of a hybrid power system (HPS) made up of a diesel generator, Parabolic Trough Solar Power (PSP), and Dish-Stirling Solar Power (DSP) (DG). While PSP using a permanent magnet synchronous generator (PMSG) doesn't require reactive power for excitation, DSP paired with an induction generator does in order to magnetise its field winding. It makes sense to conclude that PSP lowers the reactive power needed for its own operation while still being able to provide the same load demand at low voltage compensation. Higher voltage stability is achieved by requiring less voltage adjustment. Additionally, the system's dynamic responses have been improved as a result of the HPS's integration of Voltage Compensating Devices. Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and Dynamic Voltage Restorer are examples of voltage control devices (VCDs) (DVR). By including FACTS devices, the likelihood of transient voltage instability is decreased. To determine the system's viability and practicality, HPS with FACTS devices under PSP has been put to the critical change in load with positive and negative infinite slope at regular intervals of time. The suggested system's graphical and numerical analysis clearly demonstrates that the proposed HPS with PSP maintains the system voltage stability with a significant margin under DVR. Because PSP and DVR are present, an efficient hybrid power system has been created to preserve the system's voltage reliability.

Index Terms Parabolic trough solar power (PSP), Dish-Stirling solar power (DSP), Permanent magnet synchronous generator (PMSG), Dynamic Voltage Restorer (DVR), mine blast algorithm (MBA)

NOMENCLATURE

Variable	Description
QDG	Reactive power supplied by diesel generator.
QLOAD	Load demand
QDSP	Reactive power of DSP
QPSP	Reactive power of PSP
QSVC	Reactive power of SVC

QSTATCOM	Reactive power of STATCOM.
QDVR	Reactive power of DVR.
Xm	Reactance of DSP
Xeq	Equivalent reactance
Req	Equivalent resistance
IG	Induction Generator
KF	Gain of regulator stabilizing circuit
TF	Time constant of regulator stabilizing circuit
TA	Time constant of regulator amplifier
KA	Gain of regulator amplifier
ΔEfd	Change in exciter voltage
ΔEM	Change in electromagnetic energy of IG
Td, Tα	Dead zone time for zero crossings of the STATCOM controller and transport lag.
Δα	Deviation in phase angle at STATCOM.
ΔV, Vref, ΔVa, ΔVf	Change in system voltage, reference voltage, voltage of amplifier and exciter, respectively.

INTRODUCTION

Given the sustained technological development and significant potential of concentrated solar thermal energy (CSTE), it is likely that it will play a major role in future energy market. Like any other renewable energy technology, CSTE is sustainable in nature, has the potential to curb the global warming [1] while providing significant power within short time frame that would play vital role in near future to tackle global energy problem [2]. Amongst the developed CSTE technologies, parabolic trough solar power (PSP) is the most mature and commercially proven while dish-Stirling solar power (DSP) possesses highest electrical efficiency (32.17%) [4]. These technologies can be hybridized to enhance the energy harnessed and to increase the prospect of CSTE deployment [5]. In addition to this, hybridization will reduce capital cost, provide improved reliability and efficiency, and simultaneously will enhance the dispatch ability as well as flexibility [6]. CSTE is integrated with other renewable energy sources to form hybrid power system (HPS) which are well established in some of

the countries for catering the load demand and reducing the CO₂ emission [7]. Though the electrical efficiency of PSP is around 15% [8], in terms of installed capacity, Spain leads the world with 2370 MW installed capacity followed by the USA with the capacity of 1836 MW [9]. Authors in [10-11] have reported the state-of-the-art, constructional details, and its performance analysis of PSP and DSP in integration with other technologies. Several recent demonstration projects are going on especially in Australia, Japan, Europe, and USA [12].

Despite several advantages of CSTE in an HPS, there are also certain challenges; solar radiation is intermittent and unpredictable in nature. Therefore, variable output power of DSP and PSP causes serious problems of voltage and frequency fluctuations. Additionally, there is an inherent load variation in power system resulting imbalance between reactive power generation and consumption which causes voltage deviations. Such deviation may disturb the system behavior like insulation damage of the apparatus or, in the worst case, complete voltage failure [13]. There is no work that addresses the issue of reactive power/ voltage control of combination of PSP and DSP based HPS.

DSP, like wind turbines, is equipped with asynchronous generator (squirrel cage induction generator- SCIG) [14], [15]. SCIG is advantageous thanks to simple construction, low maintenance cost, and highly rugged in nature. But it requires reactive power for its operation which reduces the terminal voltage and increases the voltage stability problems. At the same time, power factor and the efficiency are also reduced [16]. However, the reactive power can be supplied to SCIG by a capacitor or capacitor bank [17]. In a DST based HPS, none of these options can be used. Capacitor bank cannot compensate the reactive power since the output power of SCIG is variable and compensation by the grid will compromise voltage stability. Furthermore, as mentioned earlier, reactive load also varies with time. Under these circumstances, only SG of the DG cannot compensate the required reactive power.

Therefore, the application of SVC, STATCOM and DVR becomes essential for HPS since these devices provide faster dynamic response required for stability enhancement [13], [18-20]. Moreover, these devices reduce system power loss and harmonics. At low voltage level these can operate over the full output

current.

Voltage control of SVC based HPS has been discussed in [19] and the responses are viable practically. However, this system has considered the controller for SVC while the excitation system of the DG is kept fixed which is not a realistic assumption.

Authors in [20] have designed the similar type of simulation model to see the system responses of the system under SVC where the separate controllers are used for SVC and AVR for proper and practical coordinated system. However, performance of other devices like SVC and AVR could be compared in such HPS for better reactive power support.

Another reactive power control pertaining to isolated HPS using STATCOM in presence of PMIG has been carried out in [21]. In this work also STATCOM controller gains are optimized while parameters of AVR are kept constant. Results are satisfactory. Nonetheless, while optimizing the STATCOM controller gains, authors considered variable wind power with step reactive power load change. Optimizing the gains of the controllers simultaneously with certain realistic features, such as random reactive power load as well as reactive power absorbed by IG would give better performance.

Recently, voltage control of dish–Stirling solar thermal –diesel based HPS has been reported in [22] using SVC. GA, PSO and FPA are used for tuning the controllers' gains simultaneously considering some realistic features such as random reactive power load as well as reactive power requirement of the IG. However, performance of other reactive power compensating device like STATCOM needs to be explored in HPS consisting of other solar thermal system also.

DVR [23, 24] attenuates the deviation in the voltage significantly and have the ability to keep the voltage at the acceptable range. The voltage is injected in series to the line through a transformer at different phase angle [24]. The off-grid HPS consisting of PV, wind, and fuel cell performs satisfactorily under the influence of DVR. Unbalanced 3-phase voltage has been noticeably improved with the help of DVR [25]. DVR plays a vital role in mitigating the voltage deviation that's why this device is used in removing the problems pertaining to voltage sags and swells [26].

and hence generator to generate the electricity. The generator employed with PSP is PMSG. Heat

Transfer Fluid (HTF) could be something like water, steam or synthetic oil [29-30]. Some of the parameters like concentrating factor of the parabolic trough and the intensity of solar radiation are utmost important to make the most of the available system. This paper has included the parabolic trough solar power system considering its advantages over the rest of solar thermal technologies. In this solar power system, reflector is constructed especially in parabolic shape so that it could concentrate the solar beam over the receiver tube at the best level. The way of developing the solar collector reduces the receiver surface as compared to the receiver aperture which leads to reduction in thermal loss [29]. In recent days PTC is developed with higher efficiency at lower maintenance cost by covering it from either side with same type of reflecting and absorbing material. Even a number of experiments are simultaneously striving to find the way to enhance the efficiency to a greater extent because there is a huge amount of possibilities to increase the circumference of its usability. Nanofluids as HTF may enhance the thermal power efficiency and this can be remarkably attained through nanoparticles like CuO and Al₂O₃ [30]. These nanoparticles can be mixed with water to improve the fluid thermal characteristics and to increase the overall power through PSP.

PSP is one of the well-established renewable sources to fulfill the dearth of energy. This is the important sector of solar power to be harnessed to its fullest. Thermal energy storage system (TESS) has increased its degree of usability and popularity in this solar power system because its capacity factor increases from 28 to 43% with TESS [30-31]. In the meantime, its capital cost is lower with higher operating efficiency. It even enriches the quality of dispatch ability of the power plant by providing the ancillary services through TESS [32].

Isolated DSP has the dearth of reactive power because SCIG is required for its operation under varying climatic conditions. The reactive power demand through SCIG may lead the isolated DSP to voltage instability. The real power supplied to the load gets reduced by the factor at which IG consumes the reactive power. But PSP in the presence of TESS can be easily connected to PMSG, and PMSG doesn't require reactive power for its own operation leading to the improvement in voltage profile and simultaneously active power supplied to the load is enhanced. That's

why PSP with PMSG may play an important role in mitigating voltage deviation at reasonable cost. Active and reactive power of PSP in Laplace transform [21] can be written as

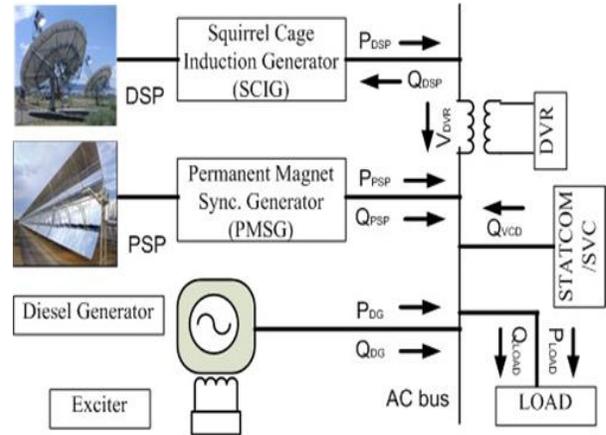


FIGURE 1 Power flow diagram of the proposed HPS

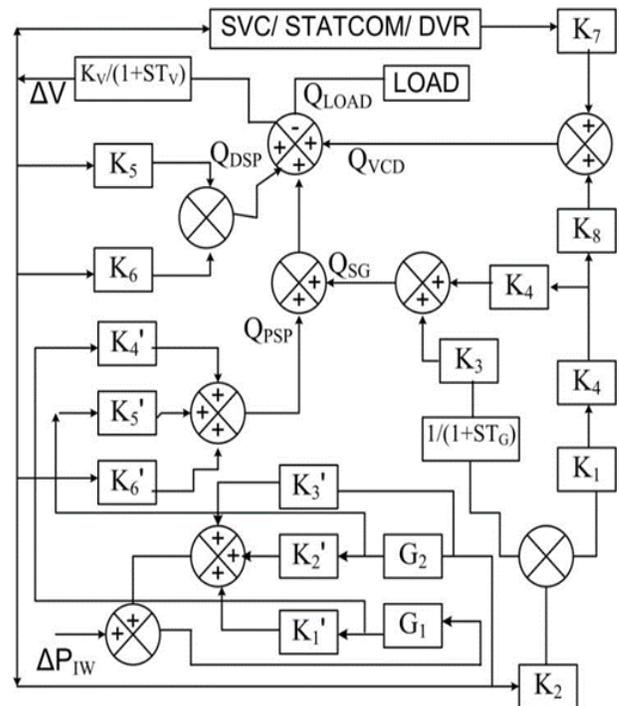


FIGURE 2 Control diagram of the proposed HPS with PMSG

line where injected voltage of DVR is perpendicular to line current to control the reactive power of the system. DVR can be dynamically controlled since its voltage magnitude and phase both are controllable. Laplace transfer function model of DVR can be represented as [23-24].

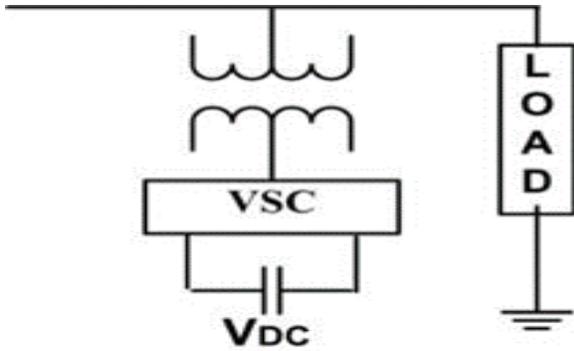


FIGURE 3. Schematic diagram and equivalent circuit diagram of DVR.

MODELLING OF HYBRID POWER SYSTEM

This work has developed the hybrid power system incorporating DSP and PSP with IG and PMSG, respectively, as shown in Figure 1(a). In addition, DG comprises of SG (0.15 p.u), for providing power under non-availability of the main sources. Here, the reactive power load of 0.75 p.u is applied and speculated its behavior in terms of terminal voltage and reactive power of all the components connected in the system. Any deviation in the system voltage can be controlled by balancing its reactive power deviation [21]. Figure 1(b) shows the Laplace transfer function model of the HPS in reactive power regime.

Table 1 PERFORMANCE PARAMETERS (MOS, MUS AND ST) OF THE VOLTAGE

		SVC	STATCOM	DVR
CASE 1	MOS (in 10 ⁻⁵)	31.42	27.85	6.09
	MUS (in 10 ⁻⁵)	83.22	72.41	55.28
	ST (ms)	16.84	4.89	1.26
CASE 2	MOS (in 10 ⁻⁵)	28.65	27.10	6.29
	MUS (in 10 ⁻⁵)	60.25	58.14	36.55
	ST (ms)	15.56	3.45	3.31

CONCLUSION

Reactive power compensation analysis of the proposed HPS with coupled DSP and PSP, and DG is presented in this research. For the first time, presented Another innovative work is the use of DVR for reactive power balancing in this form of HPS. Although DSP has a higher efficiency than PSP, it cannot operate without an induction generator, which uses reactive power. As a result, a significant voltage excursion could cause the system to enter an unstable

equilibrium. Permanent magnet synchronous generators, which are used in PSP, are able to sustain reactive load demand without the need for an additional reactive power compensating mechanism. Thus, compared to a DST-only HPS system of equal capacity, the amount of reactive power correction needed for the HPS incorporating combined DSP and PSP can be greatly decreased. By adding PSP, the hybrid power system's voltage stability margin can be expanded and the risk of system instability can be reduced. The ability of the DVR to correct for reactive power for voltage stability is greater than that of STATCOM and SVC, as this work has also made clear. Since DVR injects voltage in series with the line with a different phase angle than the line current, it has a better compensating property. In other terms, it may be claimed that voltage compensation using DVR is important due to the controllability of the injected voltage's magnitude and phase angle .Graphical analysis of the proposed system justifies that, the hybridization of different sources like PSP and DSP with proper coordination under DVR makes the system less vulnerable to the voltage instability. Economic feasibility study by comparing DVR, STATCOM and SVC could be done in our future work.

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