Hybrid DPSO based MPPT control of high static gain converter in photovoltaic system for DC microgrid applications

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Abstract. This paper deals with efficiency enhancement of photovoltaic renewable system under Partial Shaded Conditions (PSC) using Hybrid DPSO (Deterministic Particle Swarm Optimization) algorithm based maximum power point tracker embedded in a high gain DC/DC SEPIC converter. The proposed high static gain converter with Hybrid DPSO algorithm eliminates the multiple peaks under varying insolation conditions; speedup the tracking process and also dynamic responses of the converter. The performance parameters of the proposed Hybrid DPSO method are analyzed and comparing it against the PSO and classical Perturb and Observe (P&O) techniques in MATLAB simulink. The evaluation result proves that proposed method shows better tracking performance under fast varying insolation conditions.

1. INTRODUCTION
Fast development in green energy generation investments and government subsidized policies quite significant in recent years has led to a sustained development in the power sector. Renewable power consumption grew day by day and creates great impact in the world’s electricity generation. This scenario induces the researchers to attract interest towards green energy generation in the form of distributed generation (DG). Solar, wind, hydroelectricity, geothermal energy and wave power, and combustible renewable and renewable waste (solid biomass, landfill gas, liquid biofuels, and waste incineration) are the vital renewable energy among them few sources produces DC power, examples: fuel cells, PV (photovoltaic) etc. Energy storage devices such as super capacitor, lead acid, sodium ion, nickel cadmium and Li-ion secondary batteries etc, are supplying DC power. DG systems employed in DC micro-grid guarantees reliable power to consumers by optimal control of flow of power from the generation to consumers load. One more imperative feature is majority of the end user appliances are moreover DC adaptable loads (e.g. LED, BLDC fan, CCTV cameras, computers etc.). PV panel have the drawbacks of lower cell voltages and non-linear PV, IV characteristics with respect to irradiance and temperature leads to poor energy conversion efficiency. To overcome the above said limitations a power conditioning units such as Boost converter and maximum power point tracker (MPPT) are used in linking the DC bus and PV Panels. MPPT as its name signify, allows tracking of power over a period of time and detecting the peak power point (MPP) that the panel is customized to provide under varying temperature and solar insolation [4]. The process of MPP tracking is to get
optimize and superior exploit of PV systems thus maximize the PV array efficiency which depends upon the particular MPPT technique. The MPPT algorithms that are mainly categorized into two groups, namely conventional and nonconventional algorithms in several literatures. The conventional techniques includes incremental conductance method or hill climbing algorithm, P&O (perturb and observe), ripple correlation method, short circuit current, open circuit voltage etc [7-10]. The MPPT control using P&O method is most preferred method in the literatures because of its simplicity and easy implementation in real time. But under varying environmental conditions a shaded cell would act as a load and draws additional current from the main load causes tracking PV power get diminished, process of tracking get oscillates and leads to wastage of power [11]. Thus fast varying insolation conditions in P&O method alter the PV power output and distress the reliability of the system. Non-conventional techniques are biologically inspired algorithms has ability to handle multiple peaks in PV characteristics curve and faster convergence to the actual peak point [12-18]. Particle swarm optimization algorithm (PSO), ant colony systems (ACS), genetic algorithm, and flashing firefly algorithm (FA) are few accepted and recent evolutionary algorithms (EA) [19-25]. Each algorithm has its own merits and limitations, in this paper, swarm optimization algorithms are utilized because of its simple construction and easy implementation. Particle seeker optimization efficiently maximizes the efficiency of solar array by tracking optimum global peak point (GPP) [26-30]. But the random numbers makes the algorithm little slow, when tracking the peak power with complex computations at more number of iterations which causes some substantial amount of power loss. To overcome the losses occurred and speed up the tracking process, hybrid DPSO (Deterministic Particle Swarm Optimization) technique is initiated [31-33]. Hybrid DPSO algorithm tracks the global peak point in less convergence time as compared to other soft computing techniques.

![Figure 1. General Block Diagram of Photovoltaic system for DC Microgrid](image)

The proposed controller is able to track optimum global peak operating point with an optimal speed, and it indicates a very good dynamic response under exclusive partial shadowing conditions. The figure 1 indicates the blocks of proposed PV system for DC microgrid applications. The option of an appropriate converter is another imperative subject of matter when employing a PV-MPPT system. Several literatures reveal that the custom of midway converters for power conditioning and tracking applications, which are: classical boost, buck, buck-boost, SEPIC and Cuk converter topologies [9] and [13]. The above said converter topologies suffers with the problems like electromagnetic interference and reverse recovery, when it is subjected to extreme high duty cycle value D>0.8, to get higher voltage gain. The SEPIC, conventional buck-boost and Cuk topologies were ability to either step up and down the voltage applied to it. In this work, a SEPIC converter has been preferred with an intention to use the system for high static gain and high voltage applications [2]. Rest of the work is structured as follows. The hybrid DPSO technique will discuss in section 2. Section 3 and section 4 illustrates the high static gain converter. The comparison results of P&O, PSO and the DPSO hybrid techniques are disused in section 5. At last, the paper is concluded in section 6.
2. Implementation of Hybrid DPSO Based MPPT

In this paper, hybrid DPSO-P&O MPPT technique is proposed for PV systems under PSC to get maximum efficiency, fast convergence time and low complexity. In PSO based MPPT control to the DC-DC converter be capable of react to one command at an instance, the particles are initialized and assessed in a consecutive way. The successive particles intervals should be larger than the settling time ($t_s$) of the overall system in order to get acceptable voltage and current samples. Each particle takes ample amounts of time to carry out entire aforesaid steps, hence the convergence time of particles converge to the Global Peak Point (GPP) is greater and it causes some considerable power loss. To reduce convergence time, loss of power and get peak power ($P_{pv}$), Hybrid - DPSO technique is initiated. The implementation of hybrid P&O-DPSO algorithm in MPPT controller reduces the search space and hence, the time of convergence gets decreased. Moreover, each particle’s velocity is controlled to a meticulous value to remain the space surrounded by the peaks. Therefore the classical PSO composed into the deterministic construction. Figure 2 represents the flow of proposed P&O algorithm. In conventional PSO algorithm, the particles position is defined by PV array voltage as reference and all the particles should converge to GPP by updating the $P_{best}$ and $G_{best}$ using equation 1 and 2. However, this procedure involves large number of iterations and huge variation in the velocity component may cause the particle to move out as of the vicinity of global peak point [3].

\[
D_i^{k+1} = D_i^k + \phi_i^{k+1}
\]

\[
\phi_i^{k+1} = W \phi_i^k + C_1 r_1 (P_{best} - x_i^k) + C_2 r_2 (G_{best} - x_i^k)
\]

Thus, by eliminating the random number $r_1$ and $r_2$ in (2) and restraining the velocity factor ($V_{max}$) hence the conventional PSO is changed to a new deterministic construction. The basic concept is removing the random number from PSO acceleration factor in the equation 2 and modified velocity equation of PSO can therefore be written as:

\[
\phi_i^{k+1} = W \phi_i^k + (P_{best} - x_i^k) + (G_{best} - x_i^k)
\]

Hybrid DPSO-P&O MPPT algorithm is proposed by modifying the velocity represent in equation 3. The velocity perturbation with respect to $V_{P&O}$ using flowchart shown in figure 2 helps the fast tracking ability to reach the GPP. The modified velocity equation as depicted below:

\[
\phi_i^{k+1} = W \phi_i^k + (P_{best} - x_i^k) + (G_{best} - x_i^k) + V_{P&O}
\]

Where $V_{P&O}$ is the variation of voltage offer by the classical P&O algorithm illustrated on figure 2. The controlling the value of $\phi_i^{k+1}$ the values of duty cycles to SEPIC converter is decrease or increase gradually in two succeeding MPPT cycles. By realizing DPSO method, subsequent parameters are utilized: particle size is about 15. One parameter i.e. the inertia weight ($W$) required to tune so efforts for parameter regulation is very much reduced. Figure 3 represents the overall hybrid DPSO-P&O MPPT algorithm. Hybrid DPSO-P&O method is employed to extract maximum power from PV array with reduced number of computation and iteration. Power losses tracking speed and dynamic response are better as compared to other intelligent control techniques. Here, soft computing technique decides the duty signal of converter thus proposed circuit tracks peak power point effectively.
3. DESIGN OF SEPIC CONVERTER

The DC to DC conversion using DC/DC converter is heart of MPPT circuit which is generally used to regulating the voltages of PV array at the Maximum Power Point (MPP) and providing maximum power transfer by load matching. SEPIC is a DC/DC converter similar to buck-boost and Cuk converter, that has the ability to produce the output either may lesser or greater, otherwise equal to the voltage at the input terminal, but has added benefit of have non-inverted polarity output. The SEPIC converter voltages obtained at the output terminal are depending upon the switching rate of the power electronic switch. The basic structure of the classical SEPIC converter circuit is point up in figure 4. The converter construction to be modified by including two components capacitor $C_M$, and diode $D_M$ in existing SEPIC converter as presented in figure 5.

![Figure 4. Classical SEPIC converter](image)

![Figure 5. SEPIC converter with voltage multiplier](image)
By the aforementioned alteration numerous functional features of the classical SEPIC converter are transformed and get twice the time of classical boost converter gain for a duty-cycle near to $D = 0.85$. However few applications needs larger static gain at lower duty cycle less than 0.8 ($D < 0.8$). So the customized converter to be tuned to get the higher static gain at duty cycle smaller than 0.8.

4. PROPOSED DC-DC CONVERTER WITH MAGNETIC COUPLING

A simple alteration made in modified SEPIC converter to build higher the static gain at the smaller duty cycle $D < 0.8$ is by inserting a secondary coil with the $L_2$ inductor. The magnetic coupling between the winding inductor $L_{2p}$ and $L_{2s}$ will increase the voltage at output and working like a flyback transformer. Figure 6 demonstrates the modified arrangement of the proposed high gain circuit. The insertion of coil $L_{2s}$ drives the over voltages across output diode $D_0$ terminals. This enormous voltage at diode $D_0$ terminals will not suppress with traditional snubber circuit. Hence a clamping circuit consist of capacitor $C_{S2}$ and diode $D_{M2}$ are added with the secondary coil $L_{2S}$ as provided in figure 7. This clamping circuit also act as a voltage multiplier for the output diode $D_0$.

The voltage multiplier circuit helps transfer of energy from the leakage reactance to the output terminals and subsequently the stress on the diode $D_0$ gets suppressed and the voltage across the output diode is reduced than the voltage at output which guides to increase the overall converter static gain.

The high static gain SEPIC converter operates in continuous conduction mode (CCM) illustrates in two operation stages.

4.1 First Stage of operation

When the MOSFET switch $S$ is in ON state, the input voltage charges inductor coil $L_1$. The inductor $L_{2S}$ discharges their stored energy to capacitor $C_{S2}$ through the diode $D_{M2}$ which forms a closed path and block the output diode $D_0$ as shown in figure 8. Once the charging of capacitor $C_{S2}$ is completed the diode $D_{M2}$ becomes reverse biased which opens the path as illustrated in figure 9.
4.2 Second Stage of operation
When the control switch $S$ is in OFF state, the stored energy in the inductor $L_1$ discharging through $D_{M1}$ diode to the capacitor $C_M$ illustrated in figure 10. Once the energy transfer from Inductor $L_1$ makes the capacitor $C_M$ charged which reverse biased diode $D_{M1}$. The charges stored in inductor $L_2$, capacitors $C_{S1}$, and $C_{S2}$, charges the capacitor $C_0$ and energize the load $R_L$ through output diode $D_0$ as shown in figure 11 until the switch $S$ get ON.

![Figure 10. Operation at second stage](image1)

![Figure 11. Diode $D_{M1}$ blocked at end of second stage of operation](image2)

5. RESULTS AND DISCUSSION
The Matlab simulink model of overall PV system for DC microgrid environment is presented in the figure 12. The outputs of PV arrays are directly fed to the proposed high gain SEPIC converter in which the hybrid P&O-DPSO MPPT algorithm is embedded. The figure 13, 14, and 15 shows hybrid P&O-DPSO based MPPT provides better results than conventional P&O and PSO methods and tracks global maximum power point under PSC. The proposed converter can operate with high static gain ($q > 10$) and employs fewer quantity of switching devices results less switching losses. Consequently the overall PV system effectiveness and efficiency gets increased.

![Figure 12. Simulink model of Hybrid P&O-DPSO MPPT control of proposed high static gain converter](image3)
6. CONCLUSION
This paper gives a hybrid P&O-DPSO based MPPT, and a high static gain SEPIC converter. The proposed hybrid control algorithms gives better results and efficiently track the optimum peak point.
for the PV array underneath partial shading circumstance. In this proposed technique, the output voltage has very high static gain and constant under normal or shaded conditions of solar panel using hybrid P&O-DPSO based MPPT algorithm implemented on modified SEPIC converter using MATLAB / SIMULINK. The proposed high static gain converter working with low voltage input is able to produce better output voltage and efficiency at duty cycle D < 0.8. So the control mechanism is competent to utilize in grid connected renewable system using various multilevel inverter topologies.

7. REFERENCES

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